ELEMENTS OF MINERAL EXPLORATION

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Preface

In the course of the administration of Mineral Conservation and Development Rules with a view to ensuring the conservation of mineral resources and the systematic development of mineral deposits, the Bureau has noticed a general neglect of the geological assessment of mineral resources in the mining lease areas covered by small mines. Considering the limited capacity of the owners of such mines to obtain expertise, the need was felt to provide guidance to young geologists to enable them to take up the preparation of geological maps and the assessment of mineral resources. It was with this end in view that it was decided to bring out this volume "Elements of Mineral Exploration" which provides detailed information and practical guidance to geologists who do not have prior experience in mineral exploration. This then is the origin of this bulletin, the ninth in the series of bulletins brought out by the Indian Bureau of Mines so far.

2. The subjects dealt with in this bulletin include geological mapping, pitting, trenching, drilling by core drills and non-core drills for exploration, sampling, mineralogical and chemical analysis, exploratory mining, etc. which together constitute detailed exploration. Inter-disciplinary subjects like geo-chemistry, geo-botany, and geo-physics are dealt with in a cursory manner only to the extent of introducing these subjects to the reader. Subjects like petrology, mineralogy, and ore genesis have also been dealt with insofar as their importance to mineral exploration is concerned. A special feature is a discussion on the mode of occurrence of various mineral deposits in India and the manner in which the related schemes of exploration have to be designed to meet the specific needs of a given type of deposit. A fairly detailed account has been given of the application of statistical techniques. Computation and categorisation of reserves and exploration in working mines are among the salient features of this publication.

3. In contrast to the general neglect of systematic exploration in small mines, a number of government, semi-government and private organisations are engaged in the exploration of mineral deposits in free-hold areas as also in the mining-lease-areas covered by large mechanised mines. It is hoped that this publication would also be useful to the young geologists working in these organisations.

4. Our thanks are due to the publishing houses, individuals, and organisations who have consented to our reproducing extracts from their publications. Thanks are also due to Shri Kedar Naraian, Chief Geologist, Mineral Exploration Corporation Limited, Nagpur for going through the draft of the publication and making valuable suggestions.

5. The following officers of the Indian Bureau of Mines participated in the preparation of this bulletin · Dr. S.C.Singhal, Controller of Mines, Sarvashri A.R.Harwalkar, Superintending Mining Engineer, N.L.Chatterjee, and S.K.Choudhuri, Regional Controllers of Mines, H.Anantha Ramiah, Superintending Mining Geologist, G.S.Kumar, Deputy Controller of Mines, and B.George, Senior Mining Geologist. Special mention may be made of the contribution of Shri B.George who was mainly responsible for the preparation of the manuscripts.

D. N. BHARGAVA
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APPENDICES

Chapter 1

1.0 Introduction

Since ancient times, many metals like iron, copper, lead, zinc, mercury, gold and silver have been known to mankind. As these metals occur mostly in the ore form, and have to be extracted from the ores, it is natural to assume that since the very early days of civilisation, man has been aware of the existence of ore concentrations (mineral deposits) in certain places. Although the extraction of metals and their uses are widely mentioned in ancient literature, there are very few references to any organised attempts being made to locate them. However, it is reasonable to assume that the ancient people had devised some means of locating metallic ore deposits.

Minerals and mineral-based industries play a vital role in the economy of all nations. This is true in the case of India also. India produces nearly 50 major minerals annually, and is endowed with a wide variety of mineral deposits. Of these, the most important metallic mineral deposits are iron ore, manganese ore, chromite, copper, lead, zinc, bauxite, and tungsten. Precious minerals consist of diamonds, emeralds, and gold. Other minerals like magnesite, fluorite, barytes, asbestos, limestone, dolomite, talc, kyanite, sillimanite, graphite, and clay which are important to the industry are also available in substantial quantities.

Although India has been in the field of mineral industry for long, it is only after Independence that the demand for metals and ores started growing rapidly. With this, the need for discovering new deposits has also started increasing giving a fillip to the science of exploration geology.

In the earlier days, mineral exploration was done by individuals, known in the western countries as prospectors. Mineral discoveries depended upon the skill, diligence and persistence of these individuals. Though prospectors are active in countries like the U.S.A. and Canada, the days of the individual prospector are limited. Discoveries of new deposits are getting scarcer as unexplored areas are becoming smaller all the time. The prospector is getting replaced by specialised agencies and organisations. The prospector's simple tools are also getting progressively replaced by sophisticated exploration tools. Mineral exploration has become a commercial activity demanding the use of many specialised skills. Mineral exploration all over the world has been spearheaded by earth scientists in general and geologists in particular.

In India, organised mineral exploration was initiated by the Geological Survey of India sometime after its inception in 1851. At present, there are many large and small organisations involved in mineral exploration throughout the country. Since the success of all these activities depends largely on geological skill, every organisation is attempting to impart the best possible training to its geologists involved in mineral exploration.

The Indian Bureau of Mines, which is responsible for the conservation of minerals in India, has been trying to disseminate such of the information and knowledge it has in this and various other fields to the public through monographs, bulletins, etc. The present volume is one such with the object of serving as a guide and source of reference for the mining and exploration geologists. Coal, oil, and atomic minerals have been excluded from the purview of this bulletin. Among other minerals, only those which are currently under exploration and exploitation have been discussed. This volume comprises 9 chapters including "Introduction". Each one of these chapters deals with different aspects of mineral exploration presented in such a way that the reader could recapitulate the fundamentals before going into the more advanced aspects of the science of exploration geology. Thus, Chapter 2 mainly deals with rocks, minerals, and geological structures and the role played by them in exploration. A note on some modern concepts in ore genesis has also been added. Formation of rocks and the mineral deposits associated with them have been discussed in this chapter. In Chapter 3, the organisation and methods of exploration are dealt with. The legal aspects involved in exploration, recruitment of personnel and other aspects like procurement of equipments, transport, etc. have been covered under "organisation". Methods of choosing target areas, different types of exploration, special methods, three dimensional sampling by drilling, pitting, trenching and exploratory mining have been described under "methods". Chapter 4 describes surveying as it is applicable to mineral exploration. This comprises sections on methods of surveying including triangulation and traversing, levelling, tacheometry, plane tabling, etc. Underground surveying methods have also been described. A section on the norms for various surveying jobs has been added. Evaluation of the exploration work conducted from time to time forms the subject of Chapter 5. The aspects discussed in this chapter are, interpretation of data and computation and classification of reserves. The important methods of computation of reserves that are available presently like the analogous block method, geological block method, and the cross-section method have been discussed, followed by subsections on bulk density; reserves and grade. Chapter 6 is devoted to statistical methods in mineral exploration, wherein have been given the definitions of the terms commonly used in statistics. Geomathematical methods for computing the grade, number of samples at a required precision level, etc. have been described in this chapter. Chapter 7 describes in brief the Geology of India. The section dealing with tectono-metallogenic units covers shield areas, the Himalayan mobile belts and areas of secondary mineralisation. Other mineralised formations have also been discussed in this chapter. Various field guides, and the important mineral deposits and their exploration form the subject for Chapter 8. Mineral deposits associated with ultra-basic and basic rocks, igneous intermediate rocks, igneous acidic rocks, sedimentary evaporite rocks, metamorphic rocks and products of residual weathering have been described separately. Field guides for the recognition of various mineral deposits have been summarised. In addition, guides to exploration of individual minerals have also been given in this chapter. Chapter 9 deals with exploration in producing mines. This comprises a section on verification and correlation of earlier exploration data. The control of mining operations has also been described. Almost all the subjects which have a direct bearing on mineral exploration find a place in this volume.

No scientific or technical publication could claim to be all-comprehensive and this volume is no exception. In order to expose fully the reader to the various subjects dealt with, a list of references has been appended; this could be used when specific information on some specialised topic is required (Appendix 1.1).

Chapter 2

2.0 Minerals, Rocks, Geological Structures and their Importance in Mineral Exploration

2.1 Crust of the earth

The crust of the earth, about 30-70 km thick forms the outer layer of the planet in which all rocks and minerals are found. Beneath the crustal layer is the zone known as the Mohorovicic discontinuity, which is followed by heavy rocks to a thickness of 3,000 km. This is followed by a 2,000 km thick outer core of iron and nickel in a hot plastic condition, which in turn is followed down to the centre by an inner core of 1,200 km thickness[1].

The earth's surface of which the crust is a part is divided into the following components[2]:

(i) lithosphere, which is the solid rock portion of the earth constituting the continents and extending beneath the ocean floor,

(ii) hydrosphere, which includes oceans, lakes, and other water bodies, and

(iii) atmosphere, or the blanket of air which covers the crust.

The distribution of minerals in the earth's crust[3] is shown in Table 2.1.

Table 2.1 : Distribution of minerals in earth's crust

Mineral	Percentage of incidence
Felspar	49
Quartz	21
Pyroxene, amphibole, and Olivine	15
Mica	8
Magnetite	3
Titanite and ilmenite	1
Others	3
Total ...	100

Of the 104 known elements, only 8 are known to be present in quantities exceeding one percent. The outer skin which is about 16 km deep is made up of the elements— oxygen, silicon, hydrogen, calcium, sodium, potassium, magnesium, titanium, phosphorus, hydrogen, carbon, and manganese. These elements constitute 99.5 percent of the crustal rock material. Elements like platinum, gold, silver, copper, lead, zinc, tin, nickel, and others constitute the remaining 0.5 percent[3].

The hydrosphere which comprises oceans, lakes, rivers, and other water bodies, contains elements and compounds in a dissolved form. The composition of water from various bodies[4] is shown in Table 2.2.

Table 2.2 : Composition of various water bodies

(Dissolved matter only)

Element/ compound	Water of lakes, rivers, etc.	Sea water
CO_3	35.15	0.41 (as HCO_3)
SO_4	12.14	7.68
Cl	5.68	55.04
NO_3	0.90	-
Ca	20.39	1.15
Mg	3.41	3.69
Na	5.79	30.62
K	2.12	1.10
SiO_2	11.67	-
Sr, H_3Be_3, Br	-	0.31
Total ..	97.25	100.00

In all, the crust contains some 1,600 mineral species. Of these, 50 are rock-forming minerals of which 29 are most common. The remaining (1,550) come from ore minerals[3].

In order to understand the mode of occurrence of economic mineral deposits, it is necessary to know about the various types of minerals and rocks, particularly their field occurrences, and methods of identification.

2.1.1 Mineral and rock forming minerals

A mineral is defined as an inorganic substance occurring in nature, though not necessarily of inorganic origin, which has (i) a definite chemical composition, or more commonly a characteristic range of chemical composition, and (ii) distinctive physical properties or molecular structure. With a few exceptions, such as opal (amorphous) and mercury (liquid), minerals are crystalline solids[5].

Although genesis is the major criterion for classifying rocks, a given rock derives its name, uniqueness of character and distinctiveness by virtue of its mineral content. In order to study the rocks, an understanding of minerals is absolutely necessary. It is not always possible to be conversant with all the known minerals. The best one can hope for is to be able to identify some 100 important minerals in the area of his interest. However, guide books are available to help in identifying the minerals, in the field. Although meant basically for mineral and ore collectors, these books can also be used by prospectors.

2.1.2 Mineralogical characteristics

There are certain common criteria for identifying minerals in the field[6]. They are : (i) colour, (ii) streak, (iii) luster, (iv) hardness, (v) habit, (vi) fusibility, (vii) cleavage and fracture, (viii) tenacity, and (ix) crystal system.

(i) <u>Colour</u> : The colour of a mineral is usually described in comparison with certain well-known objects of similar colour, e.g. ruby-red, leaf-green, etc.

A few characteristic mineral colours[7] are summarised in Table 2.3.

Table 2.3 : Characteristic mineral colours

Colour	Mineral or element
Silver-white, tin-white	Native silver, antimony, arsenopyrite
Steel-gray	Platinum, manganite, chalcocite

Contd.

Table 2.3 : Characteristic mineral colours (*Concld.*)

Colour	Mineral or element
Blue-gray	Molybdenite, galena
Lead-gray	Galena, stibnite
Iron-black	Graphite, magnetite, hematite
Black	Ilmenite, columbite, wolframite, mica, some amphiboles
Copper-red	Native copper
Bronze-red	Bornite, niccolite
Bronze-yellow	Pyrrhotite, pentlandite
Brass-yellow	Pyrrhotite, pentlandite
Gold-yellow	Chalcopyrite, millerite, pyrite
White with greenish tinge	Amphibole, pyroxene
Blue	Azurite, lapis-lazuli, sapphire, kyanite, beryl, amethyst, fluorite, calamine
Green	Serpentine, malachite, spodumene, jadeite, talc, garnet
Yellow	Sulphur, orpiment, topaz, barite, sphalerite, siderite, goethite
Red	Ruby (corundum), garnet, cuprite, cinnabar, zircon, zincite, realgar, rhodochrosite
Brown	Staurolite, rutile, tourmaline, quartz

(ii) <u>Streak</u> : Streak is the colour of the powdered mineral and is not influenced by impurities. It is identified by rubbing the mineral against a streak plate - a piece of white chert or any surface which can show the colour of the rubbed powder[6]. In the case of soft or powdery forms of minerals, the smear of powder on a piece of white paper will help its identification. The streak of certain important elements and minerals is given[8] in Table 2.4.

Table 2.4 : Streaks of some important minerals

Streak colour	Element/Mineral
Golden yellow	Gold
Silvery white	Silver
Copper-red	Copper
Grayish white	Platinum
Black	Pyrolusite, argentite, graphite (shining black), tetrahedrite, ilmenite, magnetite, columbite
Greenish black	Chalcopyrite, millerite, pyrite
Brownish black	Niccolite, pyrite, marcasite, wolframite
Grayish black	Chalcocite, bornite, galena, pyrrhotite, covellite (shining), stibnite, cobaltite, marcasite, arsenopyrite
Gray	Antimony, graphite (shining gray)
Brown	Sphalerite, tetrahedrite (dark) rutile (pale),

(Contd.)

Table 2.4 : Streaks of some important minerals (*Concld.*)

Streak colour	Element/Mineral
Brownish red	Cuprite (shining), hematite, manganite
Brownish yellow	Goethite
Red	Cinnabar, pyrargynite (dark), hematite
Orange-red	Realgar
Orange-yellow	Crocoite
Yellow	Orpiment (pale), vanadinite
Green	Malachite (pale), vivianite (very pale)
Blue	Azurite, Lazurite
Purple	Vivianite

(iii) Luster : Luster is a measure of the reflectivity of the mineral surface and varies in degree and quality. Luster is described as dull, feeble, brilliant, and splendent. Other terms used to describe luster are adamantine, resinous, pearly, vitreous, silky, metallic, etc., which are self-explanatory[6].

(iv) Hardness : Hardness is the resistance to abrasion and is expressed on the Moh's scale given in Table 2.5.

Table 2.5 : Hardness chart

Mineral	Hardness on Moh's scale
Talc	1
Gypsum	2
Calcite	3
Fluorite	4
Apatite	5
Felspar	6
Quartz	7
Topaz	8
Corundum	9
Diamond	10

The following rough scale can also be used effectively in the field :

2 - 2.5	can be scratched by	fingernail
3 - 3.5	-do-	copper coin
5.5	-do-	glass, knife blade
6	-do-	amblygonite
6.5	-do-	vesuvianite
7	-do-	file

(v) Habit : Habit defines the size and shape of the crystal, and the structure and form taken by the aggregates. Crystals may be referred to as tabular (mica), prismatic (quartz), or acicular (kyanite), depending on the ratio of length to thickness. Aggregates may be radiating (stibnite), fibrous (asbestos), bladed (mica), columnar (quartz), granular (hematite), etc. Minerals without any crystal form but showing circular outlines are described as colloform. Other terms in use are botryoidal (iron ore), reniform, etc.[6]

(vi) <u>Fusibility</u> : This measures the ability of the minerals to melt. A scale showing the ease of the melting of various minerals is given in Table 2.6.

Table 2.6 : Scale of fusibility

Mineral	Melting point, °C
Stibnite	525
Natrolite (chalcopyrite)	965
Almandite garnet	1,200
Orthoclase	1,200
Actinolite	1,296
Bronzite	1,380
Quartz	1,600

(vii) <u>Cleavage and fracture</u> : When a mineral is broken, it splits along a crystal plane or an irregular surface. When the fracture occurs along a crystal plane, it is called cleavage and is described as indistinct, poor, good, perfect or eminent. When the breaking is not along a regular plane, it is described as a fracture. Fracture is described as uneven, hackly, splintery, fibrous, earthy or conchoidal[6]. Some common types of fractures[9] shown by the most typical minerals are given in Table 2.7.

Table 2.7 : Types of mineral fractures

Fracture	Mineral
Conchoidal	Obsedian, flint, chalcocite, sphalerite, quartz, halite
Subconchoidal	Rutile, stibnite, argentite, cordierite, staurolite
Even	Galena
Uneven	Cinnabar, millerite, chalcopyrite
Hackly	Native iron

(viii) Tenacity : Tenacity measures the ease with which a mineral breaks and is described below[6] for some minerals :

Tenacity	Mineral
Brittle	Calcite
Sectile	Gypsum
Malleable	Native gold and silver
Flexible	Talc

The criteria described above have to be studied for recognising the individual minerals. A combination of serveral criteria is necessary to identify a mineral properly. There are, however, some ores and minerals which can be identified by a single criterion. A chart showing the characteristics of some important mineral is given in Appendix-2.1.

2.1.3 Importance of mineralogical characteristics

(i) Grain size : The classification of any material according to the size of occurrence or the size to which they need to be crushed or pulverised is very important and, therefore, the sizes have to be described with precision.

The particle sizes of some of the naturally occurring material are given in Table 2.8.

Table 2.8 : Size ranges of naturally occurring materials

Main classification	Secondary classification	Diameter in mm	Example
Gravel	Boulder	256	Conglomerate
-do-	Cobble	256 to 64	-do-
-do-	Pebble	64 to 4	-do-
-do-	Granule	4 to 2	-do-
Sand	Very coarse	2 to 1	Sandstone
-do-	Coarse	1 to 0.5	-do-

(Contd.)

Table 2.8 : Size ranges of naturally occurring materials (*Concld.*)

Main classification	Secondary classification	Diameter in mm	Example
Sand	Medium	0.5 to 0.25	Sandstone
-do-	Fine	0.25 to 0.125	-do-
-do-	Very fine	0.125 to 0.062	-do-
Silt	--	0.062 to 0.005	Siltstone
Clay	--	<0.005	Shale

In the case of pulverised material, there are standard sieve sizes as per the British Standard or the A.S.T.M. Standard or the Indian Standard. All of these specifications in terms of mesh sizes are not always common in all. Therefore, it is essential to know in inches or in millimetres the exact specifications and standard tables[10] for the same (see Table 2.9).

The grain sizes are of great significance in the beneficiation tests. Normally, the microscopic size varies from 0.001 to -0.25 mm whereas the megascopic sizes range from +0.25 to 100 mm or 150 mm which could be identified by a magnifying lens. The effect of grain size has a great bearing on the method of beneficiation. According to Rehwald, the best results under various methods are expected at the following grain sizes[11].

Method of beneficiation	Best result at grain size, in mm
(1) Heavy media up to specific gravity of the medium (water, salt bath, etc.) being 5.2	2.0 to 10
(2) Heavy media solutions	10.0 to 80.0
(3) Jigging	1.0 to 25.0
(4) Tabling	0.1 to 2.5
(5) Humphrey spiral	0.1 to 1.0
(6) Cyclone	0.5 to 3.0

Table — 2.9 : Comparison of Testing Screen

A. TYLER STANDARD

Mesh	Aperture size Inches	Aperture size mm	Mesh double series
	.312	7.925	2½
3	.263	6.680	
	.221	5.613	3½
4	.165	4.699	6
6	.131	3.327	
	.110	2.794	7
8	.093	2.362	
	.078	1.981	9
10	.065	1.651	
	.055	1.397	12
14	.046	1.160	
	.039	.991	16
20	.0320	.833	
	.0276	.701	24
28	.0232	.560	
	.0195	.495	32
35	.0164	.417	
	.0138	.351	42
48	.0116	.295	
	.0097	.246	60
65	.0082	.200	
	.0069	.175	80
100	.0058	.147	
	.0049	.124	115
150	.0041	.104	
	.0035	.088	170
200 (BASE)	.0029	.074 (or 74 MICRONS)	
	.0024	.061	250
270	.0021	.053	
	.0017	.043	325
400	.0015	.037	
↑	↑	↑	

B. BRITISH STANDARD

Mesh	Aperture size Inches	Aperture size mm	Tolerance %
5	.1320	3.34	3
6	.1107	2.81	3
7	.0949	2.41	3
8	.0810	2.05	3
10	.0660	1.67	3
12	.0553	1.40	3
14	.0474	1.20	3
16	.0395	1.00	3
18	.0336	.85	5
22	.0275	.70	5
25	.0236	.60	5
30	.0197	.50	5
36	.0166	.421	5
44	.0139	.353	5
52	.0116	.295	6
60	.0099	.252	6
72	.0083	.211	6
85	.0070	.177	6
100	.0060	.152	6
128	.0049	.125	6
150	.0041	.105	8
170	.0035	.088	8
200	.0030	.076	8
240	.0026	.066	8
300	.0021	.063	8

	Method of beneficiation	Best result at grain size, in mm
(7)	Magnetic concentration	0.075 to 75.0
(8)	Electrostatic separation	0.10 to 2.5
(9)	Froth flotation	0.01 to 0.25

The above table emphasises the importance of the grain size of the mineral to which the ore has to be ground for making it suitable for beneficiation by various methods.

(ii) <u>Mineralogical identification</u> : Mineralogical identification is of great importance not only in the initial stages of prospecting and exploration but more so in the intricate process of mineral beneficiation whenever such beneficiation is called for. For example, in the case of asbestos, there are several varieties, the most important being chrysotile. The other varieties are the members of amphibole group. Though all are fibrous silicates, non-cumbustible, acid resistant and non-conducting, chrysotile is of utmost importance for commercial purposes. Similarly, the general term bauxite may cover both monohydrate and tri-hydrate ore minerals either as boehmite and diaspore or gibsite. The mineralogy of bauxite and the loss on ignition as per the chemical composition are stated to be related. An exploration geologist has to pay special attention to the ore mineralogy of bauxite as it is of great significance in the production of alumina.

Similarly, in the case of chromites, though they are spinels with the general composition of $FeCr_2O_4$, some are rich in iron and in some others magnesium replaces iron. A combination of exact chemical and mineralogical analysis will indicate whether chromite can give a grade with the desired Cr/Fe ratio.

In the case of iron ores, it is well-known that the tolerance of FeO which is the index of magnetite content (Fe_3O_4) in the otherwise hematite (Fe_2O_3) ore is very important and the presence of hydroxide minerals such as limonite and goethite is [redacted] considered deleterious. It is a different matter with magnetite ores susceptible for gravity. Magnetic separation can be worked on magnetite iron ores. Similarly, if there are deposits of mainly limonite and goethite ores, it will be possible to work them as direct pelletising ores by simply driving out the L.O.I. and enriching the ores.

Similarly, it is important to know whether the zinc ores are of gahnite (aluminate) or sphalerite (sulphide), lead ores are of galena (sulphide) or cerussite (carbonate), titanium ores are of rutile or ilmenite minerals, etc.

The intricacies of mineralogy play a very important role and the above types of instances in respect of all the ore minerals have to be borne in mind. In fact, the ore mineralogy applied to ore beneficiation is a vast discipline by itself, and a basic knowledge will be of help to exploration geologists.

(iii) Molecular composition of ore minerals : Any exploration geologist should be conversant with the molecular proportion of the chemical elements in the minerals he is handling. For example, hematite analyses theoretically up to 70 percent Fe, whereas magnetite analyses 72.4 percent Fe. In base metals, chalcopyrite analyses 34.5 percent Cu and cuprite 88.8 percent Cu. These factors also indicate that, in the physical processes of beneficiation, in no case can there be a concentrate giving assay values more than the maximum theoretical assay in pure ore mineral. Such practical factors in respect of important minerals should be familiar to an exploration geologist.

Another aspect of molecular proportion and their application is to work out the possible combination of protoxides, dioxides or sesquioxides, etc., depending upon the analytical results available. For example, if FeO is available, its equivalent of magnetite mineral in the ore may have to be worked out. Similarly, depnding upon the amount of sulphur and zinc shown in the chemical analysis of zinc ore, it is necessary to work out how much of sulphur is available for zinc to constitute zinc sulphide and the remaining zinc, if any, will have to be set-off against oxide or carbonate ore minerals as the case may be. Similarly, the L.O.I. mav be an index of whether the bauxite ore has more of monohydrate or trihydrate minerals.

The construction of the molecular composition based on assay values (taking the help of the atomic weights of elements) in order to understand the mineralogical composition should prove a worthwhile exercise for any exploration geologist. Atomic weights of most elements are given in Appendix-2.2. One should also know the factors for converting chemical composition into mineralogical values by the application of factors established on molecular proportions, for example :

P	X	2.291	:	P_2O_5
Fe	X	1.429	:	Fe_2O_3
Mn	X	1.291	:	MnO_2
FeO	X	3.22	:	Fe_3O_4

(iv) Specific gravity of minerals : The specific gravity of a mineral is one of the important criteria for its identification. The applied aspects of specific gravity in exploration geology and in the proper evaluation of tonnage, beneficiation possibilities, etc. are also of great importance.

The *in situ* bulk density (true specific gravity) is the sum total of the weighted average specific gravities of all the minerals present, weighted by the proportion in which the different minerals are present. Therefore, except while dealing with a monomineral deposit (without any gangue or associated minerals, which is rare) in all other cases the bulk density has to be determined. Besides, the word bulk density connotes specific gravity corrected for porosity voids, joints, etc. The specific gravity method is long and tedious. The best practical approach is to determine how much a specific volume of the material weighs and then determine the volume to weight ratio directly. For example, if an accurately measured one cu.m. of ore *in situ* is taken out and weighs 3 tonnes, the bulk density of the material would be 3.

To determine the specific gravity of dense and non-porous rocks like igneous and metamorphic rocks, a Walker's Steelyard balance is used. In other cases such as bauxite, sandstone, etc. which are porous, the specific gravity is determined by applying wax on the specimen and using a steelyard balance. However, a pycnometer is used for determining the true specific gravity of porous material.

In multi-metal ores having highly variable specific gravity of ore minerals such as chalcopyrite and galena (4.2 and 7.5), it would be very essential to find out the proportion of the minerals present in the ore and then apply the respective specific gravities for the two ore minerals and a common specific gravity for all the gangue minerals so that the bulk density for the ore as a whole can represent a weighted average. Unless duly weighted to the proportion of minerals of varying specific gravities, the tonnage factor adopted will not be accurate.

It will be useful to have ready-made tables (e.g. Table 2.10) so that an idea of what tonnage factor is to be considered for ores of different specific gravities could be ascertained. Table 2.10 shows the tonnage factor to be considered for various specific gravities at one percent base metal assay. This table can be conveniently used for varying percentages of assay or a combination of assays.

Table 2.10 : Tonnage factors for various specific gravities

Specific gravity	Tonnes of ore per cu.m.	kg. of base metal in cu.m.
2.5	2.5	25
3.0	3.0	30
3.5	3.5	35
4.0	4.0	40
4.5	4.5	45
5.0	5.0	50
5.5	5.5	55
6.0	6.0	60
6.5	6.5	65
7.0	7.0	70
7.5	7.5	75

2.1.4 Formation of rocks and mineral deposits

In the lithosphere, there are three major processes which are responsible for the formation of rocks and mineral deposits. They are (i) magmatism, (ii) sedimentation, and (iii) metamorphism.

These three processes give rise to three major groups of rocks[12], respectively, viz.

(1) igneous rocks,
(2) sedimentary rocks, and
(3) metamorphic rocks.

Since most of the mineral deposits are associated genetically with these three types of rocks, a study and understanding of these rocks is indispensable in any exploration effort.

(i) Igneous rocks : All igneous rocks have formed from molten magma. Varying conditions of genesis, coupled with varying chemical and mineralogical composition of the magmas have been instrumental in producing various types of rocks. Igneous rocks have been classified on the basis of chemical composition, crystallization, mineral composition, genesis, etc. and are somewhat specialised in content. The classification shown in Table 2.11 based on texture, mineral content, and chemical composition of individual rocks is ideally suited for the needs of exploration geologists[13].

Methods of studying and recording igneous rocks in the field : In studying igneous rocks, it is important to follow a set routine, so that their identification becomes easy, particularly in the field. Broadly, igneous rocks may be either (a) intrusive, or (b) extrusive.

(a) Intrusive igneous rocks : The following sequence of observations, with the accompanying terminology may be used in studying and reporting intrusive igneous rocks[14].

(i)	Dimensions	- Shape and structural relationship to adjacent rocks.
(ii)	Contacts	- Sharp, transitional, shape (plane, undulating, grooved, irregular with dimensions of irregularities), structure (jointing, faulting, brecciation) metamorphism (width of zone, mineralisation, texture, attitude strike, dip, etc.)
(iii)	Colour	- Wet, dry, fresh, weathered conditions.
(iv)	Composition	- Minerals recognisable with hand lens and their estimated proportions, estimated composition and proportion of ground mass
(v)	Texture	- Degree of crystallisation, porphyrite, equigranular, etc.

*Table 2.11 : Classification of igneous rocks

TEXTURE	Excess of light colored minerals				Excess of dark colored minerals			
Glassy	Obsidian, perlite, pumice, pitchstone				Scorias, trachylyte, basalt-obsidian			
	Feldspar orthoclase		Feldspar.		Plagioclase		No feldspar	
	Mica (and) or hornblende (and) or augite		Mica (and) or hornblende		With pyroxene		augite (and) or hornblende (and) or mica	
	+quartz	-quartz	+quartz	-quartz	+olivine	-olivine	+olivine	-olivine
Dense	rhyolite	trachite	dacite (felsite)	andesite (felsite)	basalt			augitite or hornblendite
Porphyritic	rhyolite-porphyry	trachite-porphyry	dacite-porphyry	andesite-porphyry	basalt porphyry			augitite-porphyry
Granitoid	granite	syenite	quartz-diorite	diorite	olivine-gabbro	gabbro	peridotite	pyroxenite
Fragmental	rhyolite, tuff or breccia	trachite, tuff or breccia	dacite, tuff or breccia	andesite, tuff or breccia		Basalt tuffs and breccias		

*REPRODUCED WITH THE KIND PERMISSION OF G.P.PUTNAM & SONS, NEW YORK, EXTRACTED FROM FIELD BOOK OF COMMON ROCKS AND MINERALS, REVISED EDITION BY F.B.LOOMIS, 1948.

(vi) Structure - Platy or linear with attitudes, columnar jointing, flow perlitic, spherulitic, orbicular, gneissic or other.

(vii) Hardness - Friability, partings.

(viii) Erosion and weathering products.

(ix) Interpretation as to the mode of emplacement, e.g. hydrothermal or other.

(b) <u>Extrusive igneous rocks</u> : In studying and reporting extrusive igneous rocks, the following sequence may be employed :

(i) Dimensions - Width, length, thickness.

(ii) Shape or variation in dimensions.

(iii) Relation to overlying or underlying adjacent formations.

(iv) Contacts, top and bottom (described pre-existing surface, textural differences, etc.), fault, overlap, attitude, alteration effects.

(v) Type of accumulation - Pyroclastic or flow (viscous liquid breccia flow) reworking by wind or water.

By sequential recording of data under the headings discussed above and systematic correlation and analysis, full or partial identification of most of the igneous rocks is possible. Where precise determinations are required, studies of thin sections will have to be undertaken. It should, however, be well understood that an exploration geologist's interest in igneous rocks is not purely petrological. Since various economic minerals are associated with igneous rocks, the primary aim should be to locate minerals which form economic deposits.

<u>Criteria for recognition of igneous rocks in the field</u> : Table 2.11 classifies the igneous rocks rather broadly. There are several other rocks with intermediary compositions. Identification of rocks in the field is very important. Some of the criteria which help in identifying the major rock units in the field are given below :

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(a) Granite : Minerals - felspar, quartz, with minor minerals like biotite, hornblende, magnetite, etc. Minerals are easily seen with the naked eye. Minerals may be intergrown. The rock is light in colour and weight[15]. Granite is generally hard and tough[16]. Common economic mineral deposits are cassiterite, wolframite, etc.

(b) Pegmatite : Minerals - felspar, quartz, muscovite. Very coarse grains. Minerals show intergrowth texture. Pegmatites are light in colour as well as weight[16]. They occur in a vein-like pattern. The economic mineral deposits associated with pegmatites are mica, quartz, felspar, tourmaline, beryl, etc.

(c) Granite porphyry : This rock has a granite ground mass, but has phenocrysts of felspar, quartz, etc.[17]

(d) Monzonite : Minerals - felspar, biotite, hornblende and pyroxene. The minerals are mutually intergrown and are visible to the naked eye. The rock is light coloured and light in weight[16]. The economic mineral deposits associated with granite porphyry and monzonite are copper, lead, zinc, gold, etc.[3]

(e) Syenite : Minerals - felspar, biotite and hornblende. They are visible to the naked eye, and are intergrown. The rock is light in colour and weight[16]. Sometimes they form porphyries with phenocrysts of felspars. When syenite contains nepheline mineral , it is called nepheline-syenite. Corundum deposits show genetic relationship with nepheline-syenite.

(f) Diorite : Minerals - amphiboles, biotite or pyroxenes, plagioclase, felspars. This rock is gray or dull green in colour[17].

(g) Gabbro : Minerals - felspar,pyroxene, hornblende, and olivine. Mutually intergrown minerals are visible to the naked eye. In colour, the rock is dark and of heavy weight[16]. Gabbro and anorthosite show economic concentrations of titaniferous magnetite, magnetite and ilmenite[3].

(h) Peridotite : Minerals composed of olivine,pyroxene and hornblende, and are visible to the naked eye and exhibit mutual intergrowth. The rock is usually dark in colour and heavy in weight[16]. Peridotites occur as intrusives[17]. Diamonds occur in kimberlite, a variety of peridotite. Other deposits are of platinum and chromite.

(i) Basalt : Minerals composed of pyroxene and olivine and are not visible to the naked eye. The rock is dark gray to black in colour and cannot be split into layers. It occurs as lava flows, dykes and sills[17].

Mineral deposits associated with igneous processes: During the course of emplacement of magma, various minor and accessory constituents start getting progressively concentrated till a stage is reached when the end product is rich in some constituent which under favourable conditions gives rise to economic mineral deposits. These favourable conditions are generated by three processes :

(a) magmatic concentration

(b) contact metasomatism

(c) hydrothermal process

(a) Magmatic concentration : Magmatic concentration occurs as a result of simple crystallisation, or concentration by differentiation of intrusive igneous rocks. Deposits of this type are typically associated with intermediate and deep-seated intrusive igneous rocks. Two stages of magmatic concentration have been recognised, viz. (i) early magmatic and (ii) late magmatic[3].

(i) Early magmatic : Here, the important processes are dissemination, segregation and injection. Dissemination is simple crystallisation without any concentration. Diamond-bearing kimberlites are formed by this process. Segregation is the process of crystallisation,differentiation,and accumulation. Chromité and corundum deposits are formed this way[3].

(ii) Late magmatic : Here, the important processes are residual liquid segregation, residual liquid injection, immiscible liquid segregation,and immiscible liquid injection. Residual liquid segregation is a process of crystallisation,differentiation,and residual magma accumulation. Platinum and certain types of iron ores are formed this way. Residual liquid injection is a process of filter pressing and injection. Mica pegmatites and some types of magnetitic and titaniferous magnetitic iron ores are formed this way. Immiscible liquid is separated and accumulated. Immiscible liquid injection is basically a process of injection. Chromite and magnesite deposits are formed this way[3].

(b) Contact metasomatism : During the consolidation of a magma, high temperature gases emanate from it. These gases usually contain certain mineral matter in gaseous form. When these gases travel through various rocks which are already existing, metamorphism and metasomatism (high temperature replacement) take place. Certain rocks are particularly amenable to these chemical reactions and such favourable rocks become a preferred target for the accumulation of economic mineral deposits. The effect of this reaction is to crush and chemically transform the already existing minerals into new forms. By this process of contact metasomatism, limestone and dolomite become marble, carbonaceous matter becomes graphite and sandstone becomes quartzite[3].

All magmas do not give rise to conditions of contact metasomatism. It is exclusively associated with intrusive magmas, which give rise to intrusive bodies like stocks and batholiths. Rocks which give rise to contact metasomatism have generally a granular ground mass which indicate a slow cooling of the magma[3].

Rocks which are most susceptible to contact metasomatism are pure limestones, dolomites and also limestones with impurities like silica, alumina, iron, manganese, etc. Any rock structure like cleavage, bedding plane, joints, fracture systems, etc. accelerate the invading process[3].

Mineral deposits associated with contact metasomatism are relatively small in size, irregular in shape, and the most difficult to locate in the field. Since deposits of this type occur near intrusive bodies of granular ground mass, and mostly in impure calcareous rocks, these two criteria can be used in locating them. The most typical field evidence for locating contact metasomatic deposits are chilled borders, evidence of dolomitisation, effects of baking, hardening, partial or full recrystallisation near contacts.

Economic mineral deposits are formed when the contact metasomatism takes place due to intrusions of quartz monzonite, monzonite, granodiorite, diorite, etc.

The common deposits which result are iron, copper, zinc, lead, tin, tungsten, molybdenum, emery, garnets, and corundum.

(c) Hydrothermal Process : The end product of the emplacement of magma is a fluid which generally carries metals in solution. These liquids get injected into the country rocks which offer the maximum pore spaces and other openings like fracture and fault planes. By the processes of cavity filling and replacement, various mineral deposits of economic importance are formed. Various stages of mineralisation are recognised in the hydrothermal process. The three stages most commonly recognised are (i) hypothermal, (ii) mesothermal, and (iii) epithermal. These stages have been recognised on the basis of certain distinct temperature and pressure conditions accompanying the formation of minerals[3].

Hydrothermal deposits are formed under certain optimal conditions such as (i) the availability of mineralising solutions capable of dissolving and transporting mineral matter, (ii) the availability of openings in the rocks through which the solutions may be channelised, (iii) the availability of sites for the deposition of mineral content, (iv) chemical reactions promoting the formation of deposits, and (v) sufficiently concentrated mineral matter to form a workable deposit[3].

The processes give rise to the following types of deposits[3]: (i) fissure veins, (ii) shear zone deposits, (iii) stock works, (iv) saddle reefs, (v) ladder veins, (vi) pitches and flats, (vii) breccia fillings, (viii) solution cavity fillings, (ix) pore space fillings, and (x) vesicular fillings.

In hydrothermal deposits also, there are no distinct ore to rock associations which could help recognize the deposits in the field. However, the combination of shear zones and intrusive igneous ore bodies nearby provides good enough indications for ore search. Typical field guides for locating hydrothermal mineralisation are alteration haloes, serecitisation, argillic alteration, silicification and serpentinisation which are readily visible on the ground.

(ii) Sedimentary rocks : The sedimentary or detrital rocks are those formed by the deposition of solid materials carried in suspension by the agencies of transport[12]. A number of different sedimentary rock units can be recognised.

Weathering of rocks produces soluble and insoluble components. The soluble products, like calcium, magnesium, etc. are carried away in solution. The solids are transported by water, wind, etc. Deposition of the soluble components takes place when the carrying solutions reach the point of chemical saturation usually in bodies of water which are relatively calm. The process of precipitation may be augmented by the presence of bacteria. Deposits of iron and manganese are thought to have resulted by this process. However, the most common deposits are rocks like limestone and dolomite.

The solids wear down to small sizes. When the transporting medium loses its natural velocity, deposition takes place. The resulting rocks may be sandstone, shale, siltstone, etc. Mineral deposits of economic value are found in some of these rock types, but without any known genetic link. However, placer deposits are byproducts of the process of sedimentation.

Table 2.12 shows one classification of sedimentary rocks[13]. For more precise classification, the reader may refer to standard books on the subject.

Table 2.12 : Classification of sedimentary rocks

Rock type	Inorganic	Organic
(1) Talus	Coarse fragmentary material resulting from weathering	(1) Lime made from shells - coquina, chalk, coral rock, etc.
(2) Breccia	The above cemented	(2) Silica from the shells of plants diatomaceous earth, etc.
(3) Soil	Unsorted material resulting from rock weathering	(3) Carbon from plants, peat, lignite, coal, etc.
(4) Gravel	Coarse fragments rounded by the action of water and wind	(4) Hydrocarbons from animals - petroleum asphalt, amber, etc.
(5) Conglo-merate	The same material cemented	(5) Phosphates from animals - Guano, phosphate rocks, etc.

(Contd.)

Table 2.12 : Classification of sedimentary rocks (*Concld.*)

Rock type	Inorganic	Organic
(6) Sand	Finer material deposited by water or wind	
(7) Sandstone	The same material cemented	
(8) Clay	The finest material mostly kaolin, deposited by water	
(9) Loess	The finest material deposited by wind	
(10) Shale	The same material cemented	
(11) Marl	Fine particles of lime, pure or impure	
(12) Limestone	The same material cemented	
(13) Till	Unsorted material left by glacial ice	
(14) Tillite	The same material cemented	

Methods of studying and recording sedimentary rocks in the field : In studying and reporting sedimentary rocks in the field, the following sequence and terminology may be adopted[14] :

(a) External form of the rock unit : lenticular persistent, very regular in thickness, etc. dimensions, relation to overlying or underlying units.

(b) Colour : Colour of the unit as a whole; wet or dry colour of individual particles.

(c) Bedding :

(i) How menifest, sharp by parting, by difference in texture, colour, etc. transitional, shaly.

(ii) Shape of bedding surface, plane, undulating, ripple marks, etc. irregular, if not plane; record details of form and dimensions of features.

(iii) Thickness of beds : comparative thickness, different orders. Relation of thicknesses, rhythmic, random, etc. If variable, relation between thickness and composition, bedding, etc.

(iv) Attitude and direction of bedding surface : horizontal, inclined, curved. Relation to each other; parallel, intersecting, tangential; angles between different attitudes and directions, dips, strikes, dimensions, relation of size, composition, shape, etc. to attitude and direction; relation of composition to different types of bedding.

(v) Markings of bedding surface : mud cracks, rain prints, bubble impressions, ice crystal impressions, trails, footprints, etc.

(vi) Disturbances of bedding : edge-wise or intraformational conglomerates, folding or crumbling of individual beds before consolidation.

Criteria for recognizing sedimentary rocks in the field : The more common sedimentary rocks are (a) sandstone, (b) limestone, (c) shale, and (d) conglomerate. They are identified in the field as follows :

(a) Sandstone : Mineral - quartz[16], cemented together by silica, lime or iron oxide[17]. Coarse sandstone grades into conglomerate whereas fine sandstone grades into sandy shale[12]. Sandstones may show fossil ripple marks[17].

(b) Limestone : Mineral - calcite; individual grains are invisible to the naked eye, stony appearance. Effervescence given in the acid test[16].

(c) Shale : Mineral - clay; individual grains are invisible to the naked eye. Stony appearance, can be split into layers.

(d) Conglomerate : Minerals - quartz, felspars and various other rock and mineral pieces; individual minerals can be easily identified with the naked eye. The grains have normally varied sizes and shapes. Sand fillings or some other matrix can be seen between the grains[16].

There are various intermediary varieties and other sedimentary rocks.

Mineral deposits associated with sedimentary processes : Two major ore forming processes are involved in this. They are (a) sedimentation and (b) evaporation. Besides, the processes of sedimentation are manifest in the formation of placer and certain residual deposits. These will not, however, be considered here.

(a) Sedimentation : Sedimentation involves various processes. First, the raw materials are gathered from various sources by water. They, are transported to the site of accumulation,usually a basin, where the materials are laid down. Compaction, diagenesis and chemical alteration follow, giving rise to mineral deposits[3].

All rocks contain elements like iron, copper, manganese, etc. in varying proportions and in combination with other compounds. These elements are released from their parent rock during weathering.

Solutions charged with carbonic acid, humic or other organic acids react on the rocks and dissolve various elements. Certain minerals like clay which are not chemically active, are carried away in suspension. The water containing such solutions and suspensions remain stable so long as there is no change in their physical and chemical environment. As soon as there are some changes in the above conditions, the dissolved elements precipitate and are deposited on the floor of the basin. There are also bodies of water which are fed by mineralising solutions like fumeroles, hot springs, etc. A stage is reached when the dissolved minerals precipitate to form deposits.

(b) Evaporation : By a process of rapid evaporation also, the dissolved material can accumulate to form deposits. Such deposition is typical in arid and desert terrains.

Important mineral deposits formed by sedimentation include iron ore, manganese ore, copper ore, uranium ore,etc. and also industrial minerals like limestone, phosphorite, gypsum, salt, and clay.

(iii) Metamorphic rocks : Metamorphic rocks are those formed by the mineralogical and structural adjustment of solid rocks to new physical or chemical conditions, which have been imposed at depths below the surface zones of weathering and concentration and which differ from the conditions under which the rocks in question originated. They can be classified on the basis of the following features (a) mineralogical composition, (b) structure and texture, (c) chemical composition, and (d) field occurrence.

Four major metamorphic processes are recognised. These are :

(a) cataclastic metamorphism,

(b) thermal metamorphism,

(c) dynamothermal metamorphism, and

(d) plutonic metamorphism[4].

(a) Cataclastic metamorphism : In cataclastic metamorphism, the minerals are crushed and granulated through the development of small amounts of stress and low temperatures. The typical features produced by this process are crush-breccias, micro-breccias, mylonites,flow cleavage, fracture cleavage, strain-slip cleavage, etc., which help in recognising the phenomenon in the field.

(b) Thermal metamorphism : This is a phenomenon connected with the intrusion of large-scale igneous rock bodies. Metamorphic changes take place due to the heat of intrusion and tend to produce zones of alteration around the intrusives[4], which is an excellent criterion for recognising this process. The typical rocks produced by this process are hornfels. calc-silicate hornfels, quartz-hornfels, crystalline limestone, marble, serpentinous rocks, etc. Mineral deposits of economic value are asbestos, limestone, marble and graphite[9].

(c) Dynamothermal metamorphism : In this process, the rocks are re-crystallised and ions formed by directed pressure and heat. The rock produced are phyllite, mica schist, quartz schist, and gneisses[4]. Economic mineral deposits are soapstone, talc, sillimanite, kyanite and andalusite[9].

(d) Plutonic metamorphism : Changes take place in rocks due to the combined effect of great heat and uniform pressure, a typical condition of great depths. Typical products are granulites, leptites, leptynites and gneisses[4]

Methods of studying and recording metamorphic rocks in the field : The following sequence and terminology may be used in the study of metamorphic rocks in the field[14].

(a)	Type of metamorphism	:	Cataclastic, thermal, dynamo-thermal or plutonic.
(b)	Form and field name of the rock unit	:	Shape, lenticularity, regularity of thickness and shape, dimensions, etc.
(c)	Structural relation to adjacent formations	:	
(d)	Contacts	:	(i) How manifest : sharp, transitional, intrusive
			(ii) Shape of contacts : plane, undulating, grooved, irregular, record of dimensions
			(iii) Strike and dip
			(iv) Disturbances of contacts : intraformational conglomerates, brecciation, jointing, faulting, alteration
(e)	Colour	:	Colour of the mass as a whole; wet or dry, colour of individual parts on particle, inclusions
(f)	Composition	:	List of identifiable minerals and proportion of each; compositional banding, inclusions, lateral or vertical variations
(g)	Texture and structure	:	(i) Degree of crystallisation and granularity, porphyroblasts, relic phenocrysts or pebbles

(ii) Foliation, gneissic, schistose, slaty, banded, lenticular

(iii) Contortions of compositional bands or foliation

(iv) Relic textures and structures, ripple marks, spherulites, flow lines

(v) Lateral or vertical variations in texture and structure

(h) Hardness : Friability, flakiness, cases of parting due to foliation

(i) Erosion and weathering products.

Criteria for recognizing metamorphic rocks in the field : Some criteria which help identify a few of the metamorphic rocks in the field are given below :

(a) Hornfels : Nonschistose rock of equidimensional grains. Occur typically in contact aureoles

(b) Buchites : Partially-fused hornfelsic rocks occurring as zenoliths in basalts, diabases, etc.

(c) Slates : Fine-grained rocks with perfect planar schistosity but lacking in segregation banding

(d) Phyllites : Similar to slates, but grains are coarser. New mica and chlorite impart a lustrous sheen to schistosity

(e) Schists : Strongly schistose, commonly lineated metamorphic rocks in which the grains are coarse enough to allow microscopic identification of the component minerals

(f)	Gneisses	:	Coarse-grained irregularly banded rocks with discontinuous rather poorly defined schistosity. They are products of high grade regional metamorphism
(g)	Granulites	:	Even grained metamorphic rocks, poor in mica and rich in quartz, felspar, pyroxenes and garnet which lack a prismatic or tabular habit
(h)	Mylonites	:	Fine-grained, flinty-looking, strongly coherent, banded or streaked rocks resulting from extreme granulation of coarse-grained rocks without any special chemical composition
(i)	Cataclasites	:	These are rocks formed by ruptural deformation. Cataclasites may grade into mylonites
(j)	Phyllonites	:	These rocks resemble phyllites, but are formed by mechanical degradation of initially coarser rocks
(k)	Quartzites	:	Metamorphic rocks composed of recrystallized quartz. Quartzites are generally produced by regional metamorphism of sandstones
(l)	Marbles	:	Marbles are produced by the regional metamorphism of calcareous sediments. The rock is composed of calcite or dolomite
(m)	Amphibolites	:	Metamorphic rocks composed of hornblende or plagioclase
(n)	Serpentinites and soapstones	:	Composed of serpentinous minerals, talc, chlorite, etc. and formed by metasomatism of peridotites[18]

Metamorphic processes and the resulting mineral deposits : The process of metamorphism may alter an old deposit and produce a new one or may act on any rock and produce deposit, provided the original minerals are conducive to such a transformation. The source rocks undergo recrystallisation or recombination or both. The major deposits produced by metamorphism are asbestos, graphite, talc, soapstone, sillimanite, kyanite, garnet, etc.[3]

Most mineral deposits which are formed by metamorphism are in the form of whole rocks like marble or in lenticular, linear concentrations like soapstone, asbestos, etc. These deposits can form from any favourable source rock and hence do not generally show any rock to ore deposit association or give any clear field evidence for their location.

(iv) Other ore forming processes and the resulting deposits :. Apart from those discussed above, there are two other processes which have given rise to important mineral deposits. These are :

(1) Mechanical and residual concentration, and

(2) Oxidation and supergene enrichment.

(1) Mechanical and residual concentration : Due to the continuous action of weathering agents, rocks are desintegrated mechanically and decomposed chemically. Unstable minerals like felspars, pyroxenes, amphiboles, etc., are chemically altered, and the compounds are dissolved and transported by water and wind. Stable minerals like quartz, gold, etc. are not transformed chemically but are, nevertheless, prized out of their enclosing matrix. Due to the continuing action of transporting agents like running water and wind, these particles get worn down to very small sizes and are transported to great distances. Deep and continuous weathering offers very large quantities of products both in the form of mechanical fragments and in the dissolved chemical form. The net result of the action of weathering and transportation is the creation of two types of mineral deposits known as

(i) residual concentrations, and

(ii) mechanical concentrations (placer formation[3]).

(i) Residual concentration : When due to weathering and transportation, various rock constituents are removed, the residues which have not suffered any transportation accumulate till they attain sufficient concentration, purity and size to form a mineral deposit. Naturally, certain pre-conditions are necessary for their formation, i.e. a rock containing valuable minerals, favourable climate, conditions of chemical decay and a mode of selective transportation where only the undesirable constituents are washed off. Mineral deposits which have formed by this process include iron ore, manganese, bauxite, clay, nickel, phosphate, barytes, tin, ochre, etc.[3].

(ii) Mechanical concentration : Mechanical concentration is basically a physical separation of the lighter constituents from heavier constituents accomplished by running water or moving air. Such a concentration takes place in two stages, viz. weathering and separation of stable minerals from their matrix and their concentration. The minerals involved in this process may come from the already existing mineral deposits or from rocks which contain some valuable mineral constituents in a very disseminated form. The resulting deposits are known as placer deposits which may be of four types, viz. (a) eluvial placers, (b) stream or alluvial placers, (c) beach placers, and (d) eolian placers[3].

(a) Eluvial placers : Eluvial placers are formed on hill slopes. Material released from outcrops upslope is roughly sorted, the heavier staying close to the outcrop and the lighter moving downhill. Some field guides to locate such deposits are : areas of breaks in the slope, hillside talus, scree accumulations, etc. Important deposits of tin, gold, iron and manganese are formed by this way.

(b) Alluvial placers (stream placers) : Minerals and rocks released during weathering are transported down-stream by rivers and streams. During floods, the material is carried rapidly downstream. Whenever there is a fall in the velocity of water, the heavy minerals settle down. A sufficient concentration of one mineral ultimately gives rise to an important mineral deposit. Such deposits are formed in meander bends and near natural obstructions in the stream course. Placer deposits of gold and diamond are formed in this way. Some field guides to locate such deposits are: meander bends, stream junctions, alluvial fans, cones, accumulation near points of a sudden drop in velocity, etc.

(c) Beach placer : By the action of wave and shore action, placers are formed along seashores. Sorting of heavy and light minerals takes place due to wave action. Deposits formed this way include gold, ilmenite, magnetite, monazite, diamonds, etc.[3]. Some field guides are: unusual colouration in a beach sand, sparkle and scintillation effects in reflected sunlight, etc.

(d) Eolian placers : These are formed in arid regions. The material released during weathering is carried away by wind action and sorted during transportation. When the wind current meets with an obstruction, the heavy minerals settle down. Economic deposits of gypsum found in Rajasthan desert are formed in this way.

2. Oxidation and enrichment : Mineral deposits get exposed to the atmospheric action as a result of weathering. Surface water oxidises the outcrops yielding solvents which in turn dissolve other ores. This process takes place up to the top of the water table. If the solutions penetrate the water table, their metallic content gets precipitated and rich secondary ores develop. Both oxidation and enrichment have produced big deposits of base metals.

Important products produced by the oxidation of primary ore deposits are listed in Table 2.13.

Table 2.13 : Important products of the oxidation of ore deposits

Metal	Original composition	Oxidized product
Iron	Sulphides	Hematite, limonite sulphate
	Carbonates	Limonite, ferric hydroxide
	Oxide	Hydrous ferric oxide
Copper	Sulphides	Carbonates, oxides, native copper, silicate
Zinc	Sulphides	Carbonate, silicate
Lead	Sulphide	Sulphate, carbonate
Tin	Oxide or sulphide	Oxide
Aluminium	Silicate	Oxide, silicate

Guides to locate these ores are: presence of gossans, cappings, zone of leaching, limonitic caps, etc.

Gossans have a high diagnostic value for the buried mineral deposits. Some of the diagnostic features of gossans are listed below :

	Nature of gossan	Nature of deposit
(a)	Form and size	Generally the outcrop faithfully outlines the shape of orebody
(b)	Collapsed gossan, voids in gossan	
	(i) Abundant	Sulphides
	(ii) Shape	If square, galena, pyrites in protore
	(iii) No void	No important deposit likely
(c)	Colour of limonite	
	(i) Seal brown, maroon, orange, etc.	Copper
	(ii) Yellow, brick red	Pyrite
	(iii) Deep brown/brick red, yellowish	Chalcopyrite
	(iv) Chocolate	Bornite
	(v) Deep maroon	Chalcocite
	(vi) Tan to brown	Sphalerite
	(vii) Orange	Galena
(d)	Type of box work	
	(i) Coarse, cellular with blebs, masses, coarse and angular walls	Chalcopyrite
	(ii) Fine, cellular, thin, small, friable walls specs, blebs	Bornite-chalcopyrite
	(iii) Coarse, cellular, siliceous, thin, rigid angular walls	Sphalerite

	Nature of gossan	Nature of deposit
(iv)	Cellular spongy	Sphalerite
(v)	Fine cellular, shrivelled	Sphalerite
(vi)	Triangular, crusted, curved	Bornite
(vii)	Porous	Chalcocite, covellite, bornite
(viii)	Pitchlike limonite, no cells	Chalcopyrite, bornite
(ix)	Limonite crusts	Chalcocite
(x)	Cleavage	Galena
(xi)	Diamond mesh	Galena
(xii)	Pyramidal	Galena
(xiii)	Foliated	Molybdenite

Similarly the very process of oxidation sometimes gives rise to secondary enrichment which accounts for rich sulphide deposits below the zone of oxidation. Criteria for the recognition of such enrichments are listed below:

(i)	Presence of vertical zoning	- Oxide - top followed by supergene sulphide enrichment and primary - protore
(ii)	Presence of gossans and capping	- as described above
(iii)	Mineralogy	- Sooty chalcocite, covellite, native silver, native gold, marcasite, etc. for sulphides and goethite, hematite for iron ore, pyrolusite and psilomelane for manganese

2.1.5 Some modern concepts in oregenesis

The processes discussed until now have been well accepted the world over for a fairly long time. However, concepts in oregenesis have been changing periodically. Emphasis has been shifting sometimes in favour of the epigenetic theory and sometimes in favour of the syngenetic theory. Various such periods are recognisable. The early theories seem to have been propounded by the Greeks, Romans, Arabs, Indians and Chinese. They did not lay emphasis uniformly on one concept or the other.

Basically, there are two trends of thought in ore-genesis[19]. One is the epigenetic theory which supports the notion that ore bodies were formed subsequent to the formation of the host rocks. This theory also postulates a genetic conception between intrusive igneous bodies and the nearby mineral deposits. As against this, there is another concept which supports the notion that orebodies are syngenetic, i.e. the orebodies were formed along with the host rocks[12]. However, neither of these two theories is entirely acceptable as newer theories support the view that many deposits are neither wholly syngenetic nor epigenetic.

A definite trend in favour of one of the other theories started with the 'congregationists' (1300-1500 AD) who believed that everything is congenetic. Then came the epigeneticists with Agricola (1494-1555) propounding the notion that fire is the cause of all mineralisation and that all mineralisation is epigenetic. Then came the neocongregationists led by Verner (1749-1807) who believed that water is the main agent of oregenesis but all oregenetic processes are syngenetic. Then, Von Lotta and Von Groddeck (1830-1890), who followed, tried to have a balanced view of things and emphasized observations, and geometric classification of various deposits. This was followed by the school of 'Posepeny' Lindgren and Niggli who thought that fire and water were the main oregenetic agents but most oregenetic processes were epigenetic.

The present tendency is to accept syngenesis as well as epigenesis as valid in their ocontexts but lays stress on the observational, geometric and geochemical nature of the deposit, for placing it in one group or the other. Broadly, the general view is that all congruent deposits are syngenetic and all non-congruent deposits are epigenetic[20].

Undoubtedly, there are a large number of proven cases which support the syngenetic as well as the epigenetic concepts. The occurrence of diamonds within ultrabasics is an example of the syngenetic concept. Similar clear-cut examples can be cited for the epigenetic concept also, such as deposits formed within fault planes and other structural features. However, between these two-clear-cut instances, there are a large number of cases which cannot be fitted to either one or the other theories without contradicting field evidences. The large number of base-metal, gold, and other deposits in India and the world over belonging particularly to the Precambrians, present problems which preclude their being demarcated either as distinctly syngenetic or clearly epigenetic according to the presently accepted criteria. The obvious conclusion is that few mineral deposits have any exclusive host rock association which is constant. Although these problems are essentially oregenetic, some knowledge of the various theories is of tremendous significance to exploration geologists.

Present oregenetic concepts do not view the process of mineralisation as an isolated incident in the earth's history as some of the earlier theories do, but as a part and parcel of the major processes responsible for the formation of rocks and their tectonic evolution. Many authorities have pointed out that there exists a close relationship between mineral provinces and the major belts of weakness and deformation in the earth's crust[21]. It is pointed out that the boundary between the Archaeans and the Cambrians form such a belt of weakness in all shield areas of the world, and this belt is noted for the occurrence of iron ore, gold and some base metal deposits. This phenomenon is true in the case of the Indian shield area also. The Indian iron ore (Iron Ore Series), the Singhbhum copper occurrence, the gold mineralisation of Kolar-Hutti belt, and the base metal mineralisation of the Aravalli-Delhi sequence, are all associated with this Archaean-Cambrian belts of weakness, containing greenstone schists and typical geosynclinal formations like greywackes[22,23]. Such zones are seats of ancient volcanic activity as evidenced by the various volcanic formations like lava flows included in the rock sequences. There would appear to be some connection between such volcanic activity and the dispersion of various mineral ore matter[21]. Many of the base metal, gold, iron ore and manganese ore deposits of India are located in areas of past volcanic activity and their association with volcanic-sedimentary rocks may not be purely coincidental.

This association is exemplified by the pattern of gold mineralisation in the Ramgiri area of the Kolar-Ramgiri-Hutti belt. In the Ramgiri area it has been proved that the original source of gold was the andesitic lava flows formed presumably in a geosynclinal sequence. During metamorphism induced by intrusive granites, fluids were given out which reconstituted the gold minerals from andesitic lavas and were then emplaced in the quartz bodies which form the host rock for mineralisation[24].

The orogenetic development is essentially confined to the geosynclinal areas. A typical orogeny starts with basic and ultrabasic volcanic activity with the development of large areas of serpentinisation at the bottom of geosynclinal troughs. The trough is progressively filled up with sediments and the geosynclines sink into the crust. The lower part of the geosyncline is now subjected to metasomatism, migmatisation and granitisation. Granites owing to their lower specific gravity rise within the geosynclines in the form of large plutons. Andesitic magmas rise to the surface in another cycle of volcanism which ultimately stabilises the last phase of orogeny[25].

As explained earlier in the case of gold mineralisation, mineral deposits tend to form initially within the volcanic rocks or near them in sediments originating from volcanic derivatives. The rise in temperature during the later part of orogeny which is marked by large-scale intrusion, can cause extensive metamorphism of geosynclinal rocks. This metamorphism produces ore fluids within the rocks which cause ore migration, reconcentration and also metamorphism of ore deposits. This re-mobilisation often causes wall-rock alterations, metasomatism and replacement which are compellingly similar to the characteristics of genuine hydrothermal processes. Mineral deposits resulting from volcanic-geosynclinal association are called volcanic sedimentary-exhalative deposits or simply exhalative sedimentary deposits[21].

It is thus evident that genuine hydrothermal deposits and some volcanogenic sedimentary exhalative deposits sometimes offer similar field evidences and it is necessary that there should be some criteria to distinguish them.

It is doubtful whether all the exhalative sedimentary deposits can be considered syngenetic. But they show two typical characteristics which suggest that they should on the whole be considered as syngenetic. Firstly, these deposits show clear lithological affiliations. In a particular zone, a deposit will be confined to one suite or facies of rocks only. Secondly, these deposits are invariably congruent with their host rock. This congruence in particular is very suggestive of syngenesis[20]. If this analogy is acceptable, then the following set of criteria will be useful in recognising exhalative sedimentary deposits :

(i) the syngenetic deposits are developed within definite stratigraphic zones,

(ii) interbanding of ores of contrasting composition and host rock will be common particularly when clearly sedimentary host rocks are present,

(iii) cross-cutting veins will be absent or very rare,

(iv) ore minerals vary with variation in sedimentary facies when the host rock is a sedimentary unit,

(v) metamorphism of the ore and the host rocks are isofacial, and

(vi) wall-rock alteration may be absent[26].

Mineral deposits formed by the exhalative sedimentary process in typical geosynclinal environments can be grouped into five classes roughly representing the stages of development of the geosynclinal series. These are :

(i) early orogenic deposits,

(ii) synorogenic deposits,

(iii) late orogenic deposits,

(iv) final orogenic deposits, and

(v) post orogenic deposits.

(i) Early orogenic deposits : These deposits are typically seen in association with spilitic lavas and show extensive serpentinisation. Due to their subsequent burial in deep piles of sediments, they generally occur in a strongly metamorphosed condition. The mineralized horizon may occur under a suite of pillow lava rocks, indicating post mineral sub-aqueous volcanic activity. The ore bodies are massive pyrite type with minor amounts of As, Zn, Pb and Ni. The minerals represented in such deposits are generally fine-grained pyrite, accompanied by chalcopyrite, sphalerite and hematite. Typical host rocks may be spilitic pillow lavas, chert beds or mudstones[25].

(ii) Synorogenic deposits : Deposits of this type occur in association with typically high metamorphic rocks. The degree of metamorphism generally reflects the intensity of orogeny. Typical deposits show disseminated to massive sulphides with pyrrhotites as the principal mineral constituent. Chalcopyrite, cubanite, magnetite, etc. may occur as subordinate minerals. Interbedding of the host rock with sulphides may be common[25].

(iii) Late orogenic deposits : In the late orogenic stage, the volcanicity becomes once again acidic with rhyolitic lavas and acidic tuffs predominating. The deposits of this stage tend to have very large dimensions unlike the earlier two types which generally tend to be rich in grade but small in dimension. The common deposit is the massive sulphide type with pyrites as the predominant ore[20]. The associated sediments generally show a very low grade of metamorphism[27].

(iv) Final orogenic deposits : The three types of deposits described so far have all some common genetic features; deep geosynclinal association, greywacke sediments, and pyrite or pyrrhotite forming the major ore mineral. The final orogenic phase is conspicuously free of any major volcanic activity. At this stage, the sulphide mineral may be still pyritic but different mineral assemblages both with fairly abundant Fe, Zn, Pb, Ba, etc. are also seen. The lithologic setting is distinctly calcareous or dolomitic. Biogenic agencies are thought to play a significant role in the mineralisation. Black carbonaceous rocks are present in the sequence[25].

The Sargipalle sulphide deposit bears close resemblance to the conditions described above. The host rock is a calcsilicate-quartzitic rock. Mineralisation is within a sequence of the Iron-Ore Series with grantitic intrusive rocks nearby. The mineralisation is predominantly of lead. The mineral sequence shows galena, chalcopyrite, pyrite, pyrrhotite, arsenopyrite, tennantite, tetrahedrite, silver[26], etc.

(v) Post orogenic deposits : These deposits occur after the major orogenic phase and the connection between these deposits and volcanism is very marginal. In fact, most of these deposits show more evidences of fumerolic and bio-chemical actions. The typical environments for these deposits are enclosed coastal basins of lagoon type. The minerals are generally arsenopyrite, sphalerite, galena and barytes (As, Fe, Cu, Pb, Zn, Ba[26]).

The lead-zinc deposits of Zawar might have had their origin in a setting similar to the one described above. However, they have been deformed so much that their original environment is no longer clearly discernible[21]. Such deposits may have been remobilized in their original setting during the evolution of the geosyncline[26].

A discussion of oregenesis in which volcanism plays such an important role would not be complete without some reference to certain deposits in which volcanic action is practially direct. Pipe-like orebodies, for example, show direct evidence of volcanism. In this type of orebodies, diamond bearing pipes and carbonatite bodies are very important[26]. A carbonatite body is an intrusive calcareous rock which generally shows the presence of radioactive elements. The mineral deposits under discussion so far may occur in their pristine condition in which case they are easily recognisable. They may also occur as deformed bodies or remobilized bodies in which case their genetic association is not easily understood. As mentioned earlier the Zawar lead-zinc deposits may belong to the remobilized class of post orogenic deposits. Shearing and fracturing have probably so transformed the ore that it can no longer be correlated with its original genetic setting. The copper-uranium mineralisation in Singhbhum has also been cited as a case of deformed ore body. It is suggested that the general geological setting is geosynclinal and where alteration is less, some relic sedimentary features are recognisable within the volcanic ash beds and sediments occurring close to the orebody[21].

2.1.6 Geological structures

It has been discussed earlier that mineral deposits are formed under complex geological environments. Although the formation of a deposit is largely controlled by the ore forming processes, it is the geological structure which helps in localising mineral deposits. These structures may be regional or purely local[3]. Our knowledge of the structure of earth's crust is derived from the continents. The continents themselves offer two regions which have a separate tectonic and structural history; the mobile belts and the cratons. The mobile belts are those characterised by igneous activity and earthquakes. They, also, are areas of rapid sediment accumulation giving rise to geosynclines and geanticlines. When a mobile belt is characterised by geosynclines and geanticlines they are called orogens which are the loci of mountain building activity and are structurally very complex. Compared with the mobile belts, the cratons are static and stable[28]. From the point of view of ore-genesis, the structurally complex mobile belts of the geological past are very important. It is here that most of the economically important mineral deposits of interest to mankind were formed. Therefore, a study of the most elementary to the most complex type of geological structures is a part and parcel of exploration geology. Broadly, structures may be of two types :

(1) rock structures, and

(2) geological structures.

(1) Rock structures : The rock structures may be categorised into three types :

(A) structures of igneous rocks,

(B) structures of sedimentary rocks, and

(C) structures of metamorphic rocks.

(A) Structures of igneous rocks : Two types of rock structures are recognised in igneous rocks; (a) structures due to flow, and (b) structures due to fracture[28].

(a) Structure due to flow : Two types of structures may be identified under this, viz. (i) linear flow structure, and (ii) platy flow structure.

(i) Linear flow structure : The parallel orientation of needle shaped inclusions constitutes linear flow structures[28].

(ii) Platy flow structure : The parallelism of the flat surfaces of tabular; or platy inclusions like phenocrysts, xenoliths and schlieren (flow layer) constitutes platy flow structure. It may lie in the plane of foliation but may form an angle with it[28].

(b) Structures due to fracture : Under this come joints, sheets, faults, etc.

(i) Columnar jointing : The rock is divided into hexagonal columns formed at right angles to the cooling surface.

(ii) Joints : Joints which lie perpendicular to the flow lines are termed cross joints (Q joints) and are tension joints formed due to the upwelling of the liquid magma in the centre of the intrusion; 'S' joints are steeply dipping joints which strike parallel to the flow lines[28].

(iii) Sheeting : They consist of gently curved joints which divide the rock into flat lenses parallel to the topographic surfaces. When they are closely spaced, they are called mural jointings[28].

(iv) Rift, grain and hardway : Rift is a direction of the most ready parting. Grain is another direction of ready parting lying at right angles to the rift. Hardway is any third direction of parting which may be most difficult[28].

(v) Faults : Normal and thrust faults of purely local significance are seen on the border of large intrusives. The extent of slip along the planes is usually very small. A number of such faults may be arranged in echlon. Flat lying normal faults are also not uncommon.

Besides these, broad regional structures like ring dykes, cone sheets, etc. are also recognisable in the case of igneous rocks[28].

(B) Structures of sedimentary rocks : A very large number of structures are recognisable in sedimentary rocks. Some of them are described below :

(a) Bedding or stratification planes : Sedimentary rocks are arranged in layers. The plane which separates the various layers is called bedding or stratification plane[28].

(b) Graded bedding : Beds show some gradation in size from bottom to top. The coarser grains are at the bottom and the finer ones are at the top. This textural arrangement in sedimentary bed is known as graded bedding[28].

(c) Initial dip : Initial dip is different from the dip exhibited in an exposure. Initial dip is the slope of the stratification plane during sedimentation. It is common for sediments formed in basins to exhibit this dip[28].

(d) Discordant bedding : Normally bedding planes and beds are parallel to each other. When this parallelism is lost, the bedding planes become discordant. Terms like current bedding, cross bedding, false bedding, etc., are also applied to discordant bedding[28].

(e) Ripple marks : Ripple marks are those ridge like prominences seen on sediments. These are created by the movement of air or water over unconsolidated sediments[28].

(f) Rain, Drip and Hail Impressions : These are impressions formed on loose sediments by rain and hails, dripping from trees or plants. The upper surface of these is concave which can help in recognising the orientation of beds.

(g) Mud cracks : Mud cracks are formed by the exposure of soft mud to sun's rays. They have wide mouths and tapering bottoms which help in recognising the top and bottom of beds.

Various other structures are also noticeable in sedimentary rocks. Since they are of no direct use in studying the strata sequence (top and bottom of beds particularly), they are not being discussed. The structures described above can be directly used for establishing the top and bottom of sedimentary formations.

(C) Structures of Metamorphic rocks : No distinct structures which are exclusive to metamorphic rocks can be recognised unless features like schistosity and gneissosity are considered. Although they are primary to metamorphic rocks, they are modifications of existing structures of the original rocks. Interpretation of rock structures is very important in studying major and minor geological structures. In certain types of geotechnical studies connected with open pit design and stability of slopes also, the rock structures are important.

(2) Geological Structures : Some definitions of the the commonly used terms are given below :

(i) Dip and Strike : The dip is the maximum angle of inclination made by any plane to the horizontal and is expressed in degrees. The compass bearing of the dip defines its direction. The strike of a plane is a horizontal line along the direction of the bed and is at right angles to the dip. The strike of a plane is expressed by its compass bearing[29].

Dip and strike may be of any planar feature like bedding or stratification, foliation plane, cleavage, joint, fault plane, fold axis, etc. The linearity of the above features is the strike of the feature (Fig.2.1).

(ii) Plunge : Plunge is the angle made by the projection of a planar feature with the horizontal plane[30]. Expressions like plunge of the fold axis, plunge of foliations, etc., are of common usage. When a planar features like a fold axis plunges in two directions, it is called a double plunge. There may be double plunges towards each other or away from each other.

The important geological structures described in the following pages are (A) folds, (B) faults, and (C) unconformities.

(A) Folds :

Some definitions : Folds are undulations or waves in the rocks of the earth. They are best displayed by stratified rocks, mainly sedimentary rocks[30].

A fold is defined by the following terminology - limbs, axis, crest and trough as shown in Fig.2.2 and 2.3 When the dip of the limbs is away from the axis, the structure is called an anticline. When the dip of the limbs is towards the axis, the structure is called a syncline.

Various types of folds are recognised depending upon the attitude of the axial plane, and the disposition of the limbs. The major folds are described below:

Symmetrical fold : Axial plane is vertical[30].

Asymmetrical fold : Axial plane is inclined[30] with the two limbs dipping at different angles.

Isoclinal fold : The limbs of the fold dip in the same direction. There may be three cases of isoclinal folds.

(a) Vertical isoclinal folds : Axial plane is vertical[30].

(b) Inclined isoclinal folds : Axial plane is inclined[30].

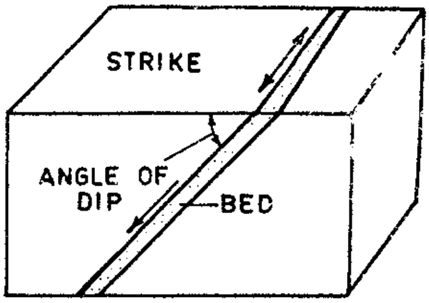


FIG: 2·1 DIP AND STRIKE

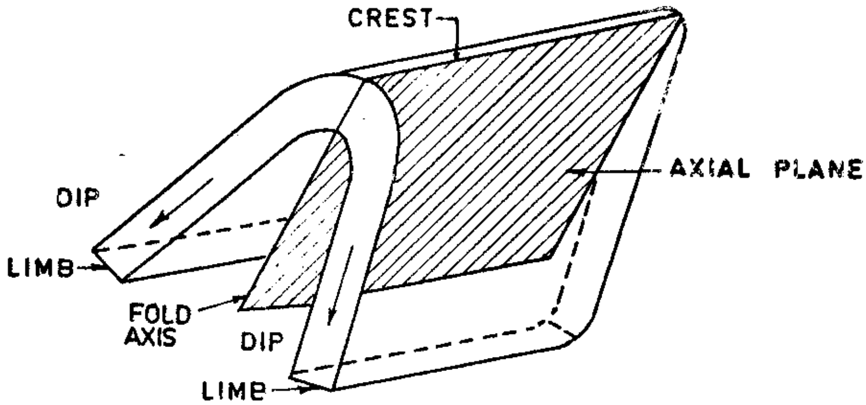


FIG: 2·2 ANTICLINE

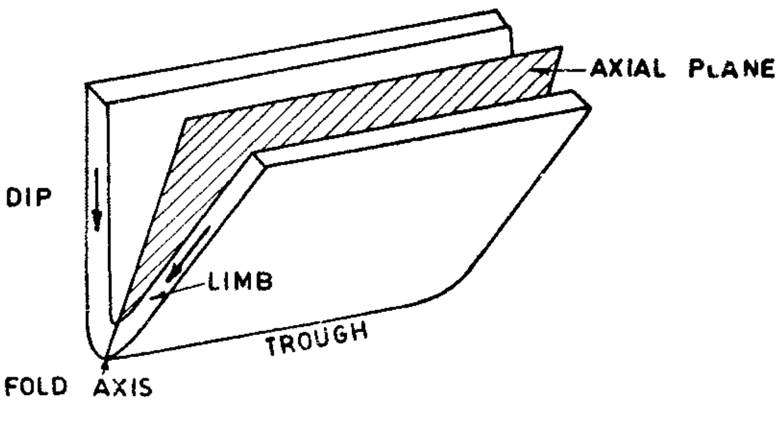


FIG: 2·3 SYNCLINE

(c) Recumbent isoclinal : Axial plane is horizontal[30].

Chevron folds : Folds with sharp crests and troughs[30].

Fan fold : Both limbs are completely overturned. Anticlines show limbs dipping towards the axis and synclines vice versa[30].

Monocline : Flat bed assuming locally steep dips[30].

Structural terrace : Dipping strata assume horizontality locally[30].

Open fold : Folding is mild so that the limbs preserve their original thickness[30].

Closed fold : Folding intense enough to cause plastic flow so that limbs have thinned out locally[30].

Drag fold : Drag folds are minor folds formed in an incompetent bed between two competent beds. They are formed due to the sliding motion of two competent beds[30].

Anticlinorium : An anticline which has been re-folded along the same axial direction.

Synclinorium : A syncline which has been refolded along the same axial direction.

Cross-fold : A second fold which folds the main fold axis.

Overturned fold : The axis is horizontal as in recumbent fold. But the beds have been completely turned upside down.

Study of folds in the field : In order to study folds systematically to enable easy interpretation, the following sequence of observation and terminology is recommended:

(a) Axes - Location, plunge, smoothly rounded or sharp, straight or curved, thickening or thinning along axes.

(b) Strike and dip of axial planes, fracture systems.

(c) Flanks (limbs), width, variations in strike and dip, smooth or irregular, thickening or thinning of beds, fracture system, evidence of slippage along bedding planes.

(d) Dating - Evidence of more than one period of movement.

(e) Topographic expression, drainage pattern, etc.[14]

Criteria for recognition of folded strata

Recognition of folding is not always easy. Only in rare cases all the limbs will be directly observable for this. Systematic study alone can help in identifying complex folds. There are however a few keys which help in recognising folds.

(i) Repetition of beds : One bed may be seen in a traverse repeated at several places. By plotting and interpretation and eliminating the possibility of faults, the fold can be reconstructed.

(ii) Topography : In certain types of terrain, folds are easily inferred by topography. This is particularly true in the case of aerial photography[30]. Folds can also be studied by geophysical methods and drilling.

In areas where folding has been simple, the study and recognition of fold is not difficult. In a terrain of complex folds, particularly where beds are overturned, it is difficult to correlate the strata. It is also difficult to determine the chronological sequence of beds. Some criteria for recognising the top and bottom of beds are essential. A few criteria commonly used are discussed below.

When beds are overturned, primary features are made use of in recognising the top and bottom. Such criteria are cross bedding, ripple marks, graded bedding, mud cracks, etc., in the case of sedimentary strata. In case of igneous rocks, the vesicular tops and flow structures can be made use of. The correct orientation of these minor features has to be fixed by field observations. In the case of mud cracks, the tapering end is the bottom. In ripple marks, the crests are at the top. In cross bedding, the laminae are parallel to the bedding at the bottom, but form sharp angles at the top.

In graded bedding the coarser grains are always at the bottom. By carefully studying these features and correlating them the top and bottom of beds can be fixed.

(iii) Drag folds and their relation to the main folds : Drag folds are minor folds in incompetent strata and are formed essentially as a result of the major folding movement of the area. Naturally, they show characteristics which are in harmony with the major folds. Drag fold axes will be parallel to the main fold axes and they will show the same plunge as the main folds. Where major fold axes are difficult to locate, drag folds help in studying them[30].

(iv) Cleavage and its relation to the folds : Cleavage (rock cleavage as distinct from mineral cleavage) is the ability of the rocks to break along parallel surfaces, of secondary origin[30].

Type of cleavage :

Four types of cleavage are recognised. They are (a) flow cleavage, (b) fracture cleavage, (c) shear cleavage, and (d) bedding cleavage. Of these, only flow cleavage is genetically related to folds.

(a) Flow cleavage : Flow cleavage, also known as slaty cleavage or axial plane cleavage, is formed due to parallel orientation of platy minerals. Flow cleavages are formed parallel to the fold axis and can be used in the study and interpretation of major folds[30].

Cleavage in non-plunging folds : Fig.2.4 shows the exposure of a bed involved in folding. The bed shows cleavages. The cleavages dip at a sharper angle than the bed but in the same direction. In this case, the anticlinal axis is towards the right of the figure.

Fig.2.5 shows the exposure of a folded bed which is vertical. The cleavages are dipping to the west. The synclinal axis is towards the right.

Fig.2.6 shows the exposure of a folded bed in which the bedding plane dips steeper than the cleavage. The synclinal axis is towards the right of the figure.

Plunging folds : Fig.2.7 shows a vertical bed in a plunging fold with cleavages. The trace of the cleavage in

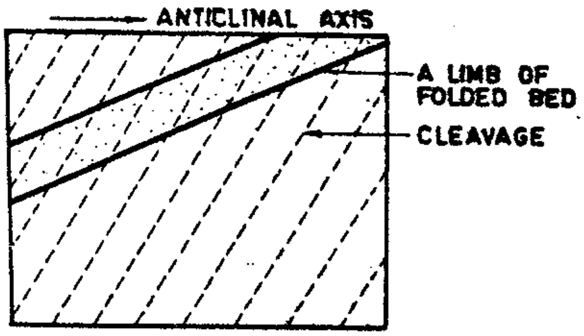


FIG: 2·4

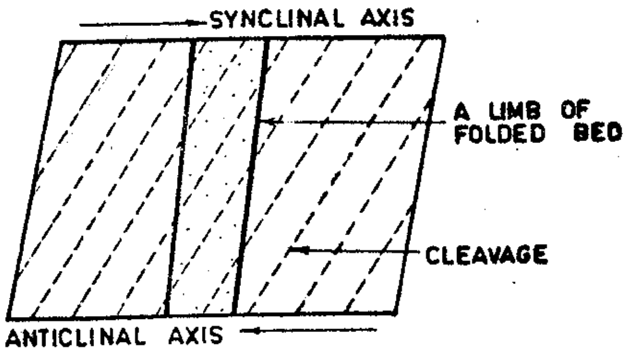


FIG: 2·5

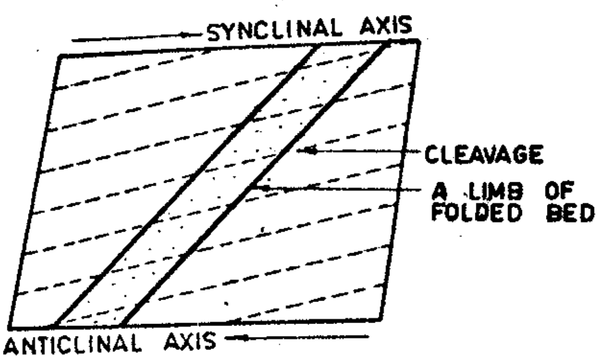


FIG: 2·6

CLEAVAGE IN NONPLUNGING FOLD AND THEIR INTERPRETATION its horizontal section is also projected. The synclinal axis is towards east and the plunge is towards north[30].

Fig.2.8 shows a folded bed with cleavages, both in their vertical and horizontal disposition. The synclinal axis is to the right and the plunge is towards south[30].

Both the cases are extreme, being vertical. The same principle applies to beds with gentler dips.

Cleavage can also be used to locate the crest of anticlines or the trough of synclines, where they intersect bedding planes. This is a special case when the cleavage develops parallel to bedding in isoclinal folds.

(v) Lineation - its relationship to fold : Lineation or linear parallelism or linear structure is due to some directional property in the rock. This may be by the linear arrangement of some secondary mineral or elongated pebbles, etc. In structural interpretation, lineations can be used in exactly the same way as the cleavages as explained earlier, as both have the same genetic relationship with major folds. Where it is possible, it is advisable to use lineation and cleavage together to obtain the best results[30].

(vi) Cross folds - its relations to main fold : In certain areas, two or more generations of folding can be recognised. The mutual interference of the two produces many complex structures; particularly when the axial systems of the folds are not parallel[31]. Such folds are rather loosely referred to as cross folds. The structures which such folding can produce are the following:

(a) Anticline crossing anticline : In this case, an already existing anticline is refolded by a cross fold and the resulting structure is shown in Fig.2.9 where ABCD is the axial plane of the first anticline, and A',B' C' D' the axial trace of the second axial plane. The crest of the two anticlines will coincide to form a doubly plunging anticline.

(b) Anticline crossing syncline : In the case of an anticline crossing a syncline, the structure will be as shown in the Fig.2.10. ABCD is the axial plane of the syncline and A'B'C'D' the axial plane of the anticline. The synclinal trough will come up at the crest of the cross folded anticline.

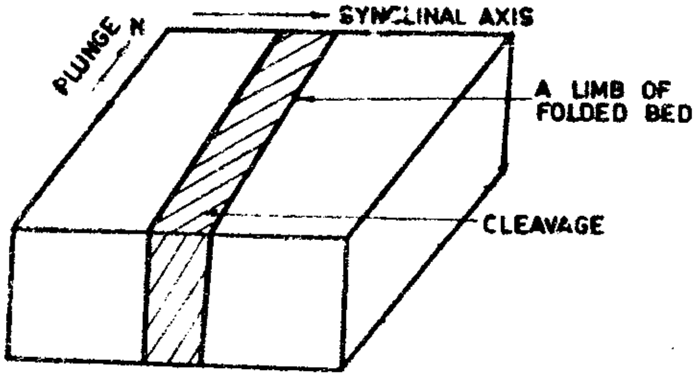


FIG: 2·7

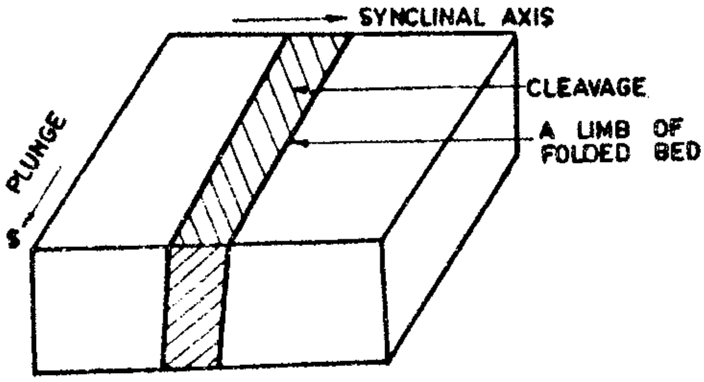


FIG: 2·8

CLEAVAGE IN PLUNGING FOLDS AND THEIR INTERPRETATION

(c) Syncline crossing syncline : In the case of a syncline crossing another syncline, the structure will be rather like the one shown in the Fig.2.11. ABCD is the axial plane of the first syncline, and A' B' C' D' the axial plane of the second syncline. The resulting structure will be a double plunging syncline. The synclinal trough will go deep.

(d) Syncline crossing anticline : The figure represents a syncline crossing an anticline. ABCD is the axial plane of the anticline and A' B' C' D' the axial plane of the syncline. The crest of the anticline will go down. Fig.2.12.

It is now widely recognised that cross folds have a profound influence in localising mineral deposits of both epigenetic and syngenetic types. Ore localisation with thickening of strata at the axial regions of cross folds has been recognised in the gold-bearing lodes of Kolar Gold fields, copper deposits of Singhbhum and Agnigundala, and many manganese and iron ore deposits of Madhya Pradesh, Bihar, Karnataka, and Andhra Pradesh[32].

In the Precambrian formations of India, four types of cross-fold are known. They are :

(i) Cross folds with axes perpendicular to the axes of the earlier folds.

(ii) Cross folds with axes at an angle to the earlier fold axes (about 45^{o} or less).

Here there may be two separate cases :

(a) axes opposed to the direction of plunge of the earlier folds and

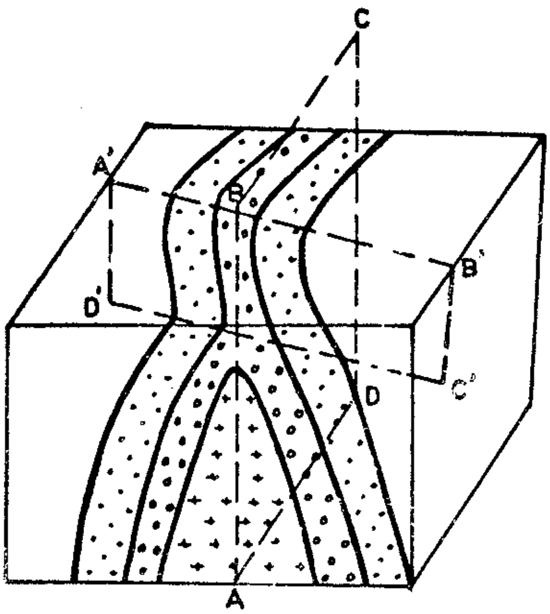
(b) axes nearly in the same direction as the plunge of the earlier folds.

(iii) The axes of cross folds are almost parallel to the axes of earlier folds in both strike and dip but the axial plunge is

(a) opposed to the plunge of earlier fold axes and

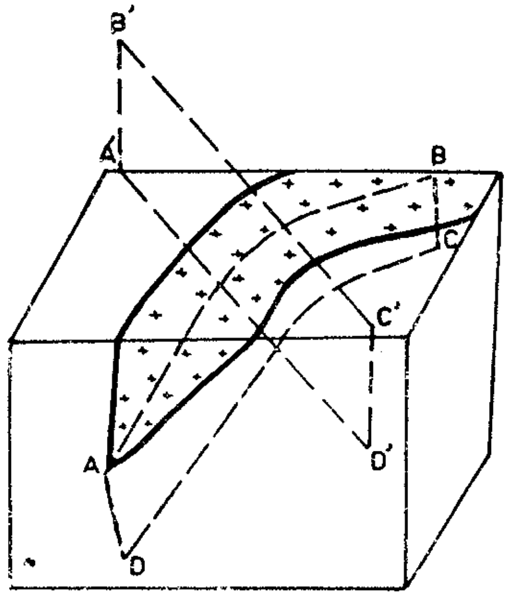
(b) parallel to the direction of plunge of the earlier folds.

CROSS FOLDS: ITS RELATION TO MAIN FOLD



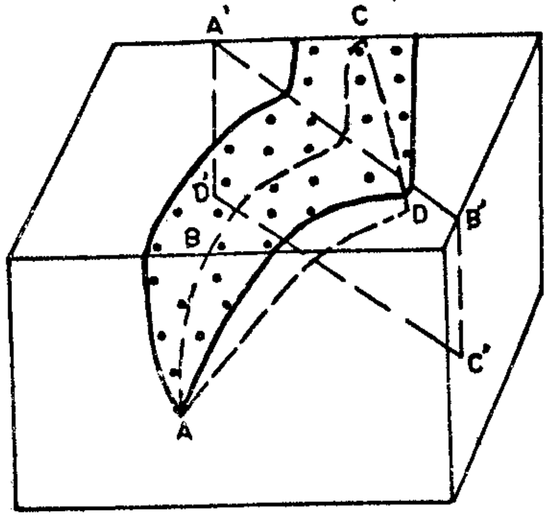
ABCD AXIAL PLANE OF THE FIRST ANTICLINE
A'B'C'D' AXIAL PLANE OF THE SECOND ANTICLINE

FIG: 2·9 ANTICLINE CROSSING ANTICLINE



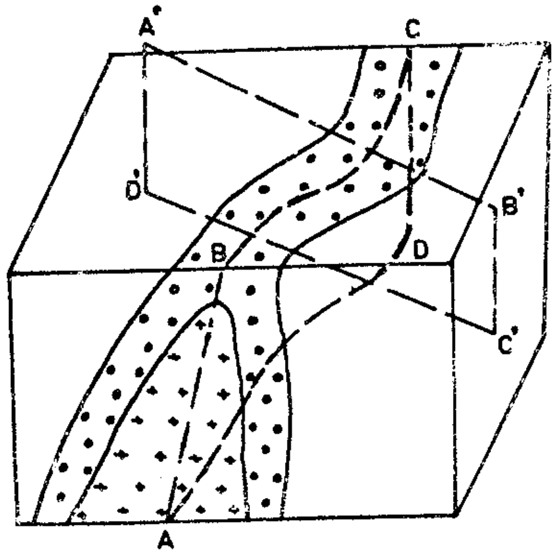
ABCD AXIAL PLANE OF THE SYNCLINE
A'B'C'D' AXIAL PLANE OF THE ANTICLINE

FIG: 2.10 ANTICLINE CROSSING SYNCLINE



A B C D AXIAL PLANE OF THE FIRST SYNCLINE
A' B' C' D' AXIAL PLANE OF THE SECOND SYNCLINE

FIG: 2.11 SYNCLINE CROSSING SYNCLINE



A B C D AXIAL PLANE OF THE ANTICLINE
A' B' C' D' AXIAL PLANE OF THE SYNCLINE

FIG: 2.12 SYNCLINE CROSSING ANTICLINE

(iv) In this case, the only visible effect is the reversal in the direction of plunge of the axes of the earlier folds, resulting in culminations and depressions, canoe folds and dome structures[32].

<u>Common problems posed by folds in mineral exploration</u> : Folds create many problems for the exploration geologist. Ore bodies die out suddenly or blossom into rich shoots depending on the relationship between structure and mineralisation. Mineralisation and structure may have two types of relationship:

(a) where mineralising fluids have followed the already existing structure, and

(b) where structure has transformed the shape of already existing mineral bodies.

In the former case, the folding existed prior to mineralisation and ores concentrate wherever there are favourable openings. This may be the bottom of synclines or the crest of anticlines and only rarely the limbs of the folds. The important point here is to establish the correct relationship between folding and mineralisation. Such relationships tend to show regional characteristics. In some regions, mineralisation may be exclusively in anticlinal crests. In others, only the synclinal bottom may be mineralised.

In the second case, mineralisation may be uniform but may show exaggerated thicknesses in anticlinal crests or synclinal troughs. Such areas offer attractive mining possibilities and should be studied and recognised.

The choice of exploration methods is also influenced by folds. Where mineralisation is preferentially in synclines, the area might require to be proved by drilling, whereas anticlines may be amenable to pitting, trenching, etc.

The correct delineation of the depth of the fold is a problem of considerable consequence in exploration. Some standard formulae are available for this but are not universally applicable. One such method recommended by Billings is given below[30].

* Fig.2.13 shows a fold in which a key bed is folded. The term b is the present breadth of the folded area; the l, which is the original width before folding, is measured along some convenient bed in the folded belt. The term h is the amount of uplift due to folding.

In Fig. 2.13, the heavy black line represents a single bed. At the left end of the section, it is flat and has not been affected by the folding. In the folded area it has been uplifted from the position of the broken line to the position shown by the heavy solid line. The average uplift h can be determined in several ways. The simplest is to measure the actual uplift at stated intervals - such as at every millimeter in the figure shown - and to compute the average. All the factors in the equation given above, except d, are known. For convenience in computation, the equation can be rewritten :

$$d = \frac{bh}{l - b}$$

The answer d gives the depth of folding measured from the key bed where it is horizontal.

A better method is to project the geometry of each fold by vertical projections with the help of cross-sections and planar features. The method is explained in Annexure-I, where a rather complex case has been dealt with.

(B) Faults

Faults are defined as ruptures along which the opposite walls have moved past one another. Some faults have a small displacement whereas the displacement of some faults is measured in kilometres[30]. The major elements by which a fault is described are :

(i) Fault plane - The plane along which faulting took place.

(ii) Hade - The component of the dip - the angle between fault plane and vertical.

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(iii)	Dip of fault plane	-	The angle between the fault plane and horizontal.
(iv)	Net slip	-	Displacement along the fault plane. In Fig.2.14 ac is the net slip.
(v)	Throw	-	Throw is the vertical displacement. In Fig. 2.14 it is ab.
(vi)	Heave	-	The horizontal component of the movement along the fault plane. In Fig.2.14 it is bc.

Different types of faults

Faults are classified into six categories. Each classification lays emphasis on some particular characteristic of the fault.

(i) Classification based on net slip

(a) Strike slip fault. Net slip is parallel to the strike of the formation.

(b) Dip slip fault. Net slip is parallel to the dip of the formation.

(c) Diagonal slip fault. Net slip is diagonal to both strike and dip[30].

(ii) Classification based on attitude of fault relative to attitude of adjacent beds

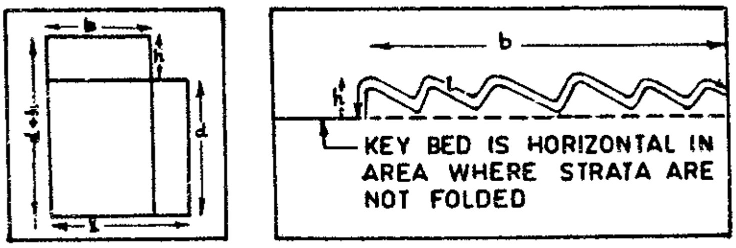
(a) Strike fault - Fault is parallel to the strike of the beds.

(b) Dip fault - Fault is parallel to the dip of the beds.

(c) Oblique fault - Fault is at an angle to the strike of the bed.

(d) Longitudinal fault - Fault is parallel to the regional structure parallel to the major fold axis.

(e) Transverse fault - Fault is perpendicular or diagonal to the regional structure - say, fold axis[30].



b PRESENT BREADTH OF FOLDED BELT
h AVERAGE UPLIFT DUE TO FOLDING
l ORIGINAL BREADTH OF FOLDED BELT
d DEPTH OF FOLDING
(A) SQUARE DEFORMED INTO A RECTANGLE NO CHANGE IN AREA
(B) FOLDED STRATA

FIG: 2·13 METHOD OF CALCULATING DEPTH OF FOLDING

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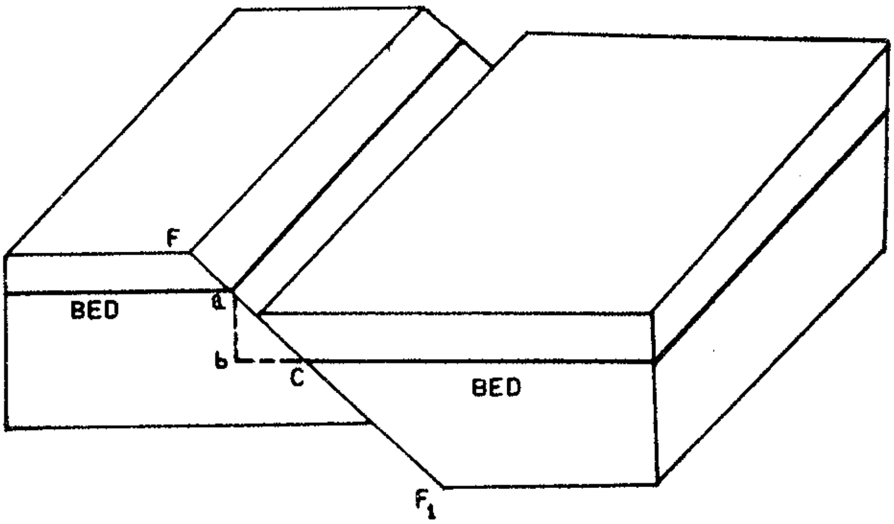
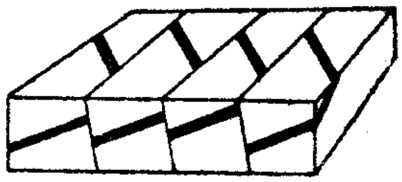
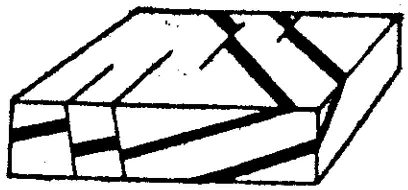


a C : NET SLIP
a b : THROW
b C : HEAVE
F F1 : FAULT PLANE

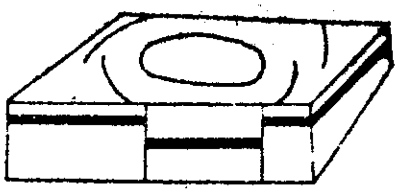
FIG: 2.14 NET SLIP, THROW, HEAVE OF A FAULT



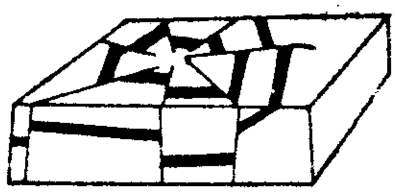
PARALLEL FAULTS



EN ECHELON FAULTS



PERIPHERAL FAULTS.



RADIAL FAULTS

GEOMETRICAL CLASSIFICATION OF FAULTS

(iii) <u>Classification based on fault pattern</u>

(a) Parallel fault - Strike and dip of several faults are parallel .

(b) En echelon fault - Short faults that overlap one another.

(c) Peripheral fault - Arcuate faults that bound a circular area.

(d) Radial fault - Faults radiate from one point[30].

(iv) <u>Classification based on value of dip fault</u>

(a) High angle fault - Dip of the fault plane higher than 45^o.

(b) Low angle fault - Dip of the fault plane lower than 45^o.

(v) <u>Classification based on apparent movement</u>

(a) Normal fault - Hanging-wall side of the fault moves down relative to the foot-wall.

(b) Reverse fault - Hanging-wall moves up relative to the foot-wall[30].

(vi) <u>Genetic classification</u>

(a) <u>Classification based on relative movements</u>

(i) Thrust fault - Hanging-wall moves up relative to footwall. Fault is of regional dimensions.

(ii) Gravity fault - Hanging-wall moves down relative to footwall.

(iii) Rift fault - Longitudinal fault with displacement parallel to the strike of the fault.

(iv) Tear fault - Transverse fault with displacement parallel to the strike of fault[30].

(b) Classification based on absolute movements :

Based on the absolute movement of blocks, four types of thrust and an equal number of gravity faults can be recognised.

Gravity faults - Thrust faults.

(i) Footwall stayed in place - hanging-wall moved down.

(ii) Footwall moved up - hanging wall stayed still.

(iii) Both blocks moved down - but the hanging wall moved more.

(iv) Both blocks moved up - but the hanging wall moved less[30].

Other faults are :

(a) Upthrust - High angle fault with the uplifted block as the active element.

(b) Underthrust - Thrust fault in which footwall has moved.

(c) Overthrust - Thrust fault in which hanging-wall has moved[30].

Study and recognition of faults in the field

Sequence and terminology used for faults are :

(i) Kind of fault, strike and dip with their vertical or lateral variations, displacement and direction of movement.

(ii) Drag and brecciation. Auxiliary fault slices, drag folds, width of brecciation.

(iii) Linear elements. Striations, grooves and slickensides.

(iv) Dating. Evidence of more than one period of movement.

(v) Possible mineralisation and effect on ground water.

(vi) Topographic expression[14].

Criteria for recognition of faults

In many cases faults are directly recognisable. Where they are not, careful observation of certain typical features of faults is very essential for pinpointing the fault. Six groups of criteria are generally recognised[30]. They are :

(a) discontinuity of structures,

(b) repetition or omission of strata,

(c) features characteristic of fault planes,

(d) silicifications and mineralisation,

(e) sudden changes in sedimentary facies, and

(f) physiographic evidences.

(a) Discontinuity of structures : Features like dykes, sills, veins, prominent fractures, folds, etc., may be seen ending abruptly against a plane in an exposure. This may be due to faulting.

(b) Repetition and omission of strata : In a traverse line, a strata may disappear altogether in a sharp contact or may be repeated sequentially in association with sharp contacts. Both may indicate faulting.

(c) Features characteristic of fault-planes : In some cases, it is possible to recognise the fault plane by virtue of certain characteristic features. They are (i) slickensides, (ii) mullion structure, (iii) drag, (iv) gouge, (v) breccia, (vi) mylonite, and (vii) horses (caught up blocks).

(i) Slickensides : These are striations in the fault planes caused by movement and can be easily recognised by the glistening surfaces and striations.

(ii) Mullion structures : They are large grooves or furrows with a definite crest and bottom.

(iii) Drag : The end of the beds affected by fault is dragged up and down.

(iv) Gouge : Fine-grained clay like powdery rock.

(v) Breccia : Mixture of angular and subangular rock pieces of varying sizes in a finely crushed matrix.

(vi) Mylonite : Microbreccias with streaked or platy structure, which are typically dark and fine grained. The coherence of a microbreccia is maintained during deformations.

(vii) Horses : Small blocks of rocks caught up in a wide fault plane.

(d) Silicification and mineralisation : Silicification may occur along the zones of fracture. Similarly, mineralisation may also occur.

(e) Sudden change in the sedimentary facies : The phenomenon of a coarse-grained sandstone abutting against a shale of the same age and other similar instances is indicative of faulting during sedimentation.

(f) Physiographic evidences : The following physiographic evidences are suggestive of faults; (i) offset ridges, (ii) scarps, (iii) triangular facet, and (iv) truncation of structures by a mountain front.

(i) Offset ridge : Due to fault, a resistant sedimentary stratum may show discontinuity. This is called an offset ridge.

(ii) Scarp : A steep straight slope of any height.

(iii) Triangular facet : On scarp faces, some 'V' notches may form due to erosion during movement. The sum-total is a structure known as a triangular facet.

(iv) Truncation of structure : Sudden termination of structures, particularly against a mountain front is suggestive of faulting.

Other field evidences are springs in a linear arrangement, trees in a line, and lakes in a line, all of which may coincide with the alignment of the fault. The sudden steepening of a stream bed, abrupt ending of a stream, etc., also may indicate faulting[30].

The criteria discussed above are all indicative of faulting but individually none of them offer any conclusive evidence. Besides, some of them also indicate other structures like folds, unconformities, etc. Careful study and a series of eliminations at each stage is essential before a particular set of criteria can be correlated to a fault. Usually, a combination of several criteria is essential before any conclusion can be drawn[30].

Effects of faults on folds

When a tectonic disturbance takes place in an area, it may give rise to new structures either by partial or total destruction of old structures or by superimposition of a new set of rocks over the reliefs of existing structures. Faults, folds, shears, joint, etc. are all geological deformations caused by stress and strain. In a normal sequence of events, it can be expected that folds are formed first, whether synclines or anticlines, and if the forces causing the folding are still intense, then the rocks yield to these forces forming faults, shears, etc. Hence, in an area which is geologically least disturbed, it is not difficult to establish the sequence of events. But, in an area that has experienced such disturbances repeatedly, it is very difficult to establish the generations to which an individual structure belongs to and its effect on other structures.

The effect of folds on faults is now widely known. But the reverse of this, i.e. the effect of faults on folds, is still a subject of controversy. However, many examples have been given by authorities as to the influence of faults on folds, though on a regional scale, which go to establish that folding in blanket sediments on a known basement rock followed the faults in the basement[31]. Goguel[33] has shown that the fault planes may become anchor sheets against which folds localize. According to this author, groups of faults often delimit a collapsed structure as a trench or "pinched" belts, the crushing of which may produce a folded character. Often, the resultant, structure is controlled by the nature of the rock or its resistance to deformation, e.g. when resistant beds come into contact with plastic beds, an overthrust fault may form.

Common problems posed by faults in mineral exploration :

Just like folds, faults also present various problems to the exploration geologist. Many fault planes act as passages for the mineralising solutions and many deposits are formed in the fault plane itself. Faults may cut off mineralising solutions in a favourable host rock or may act as a connection to a favourable host rock. Faults may also block off the already existing deposits. As in folds, in faults also, it is important to establish the exact relationship existing between faults and mineralising solutions. If the fault is premineral, then there is every chance of the fault plane influencing the mineralisation. On the other hand, if the fault is postmineral, then the deposit may be merely displaced. Such problems are not amenable to any standard solutions. Each case has to be studied on its own merits and solutions found on the basis of the observations. The following criteria are sometimes useful in distinguishing the premineral faults from the postmineral faults :

(a) Premineral fault :

(i) Mineralisation will be in the fault plane. Ore may be in breccia and vugs, and

(ii) localising effect of the fault on ore. Ore bodies tend to be in the fault[34].

(b) Postmineral fault :

(i) Ore will be slickensided or brecciated. Drags will be clearly visible in many cases, and

(ii) observable offsetting of veins or orebodies[34].

The presence or absence of a fault in a region will substantially influence an exploration strategy particularly in the choice of methods. Ore bodies may come close to the surface in certain faults making it an attractive target proved easily by shallow drill holes. It can also affect the economic workability of an ore body adversely by throwing it down to great depths.

In many cases, the determination of the downthrown or upthrown block is of great importance. The criteria for such recognition are discussed below :

(i) Correlation of wall rocks - If the sequence of the rocks which have been faulted is known, it is easy to find out the displaced block.

(ii) Drag - This has been explained earlier. The drag is always against the direction of movement.

(iii) Slickensides - The groove of a slickenside will be smooth in the direction of movement and rough against it.

(iv) Throw of minor and sympathetic fault - since minor and sympathetic faults form in harmony with the main faults, their direction of throw will indicate the direction of the throw of the main fault[31].

(c) Unconformities : Unconformity is defined as a surface of erosion, which separates the younger strata from the older. Four types of unconformities are recognised. They are -

(i) angular unconformity,

(ii) disconformity

(iii) local unconformity, and

(iv) non-conformity[30].

(i) Angular unconformity : When the beds on either side of the plane of unconformity are not parallel.

(ii) Disconformity : The formations on either side of the plane of unconformity are parallel.

(iii) Local unconformity : Basically, a disconformity but of a strictly local nature.

(iv) Non-conformity : When the older rock is of plutonic origin[30].

Study and criteria for recognition of unconformities in the field :

For the recognition of an unconformity, the following criteria may be made use of :

(a) Difference in the degree of induration : the rocks on either side of an unconformity are likely to show different degrees of induration, the older rock showing greater induration.

(b) Differences in the grades of metamorphism : the younger rocks are likely to be less metamorphosed than the older ones on either side of an unconformity.

(c) Differences in folding : in some cases, the younger rocks will show less intense folding than the older on the two sides of an unconformity.

(d) Relation to intrusives : in some cases, the presence or absence of an intrusive may determine the presence of an unconformity[30].

Unconformities are studied best in a single sharp exposure. Aerial photographs are very useful in the study of unconformities.

Common problems posed by unconformities in mineral exploration :

Since unconformities separate rocks of differing ages, it is natural that they should act as barriers in mineral deposits associated with either of the two sets of rocks. Some of the problems posed by unconformities are similar to those posed by faults. But the solutions in this case are different. Thus dying out of deposits at the plane of unconformity is common but, unlike in faults, their continuity also ends at the plane of unconformity. The plane of unconformity itself is the seat of a large variety of residually and mechanically concentrated mineral deposits like bauxite, clay (in conglomerates), gold, etc. or planes of unconformities may also act as a channel for mineralising solutions.

The major problem in most unconformities is that the planes may be too irregular and undulating, and the resulting mineral deposits are likely to be very irregular. This problem has to be overcome by a systematic geological mapping followed by drilling to trace the continuity of the plane of unconformity itself. The proving of any deposit will come only at a later stage.

<u>The role of structure in ore localisation</u> :

Most of the rock and geological structures described earlier offer controls in localising mineral deposits. The most common structures which have a direct bearing on ore localisation are (i) bedding planes, (ii) cleavages, (iii) joint planes, and (iv) faults and folds[35].

Of these, the role played by fault and shear zones is most important. The pre-ore faults in particular offer a ready passage to mineral and ore carrying solutions. Faults and shear zones are widened when the ore or mineral fluids penetrate and travel along the planes of weakness[35].

Examples of shear zones acting as ore paths are very typically seen in deposits of barytes (Pulivendala), fluorite (Chandidongri), copper (Khetri and Mosaboni) and lead-zinc (Zawar). In all these cases, the shear zones, fault zones, etc. have provided excellent field guides.

The localising influence of fold is typically seen in the iron and manganese ore deposits. The synclinal troughs have usually shown a better concentration in many iron and manganese deposits than anticlinal crests. Thus, the manganese deposits of Madhya Pradesh and Maharashtra show evidence of structural influence, particularly the influence of synclines. The Sandur and North Kanara manganese deposits have also shown preferential concentration along synclines, although many anticlines have also shown excellent ore concentrations. Cross folded anticlines have played a major role in bringing out manganese ore deposits near the surface in Sandur where these doubly plunging anticlines have provided excellent field guides. Iron ore deposits of Goa and Karnataka also have shown evidence of structural influence. Most of the major iron ore deposits in the Sandur synclinorium like Donimalai, Kumaraswamy, NEB range, etc., have been preserved in cross folded synclines.

The influence of bedding planes, cleavage, schistosity, etc. is best demonstrated by the mica deposits of Nellore and Hazaribagh where the mica bearing pegmatites have intruded along the planes of schistosity and cleavage. In this case also, the relationship has been made use of as a field guide.

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ANNEXURE - I

* RECONSTRUCTION OF A FOLD BY DRAWING A "RIGHT SECTION" AND DETERMINATION OF THE DEPTH OF FOLD

Data Provided

The surface geological information for a syncline shown in Fig. 2.15 is available (solid lines).

Determine

Construct a right section normal to the plunge of the syncline to illustrate the true configuration of the structure.

Method

Examine Fig. 2.15 and determine the average bearing and inclination of plunge lines. The plunge can be determined by taking any two planes on the map (Fig. 2.15), such as the intersection of bedding and cleavage, or the intersection of two bedding planes (e.g., intersection of bedding planes at outcrop X, 342/48° WSW, with bedding planes at outcrop Y, 315/28° SW), and determining the bearing and inclination of the line of intersection of the two planes. In the example mentioned, the plunge of the intersection line approximates due South and 20° of inclination. This appears to be the average for all of the plunge lines.

Draw lines AB perpendicular to the average bearing of the plunge lines, and then draw perpendiculars to AB through points A and B.

Then select any points C, E, F, etc., on one of the formation contacts, and draw lines CC', EE', FF', etc., parallel to AB. The lines C'C", E'E", F'F" are then drawn in on the longitudinal sections with a 20° plunge from the horizontal. The lines BH and AJ are established by making the angles C'BH and DAJ = 70°, which is the complement of the 20° plunge angle. The lines BH and AJ thus represent the traces of the right sections as seen in the longitudinal view. Then using A or B as centres, and BE", BC", AF" as radii, draw in the arcs E"E"', C"C"', and F"F"', etc. Finally draw in lines E"'E"", C"'C"", and F"'F"" parallel to AB, making the lengths of these lines equal to EE', CC', and FF', respectively. The points E"", C"", F"" thus establish the position of the formation contact in their right section. This procedure may be repeated for numerous points to establish the complete structural picture for the right section. The process may be speeded up if proportional dividers are available by setting the dividers in the ratio of CW : BC". With this ratio, the distance CW is quickly reduced to WC"". The same ratio can be applied to any points on the plan view.

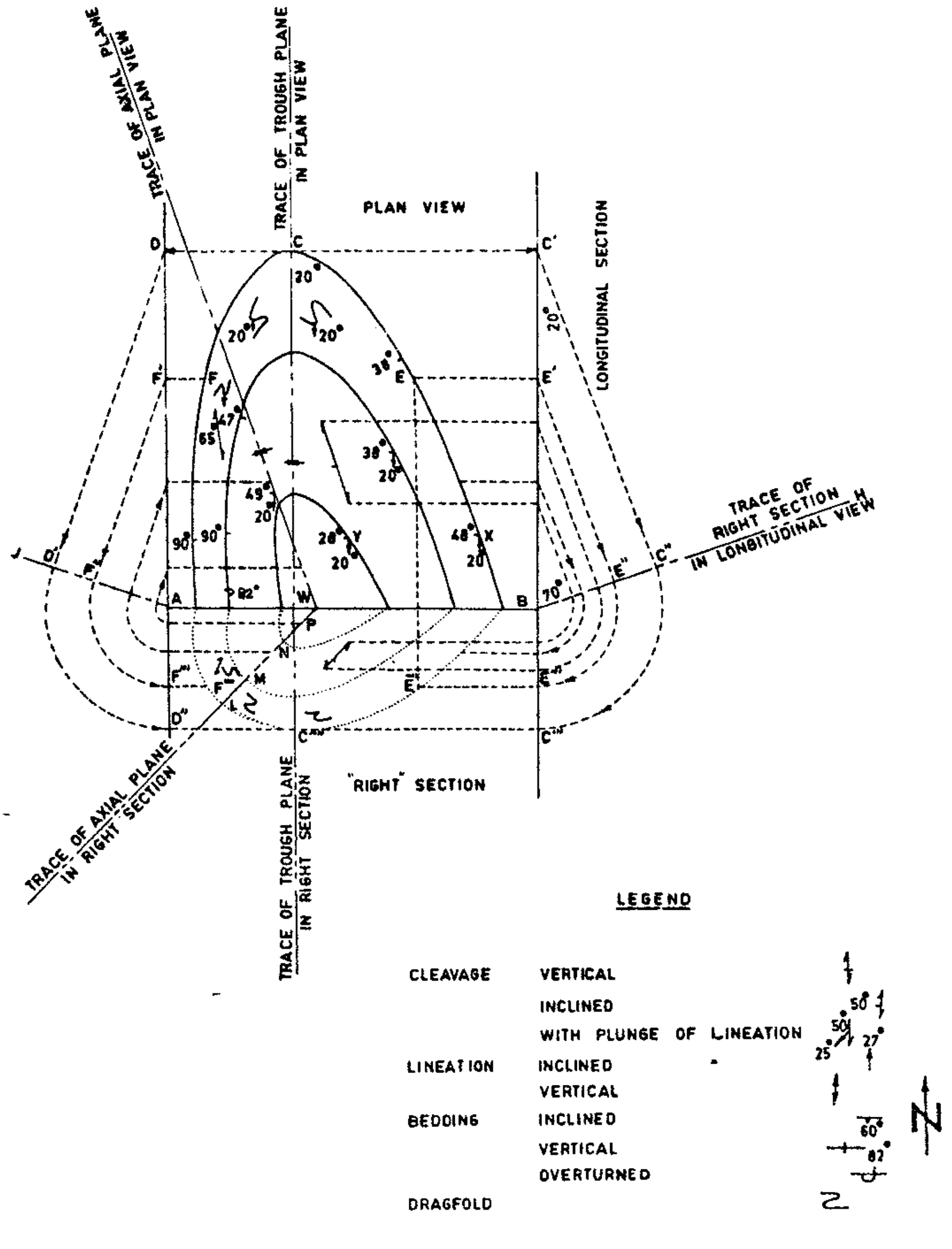


FIG: 2·15 RECONSTRUCTION OF A FOLD BY DRAWING A "RIGHT SECTION" AND DETERMINATION OF THE DEPTH OF FOLD

Chapter 3

3.0 Organisation and Methods

Exploration aims at searching out new mineral deposits. In a virgin terrain, this may involve the location of possible targets by prospecting. In an already known area or in a developed mine, exploration may be done solely to study the potential of a new mining block. The object of all such efforts is to locate and develop more mining blocks in the minimum of time and cost. Exploration is in short an important economic function of the mineral industry, its main aim being the creation of new profit centres for tomorrow[1]. In the national context, however, in some cases it may not be a centre of profit monetarily, but a national need.

3.1 Organisation

Prospecting and exploration have for long been dominated by individual efforts[1]. This has been true throughout the world. In India also, in a sense it has been true. Exploration has become a business activity of the mineral industry only in recent times and the concept of management is in a state of development even in very advanced countries. In India, the management concept is yet to develop fully.

Proper organisation and management are, however, essential ingredients in the successful execution of exploration. The major function of exploration management is to coordinate the three major factors required for locating new deposits, viz., ideas, money and luck[1]. Of these, the factor of luck is the major imponderable in every exploration effort. By quantifying and eliminating various unknowns, the factor of luck can be reduced to some specific risk level which can be foreseen and measured.

Prospecting for new deposits, apart from exploring known ones, is a major gamble. The law of "gambler's ruin" applies here too. The rule expresses the chances of going broke in a short run of bad luck. Such spells of bad luck can be compared to the non-discovery of any new deposit in a continuous series of search in an apparently favourable terrain. The law of "gambler's ruin" suggests that, in order to overcome such a row of failures, it is essential to keep trying despite failure. Such decisions are possible only when large capital is available and the decision to continue is based on a logical and scientific reasoning[2]. Scientific reasoning in this case comes only from geological knowledge.

It is logical therefore that exploration management should be in the hands of a geologist. An exploration manager should combine broad geological knowledge with imagination, physical endurance, tenacity of purpose, readiness to assume risks and should be prepared to take decisions quickly in the best possible way, in many cases even without knowing all the facts. It is also important that exploration management should be as close to the field as is feasible, the authority for making technical decisions in particular resting at the field level[1]. The management functions of mineral exploration can be broadly identified in the following types of activities:

(1) selection of minerals for exploration,

(2) acquisition of mineral rights,

(3) recruitment and organisation of personnel,

(4) procurement of equipment, and

(5) co-ordination and administration.

3.1.1 Selection of Minerals for Exploration

The process of selection is essentially guided by market conditions for a particular mineral or mineral-based industry. Thus, a cement plant may require limestone, a steel plant may need iron ore, limestone and dolomite, and a pottery may look for clay deposits. The demand may be for the export of raw ore like iron and manganese ores. The organisation or geologists entrusted with the task of prospecting and exploring for any deposit should know the type of ore, quantities, specifications, location and also the rate at which the ore materials are needed. Normally, in such cases, the choice of the mineral/ore is outside the control of exploration management. The specific needs are conveyed to the exploring agency by the industry which is looking for the specific ore or ores.

The exploration geologist/organisation may have a purely commercial aim in finding and developing ore bodies to attract interested investors to develop them commercially.

In such cases, it is essential to study the market conditions, and select minerals which are easy to locate and have a ready market. Here, the selection of the mineral is largely in the hands of the exploration organisation.

When the mineral/ore to be looked for is known, the next step is to look for information as to where to look for them. The memoirs, records, and bulletins of the Geological Survey of India and the geological maps accompanying them represent the main source of such information. The reports and other records of State Geology and Mines Departments, the publications of the Indian Bureau of Mines and other agencies and quite often the district gazetteers at the district headquarters, or the State Atlas may also provide the required key data for further field work.

3.1.2 Acquisition of Mineral Rights

In India, anyone who wishes to undertake mineral exploration would be legally required to possess a certificate of approval from the State Government and then obtain a prospecting licence or mining lease[3]. Mineral discoveries are made during routine geological work like systematic geological mapping or other exploration work done by the Geological Survey of India or the State Departments of Geology and Mining. Such discoveries can be studied from a scientific angle without disturbing the surface, but for chipping pieces of rock, without recourse to any legal sanction. However, for mineral exploration for purposes of opening up and mining mineral deposits, certain legal sanctions are required. The procedures to be followed are embodied in the various statutes of the Central and State Governments. For acquiring the mineral rights of an area, the pre-requisites in stages are (i) Certificate of Approval, (ii) a Prospecting Licence (P.L.) and/or a Mining Lease (M.L.)[3] if already issued, (iii) an incometax clearance certificate from the Incometax officer concerned, and (iv) a valid clearance certificate of payment of mining dues such as royalty, surface rent, etc.

(i) Certificate of Approval : Before venturing to prospect or exploit any major mineral, an entrepreneur must possess a Certificate of Approval. This certificate is issued by the concerned State Government and signifies the financial and/or technical ability of the person to enter the field of mining industry[3].

(ii) Prospecting Licence : A prospecting geologist should be well conversant with the procedure for acquiring the rights to prospect and mine mineral deposits. It is essential to obtain a P.L. for the areas to be investigated. Generally, a large area should be chosen as a prospecting target which can be progressively reduced after locating some promising mineral deposits. Finally, the mining lease may be taken only for such areas which can sustain mining.

A Prospecting Licence is issued for a period of 1-2 years, which is renewable for an additional year. During this period, the licencee is expected to prove the deposit in order to enable the opening up of a mine. During this period, no ore can be raised for commercial purposes except in the case of mica, gold, silver, and precious minerals[3].

(iii) Laws governing mining lease : A Mining Lease may be taken directly in areas where the presence of mineral deposit is known. Or it may be taken after prospecting of a few targets in an area of promise. A mining lease area should cover the deposit and some adjacent areas for the development of ancillary facilities like waste disposal, construction of surface structures such as office, colony, explosive magazine, processing plants and space required for other facilities connected with mining. The mining lease is issued for periods of 20 or 30 years and can be renewed for a similar period. The lease provides exclusive rights to the lessee to exploit, process and market the ore and ore products .

The salient features of the Mineral Concession Rules governing the issue of the Certificate of Approval, Prospecting Licence and Mining Lease in respect of minerals other than coal, oil, atomic and minor minerals are given in Appendix - 3.1 A. The rights and obligations of the holder of a prospecting licence or a mining lease are abstracted and incorporated in Appendix 3.1 B.

3.1.3 Recruitment and Organisation of Personnel

The success of any exploration venture depends on the training and background of its personnel. The recruitment of exploration personnel should be done carefully giving due emphasis to the academic background and qualifications, professional experience and scientific temperament. In addition, an exploration geologist should have the following qualities:

(1) Ability to keep track of various technical developments in the subject.

(2) Ability to keep in touch with organisations or persons who can provide the best possible information on a variety of geological and allied subjects like : (i) geochemistry, (ii) geophysics, (iii) drilling and exploratory mining, (iv) mining methods, (v) ore dressing, (vi) metallurgy, (vii) mineral industry and trade, (viii) economics and financing, and (ix) mineral and taxation laws, etc.

(3) Ability to impart proficiently various necessary skills to the less trained persons. This includes the training of people in specific practical skills like the excavating of a pit or trench, cutting of channels for sampling, sampling and sample preparation, etc.

(4) Ability to report lucidly, legibly and in time.

(5) Ability to negotiate with various State and Central Government agencies and other parties on technical and, non-technical details like acquiring land, establishing camps, arranging of provisions, services, security, etc.

(6) Ability to establish good contacts with the local community.

(7) Ability to foster a spirit of co-operation among the members of the team[4].

(8) An open mind free of prejudices.

Field organisation

Since all, or most, exploratory efforts do not assure any immediate financial returns, the field organisation should be small and should be efficiently managed. The field party should be assisted by a few trained and skilled persons who can help in survey, sampling and other work. Apart from this, there will have to be some office help to keep track of the day-to-day running of the organisation, maintain accounts, records, etc. There may have to be a few guards to take care of the equipment, records and camps.

Other personnel may include cooks, water carriers, khalasis and labourers to do heavy manual work.

Co-ordinating such units for the general success of the exploration effort is a skilled managerial job. Each unit should be assigned the job for which it is best suited and should work according to the general time schedule.

The administration of any exploration unit should be organised to keep track of all activities, arrange for the supply of equipment and materials and relieve technical personnel from routine details. Speed, efficiency and proper co-ordination and accountability should be the keynote of administration.

Some of these items of work are beyond the general sphere of activities of the individual geologists but they are being mentioned here to keep them well informed about organisational details.

An exploration party may consist of many people, depending upon the extent and intensity of the work involved. The choice is left to the individual geologist who should be able to choose and deploy personnel according to the specific job requirement. In addition, the services of specialists like photogeologists, geochemists, geophysicist petrologists, ore dressing engineers, etc. may be deployed as consultants when so required.

Camping

Camping for short duration is not a major problem in most parts of India where some kind of public accommodation in the form of rest houses, tourist homes, etc. is available. Even in villages, temporary accommodation can be fairly easily arranged.

In cases where the prospective area is deep within virgin terrain, it would become necessary to establish a temporary camp. The camp site should be chosen as near to the target area as possible and should have a source of clean drinking water nearby. It would be preferable to camp as near a village as the circumstances permit so that provisions, labour and communications are easily arranged. The erection and maintenance of some temporary structures to house the personnel and equipment would be necessary in case of such camps. In the conditions obtaining in most parts of India, it would be best to erect mud huts with straw/grass or galvanized iron sheet roofs. Tents are useful if their occupation is confined to the dry months only. The common types of tents used by field exploration units along with an itemized check list is shown in Table 3.1.

Table 3.1 : Check list of Items of various Tents

	Description	D.F.Shouldhary (Junior staff members)	Kabul Pal (Senior staff members)	M.S. (Officers)	Bath Tent (Officers)
1.	Dimensions	2.44 m X 2.44 m (8' X 8')	2.74 m X 2.44 m (9' X 8')	3.05 m X 3.05 m (10' X 10')	1.52 m X 1.52 m (5' X 5')
2.	Poles	3	3	3	4
3.	Iron Pegs 18"	8	16	25	4
4.	Iron Pegs 7"	14	26	36	6
5.	Wooden Pegs 18"	2	6	9	2
6.	Wooden Hammer	1	1	1	1
7.	Sludge Hammer	1	1	1	1
8.	Jute canvas Bag for Pins	1	1	1	1
9.	Salitah of Jute canvas with rope	1	2	2	-
10.	Mallet	-	-	-	1
11.	Durries 3.05 m X 1.8 m	-	2	-	-
12.	Durries 2.74 m X 2.44 m	-	1	-	-
13.	Inner Fly with door	-	-	1	-
14.	Outer fly	-	-	1	-
15.	Durries 3.05 m X 3.05 m	-	-	1	-
16.	Durries 3.55 m X 1.83 m	-	-	1	-
17.	Chick kanat 7.30 m X 1.40 m	-	-	1	-
18.	Chick Purdah for Kanat (1.40 m X 0.95 m)	-	-	1	-
19.	Chick Purdah 1.65 m X 0.95 m	-	-	2	-
20.	Cloth kanat with a set of ten poles	-	-	1	-
21.	Bags for kanat	-	-	1	-
22.	Bags for cloth kanat	-	-	1	-

A camp in remote areas should have a first aid kit and also some patent medicines. The geologist who heads the operation or someone as responsible should have training in first aid and also in the administration of a few drugs. This will normally ensure the availability of first aid and a necessary minimum of medical attention, for the personnel. It would be advisable to arrange a source which can periodically replace provisions.

3.1.4 Procurement of Equipment

A large variety of equipment is needed for mineral exploration purposes. Of these, some are for constant and continuous use and should be purchased for permanent retention. Others may be needed only occasionally and might be hired when a specific need arises. Some of the items of equipment which are of constant and continuous use are dealt with below:

Map

A well-prepared topographical and geological map of the area which is to be investigated is the most important ingredient of a prospecting expedition. The plan should show topographical and geological details on sufficiently large scale. In India, the standard scales for systematic geological mapping are ¼" = 1 mile or 1 : 63,360 (presently 1 : 50,000). Some mineralized belts are mapped on 4" = 1 mile or 1 : 15,000 (approx.). Such maps are available with the Geological Survey of India and its regional offices or with the Directorates of Mines and Geology of the respective States. A list of the offices of the Geological Survey of India is given in Appendix - 3.2.

Where a geological map is not available, a geologist may have to map the area first. For this, topographic base maps are a must, and those (toposheets) of the Survey of India are an ideal choice. Such maps can also be obtained from the offices of the Survey of India shown in Appendix - 3.3. When toposheets are not available, use may be made of forest maps, revenue and cadastral maps available with the district revenue and/or forest authorities. When no base maps are available, it has to be prepared by the Surveyor first if a surveyor is available, or else, a geologist himself should be able to prepare one.

Where necessary, maps have got to be enlarged systematically on to a suitable scale before using for geological mapping. Square method, protractor and proportionate compass method, photographic or pantograph methods are commonly used depending on the urgency and availability of the facility. In the case of areas already worked, it is possible that some plans and other details may be available with government agencies like Indian Bureau of Mines. Where legally feasible and technically relevant the possibility of these being used deserves to be considered. Addresses of the Indian Bureau of Mines offices are given in Appendix - 3.4.

In the field, a map comes to be used rather roughly. Precautions are necessary to prevent the map from getting torn and damaged. The best precaution is to mount the paper map on a cloth backing and bind it with card board covers in such a way that they can be loosely folded into a book (see Fig.3.1 for details). Facilities for map mounting and even mounted maps are available at the map sales offices of the Survey of India. Such a book covered with a thin transparent plastic sheet would completely protect the map from most of the damages normally encountered in the field. A permanent map case of suitable shape and made of light, rust-free metal would also be advisable[5] for safe transit and storage of unmounted maps and plans.

Compass

A compass is used for finding directions, taking traverses and locating one's own position in the map. The magnetic needle of the compass always points towards the magnetic (and not the true) north. A compass meant for a geologist's field work usually has some built-in arrangement for measuring dips of bedding planes and inclinations of the various planar features. For versatality in use, a Brunton Compass is the best. A Brunton compass is designed in such a way that it can be used as a compass, clinometer and hand level[6]. For most uses, this instrument can be held in one's hand. When accurate measurements are required, it may be mounted on a tripod stand. Brunton compass may be used for making the following observations : bearings, vertical angles, strike and dip, geological mapping, contouring (though difficult), etc.

Hammer

Hammer is essential for breaking rocks and collecting samples. Several types of geological hammers are available; the most useful of them may have a square hammer on one side and a chisel edge on the other. A hammer of this type with a longer handle than usual may be used as a pick in climbing steep inclines[5]. A light wooden handle with some flexibility or a steel or wooden handle with shock absorbing material will protect the striker from shock. The usual field hammer may weigh 0.5 to 1 kg.

Chisel

Chisel is necessary to wedge out rock samples as also in cutting channels for sampling and collecting chip samples. A chisel-like tool with a pointed end is termed a moil and is useful in cutting and chiselling out rock specimens[5].

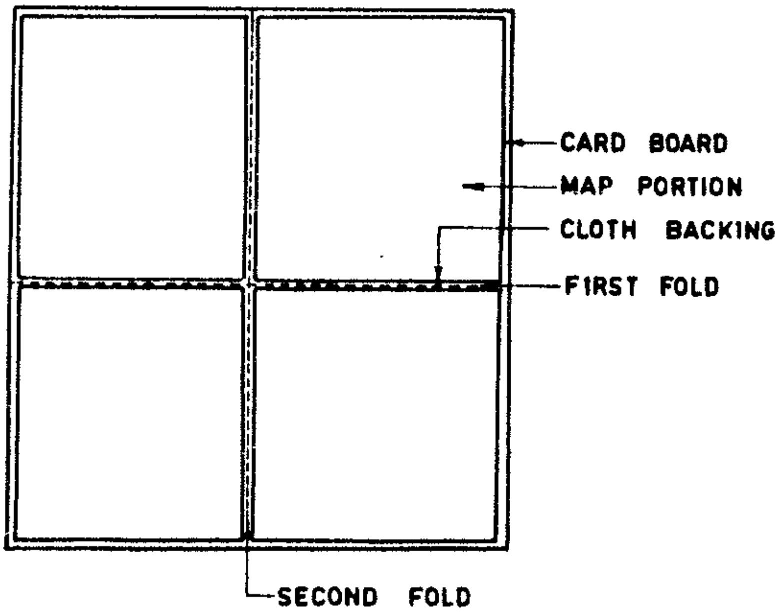
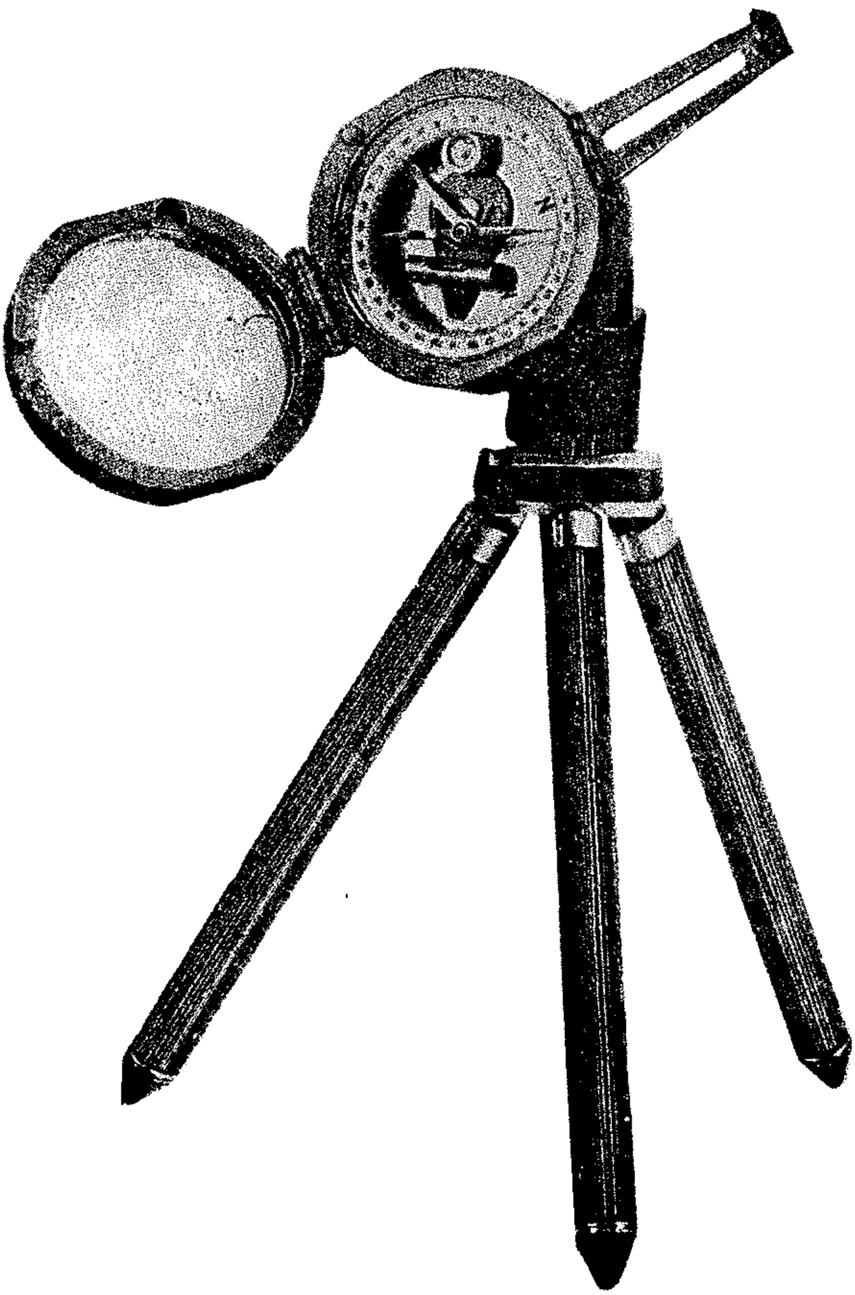


FIG. 3·1 MOUNTING AND BINDING OF A MAP

86 A



'BRUNTON' UNIVERSAL POCKET TRANSIT

Chapter 3

3.0 Organisation and Methods

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An exploration party may consist of many people, depending upon the extent and intensity of the work involved. The choice is left to the individual geologist who should be able to choose and deploy personnel according to the specific job requirement. In addition, the services of specialists like photogeologists, geochemists, geophysicist petrologists, ore dressing engineers, etc. may be deployed as consultants when so required.

Camping

Camping for short duration is not a major problem in most parts of India where some kind of public accommodation in the form of rest houses, tourist homes, etc. is available. Even in villages, temporary accommodation can be fairly easily arranged.

In cases where the prospective area is deep within virgin terrain, it would become necessary to establish a temporary camp. The camp site should be chosen as near to the target area as possible and should have a source of clean drinking water nearby. It would be preferable to camp as near a village as the circumstances permit so that provisions, labour and communications are easily arranged. The erection and maintenance of some temporary structures to house the personnel and equipment would be necessary in case of such camps. In the conditions obtaining in most parts of India, it would be best to erect mud huts with straw/grass or galvanized iron sheet roofs. Tents are useful if their occupation is confined to the dry months only. The common types of tents used by field exploration units along with an itemized check list is shown in Table 3.1.

Table 3.1 : Check list of Items of various Tents

	Description	D.F.Shouldhary (Junior staff members)	Kabul Pal (Senior staff members)	M.S. (Officers)	Bath Tent (Officers)
1.	Dimensions	2.44 m X 2.44 m (8' X 8')	2.74 m X 2.44 m (9' X 8')	3.05 m X 3.05 m (10' X 10')	1.52 m X 1.52 m (5' X 5')
2.	Poles	3	3	3	4
3.	Iron Pegs 18"	8	16	25	4
4.	Iron Pegs 7"	14	26	36	6
5.	Wooden Pegs 18"	2	6	9	2
6.	Wooden Hammer	1	1	1	1
7.	Sludge Hammer	1	1	1	1
8.	Jute canvas Bag for Pins	1	1	1	1
9.	Salitah of Jute canvas with rope	1	2	2	-
10.	Mallet	-	-	-	1
11.	Durries 3.05 m X 1.8 m	-	2	-	-
12.	Durries 2.74 m X 2.44 m	-	1	-	-
13.	Inner Fly with door	-	-	1	-
14.	Outer fly	-	-	1	-
15.	Durries 3.05 m X 3.05 m	-	-	1	-
16.	Durries 3.55 m X 1.83 m	-	-	1	-
17.	Chick kanat 7.30 m X 1.40 m	-	-	1	-
18.	Chick Purdah for Kanat (1.40 m X 0.95 m)	-	-	1	-
19.	Chick Purdah 1.65 m X 0.95 m	-	-	2	-
20.	Cloth kanat with a set of ten poles	-	-	1	-
21.	Bags for kanat	-	-	1	-
22.	Bags for cloth kanat	-	-	1	-

A camp in remote areas should have a first aid kit and also some patent medicines. The geologist who heads the operation or someone as responsible should have training in first aid and also in the administration of a few drugs. This will normally ensure the availability of first aid and a necessary minimum of medical attention, for the personnel. It would be advisable to arrange a source which can periodically replace provisions.

3.1.4 Procurement of Equipment

A large variety of equipment is needed for mineral exploration purposes. Of these, some are for constant and continuous use and should be purchased for permanent retention. Others may be needed only occasionally and might be hired when a specific need arises. Some of the items of equipment which are of constant and continuous use are dealt with below:

Map

A well-prepared topographical and geological map of the area which is to be investigated is the most important ingredient of a prospecting expedition. The plan should show topographical and geological details on sufficiently large scale. In India, the standard scales for systematic geological mapping are ¼" = 1 mile or 1 : 63,360 (presently 1 : 50,000). Some mineralized belts are mapped on 4" = 1 mile or 1 : 15,000 (approx.). Such maps are available with the Geological Survey of India and its regional offices or with the Directorates of Mines and Geology of the respective States. A list of the offices of the Geological Survey of India is given in Appendix - 3.2.

Where a geological map is not available, a geologist may have to map the area first. For this, topographic base maps are a must, and those (toposheets) of the Survey of India are an ideal choice. Such maps can also be obtained from the offices of the Survey of India shown in Appendix - 3.3. When toposheets are not available, use may be made of forest maps, revenue and cadastral maps available with the district revenue and/or forest authorities. When no base maps are available, it has to be prepared by the Surveyor first if a surveyor is available, or else, a geologist himself should be able to prepare one.

Where necessary, maps have got to be enlarged systematically on to a suitable scale before using for geological mapping. Square method, protractor and proportionate compass method, photographic or pantograph methods are commonly used depending on the urgency and availability of the facility. In the case of areas already worked, it is possible that some plans and other details may be available with government agencies like Indian Bureau of Mines. Where legally feasible and technically relevant the possibility of these being used deserves to be considered. Addresses of the Indian Bureau of Mines offices are given in Appendix - 3.4.

In the field, a map comes to be used rather roughly. Precautions are necessary to prevent the map from getting torn and damaged. The best precaution is to mount the paper map on a cloth backing and bind it with card board covers in such a way that they can be loosely folded into a book (see Fig.3.1 for details). Facilities for map mounting and even mounted maps are available at the map sales offices of the Survey of India. Such a book covered with a thin transparent plastic sheet would completely protect the map from most of the damages normally encountered in the field. A permanent map case of suitable shape and made of light, rust-free metal would also be advisable[5] for safe transit and storage of unmounted maps and plans.

Compass

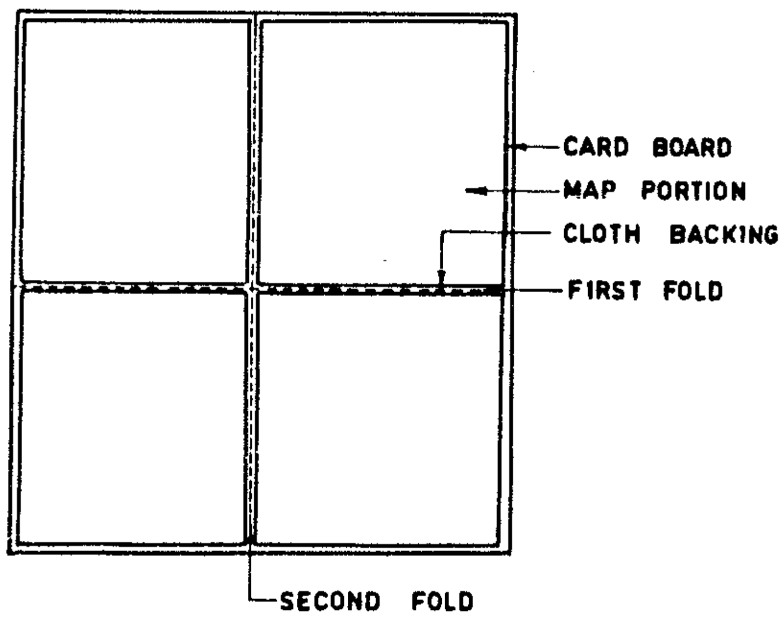
A compass is used for finding directions, taking traverses and locating one's own position in the map. The magnetic needle of the compass always points towards the magnetic (and not the true) north. A compass meant for a geologist's field work usually has some built-in arrangement for measuring dips of bedding planes and inclinations of the various planar features. For versatality in use, a Brunton Compass is the best. A Brunton compass is designed in such a way that it can be used as a compass, clinometer and hand level[6]. For most uses, this instrument can be held in one's hand. When accurate measurements are required, it may be mounted on a tripod stand. Brunton compass may be used for making the following observations : bearings, vertical angles, strike and dip, geological mapping, contouring (though difficult), etc.

Hammer

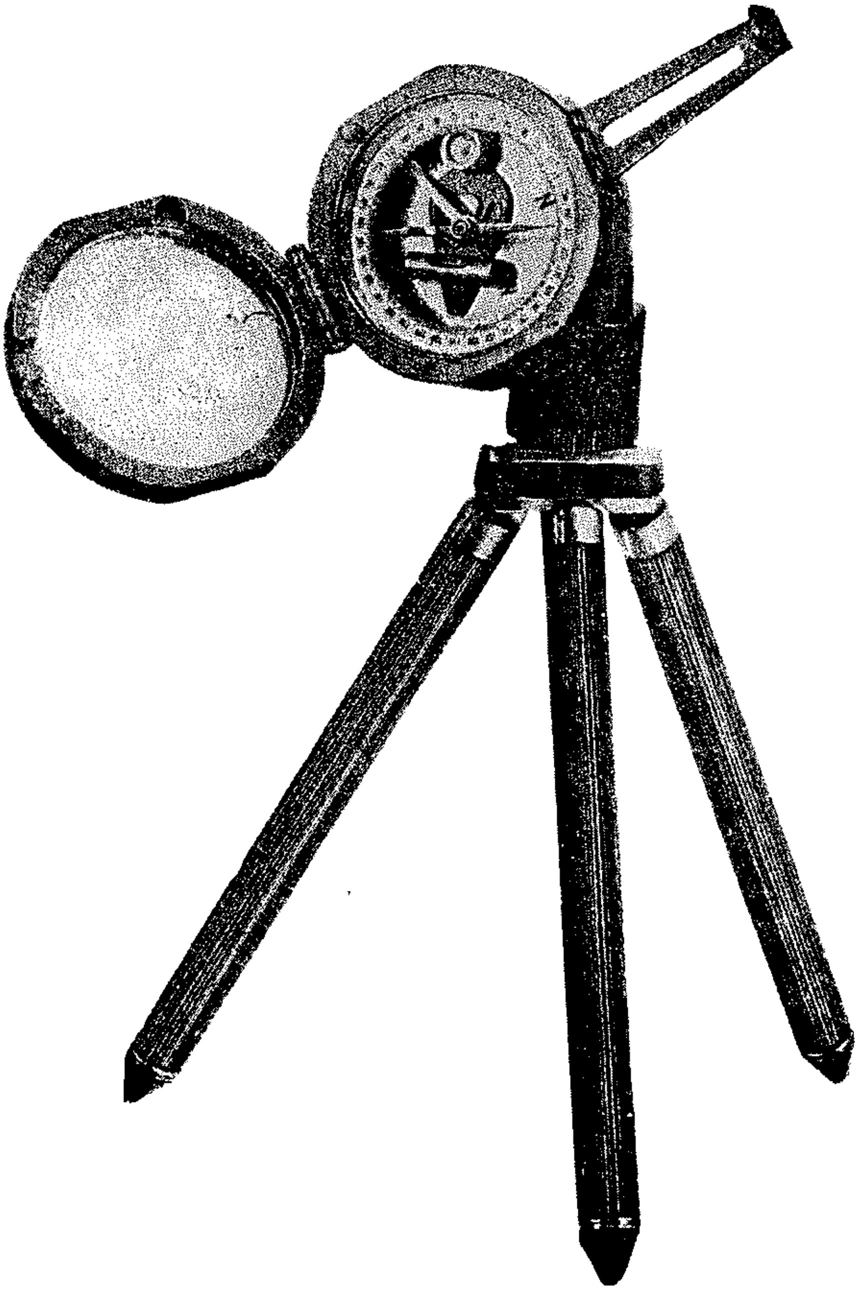
Hammer is essential for breaking rocks and collecting samples. Several types of geological hammers are available; the most useful of them may have a square hammer on one side and a chisel edge on the other. A hammer of this type with a longer handle than usual may be used as a pick in climbing steep inclines[5]. A light wooden handle with some flexibility or a steel or wooden handle with shock absorbing material will protect the striker from shock. The usual field hammer may weigh 0.5 to 1 kg.

Chisel

Chisel is necessary to wedge out rock samples as also in cutting channels for sampling and collecting chip samples. A chisel-like tool with a pointed end is termed a moil and is useful in cutting and chiselling out rock specimens[5].



FIG; 3·1 MOUNTING AND BINDING OF A MAP



'BRUNTON' UNIVERSAL POCKET TRANSIT

Magnifying glass

A pocket lens with a magnification of 10 times is useful for most of the field examinations[5]. Special large diameter lenses with a large field and high magnifying power may be required when working in a multimineral area. For purposes of reading maps, a map reading hand lens will be useful.

Magnet

A horseshoe or bar magnet of small size is essential for testing magnetic minerals.

Measuring tape

A geological field party should have at least one steel or metallic (cloth) tape of 30 m.length and another pocket steel tape of 2 m.length, the first for ground measurements, measuring traverse lines, etc., and the other for measuring in shorter units, such as thickness of veins, beds etc. The survey teams require 60 m.steel tape as well as pocket steel tape of 2 m.length.

Protractor

A rectangular protractor scale made of plastic and of convenient size to be carried in one's pocket is most advisable. For purposes of plotting and measuring the bearings, the protractor may be circular showing 0 to 360° divisions and made of good transparent plastic.

Field notebook

A field notebook may be about 18 x 12 cm in size containing some 200 pages. Most of the pages should be unruled. Some graph pages and a few ruled pages should be included at intervals. Some detachable perforated plain sheets at the end of the book will be of immense use. The book should have a hard cover of paste board or plastic material and should show the name and address of the geologist, details of the project, and date of operation.

In addition streak plate, glazed porcelain pieces and pocket knife should be available with the field party.

Survey work requires special field books to put down all the recordings made in the field.

Pickaxes, shovels, baskets, etc.

When some minor excavations become necessary to study an outcrop, pickaxes, shovels, etc., may be needed. These may be chosen from the wide variety available in the market.

Other essential items are mostly non-specialised equipment and may be chosen from among the various standard brands available. A checklist of these items is given below :

Checklist of general items

(1)	Haversack	-	For carrying compass, note-books, etc.
(2)	Scale, setsquares	-	For measuring, drawing lines, etc.
(3)	Pencils, colour chalk	-	Writing, sketching, marking, etc.
(4)	Hydrochloric acid	-	For testing carbonate rocks.
(5)	Adhesive tape	-	For labelling samples.
(6)	Tracing sheets	-	Tracing and sketching.
(7)	Sample bags	-	For collecting samples.
(8)	Washing pans	-	For washing some types of float ore.
(9)	Screens	-	For screening the float ores.

Check list of sampling equipment

(1) Hammers 1, 2, 4 kg and also 8 kg.

(2) Chisels - assorted sizes.

(3) Moils

(4) Canvas 1 x 1 m (for collecting samples at site)

(5) Marking paint, chalk, etc.

(6) Gunny-bags

(7) Metallic or wooden tags

(8) Wire brushes

(9) Hair brushes

(10) Iron pans and shovels

(11) Metallic plates 3 x 3 m (sizing board)

(12) Large canvas sheets, (tarpaulins) 6 x 6 m, 3 x 3 m, 6 x 3 m (for spreading collected samples)

(13) Spring balance
(14) Screens of varying sizes and sieve sets
(15) Brushes of soft hair
(16) Sampling bags - cotton and polythene
(17) Rope, thread, twine
(18) Mortars and pestles of iron
(19) Smithy tools for upkeep of hand-tools.

3.1.5 Transport

Some form of transport is essential in exploration camps. Petrol/diesel driven jeeps and trucks are the most versatile forms of transport. However, if such transport is too costly or cannot be used, and for small-scale operations, animals or animal drawn vehicles like bullock carts could be used.

3.2 Methods

Mineral exploration consists of two activities. One is prospecting which, in essence, is the choosing of suitable mineral targets for exploration. The other is exploration which is the proving of targets located during prospecting. The methods employed during either of the activities cannot be rigidly isolated. However, certain types of activities are typical of both and can be broadly recognised. But prior to starting prospecting or exploration it is necessary to choose the target areas which can yield mineral deposits. The methods of choosing such target areas are discussed below.

3.2.1 Methods of Choosing Target Areas

The selection of target areas should be done by a process of sequential elimination of areas of poor potential. Such eliminations are possible by reference to the available literature alone in most cases. However, the whole process of target selection involves much more than a mere study of the literature. The following sequential approach is followed by most organisations, and is recommended.

Study of background literature

Before embarking on a prospecting mission, all available literature of the prospective ground should be carefully examined. Such literature may be in the form of published geological reports with maps, unpublished geological reports, memoirs, records, etc. of State Departments of Geology and Mining, Geological Survey of India and sometimes reports of private parties which have examined the area before. A thorough and systematic search should be made to locate all available literature which should be studied well.

The Geological Survey of India should be considered as the important source of geological literature in India. The Geological Survey of India publishes records, memoirs, bulletins and other miscellaneous publications which, among other things, list the occurrence of various mineral deposits in India. In addition, there are the Directorates of Mines and Geology in all States of the Union which also bring out relevant publications. A consolidated list showing the addresses and other details of all State departments is given[7] in Appendix - 3.5.

Revenue departments at the district level also may have records and land details and district gazetteers which might help. For this, the office of the Collector/District Commissioner of the district should be contacted. After gathering the relevant information, the prospecting geologist should have a clear idea about the topography, geology and the ore occurrence of the prospective terrain. He will also have some idea about the climate, people, the availability of camping grounds, etc. near the prospective terrain, which are of practical importance. For locating target areas, the geologist may choose the easier and less costly ground methods when the areas are small, or the more sophisticated and also expensive aerial methods which are ideally suited for coverage of very large areas. The ground methods include reconnaissance, tracking of boulders, outcrops, etc., for evaluating direct field criteria leading to mineral discoveries.

Ground methods-Reconnaissance

When the geologist has a sufficient number of areas which deserve field examination, these are marked in the appropriate plans. He should now move to the field for a direct examination of these target areas. His first step should be to undertake a rapid reconnaissance of the various target areas. At this stage, no detailed examination is done, but the lay of the ground is studied carefully.

During the rapid reconnaissance, efforts should be made to see all the rock exposures. If the geological map of the area is available, this task becomes very easy. A few rapid checks should be made to study the accuracy and authenticity of the geological map also.

A prospecting operation may aim at locating one single mineral or several minerals. In either case, direct or indirect evidence of mineralisation should be expected to be present in favourable terrain.

After rapid reconnaissance, the geologist will have some idea of the possible loci of mineralisation. In any case, the next step is to conduct detailed field traverses to locate evidence of mineralisation. Natural or man-made cuttings generally expose the rocks for easy examination. The beds of river courses, nalas and streams are the best available nacural openings. If any float ore is found in such stream beds, efforts should be made to locate the original sources. This can be done by traversing the stream course upstream. All tributary nalas, streamlets, etc., should be searched till the source is found.

Sometimes, one might suspect the presence of float ore without being able to locate it because of its small size. A typical example is the gold float ore which is so small that it is practically microscopic in size. In such cases, pan washing will have to be done systematically in river beds upstream from the mouth of the river or target area limit. In stream beds also, there are certain areas which have a better chance of retaining heavy detrital matter. Such areas include the outside channel of meanders, oxbows, flood plains just after a water fall and upstream sides of underwater obstructions. All such areas should be thoroughly searched.

Rocks and mineral deposits may be exposed in road cuttings, rail cuttings, wells, old mine workings, etc. Such areas should also be examined thoroughly. Old mine workings, ore dumps and waste dumps should be examined with great care. Any old record of the mine, plans and sections should also be examined and reasons found for stopping the mine. samples from the dumps and workings should be analysed to see the extent of mineralisation.

Various types of evidence indicate the presence of mineral deposits, depending upon the nature of mineralisation, physico-chemical nature of the deposit, association with host-rocks and duration and intensity of the action of weathering agents on the deposit. In areas of recent oxidation, gossans may be well preserved particularly in the case of sulphides. Such gossans may lead to ore discovery if pursued carefully. The presence of mineralisation may be indicated by direct evidence in many cases.

Direct field evidence

The following features need to be examined in detail to locate mineral deposits :

(1) float ore,

(2) topography,

(3) stratigraphy,

(4) lithology,

(5) contact surfaces,

(6) structure,

(7) alteration haloes, and

(8) old workings, tailing dumps and evidence of smelting activity of metallic ores, etc.

Float ore

In practically every case of exposed deposits, float ores will be present. Float ores may be close to the outcrop or they may be at considerable distances. Therefore, the first thing that a prospecting geologist should look for is the presence of float ore. Float ore accumulates in certain topographically favourable terrains. Where ore is exposed in an escarpment, the escarpment will have float ore but the dip slopes may not. As mentioned earlier, float ore should be traced upstream or up the slope to locate the source rock.

A very typical case of the relationship between float ore and in situ ore is demonstrated by the iron ore deposits of N E B range in Sandur Basin in Bellary district, Karnataka. Here, the iron ores are exposed on ridge tops with a dip slope and an escarpment. The dip slope contains little or no float ore whereas the escarpment side is full of float ore. Here, the ore occurs in sizes varying from a peanut to large boulders individually weighing hundreds of tons. The maximum float ore concentration is at the point where the slope breaks from a steep incline to a gentle plain. From the bottom of the slope if a traverse is undertaken, one would ultimately come to the original in situ source. The general regional outline of float ore occurrence coincides with the outline of the exposure of the iron ore deposits in this area.

Topography

All rocks, minerals and mineral deposits are consistently under attack by natural weathering agents. It is to be expected that the more resistant formations would give rise to a prominent land form. This phenomenon has presented us with two practical field guides which are in topographically prominent features and topographically subdued features. The topographically prominent features are generally associated with hard resistant ore deposits.

A typical example of this guide is the case of the iron ore deposits of India. Almost all the iron ore deposits occur on top of prominent ridges and other topographical land marks. Thus, in a geologically favourable terrain, iron ores will generally be confined to hill/ridge/plateau tops and this forms an important field guide for locating them. Iron rich gossans and cappings form prominent land marks in the Khetri copper belt in India although it never served as a guide to the location of the deposits. Rather, the old workings seem to have acted as a better guide in this case[8].

Subdued topography generally indicates less resistant rocks. Thus, an easily weathered rock like limestone or dolomite generally gives rise to a flat topography. This phenomenon is typically demonstrated by the limestone of Kaladgi Basin, Vindhyan and Cuddapah rocks which are structurally less disturbed. In all these cases, limestones occur interbedded with sandstones and quartzites, the former giving rise to a flat topography and the latter standing out prominently as ridges. This is however not true in the case of limestone associated with the Dharwars where prominent structural disposition also has a bearing on the topographic features of limestone. For example, crystalline limestone of Tumkur district, Karnataka shows topographically prominent exposures. This may be partly because of the structure as also interbedding with phyllites which are softer or because of its slightly higher iron and manganese contents which make them resistant. Similarly, in a geologically younger region like the Himalayas, various limestones (like the Krol limestone of Mussoorie) stand out as prominent topographic land marks. This may be because of the recent uplift which is to be expected in the geologically younger terrain. Therefore, both the guides discussed above may have to be used with caution in areas of geologically younger strata with an active tectonic background.

Stratigraphy

In a sedimentary sequence, if ore is associated exclusively with a group of rocks, this can be referred to as a stratigraphic guide[9]. A typical example is the association of iron ore with the Banded Hematite Quartzite/Jasper formation. The association is so universal that it is safe to say that where there is an exposure of this formation, iron ore deposits may be nearby. The same principle applies to some of the Indian manganese ores also, but with the limitation that in the case of manganese ore the lithological association is purely local. However, sequentially, the manganese ores occur just below the iron ores in many Indian iron ore districts and hence where iron ores are known to be present, manganese ore also may be present nearby. Another example is the diamond deposits of Vindhyan conglomerates where the conglomerate beds show prominent unconformities. Deposits of bauxite, clay, etc. also show association with unconformities and disconformities. Fireclay beds show stratigraphic association with coal beds. Phosphorites show association with limestones, which themselves are typical examples of stratigraphic control on mineral localisation. Stratigraphic guides are too broad to be specific except in certain special cases and should be used in combination with other gudies for maximum utility.

Lithology

Certain mineral deposits show specific lithological affiliation to certain rocks. This association can be recognised in syngenetic and epigenetic deposits and used in the search for minerals. Thus, chromite, platinum, etc. occur exclusively in ultrabasic rocks. Lead, zinc and silver ores show a preference for limestones. Diamonds occur only (in their original form) in eclogite (Kimberlite). Mica occurs only in pegmatites. Such guides can be used in a broad regional search and also in a purely local search for the ores. In fact, it is the primary job of the exploration geologist to establish the lithologic controls.

Contact surfaces

Contacts between two lithological units form excellent guides in the case of many deposits. This is mainly because such surfaces tend to be zones of weakness. Contacts of intrusive rocks like sills, dykes and also other intrusives, like granite, etc. are preferential targets of ore concentrations. Thus, in searching for mica, it is the pegmatite contact with the mica-schist country rock which is likely to have greater concentration of mica. Similarly, in the case of asbestos, serpentinisation and formation of asbestos are more intense near the contact of the intrusives with the limestone (e.g. Cuddapah). Contacts of serpentinised ultra-basics with dotted peridotites may also represent good asbestos-bearing zones.

Structure

Structural features like folds, faults, shear zones, fracture zones, etc. may act as the focal point of mineralisation. In such cases, the search for deposits should be concentrated around favourable structures.

Alteration haloes

Mineralisation associated with igneous and metamorphic processes usually leaves an alteration halo around the orebody which is a direct evidence of mineralisation. This halo may be defined by the occurrence of one or more minerals or by the intensity of fracturing or by metal ratios[9]. Naturally, the recognition of such evidence calls for careful search, geological mapping, collection of chip samples for chemical analysis, etc.

Such haloes are common in the asbestos deposits of Cuddapah where asbestos veins are surrounded by a halo of serpentinisation.

Old workings, tailing dumps, etc.

In India where mining dates back to thousands of years deposits which have rich outcrops are likely to have been worked at one time or the other. Old workings, tailing dumps, slag heaps, etc. are very common in the copper, lead-zinc and gold deposits of India. The deposits of copper at Khetri, gold at Kolar Gold Fields and other places were located by this field evidence. Tailing dumps/waste heaps may themselves be the source for some other minerals e.g. tailing dumps at K.G.F. are now found to yield scheelite.

Aerial and special methods

Where exploration is to cover very large areas near known mineral districts, aerial and other special methods are ideally suited. Before resorting to these costly techniques, a thorough study of available literature and data of the following types should be made :

(1) aerial photographs of various types,

(2) metallogenic, minerogenic and tectonic maps,

(3) gravity, magnetic and electromagnetic survey maps,

(4) geochronological data, and

(5) geochemical and geobotanical data.

A study of the metallogenic, minerogenic and tectonic maps together with the help of aerial photographs, gravity and other anomaly maps, geochemical and geobotanical data, will make easy the selection of large target areas of exploration. These maps may be had from the Geological Survey of India, Survey of India, National Geophysical Research Institute and National Remote Sensing Agency (the latter two in Hyderabad)

3.2.2 Criteria for Accepting or Rejecting Target Areas

(1) Presence of marketable products in reasonable quantities: This is determined by the size and mineral content of the deposits. The size of a deposit may be highly variable under varying circumstances. It may contain a few thousand tonnes of ore or a few millions of tonnes. The economic viability of a deposit is often a function of its size and mineral content. If the mineral content is poor, even large tonnages may be useless.

Prior to exploration, it is difficult to determine the size of the deposit. However, the geologist's experience in the district, and his judgement as to the possible size of the discovery play important roles. By a process of reasoning, the relation between the size of an outcrop and the size of a deposit can be established particularly in a well-known mining district. If no such data are readily available, the nearby mines should be studied to establish this point.

Mineral deposits generally contain some portions with rich ore and some others with lean ore. In such cases, before developing or abandoning a prospect, the average grade and the corresponding tonnage should be approximately estimated. In many cases, particularly of base metals scout drill holes may become necessary at this stage.

(2) Availability of local demand : The discovery of a deposit near an already established industry which can make use of the produced ore surely enhances its value. For example, the location of new deposits of iron ore, manganese, etc. near a steel mill will ensure their suitable exploitation. If transportation costs permit, the assurance of an established consumer at some distance can also ensure the

development of a deposit quickly. Targets which fulfill the above criteria can be readily chosen for detailed exploration.

(3) Availability of export market : In many cases, there may not be an immediate demand for certain types of ores. If the newly located target falls within this category, then an export market should be examined. If it is found that there is a steady export demand for the material likely to be available, such a deposit can be accepted for intensive exploration.

(4) Necessity for developing a new industry : Certain mineral based industries may need development in specific national contexts. Mining and milling of ore from such a deposit would be economically viable because of the special material demands. Under such circumstances also newly located deposits can be adopted for detailed exploration.

(5) Nearness to market : A deposit which is near a ready market is obviously more valuable than the one located at a great distance. The market may be a plant utilising the ore for manufacturing, or a port from where ore is exported or, in some cases, an ore concentration facility.

A prospect can be chosen for development or rejected on the above criteria in most cases. In some cases, more complex factors are likely to come into play. For example, if a mineral is of strategic importance irrespective of any of the above considerations, the prospect may be accepted for development at the instance of the Government.

(6) Amenability to being mined economically : Whether the ore is exposed on the surface or is exposed but continues linearly in depth will determine its amenability to being mined by cheap opencast or costly underground methods. For underground mining to be economical, the ore should be rich in grade and should be available in reasonable quantities.

(7) Location and transportation : The value of a deposit is also a function of the location of the deposit and the availability of a cheap mode of transportation. Topography also plays an important role. If the deposit is on a hill, transportation may be done by ropeways run on gravity which may effect savings.

The availability of readymade roads or other forms of transport adds considerably to the economic attractiveness of a deposit. In this context, the case of iron and manganese ores of Goa is noteworthy. Although generally low in grade, they have become economically viable because of the availability of navigable rivers nearby, making transportation to the shipping points cheap.

If a deposit is located near a settled township or area, labour would be available and the need for developing fresh facilities for living and recreation would be limited and thus its value would be enhanced.

3.2.3 Methods of Prospecting and Exploration

A variety of methods are available for exploration. Each has specific use, value and some inherent limitations[10]. Choosing the techniques for specific field conditions calls for a broad knowledge of the methods and their limitations.

These methods can be broadly divided into: (i) airborne exploration methods and (ii) ground exploration methods. The airborne exploration methods are listed below :

Airborne Exploration Methods

Remote sensing

Photogeological study — Colour / Black and white / Multispectral

Aerial examination

Aerial geophysical exploration

Aeromagnetic surveys

Electromagnetic surveys

Ground exploration methods are the most important in delineating the physical boundaries and chemical nature of the individual deposits and consist of two operations, viz. detailed ground definition of targets and three dimensional sampling. Ground exploration methods are listed blow :

Ground Exploration Methods

Detailed ground definition of targets

Regional geological mapping

Geochemical sampling and mapping

Soil sampling

Stream sediment sampling

Water sampling

Rock sampling[3]

Geobotanical sampling and mapping

Grid sampling of plant species[11]

Geophysical methods

Gravity method
Magnetic method
Seismic method
Electrical method .... Resistivity
Self-potential
Induced polarisation
Down the hole electrical

Scout drilling and rapid sampling

Three dimensional sampling

Detailed geological mapping (Surface / Subsurface)

Trenching and pitting

Drilling .... (Surface / Subsurface)

Exploratory mining

Sampling related to the above operations.

Out of the various methods described above, three dimensional sampling (detailed ground exploration) is most important in the final evaluation of a deposit.

All other techniques are seldom used together and some of them (remote sensing, colour photography) are still in a developmental stage and have only experimental value. Most of the techniques listed above are available in India although airborne geophysical data are not available as yet for wide public use.

The major criterion for making a choice should be the discriminating capacity of the method being considered[10]. Some of the techniques like geochemical sampling, geobotanical sampling, remote sensing, colour photography, etc. have a low discriminating capacity. These techniques do not lead to a direct discovery of mineral deposits but are tools required for rather general investigations. They are best utilised when combined with methods of high discriminating capacity.

Another criterion which may be considered in choosing the technique is the status of the terrain. In virgin areas, one might have to choose large target areas and it is important that the first stage of elimination be done rapidly. Here, choice may be made in favour of rapid techniques even if they have poor discriminating capabilities. Expense and ready availability of equipment and skills also may influence the choice of techniques.

AIRBORNE EXPLORATION METHODS

Remote sensing : The principle of remote sensing centres around the capacity of all objects to reflect electromagnetic energy. Theoretically, all objects display a characteristic spectrum of emitted, absorbed and reflected radiation. In practice, however, this spectral reflectance is influenced by the reflectivity characteristics of the object as well as atmospheric transmissivity. The former characteristic is made use of in most remote sensing operations. The electromagnetic spectrum contains many bands and wave lengths of which only a few are useful for remote sensing applications. These are:

(1) ultraviolet,

(2) visible spectrum,

(3) infra-red,

(4) near infra-red, and

(5) microwave.

Visible light and near infra-red are used for conventional photographic reproduction in aerial and space photography. The other wave bands need special photographic emulsions which are sensitive to these wave lengths for photographic reproduction.

Various camera-filter combinations with special emulsions are used for photographing and reproducing earth surface features in images which are physically similar to conventional photographs. Such photography is done with the help of aircrafts or satellites. In another application of remote sensing, radar waves are emitted from a source mounted on a aircraft and the reflected waves captured to form images of the earth's surface which are broadly similar to conventional aerial photographs. This system is called Side Looking Airborne Radar or SLAR. Interpretation of such images is very helpful in identifying geological formations, structural features and certain indirect indications of mineralisation[11].

Fig. 3.2 shows the electromagnetic spectrum available for remote sensing and the possible types of sensors which can be used. Remote sensing has certain advantages in geological work which other methods do not have. These are :

(1) a comprehensive, instantaneous synoptic view of large areas of the earth's surface is possible;

(2) repetitive observations are possible;

(3) data are uniform, and

(4) data can be had in a wide choice of scales, particularly for regional work[12].

The most versatile branch of remote sensing is photogeology which has wide applications in mineral exploration.

Photogeological study

In India, most of the Peninsular region has been aerially photographed and photography on some scale is available for most of the areas. Aerialphotos (mostly in black and white) can be obtained only from the Surveyor General of India, Survey of India, Hathibarkala Estate, Dehra Dun (U.P.). The scales of the photographs are 1:60,000, 1:40,000, 1:30,000, 1:15,000 and 1:10,000 (all approx.) although the larger scale photographs are available only for very small areas. The Survey of India has a plan to establish regional aerial photographic libraries to enable the public to use these photographs in a wide area of earth science disciplines. Geologists can also derive benefit out of them when ultimately established[13].

Aerialphotos are made by cameras mounted on aeroplanes. The terrain to be covered is photographed in continuous and lateral overlaps so that stereophotomodels of areas can be seen, when a set of overlapping photographs are placed under a stereoscope.

Photographic scales are approximate and when accuracy is required, the photographs should be scaled down suitably by either correcting the photographs (orthophotos) or by the slotted template assembly process, and then assembled in a mosaic.

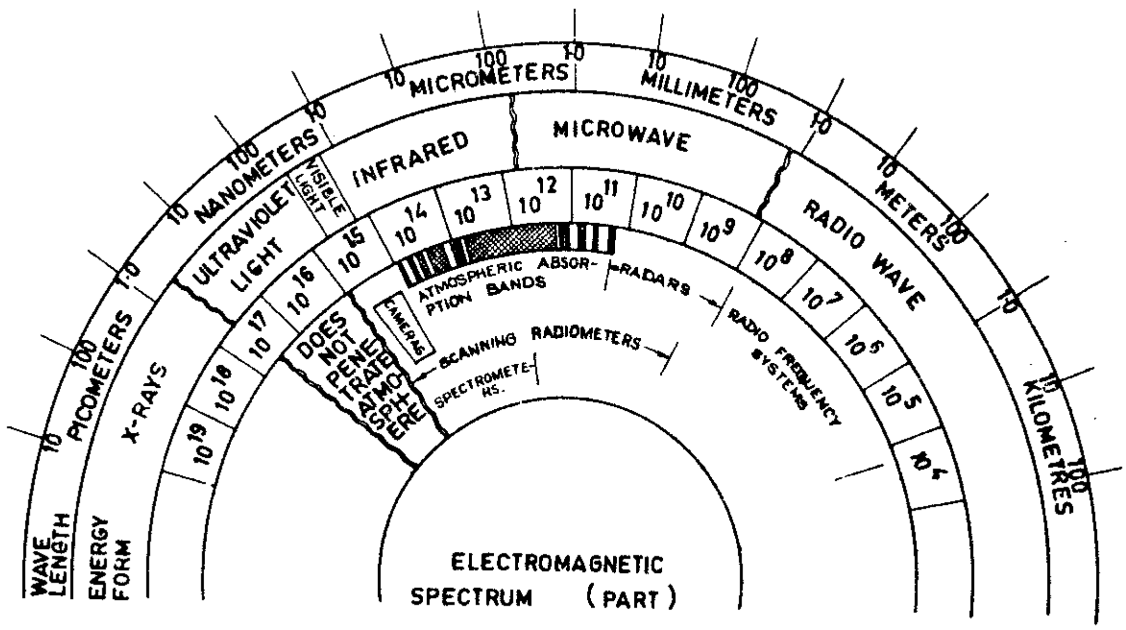


FIG:3·2 ELECTROMAGNETIC SPECTRUM

(ADOPTED FROM U.S. GEOL. SURVEY, EROS PROGRAM, REPRODUCED FROM CENTO, SEMINAR ON THE APPLICATION OF REMOTE SENSORS IN THE DETERMINATION OF NATURAL RESOURCES HELD IN ANKARA, TURKEY, NOV. 1971.)

Geological features are studied on aerial photographs by certain recognition elements which can be broadly recognised as (i) tone, (ii) texture, (iii) characteristic shapes and patterns, (iv) shadowing, (v) drainage pattern, (vi) land form pattern, (vii) vegetation distribution, (viii) soil formation, and (ix) moisture distribution[4,14].

Local elements and combinations of recognition elements help in recognising various rock units and also lithologic units.

Mineral deposits are seldom discovered directly by aerial photography. Photogeology helps in mapping large areas rapidly and recognising megastructural units. Speed and rapid understanding of the geology are the chief advantages of photogeology. However, there are certain characteristic features which help in recognising certain types of mineralisation. For example, hydrothermal mineralisation may be recognised in aerialphotographs by the following criteria :

(i) geomorphic or land form features, their topographic expression or appearance,

(ii) bleached haloes with change of tone and texture,

(iii) stratigraphically and lithologically favourable host rock, and

(iv) structural features like contacts, fracture patterns, and flow structures[14].

Photogeology is an ideal tool for exploration in alluvial terrain particularly where geomorphological features have an influence on mineral occurrence and concentration.

Maps made by photogeological methods are not complete without selective or detailed field checks. Features like lithology, structure, dip, etc., particularly need verification and confirmation before a map is finally accepted for use.

Photogeology was used in locating several bauxite bearing laterite cappings in the east coast[15].

Aerial examination

Direct aerial examination is a good method particularly in the early stages provided the area is inaccessible otherwise and flights can be arranged inexpensively. The method merits attention in the Indian context only in the Himalayan terrain.

Airborne Geophysical Exploration

In airborne methods, as the name suggests, all the instruments are mounted on aeroplanes. The advantage is that large areas can be rapidly covered by this method. The methods are listed below :

(1) aeromagnetic survey, and

(2) electromagnetic survey.

The principles involved are the same as for ground geophysical methods described elsewhere in detail.

GROUND EXPLORATION METHODS

By aerial or other methods, target areas are selected for ground exploration. During ground exploration, the deposits will have to be broadly delineated. Such a delineation can be achieved by regional geological mapping, scout drilling, followed ultimately by three-dimensional sampling.

Detailed ground exploration of targets

Regional Geological Mapping - Regional geological mapping is done for delineating potential mineral bearing areas, and is generally done on a small scale toposheet of scale 1:250,000 (1/4 inch) to 1:50,000 (1 inch). Such maps are generally not made by exploration agencies as the task falls within the purview of agencies like the Geological Suvey of India. If such maps are not available and the area is totally virgin then only the exploration agency need make maps.

The exploration agency may mark out potential mineral bearing areas on the basis of rapid field observations. Outcrops, river and stream cuttings, old workings if any are the most important features to be marked out. Certain promising areas may be chosen and a more detailed map on a scale 1:25000 to 1:5000 may be prepared showing the mineral deposit, outcrops, and details like old workings, etc.

The purpose of a geological map is to show the geological set up of an area in terms of the occurrence and distribution of various rock types, their mutual relationships, their attitudes, structure and also their association with topography and drainage. A geological map is essentially two dimensional.

A geological map is constructed step by step, by collecting and recording geological data on a base map. Therefore, the first requirement of a geological map is a base map. A base map should show the permanent topographical and drainage details of the area and also other man-made details such as roads, railways, villages, etc. The maps should be suitably contoured with reference to the permanent bench marks and should have standard co-ordinates. In case of large-scale plans, a system of artificial co-ordinates is often used which will have only local reference value. For geological mapping on a regional scale, small-scale toposheets published by the Survey of India are good enough and cadastral maps can be used for some large-scale work. However, for large-scale work, it is better to prepare a base map according to one's own specific needs[16].

A geological map can be made by ground survey, or by using aerial photographs. In ground survey, geological features may be mapped by a compass and tape, or pacing traverses from known fixed points indicated on the map. In case, a very great precision is required, a theodolite may be used. Plane table, telescopic alidade, etc. can also be used where detailed mapping is to be done.

<u>Geological mapping by compass and tape/pacing</u>

The method is applicable in the case of mapping on small-scale toposheets or on large-scale maps. In either case, the principles involved are the same and can be summarised in the following steps.

<u>Orientation of the map</u> : This is done by finding the magnetic north of the place by compass and aligning the north of the map absolutely parallel to the compass needle.

<u>Location of oneself on the map</u> : Objects or landmarks on the ground which are indicated on the map are identified. A bearing to these objects is taken. The distance is estimated either by tape or by pacing. The angle and distance are plotted and the position fixed. In case it is possible, the position can be fixed by taking a bearing each from two objects and by locating their plotted intersection.

Mapping : Various geological data can be systematically plotted by the methods mentioned above. Various geological data are located by a single bearing and measuring of distance or by intersection of two bearings from various fixed landmarks. Where actual measurements are involved, the distance can be measured by pacing or by actual tape measurements.

Geological mapping by plane table

This method is very useful in large-scale geological mapping, particularly when the ground is not rugged. A plane table consists of a drawing board fitted on a tripod in such a way as to enable levelling and orientation. The base map is fixed on the board firmly and an **alidade,** occasionally with telescope and vernier, is used for taking the bearings. Instead of an alidade, open sights fixed on a straight edge can also be used. In mapping with a plane table, first, two known points located on the base **plane** are identified on the ground. A base line is fixed between these points which are designated as A and B. To locate the points to be mapped, first, the plane table is fixed directly above the point A and the table aligned with the alidade so that the base line AB is in direct line with point B. Now, the alidade is turned toward the point to be mapped, say C. After aligning the alidade, a ray is drawn from A in the direction of C. Now we have the ray AC. The table is shifted to B and the base line BA is aligned with point A as was done for AB. Now the alidade is pointed toward C and the ray BC drawn. The two rays will intersect at the position C which is the map position of the object C[17].

Plotting can be done by direct alignment of the alidade with an object of interest and measuring the ground distance by tape. Here, only one ray is involved and the distance is actually measured and plotted[17].

Mapping can also be done by resection. In resection, the point C is fixed as follows. The instrument is placed on A and oriented toward point B. Now, decline AC is drawn in the direction of C. Now, the table is taken to C and oriented toward point A. From point B now a line is drawn toward C. The lines AC and BC intersect at C[17].

Geological mapping by Theodolite

To handle a theodolite, it is always preferable for a professional surveyor to join the geologist. The principles invovled here are not very different from those described for compass traverses and plane table survey. The major difference is that a theodolite can be used for tacheometric survey for finding the distance between points. This is a great advantage where linear tape measurements are difficult due to terrain conditions. For mapping in open pit or underground, theodolite is the best instrument. When a surveyor and geologist work together, the work of mapping and surveying can be combined. This will effect considerable savings in time.

A geological map should show at least the following features :

(1) contacts between various formations (formational in small scale maps and lithological in large-scale maps),

(2) strike and dip of contacts,

(3) outcrop position of faults, folds, etc. with strike, dip and plunge where observable,

(4) planar features like cleavage, schistosity and joints, and

(5) soils, and geomorphic features which have interpretational geological value. These may include alluvial formations, land slides, meander bends, etc.

In large-scale maps, the amount of details will be large and even very small-scale features might have to be mapped in. A mineplane for example might show even the position of thin stringers and veins and their lithological and structural disposition. Anything of interpretational value should find a place in a geological map.

In reading and interpreting, the two dimensional data depicted in a geological map will have to be imagined in a three-dimensional plane. A projected picture of the structure below the ground is very essential. This is obtained by the construction of cross-sections. Here, first a line of section will have to be chosen. The maximum information is generally available in a section line which is across the general strike of the formations. A profile is drawn by placing the contour values on the section line and projecting from the lowest available elevation. The various elevations are then projected by scale from the base. Next, the various geological and lithological contacts, fault traces, fold traces, etc. are plotted on the profile outline showing their respective dips, in amount and direction, and appropriate projections made to bring out the sub-surface disposition of the deposit. The resulting picture provides a fairly good view of the geological features in the third dimension[16].

In the geological map, it is customary to show various geological formations in symbols or in colour.

Boulder tracking or float ore tracing

Float ores are bouldery ore fragments priced out of outcrops of mineral deposits by the process of atmospheric weathering. These fragments are distributed by surface drainage and wind over large areas by transport agencies like river systems and other weathering agents. Naturally, they are found in stream beds and stream banks more frequently. They may occur in alluvial formations also. Generally, the angular edges of a float indicate the nearness to the source in contrast to rounded pebbles which signify considerable transportation over a long distance. The float ores should be traced upstream to locate the original outcrop. This can be done by systematically traversing upstream and examining every water course to its origin[18].

In minerals like gold, diamond, cassiterite, etc., panning is advisable to locate minute quantities of the ore as explained earlier. It should be done systematically, also upstream as in the case of float ores. Panning can accomplish two tasks, viz. the location of primary deposits of various minerals and the location of areas of eluvium, eluvium, and alluvium carrying increasing quantities of minerals in the form of placer deposits[18].

Geochemical sampling and mapping

The quantitative determination of the anomalous distribution of certain elements in the surface soil and sub-surface overburden and comparison with a known background value give an idea of the rocks and mineral deposits hidden below the ground. This is the essential principle of geochemical prospecting[19].

The common practice followed in geochemical method is the collection of soil, stream-sediment/water/ rock chip samples at regular intervals, the grid lines being transverse to the strike of the suspected zone of mineralisation. Air samples are also collected for certain geochemical surveys. The metal content is determined by rapid geochemical analysis of samples. Geochemical methods are very effective in locating targets of basemetal mineralisation and are used extensively in India[20].

Soil sampling : Residual soils are common in both temporate and tropical regions the latter giving rise to very thick soil caps. These soils always carry mineral particles of the parent rocks. Soil geochemical sampling aims at recognising such values, anomolously high value concentrations indicating a soil-capped target. Samples of 100 gm. are collected at predetermined intervals for rapid analysis[21].

Stream sediment sampling : This is the most widely used technique in geochemical surveys. Fine stream sediments are collected from surface stream channels. These sediments usually carry mineral matter in fine form derived from their original source rock. Samples are collected from the active stream channels or from flood plains. The samples should be collected[21] at intervals of 0.15 km.

Water sampling : Water sampling is of relatively little value except in the case of uranium and, in rare cases, zinc and copper[21]. Water samples are collected from lakes, rivers, and also from underground sources.

Rock sampling : Rock samples are collected from visible rock outcrops by cutting out chips of rocks from predetermined grid points. Samples of -100 mesh size are prepared for analysis.

One of the major problems in geochemical exploration is the treatment and interpretation of data. A single investigation may produce some 50,000 to 60,000 individual readings and they have to be classified, processed and analysed to produce any useful information. Generally, such studies require the help of a computer, or at least an electronic desk calculator.

In presenting the interpreted data, one which is easiest to understand is the method of value contouring[22].

Geochemical prospecting data can be more effectively interpreted by following graphical statistical procedures or by computer methods. Briefly the methodology is based on the following concepts. Any area under investigation will have three types of geochemical values. One is the background value which describes the average metal value of the area. The other is the threshold value which describes the zone separating the average values from the anomalous values. Lastly, there are the anomalous values which are above the threshold values. The area of anomalous values forms the best target for exploration.

Geobotanical sampling and mapping

The presence and variety of a particular plant species in the area of mineralisation have been recognised as a guide to locating ore since many years. However, it is only in the recent times that it has started becoming an organised science and a method of exploration.

The growth and distribution of a particular plant in a given area are known to be influenced by sub-surface geology. Geobotanical survey involves a visual study of the nature and distribution of the vegetative cover, plant distribution, the presence of indicator plants, mutational or morphological changes in species introduced by mineral enrichment, etc.

The mapping technique in geobotanical surveys is as follows. Plots of 5 sq.km. are chosen and the plant species found in them, their growth, density of growth, new species rare species, etc. are marked out. A species which shows special affinity to the area is chosen by a process of progressive elimination. The association of these species with any known mineral occurrence in the area is established if such a correlation exists. This correlation can be used for searching adjacent larger areas.

However, tracking of indicator plants is more useful in this type of exploration. Two types of indicator plants are recognised. These are - (i) universal indicators and (ii) local indicators. Universal indicators grow only in a mineralised terrain and are seen the world over in similar setups. They are of course rare in their occurrence and distribution. Some of the common universal and local indicators are given in Table 3.2. The list also shows the effect of the presence of certain metals on certain plant species. These also may form useful guides. The local indicators are

Table 3.2 : Some Universal and Local Plant Indicators with their Associated Metals

Element	Universal indicators	Local indicators
1. Cobalt	Crotalaria cobalticola Silene cobalticola	
2. Copper	Acrocephalus robertii Astragalus declinatus Becimum homblei Gypsophila patrini Merceya latifolia Merceya ligulata Mielichhoferia macro-carpa Mielichhoferia mielichhoferi Tephrosia sp. Viscaria alpina	Armeria maritima Elsholtzia haichowensis Eschscholtzia mexicana Polycarpaea glabra Polycarpaea spriostylis Polygonum posumbu
3. Iron		Betula sp. Clusia rosea Dacrydium caledonicum Damnara ovata Eutessa intermedia
4. Lead		Baptisia bracteata Erianthus giganteus Tephrosia polyzyga
5. Manganese		Digitalis purpurea Fucus vesiculolus Trapa natans Zostera nana
6. Molybdenum		Astragalus declinatus
7. Nickel		Alyssum bertolonii Asplenium adulterium Pulsatilla patens
8. Phosphorus •		Convolvulus althaeoides
9. Selenium	Aster venusta Astragalus spp. Oonopsis spp. Stanleya spp.	Neptunia amplexicanlis
10. Selenium & Uranium	Astragalus (Certain spp.)	
11. Silver		Eriogonum ovalifolium Lonicera confusa

Table 3.2 : Some Universal and Local Plant Indicators with their Associated Metals (*Concld.*)

Element	Universal indicators	Local indicators
12. Vanadium	Astragalus bisulcatus	
13. Zinc	Thlaspi calaminare Thlaspi cepaeacfolium Viola calaminaria Viola lutea	Gomphrena canescens Matricaria americana Philadelphus sp.

(The presence of these plant species is indicative of the presence of the corresponding elements. Some mutational effects caused by the presence of certain elements on certain plants are also very useful in recognising them. This recognition is particularly significant in the case of multispectral aerial photography where the mutational effects can be recognised. Thus, they provide an indirect evidence of the possible presence of certain elements in regional scale explorations. A list showing the mutational effect and the corresponding causative elements is given below.)

Element or mineral	Mutational effect
1. Chromium	Chlorosis of leaves.
2. Cobalt	Increase of chlorophyll in some species and chlorosis in others.
3. Copper	Chlorosis of leaves and dwarfism.
4. Iron	Darkening of leaves.
5. Manganese	Chlorosis of leaves with white blotches
6. Molybdenum	Formation of abnormally coloured shoot.
7. Nickel	Chlorosis and necrosis of leaves.
8. Serpentine	Dwarfism; colour changes of flowers.
9. Uranium and radioactivity	Variation in flower colour, presence of abnormal fruits, increase in chromosomes of nucleus, stimulation.
10. Zinc	Chlorosis of leaves; symptoms of manganese deficiency.

more common. Some 63 species of local indicators have been recognised. But opinion is divided about their ultimate practical utility[23].

In North Kanara district of Karnataka, local prospectors believe that manganese deposits show association with plants like 'nama', 'kundal', 'jamka' and 'karipatha'[24]. This association has not been scientifically established.

Geophysical methods

Geophysical prospecting is the search for hidden mineral deposits by the measurement of certain physical properties of the earth's surface. This involves the field measurement of certain properties like gravity, magnetism, seismosity and electrical conductivity of rocks by sensitive instruments and the interpretation of such data along with the available geological data. A knowledge of the potential of this method is essential for exploration geologists. Five major geophysical prospecting methods are available : these are gravity, magnetic, electrical, seismic and radioactive methods. Since this bulletin deals with non-radioactive mineral deposits, only the first four methods are discussed here. Despite a high degree of sophistication in instrumentation and skill, mineral discoveries by this method have been relatively few even in industrially advanced countries[25].

Gravity method

The principle utilised here is to locate the anomalies of gravity from place to place in an area of search. If a plumb bob is suspended freely it will point towards the centre of the earth. If a heavy mass is nearby it will exert a gravitational influence on the plumb bob with the result that the bob will show a deflection[25]. The heavy mass may be a body of massive sulphide ore, iron ore, bodies of chromite, etc. all of which are known to cause such deflections. The deflections are measured by instruments. Three such instruments are in common use. They are the pendulum, torsion balance, and gravimeter. Of these, the gravimeter is the most useful.

In the field, traverses are laid at intervals, varying with the scale of operations, just as in the case of geological traverses. Measurements of gravity are made at predetermined points and the readings are plotted on a graph with distances on the X-axis and deflections on the Y-axis.

The resulting graph will show an 'anomaly' if the traverse is over a body which exerts a gravitational pull of its own. Fig.3.3 illustrates the concept and the peaked portion of the graph represents the anomaly. Anomalies can be interpreted by contouring also where the peaked values will be better reflected in the areas of anomaly.

Magnetic method

Certain rocks have magnetic properties. They exert their magnetic influence above the normal magnetic field of the earth. Certain minerals which contain magnetite in a subordinate form such as magnetite in asbestos, and pyrrhotite associated with base metals also may exert magnetic influence. This magnetic influence causes deflections of a magnetic needle which are measured by sensitive instruments such as a magnetometer on traverses just as in the case of gravity measurements[25]. The data can be interpreted in the same way as gravity data.

Electrical methods

The following methods are generally recognised : resistivity, self-potential, induced polarisation, and down the whole electrical methods.

The principle involved is as follows : Electrical methods are particularly relevant in surveys for metallic mineral deposits. Within these, there are various techniques. Some make use of conductivity and self-potential while others make use of the inductive responsive properties of rocks. In the self-potential method, the electrical energy inherent in the rock is directly measured. In the resistivity methods, measurements are made to find out the different resistivities of rocks. In the inductive response method high frequency alternating current is introduced into the earth and the length and phase differences of the induced potential are measured on the surface. These phase and length differences are influenced by the electrical properties of rocks and are used in recognising specific formations[25].

Seismic methods

In this, the capacity of rocks to transmit earthquake waves is studied. In dense rocks, the waves travel very fast. Artificial earthquakes are produced by explosions and the waves measured by sensitive seismographs. There are

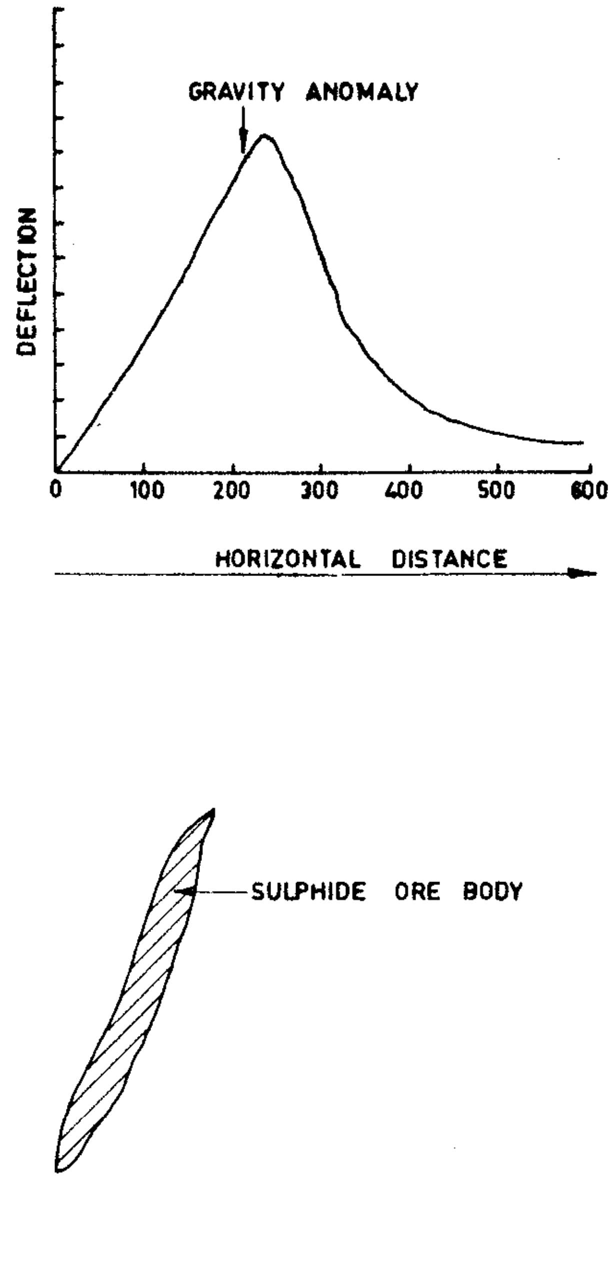


FIG: 3·3 GRAVITY ANOMALY GRAPH

two types of measurements in this method. One measures the property of reflection and the other the property of refraction. In the reflection method, the time taken by the various surfaces to reflect seismic waves is measured. In the refraction method, the principle used is that surface waves travel at a slower speed compared to the deeper waves[25].

All the methods, except the seismic, are capable of being executed by airborne instruments for covering large areas rapidly. Electrical methods offer the best scope for application in small areas.

Geophysical methods are best done by geophysicists. The exploration geologist's function is essentially to decide at what stage and in which terrain geophysical surveys are most useful and then to carry out the follow up action on the basis of geophysical findings.

Scout drilling and rapid sampling

Scout drilling is done exclusively for confirming the presence of deposits discovered on the basis of exploration conducted by geochemical, geobotanical, and geophysical methods. Scout drilling can be done by coring or non-coring drills. The samples resulting from such drilling are analysed to study the major elements and their percentage availability by rapid methods. Scout drilling helps in understanding the nature of a newly discovered deposit.

THREE-DIMENSIONAL SAMPLING

Three-dimensional sampling aims at establishing the dimensions and grade of the deposit in all its details. This operation involves detailed geological mapping, trenching and pitting, drilling, exploratory mining and sampling pertaining to each operation.

Detailed geological mapping

Detailed geological mapping (surface) : The methods of mapping have already been discussed. In detailed geological mapping, the details plotted are substantially more and the scales may be of the order of 1:2000, 1:1000, 1:500 or even larger with contours of 2 to 5-metre intervals. Closely-spaced grid points should be made use of in actual plotting. The details to be plotted may be lithological boundaries, ore type contacts, structural features, etc. Detailed mapping should aim at establishing correct boundaries of all these features and should help in depicting the correct two dimensional picture of the deposit.

Detailed mapping should also be done to project subsurface information which should be confirmed by drilling and thus will form the basis of planning out a drilling, pitting or trenching programme.

When a deposit is being proved by exploratory mining, underground mapping of the various openings may become necessary. Methods of underground mapping are discussed below.

Underground mapping

Underground mapping consists of mapping of levels, drives, raises, winzes, crosscuts, stopes, etc. Although the broad principles of geological mapping discussed earlier are valid for underground mapping, the latter requires certain special skills and also a slightly different methodology. Particular attention has to be paid to the plane of projection, which is a horizontal plane. In underground openings, all mineable details will have to be visualised in three-dimensions. In order to depict this three-dimensional view, all mapping data should be projected on to a single plane. In most cases, this plane coincides with breast or waist level. In certain special cases, the plane may coincide with the back of the drift[8].

The underground map base should be an accurately prepared survey plan showing all details of underground working. In a working mine, such up-to-date maps are always available. The map should be of a large scale (1:200, 1:100 or in some vein and stringer type of deposits even larger scales may be necessary[26]). Since underground workings are often dirty, maps and instruments used in mapping should be properly protected by sturdy waterproof material.

In underground mapping, the most versatile tool is the Brunton Compass for taking bearings and dips and strike of linear features. For taking dips underground, under conditions of poor light and awkward points, a clino compass is more suitable. In measurements, a cloth tape would be most suitable. However, the normal practice should be to establish a large number of stations, evenly distributed in every working, which can act as reference points from which measurements may be taken. Such reference points should be surveyed by theodolite and connected to the main survey. The stations should be marked by luminescent paint for visibility.

Various items of geological significance to be mapped are summarised below :

lithology of the various rock units exposed with their contacts,

ore zone with its footwall and hanging wall contacts, ore types and various host rocks of each type of ore where feasible,

strike and dip of the various formations and also various planar features like cleavage, joints, contacts, etc.,

structural features like folds, faults, unconformities, intrusive rocks, crushed zones, ore solution channels, etc. wherever possible, and

reaction rims, zoning etc.

Plotting of all details should invariably be done simultaneously with the measurements.

Special care and attention are required for measuring the various planar features underground. In taking strike, the planar features should be taken, with the reader standing close to the exposure on one wall and aligning the compass exactly in line with the exposure of the same feature on the other wall. Measurements from known points nearby on both walls can be of help in confirming measured positions of the planar features on the map[7]. In most cases, the wall exposures of the planar features may not be clear enough to take a direct measurement of the dip. In such cases, the procedure is to measure the correct strike and then measure dip exactly at right angles, with the clinometer plane, coinciding with the exposed dip plane. This can be done very well by holding the compass in hand and aligning the two planes by eye. Direct measurement of dip should be resorted to only when the dip plane is very clearly exposed on one wall[9].

In underground measurements of strike and dip, the help of a string is recommended. By tying the ends of the string on both walls of the opening suitably, dip and strike measurements become easy. In dip measurements, the string is aligned to the plane of dip by tying it at two points within the dip plane. Aligning the compass to the string may prove easier than aligning the compass directly. Dips may be measured by a plumb bob too. For this purpose a plumb bob is suspended from the top of the exposure. The distance from the plumb bob to the back of the planar feature is then measured. The length of the plumb line divided by the distance of the plumb line to the back of the planar feature gives the tangent of the angle of dip[9].

Trenching and pitting

A trench is a narrow linear excavation which is generally done to expose concealed outcrops where the soil or other secondary cover is not too deep (say less than one metre). A trench may be very deep and very long in certain specific cases where the distribution, size and shape of the mineral concentration is to be studied. Normally, however, trenches are put to expose the outcrops preferably from the footwall contact to the hanging wall contact. The actual excavation may be done either by manual methods or by excavating machines.

Trenches are most valuable when the ore outcrop is narrow and linear. In a capping type of deposit where the outcrops have larger widths, trenches may be hundreds of metres long and may be too expensive. Similarly, wherever excavations are deeper than one metre trenching may become very expensive. Briefly, therefore, trenching may be chosen as an exploration method only when the outcrops are narrow and the cover thin.

Trenches may be done for purely exploratory purposes such as exposing the outcrops, sampling, etc. or for purposes of mining in which case it serves a dual purpose, that of exposing the orebody and later for developing the mine. A trench of the latter type will be of larger dimensions but generally pays for itself through the ore produced in the process.

A trench provides considerable geological information, the recording and safekeeping of which will be of great importance. Table 3.3 gives a proforma which may be used for the collection of trench data.

Trenching has been adopted as a major exploration method in many iron ore and bauxite deposits.

Trenches can give detailed information about the nature of the hanging wall and footwall rocks, the lithological and grade variation of the ore body, the structural details of the orebody, etc.

Depending on the topography and strike continuity, an orebody may be studied in a number of trenches at close intervals. The information from closeby trenches can be compared and the strike continuity of the orebody established by interpretation. Similarly, if trenches are at various elevations of the same orebody certain depthwise predictions about the physical continuity of mineralisation and grade can be made. Wherever possible, the trench should be cut close to and parallel to the nearest dip profile section for easy interpretation. When surface trenching is followed by boreholes, the data of the corresponding pair of nearest borehole and trench will be of great help in studying the variability of the orebody at depth.

<u>Sampling in trenches</u> : In sampling a trench, it is better to cut channels, restricting channel lengths to specific types of ores or group of exposures, etc. depending on the type of mineralisation.

Table 3.3 : Presentation of Trench Data— Suggested Proforma

Name of the Investigation	
Trench No.	Date of commencement
Location in co-ordinates	Date of completion
Length	R.L. of floor and top of trench
Width	
Depth	
Recorded by	

L o g (of each wall)

From Footwall	To Hanging wall	Lithology	Contact dip and strike	Planar strike and dip

Other details

(1) Total volume of material excavated in cu.m. estimate of total weight of material excavated.

(2) Number of samples taken with details.

(3) Thickness of overburden if any.

To be accompanied by a sketch map prepared on scale 1 cm = 1 m or 1 cm = 2 m showing all details.

Ore material dug out of a trench as a whole can also be used as a sample for bulk test. It is seldom used for chemical analysis due to the labour involved in breaking down to the proper sample sizes. In case the outcrop is weathered, the trench should go deep enough to expose fresh ore.

Pitting

Pitting is the process of digging openings to penetrate soil cover and other loose material to reach mineral ore bodies concealed underneath. Pitting is also done for the specific purpose of sampling an already existing orebody or for testing the depth or thickness of exposed orebodies and outcrops. A depth of penetration up to 30 m. is possible by pits under ideal conditions[27]. But pits of over 12 m are seldom feasible and even if technically feasible are likely to be prohibitively expensive. The dimensions and design of pits are given in Fig. 3.4.

The major advantage of a pit is that the opening is sufficiently large so that the exposed section of the orebody can be directly examined and if necessary sampled repeatedly. For collecting and compiling the pit data, a proforma is given in the Table 3.4.

Pitting can be done manually or with the help of machines. In many cases, when the ore is hard, some amount of drilling and blasting might become necessary.

Pitting is a very widely used exploration method and may be very effective in proving deposits which are widely exposed on the surface and are relatively thin. They are least effective when the outcrop is linear and narrow and the orebody steeply dipping. Pits may be sunk for purposes of developing them into a mine in which case they serve the purpose of exploration as well as exploitation. Such pits are referred to as trial pits and may have a very large opening. In opening such pits, one is assured of a return in terms of the mined ore, the sale value of which may underwrite the cost of pitting. Such considerations are often valid in trenching also. Pitting has been exclusively used as an exploration method in many bauxite and iron ore deposits.

Sampling of pits : Pits usually expose orebody on the four walls. It is not necessary in all cases to cut channels in all the walls, particularly in mineral deposits like iron ore, limestone, etc. But in deposits like bauxite and manganese, where the ore is lensoid and the ore values tend to be erratic, it is advisable to sample all the four walls and make a composite sample or have four separate samples analysed and the values combined by weighted average.

The whole material dug out from a pit car also form a sample but as in the case of trenches, bulk reduction

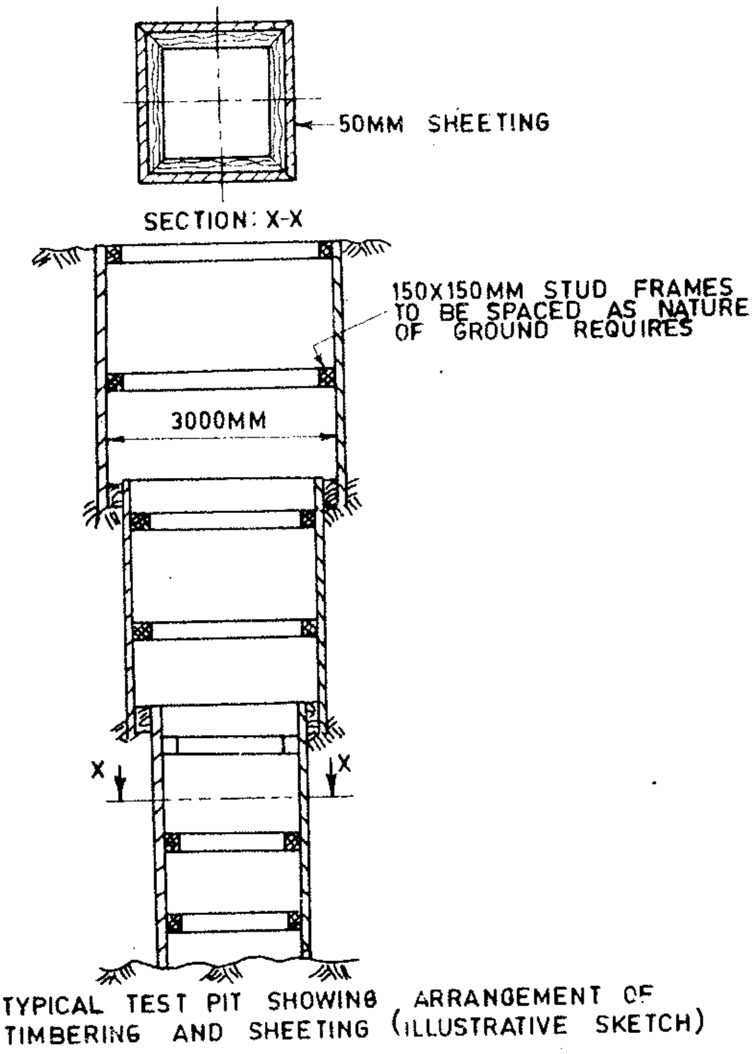


FIG: 3·4 DIMENSIONS AND DESIGN OF PIT

Table 3.4 : Presentation of Pit Data— Suggested Proforma

Name of the Investigation

Pit No.

Location in co-ordinates

Pit top measurements
- (a) Length
- (b) Breadth

Pit bottom measurement
- (a) Length
- (b) Breadth
- (c) Depth

Benches if any with their measurements

Recorded by :

Date of commencement

Date of completion

R.L. at pit top

R.L. at pit bottom

Face I (give for all the 4 faces)

From	To	Lithology	Contact strike and dip	Planar strike and dip

Other details

(1) Volume of the final pit

(2) Volume of the total excavated material

(3) Volume of the ore portion

(4) Volume of the reject (undersize, undergrade, etc.)

(5) Volume of the overburden and details

(6) Number of samples from the excavated material

(7) Number of details of channel samples

All these details should be accompanied by sketch map of each wall of the pit on a scale 1 cm = 1 m.

is laborious and may be avoided. In float ore exploration, however, the whole material has to be treated as a sample. In order to know the depthwise distribution of ore every 50 cm or 1 m depth of excavation may be separately sampled. The ore recovered is also subjected to screening to study size.

Drilling

Drilling or boring is the process of driving holes into rocks. The material which is cut during the process of drilling may be used for purposes of tests, chemical analysis, etc. which is the prime purpose of drilling in mineral exploration[28]. Drilling may be to very shallow depths in which case simple wash boring can be made use of. In the case of mineral exploration, depths of hundreds of metres will have to be penetrated which require the use of sophisticated **equipment**[29].

Five methods of drilling are generally recognised. They are: percussive, attritive, rotative cutting, rotative shearing, and rotative crushing.

In percussive drilling, the rock is broken by repetitive impaction. In this group, five types of drills can be recognised. They are pneumatic rock drills, down-the-hole drills, independent rotation drills, motor drills and cable-churn-drills. In attritive drilling, the rock is ground away by abrasive action. Two types of drills are recognised in this group. They are diamond drills and shot calyx drills. In rotative cutting drilling, the rock is cut or planed away. All auger drills fall within this group. In the rotative shearing method, rocks are fragmented by wedge action. This group includes drag-bit drills and rotary percussive drills. In rotary percussive drilling also, rocks are broken by wedge action, but the wedge action is used in combination with a thrust. All heavy rotary drills fall within this group[28]. Of all the drilling methods and drills discussed above, diamond drilling is the most versatile and of maximum use in mineral exploration. Churn drilling and rotary drilling also find use in mineral exploration although their use is rather limited.

Any drilling programme should aim at establishing the strikewise and dipwise continuity or discontinuity. For this purpose, the interval of drilling has to be chosen on the basis of available geological information. This should be kept in view for establishing the continuity of the orebody at depth and also for intersecting the orebody at various future mining levels. Drilling also should aim at establishing the various structural projections.

Diamond Drilling

Diamond drills can be used for surface as well as sub-surface drilling[30]. In diamond drilling, a cylindrical bit (cutting tool) impregnated with diamonds is connected to a string of hallow jointed tubes and rotated by a mechanical device which may be a diesel engine or a pneumatic compressor device. Water, drilling mud, and in some cases air are circulated through the hollow tubes to keep the bit cool and wash out the cuttings. The diamond cutting edge cuts a cylindrical core as it penetrates the various rock strata. Such a core is collected in a core barrel which is fitted immediately above the bit. From the core barrel the core is collected periodically either by withdrawing the tool string (conventional method) or by removing only the barrel and bit (wireline core barrel). In drilling shallow or moderately deep holes, the time consumed in lowering the drill bit, core barrel, etc. into the hole and hoisting them up repeatedly for collecting the core may be less significant than other considerations. Where time is an important factor, wireline drilling may be resorted to. Wireline drilling differs from conventional drilling in that the inner tube that contains the core can be lifted to the surface without hoisting the entire drill string, by releasing it from the outer tube of the core barrel. The core so collected forms the sample which may be subjected to tests or analysis. The core barrel is constructed in such a way that core is retained during rotation. To ensure complete recovery, the core barrel may have an inner stationary tube which retains the core with an outer rotating tube which transmits the rotation to the bits. Such a core barrel is called a double tube core barrel. In a double tube core barrel water is circulated between the outer and inner walls and the core is not washed by water and, because of this, better core recovery is ensured, particularly in weak and fractured zones. Drilling can also be done without the circulation of water in which case it is called dry drilling. In dry drilling, the core recovery is always very high, but the bit losses are also correspondingly high. Table 3.5 shows the sizes of bits and barrels.

Calyx drilling which is of fairly wide application is done on the principle of diamond drilling but instead of diamond bits it uses chilled steel shots as a cutting tool.

These days, however, as a substitute to diamond drilling, dry drilling by tungsten carbide bits is being resorted to quite extensively by many exploration agencies.

Churn drilling

In churn drilling, a hollow tube suspended on a cable and attached with a cutting tool is driven into the ground by rectilinear motion. The motion is imparted to the bit by continuous dropping and raising of the tool string. The cuttings so generated are collected periodically by a

Table 3.5 : DCDMA Standards Regarding Diamond Drill Holes

Size		Casing and casing coupl-ing outside diam.	Casing coupling inside diam.	Casing bit outside diam.	Core barrel bit outside diam.	Drill rod outside diam.	Diam. of hole by core barrel bit*	Approx. diam. of core
Casing, coupling and casing bits	Rod and rod coupl-ing							
EX	E	46 mm ($1\frac{13"}{16}$)	38 mm ($\frac{11"}{2}$)	47 mm ($1\frac{7"}{16}$)	36 mm ($1\frac{7"}{16}$)	33 mm ($1\frac{5"}{16}$)	37 mm ($1\frac{15"}{32}$)	22 mm ($\frac{7"}{8}$)
AX	A	57 mm (2¼")	48 mm ($1\frac{29"}{32}$)	59 mm ($2\frac{5"}{16}$)	47 mm ($1\frac{27"}{32}$)	41 mm ($1\frac{5"}{8}$)	48 mm ($1\frac{7"}{8}$)	28 mm ($1\frac{1"}{8}$)
BX	B	73 mm ($2\frac{7"}{8}$)	60 mm ($2\frac{3"}{8}$)	75 mm ($2\frac{15"}{16}$)	59 mm ($2\frac{5"}{16}$)	48 mm ($1\frac{29"}{32}$)	59 mm ($2\frac{11"}{32}$)	41 mm ($1\frac{5"}{8}$)
NX	N	89 mm (3½")	76 mm (3")	90 mm ($3\frac{9"}{16}$)	75 mm ($2\frac{15"}{16}$)	60 mm ($2\frac{3"}{8}$)	75 mm ($2\frac{31"}{32}$)	54 mm ($2\frac{1"}{8}$)

*Assuming the hole 0.8 mm ($\frac{1"}{32}$) is larger than bit.

sludge collector or bailer. The method is not widely used in mineral exploration. However, in the exploration in alluvial terrains, this type of drill is excellent.

Rotary drilling

In cases where the information sought is purely of a confirmative nature and can be interpreted from chips and cuttings, rotary drilling is useful. In mineral exploration, such drilling can be used most effectively in the mine exploration stage when bench drilling becomes necessary.

Apart from the drilling methods described above, some simple devices like augur drilling are also used while exploring for soft and non-compact material like clays and bauxite.

A proforma suggested for keeping drill core records is given in Table 3.6.

Collection and preservation of drill samples

Three types of samples come out of drilling: Core samples from diamond drills or various other coring and calyx drills; Wet cutting or sludge from churn drill, diamond drill, or wet rotary or percussive drilling: and Dry cutting from air flushed diamond rotary augur or percussion drilling.

Among all these, the diamond drill core and the calyx drill core can be considered almost identical with the host rock from which they have been removed. When the core recovery is 100 per cent, the core reflects the strata faithfully. However, 100 per cent core recovery is seldom achieved. When core losses occur, the sludge (cuttings), coming out with the circulating water mud or air must be given due weightage. In other forms of drilling, only sludge is obtained. Table 3.7 shows the core, sludge ratios and their computation[31].

In core drilling, the core is the principal sample and is collected from the barrel at intervals of 3 or 6 m. (10 to 20 ft) which are the standard lengths of core barrels. Shorter drill runs and shorter core lengths are preferred in some cases when specific information is to be had from short lengths of core. After recovery from the barrel, the core is dried to remove only the superficial moisture and kept in a core box. For preserving and indexing the drill cores, the Indian Standards Institution has evolved a standard procedure IS-4078 : 1967 which may be referred to for proper upkeep of drill cores[32]. The method is demonstrated in Fig. 3.5. The box shown in Fig. 3.5 may be made of wood or aluminium and should be sturdy and durable.

Table 3.6 : Presentation of Drill Hole Data Suggested Proforma

Name of the Investigation :
Borehole No. :
Angle of inclination :
Bearing :
Location in co-ordinates :
Recorded by :

Date of commencement :
Date of completion :
R.L. at the collar of the borehole :
Total depth of borehole :

Sample No.	Length of run		Total width	Recovered length/ weight of core/sludge recovery %	Core size	Sampled section (m)	Rock type and litho-logical descrip-tion	Length of sampled section	Extra-polated length of sampled section	Specific gravity	Assay %	Width x assay	Sampled width	Average of ore zones		Nomen-clature of zones	Remarks
	From	To												True width	Average assay		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)

Table 3.7 : Core to Sludge Ratios in core Drill Samples 1 to 100% Recovery

Percentages of Volumes of Core and Cuttings in a Core Drill Sample for Each Per Cent of Core Recovered, to be Used as Multipliers in Combined Analyses of Core and Cuttings

Per cent of core recovery	EX		AX		BX		NX		Per cent of core recovery
	Core	Cuttings	Core	Cuttings	Core	Cuttings	Core	Cuttings	
1	0.4	99.6	0.4	99.6	0.5	99.5	0.5	99.5	1
2	0.7	99.3	0.7	99.3	1.0	99.0	1.0	99.0	2
3	1.1	98.9	1.1	98.9	1.4	98.6	1.5	98.5	3
4	1.4	98.6	1.4	98.6	1.9	98.1	2.0	98.0	4
5	1.8	98.2	1.8	98.2	2.4	97.6	2.5	97.4	5
6	2.1	97.9	2.2	97.8	2.9	97.1	3.1	96.9	6
7.	2.5	97.5	2.5	97.5	3.4	96.6	3.6	96.4	7
8	2.8	97.2	2.9	97.1	3.8	96.2	4.1	95.9	8
9	3.2	96.8	3.2	96.8	4.3	95.7	4.6	95.4	9
10	3.5	96.5	3.6	96.4	4.8	95.2	5.1	94.9	10
11	3.9	96.1	4.0	96.0	5.3	94.7	5.6	94.4	11
12	4.3	95.7	4.3	95.7	5.8	94.2	6.1	93.9	12
13	4.6	95.4	4.7	95.3	6.3	93.7	6.7	93.3	13
14	5.0	95.0	5.0	95.0	6.7	93.3	7.2	92.8	14
15	5.3	94.7	5.4	94.6	7.2	92.8	7.7	92.3	15
16	5.7	94.3	5.8	94.2	7.7	92.3	8.2	91.8	16
17	6.0	94.0	6.1	93.9	8.2	91.8	8.7	91.3	17
18	6.4	93.6	6.5	93.5	8.7	91.3	9.2	90.8	18
19	6.7	93.3	6.8	93.2	9.1	90.9	9.7	90.3	19
20	7.1	92.9	7.2	92.8	9.6	90.4	10.2	89.8	20
21	7.5	92.5	7.6	92.4	10.1	89.9	10.8	89.2	21
22	7.8	92.2	7.9	92.1	10.6	89.4	11.3	88.7	22
23	8.2	91.8	8.3	91.7	11.1	88.9	11.8	88.2	23
24	8.5	91.5	8.6	91.4	11.5	88.5	12.3	87.7	24
25	8.9	91.1	9.0	91.0	12.0	88.0	12.8	87.2	25

(Contd.)

Table 3.7 : Core to Sludge Ratios in core Drill Samples 1 to 100% Recovery (Contd.)

Percentages of Volumes of Core and Cuttings in a Core Drill Sample for Each Per Cent of Core Recovered, to be Used as Multipliers in Combined Analyses of Core and Cuttings

Per cent of core recovery	EX		AX		BX		NX		Per cent of core recovery
	Core	Cuttings	Core	Cuttings	Core	Cuttings	Core	Cuttings	
25	9.2	90.8	9.4	90.6	12.5	87.5	13.3	86.7	26
27	9.6	90.4	9.7	90.3	13.0	87.0	13.8	86.2	27
28	9.9	90.1	10.1	89.9	13.5	86.5	14.3	85.7	28
29	10.3	89.7	10.4	89.6	13.9	86.1	14.8	85.2	29
30	10.7	89.3	10.8	89.2	14.4	85.5	15.4	84.6	30
31	11.0	89.0	11.2	88.8	14.9	85.1	15.9	84.1	31
32	11.4	88.6	11.5	88.5	15.4	84.6	16.4	83.6	32
33	11.7	88.3	11.9	88.1	15.9	84.1	16.9	83.1	33
34	12.1	87.9	12.2	87.8	16.4	83.5	17.4	82.6	34
35	12.4	87.6	12.6	87.4	16.8	83.2	17.9	82.1	35
36	12.8	87.2	13.0	87.0	17.3	82.7	18.4	81.6	36
37	13.1	86.9	13.3	86.7	17.8	82.2	18.9	81.1	37
38	13.5	86.5	13.7	86.3	18.3	81.7	19.5	80.5	38
39	13.8	86.2	14.0	86.0	18.8	81.2	20.0	80.0	39
40	14.2	85.8	14.4	85.6	19.2	80.8	20.5	79.5	40
41	14.6	85.4	14.8	85.2	19.7	80.3	21.0	79.0	41
42	14.9	85.1	15.1	84.9	20.2	79.8	21.5	78.5	42
43	15.3	84.7	15.5	84.5	20.7	79.3	22.0	78.0	43
44	15.6	84.4	15.8	84.2	21.2	78.8	22.5	77.5	44
45	16.0	84.0	16.2	83.8	21.6	78.4	23.0	77.0	45
46	16.3	83.7	16.6	83.4	22.1	77.9	23.6	76.4	46
47	16.7	83.3	16.9	83.1	22.6	77.4	24.1	75.9	47
48	17.0	83.0	17.3	82.7	23.1	76.9	24.6	75.4	48
49	17.4	82.6	17.6	82.4	23.6	76.4	25.1	74.9	49
50	17.7	82.3	18.0	82.0	24.1	75.9	25.6	74.4	50

(Contd.)

Table 3.7 : Core to Sludge Ratios in core Drill Samples 1 to 100% Recovery (Contd.)

Percentages of Volumes of Core and Cuttings in a Core Drill Sample for Each Per Cent of Core Recovered, to be used as Multipliers in Combined Analyses of Core and Cuttings

Per cent of core recovery	EX		AX		BX		NX		Per cent of core recovery
	Core	Cuttings	Core	Cuttings	Core	Cuttings	Core	Cuttings	
51	18.1	81.9	18.4	81.6	24.5	75.5	26.1	73.9	51
52	18.5	81.5	18.7	81.3	25.0	75.0	26.6	73.4	52
53	18.8	81.2	19.1	80.9	25.5	74.5	27.1	72.9	53
54	19.2	80.8	19.4	80.6	26.0	74.0	27.6	72.4	54
55	19.5	80.5	19.8	80.2	26.5	73.5	28.2	71.8	55
56	19.9	80.1	20.2	78.8	26.9	73.1	28.7	71.3	56
57	20.2	79.8	20.5	79.5	27.4	72.6	29.2	70.8	57
58	20.6	79.4	20.9	79.1	27.9	72.1	29.7	70.3	58
59	20.9	79.1	21.2	78.8	28.4	71.6	30.2	69.8	59
60	21.3	78.7	21.6	78.4	28.9	71.1	30.7	69.3	60
61	21.7	78.3	22.0	78.0	29.3	70.7	31.2	68.8	61
62	22.0	78.0	22.3	77.7	29.8	70.2	31.7	68.3	62
63	22.4	77.6	22.7	77.3	30.3	69.7	32.3	67.7	63
64	22.7	77.3	23.0	77.0	30.8	69.2	32.8	67.2	64
65	23.1	76.9	23.4	76.6	31.3	68.7	33.3	66.7	65
66	23.4	76.6	23.8	76.2	31.7	68.3	33.8	66.2	66
67	23.8	76.2	24.1	75.9	32.2	67.8	34.3	65.7	67
68	24.1	75.9	24.5	75.5	32.7	67.3	34.8	65.2	68
69	24.5	75.5	24.8	72.2	33.2	66.8	35.3	64.7	69
70	24.9	75.1	25.2	74.8	33.7	66.3	35.8	64.2	70
71	25.2	74.8	25.6	74.4	34.2	65.8	36.4	63.6	71
72	25.6	74.4	25.9	74.1	34.6	65.4	36.9	63.1	72
73	25.9	74.1	26.3	73.7	35.1	64.9	37.4	62.6	73
74	26.3	73.7	26.6	73.4	35.6	64.4	37.9	62.1	74
75	26.6	73.4	27.0	73.0	36.1	63.9	38.4	61.6	75

(Contd.)

Table 3.7 : Core to Sludge Ratios in core Drill Samples 1 to 100% Recovery (Concld.)

Percentages of Volumes of Core and Cuttings in a Core Drill Sample for Each Per Cent of Core Recovered, to be used as Multipliers in Combined Analyses of Core and Cuttings

Per cent of core recovery	EX		AX		BX		NX		Per cent of core recovery
	Core	Cuttings	Core	Cuttings	Core	Cuttings	Core	Cuttings	
76	27.0	73.0	27.4	72.5	36.6	63.4	38.9	61.1	76
77	27.3	72.7	27.7	72.3	37.0	63.0	39.4	60.6	77
78	27.7	72.3	28.1	71.9	37.5	62.5	39.9	60.1	78
79	28.0	72.0	28.4	71.6	38.0	62.0	40.4	59.6	79
80	28.4	71.6	28.8	71.2	38.5	61.5	41.0	59.0	80
81	28.8	71.2	29.2	70.8	39.0	61.0	41.5	58.5	81
82	29.1	70.9	29.5	70.5	39.4	60.6	42.0	58.0	82
83	29.5	70.5	29.9	70.1	39.9	60.1	42.5	57.5	83
84	29.8	70.2	30.2	69.8	40.4	59.6	43.0	57.0	84
85	30.2	69.8	30.6	69.4	40.9	59.1	43.5	56.5	85
86	30.5	69.5	31.0	69.0	41.4	58.6	44.0	56.0	86
87	30.9	69.1	31.3	68.7	41.8	58.2	44.5	55.5	87
88	31.2	68.8	31.7	68.3	42.3	57.7	45.1	54.9	88
89	31.6	68.4	32.0	68.0	42.8	57.2	45.6	54.4	89
90	31.9	68.1	32.4	67.6	43.3	56.7	46.1	53.9	90
91	32.3	67.7	32.8	67.2	43.8	56.2	46.6	53.4	91
92	32.7	67.3	33.1	66.9	44.3	55.7	47.1	52.9	92
93	33.0	67.0	33.5	66.5	44.7	55.3	47.6	52.4	93
94	33.4	66.6	33.8	66.2	45.2	54.8	48.1	51.9	94
95	33.7	66.3	34.2	65.8	45.7	54.3	48.6	51.4	95
96	34.1	65.9	34.6	65.4	46.2	53.8	49.2	50.8	96
97	34.4	65.6	34.9	65.1	46.7	53.3	49.7	50.3	97
98	34.8	65.2	35.3	64.7	47.1	52.9	50.2	49.8	98
99	35.1	64.9	35.6	64.4	47.6	52.4	50.7	49.3	99
100	35.5	64.5	36.0	64.0	48.1	51.9	51.2	48.8	100

Example :

AX bit sample giving core recovery of 63 per cent. Analysis of core, 57.60 per cent; of cuttings, 61.00 per cent.

$$\text{Combined analysis} = \frac{57.50 \times 22.7 + 61.00 \times 77.3}{100} = 60.23\%.$$

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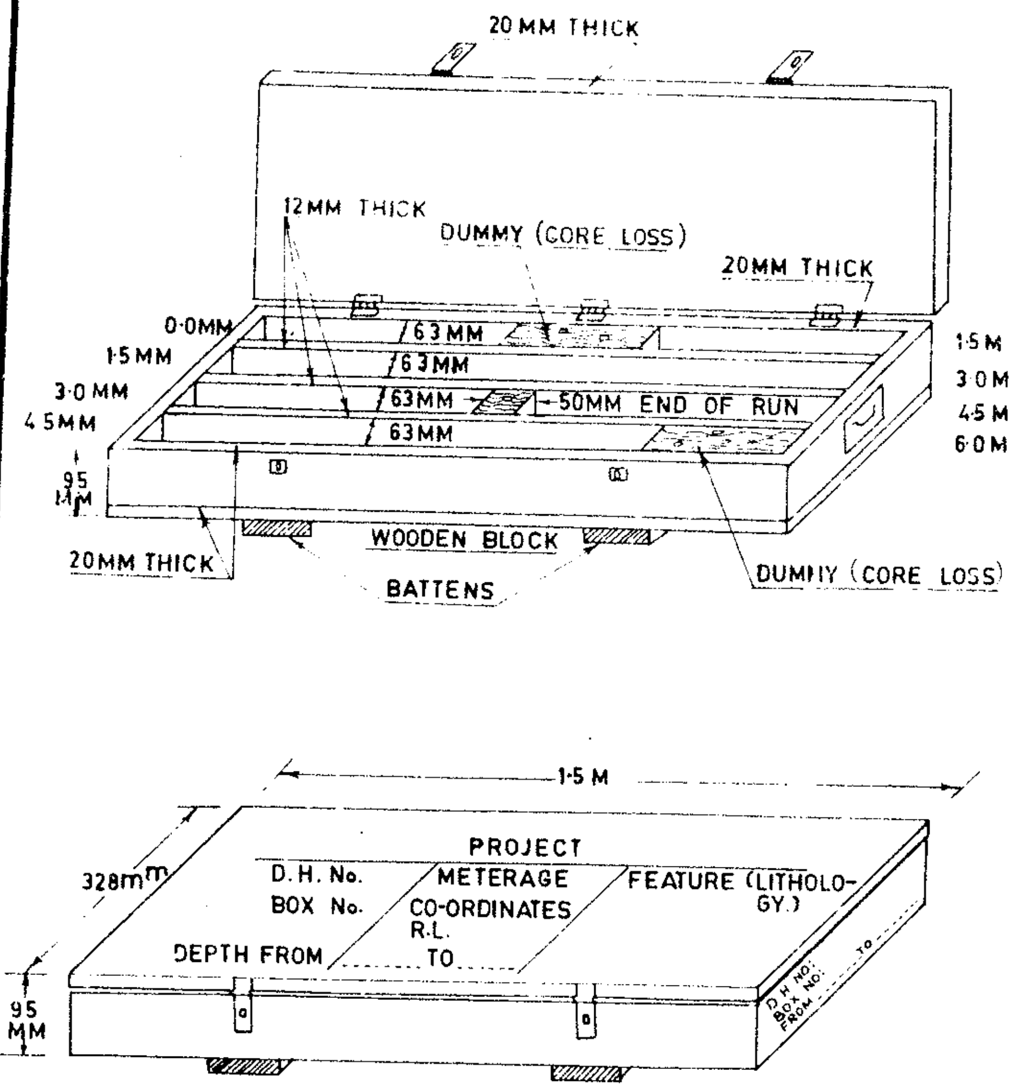

FIG. 3·5 CORE BOX

Portions of core which are needed for analysis are first split into two by a core splitter. One portion is kept in the box. The other portion is again split into two. One portion is sent for assaying. The other is sent for physical and mineralogical studies.

When the core recovery is poor, the sludge representing the core loss will have to be assayed and computed with the core portion.

Collection of sludge

In collecting sludge during core drilling, a Thompson sludge cutter can be used. In this, there is a cast aluminium box with an overshot waterwheel type of impeller in which one or more compartments are open.

This impeller has several open compartments and allows the passage of 10 per cent of the sludge to a special paper bag where it is collected. The cutter is directly fitted to the return water hose so that the motion of the water moves the impeller[30]. The sludge collector is shown in Fig. 3.6.

In the case of non-coring drills with water circulation arrangement, the Thompson sludge cutter or a sludge box can be made use of. The box has a water inlet and an outlet and is divided longitudinally by three baffle plates. After stopping drilling, the circulating water is connected to the sludge box and the water is allowed to settle. Excess water can be siphoned off. Samples can be removed periodically, dried and sent to assay[30]. The sludge box is shown in Fig. 3.7.

In the case of non-coring drilling using air for removing the cuttings two arrangements are possible. One is to have a cutting collecting arrangement attached to the tool string which can be periodically reclaimed and the samples removed. The other is to allow the cuttings to accumulate at the mouth of the drill hole and then collect the cuttings sequentially, the topmost representing the deepest stratum.

Sampling of drill core, sludge and cuttings

It was mentioned earlier that the core sample is split and one is taken for analysis and another kept for reference. That half selected for sampling is again split into two, longitudinally and one half is taken for sampling. Samples may be made from 50 cm, 1 m, 2 m, or even 3 m section lengths of core. Or even the whole mineralised band can be taken as one sample, if the mineralisation is visibly of uniform quality and distribution. When mineralisation is irregular, shorter lengths of samples are better. However, less than 50 cm length samples are impractical in most cases. The selected core lengths are sized down to the appropriate sample size and sent for analysis.

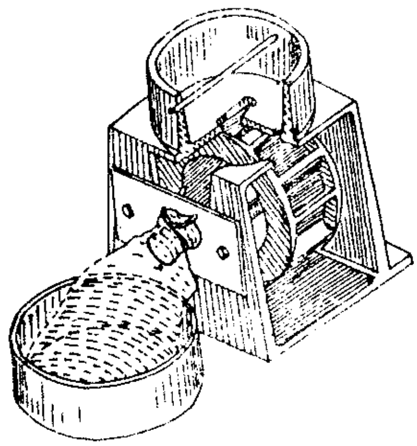

FIG: 3·6 THOMPSON SLUDGE CUTTER

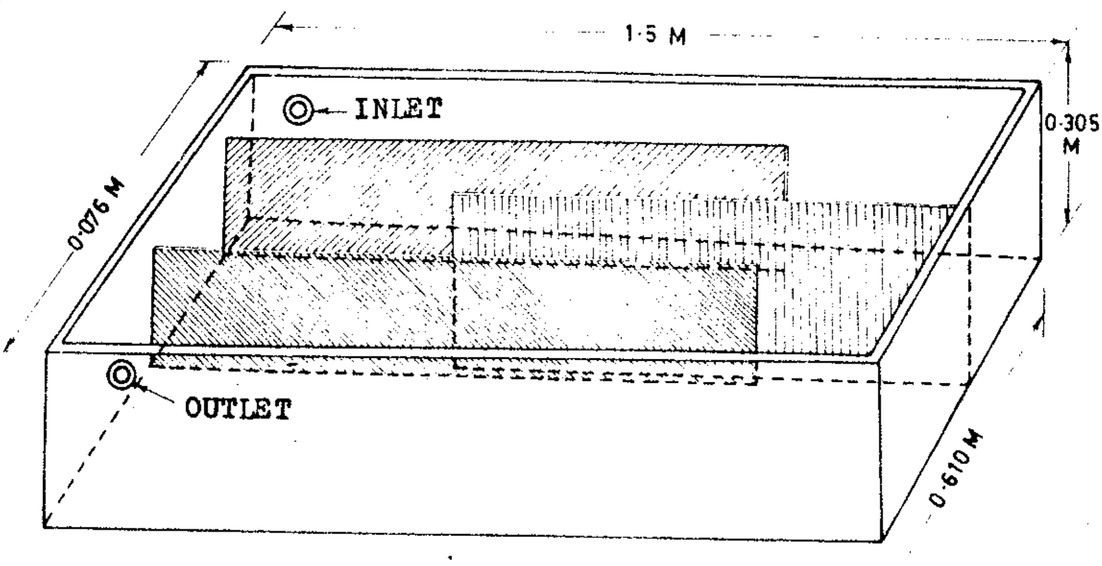

FIG. 3·7 SLUDGE BOX

In core drilling, as mentioned earlier, it is rarely that recoveries are 100 per cent. For computing the loss of core the Table 3.7 given above will be helpful. The table shows core to sludge ratios in core drill samples. It becomes necessary to compensate for this loss. This is done by sludge analysis. However, the sludge and core assays cannot be combined by weighted averaging. One easy method is suggested below[29].

$$A = \frac{C}{L} \times \frac{D_1^2}{D^2} (A_1 - A_2) + A_2,$$

where A = average assay,

C = recovered core,

L = Length of the hole (relevant to the calculated portion)

D = diameter of the hole,

D_1 = diameter of the core,

A_1 = core assay, and

A_2 = sludge assay.

In the case of non-coring drilling, sludge or cutting is sampled. Here also, analysis may be of samples of 50 cm, 1 m, 2 m, or 3 m lengths depending on the type of mineralisation.

Deviation and surveying of drillholes

Drillholes may be vertical or inclined. When inclined, it is usual to plan the intersection angle of the tool string with the hanging wall contact of the projected orebody at about 90°. In any case, the exact angle at which the tool string is aimed to go through is never achieved. An angle is often made either with the vertical plane of the hole or the horizontal or even at angles to both the planes. Although basically a drilling problem, an exploration geologist should be conversant with the phenomenon of hole deviation and the various devices available for correctly surveying these deviations, to enable him to make correct sub-surface interpretations. Most of the deviations are caused by a sudden change in the hardness of various drilled formations, fracture zones, joint planes, etc. present in the formations. Deviations can also be caused by poor equipment and improper alignment of the machinery. Deviations pose serious problems in deep drilling, particularly directional drilling with a small angle from the horizontal[28,29]. Since the deviation of a borehole from its assigned course is very common, some corrective steps have been developed for either bringing back the hole into the proper course or hitting the formation at a known point. This method is called directional drilling. It can be achieved by employing some special type of wedges. One side of the wedge is firmly anchored to the wall of the hole and the other side that projects out of the wall helps the drill bit to manoeuvre into the desired course.

An accurate measurement of the angle at close depth intervals and direction of deviation is essential for a proper interpretation of subsurface information. This measurement is called borehole surveying[33]. Various instruments available for borehole survey are listed below.

Elinometer,

Mass compass,

Tropari drill hole surveying instrument,

Photographic angle recording devices,

Surwel gyroscope instrument, and

Electronic and electrical surveying instruments[30].

The principle of these instruments is discussed below :

(1) Etch method using hydrofluoric acid : The property of hydrofluoric acid, namely to corrode glass is made use of in this method. The acid with varying concentrations depending on the circumstances is put in a glass culture tube and lowered into the borehole which is to be surveyed, along with the drill rods. The glass tube is allowed to remain stationary in the hole for a few minutes when the acid makes an etch line on the tube. The angle made by etch line with the index line gives the angle of deviation.

(2) Mass borehole (Canson) compass : This is a very simple device but can be used with moderate accuracy only in non-magnetic ore bodies. Even deeper boreholes can be surveyed by this method though the time consumed is relatively high. The instrument consists of two parts; (i) a compass placed in a glass tube containing liquid gelatine, and (ii) a glass tube partially filled with hydrofluoric acid. The whole instrument, encased in a non-magnetic clinometer case, is lowered in the hole and left suspended for nearly 90 minutes at the point of survey. The gelatine gets solidified and therefore holds the compass in a fixed position. The etch line of the glass tube containing hydrofluoric acid gives the angle of deviation and the fixed position of the compass gives the deviation from the assigned direction. Sometimes, as in surveying shallow holes, a single glass tube is used instead of two.

(3) Tropari : This is a precision instrument for measuring deviations both in inclination and direction. The instrument consists of a compass for measuring the direction and a dip indicator for the inclination. After lowering the instrument into the hole, its movements, i.e. the movement of the compass needle and the dip indicator, can be arrested by

a preset timing mechanism. In other words, locking takes place after the expiry of a given time (at 5 minutes interval) when the instrument is lifted again to the surface, readings can be taken directly. Hence, it is essential to know what point is likely to be reached after the expiry of the time already set.

(4) Multishot directional Survey Instrument : This device consists of 4 units, a watch, a camera section, a fluid dampened compass and a plumb bob suspended on gimbals. At regular intervals, the camera goes on taking multiple shots of the direction as indicated by the compass and inclination by the angle unit. This is a very sophisticated instrument and can take up to 400 shots in one lowering. In view of the cost of the instrument, casing of the hole with non-magnetic drill casings may be necessary.

(5) Electronic Borehole Survey Instrument : In this method, a stable radio frequency oscillator that is lowered into the hole is connected to another frequency oscillator stationed on the surface. The oscillator in the survey unit is turned by a variable condenser, the changes in which are indicated by the change in the frequency of the oscillator. The difference in frequencies recorded by the two oscillators is converted to degrees of inclination. In the same way, the deviation in direction can also be measured.

(6) Surwel Gyroscope Instrument : This instrument makes use of a gyroscope to maintain the same directional orientation over a considerable time period. A camera fitted with other units such as timer, angle unit, etc. takes pictures at desired intervals. A log of depth versus time can also be kept at the surface for computing the deviation. The measurements can be taken both while going down and coming up the hole.

(7) Dip meter : By this method, the oriented cores are dispensed with in measuring the direction and amount of the dip. This method has to be used carefully.

Underground drilling

Surface drilling has been discussed earlier. The methods of drilling are much the same, but the scope of underground drilling is a little different. Directional, particularly horizontal and upward vertical and various inclined drillholes are more common in underground drilling. Besides, sub-surface drilling is done under many constraints, the important ones being the space restriction, lowering and hoisting of drilling equipment and the motive power required for driving the machinery. Therefore, the machinery and equipment necessary for underground drilling are different from those used for surface drilling. Generally EX-core drills or electric drills are employed in underground operations.

Coring as well as non-coring drilling is done underground. Collection of core, sludge and cuttings is done as in surface drilling except in the case of vertical and inclined upward drilling where special equipment is necessary for collecting cuttings.

Underground drilling for finding new mica pegmatites is being done in Indian mica fields with extension rods in a normal jack hammer used for drilling blastholes. The cuttings so collected are examined for signs of mica mineralisation.

Exploratory Mining

In many cases of disseminated and vein-like deposits, surface exploration alone is not sufficient to get reliable data. Even in some massive deposits exposed on the surface, it becomes often necessary to get detailed data about the nature of the ore and the ore to waste contacts underground. Subsurface exploration is necessary in such cases. In order to learn more of a particular deposit, exploratory mining is resorted to in a detailed manner in the intensive exploration stage. Such mining may be either opencast or underground. Opencast methods are used for massive ore deposits like iron ore, bauxite, etc. and may consist of a few benches for studying the behaviour of the ore in the faces. Copper, lead, zinc, mica and such other minerals are explored mostly by underground or sub-surface methods.

As mentioned earlier, the common sub-surface exploration methods are aditing, drifting, cross cutting, raising, winzing, and underground drilling. All these methods cannot, however, be claimed as exclusively exploration methods. Drifts, cross-cuts, raises and winzes are put up for purposes of mining, blocking of ore and simple underground connections. However, whenever such openings show ore, observations are possible. In fact, in the early development stage of an ore body these openings are made more often to expose ore.

Aditing

An adit is a horizontal or near horizontal opening driven into the ore body from some surface so that a cross-section of the ore body is available for study and sample collection. In large ore bodies, a number of adits may be required to study several cross-sections. If the orebody is amenable only to underground exploitation, the adit should be put at intervals of 2 to 3 times the height of the prospective levels[18].

Three types of adits are recognised, viz. adits driven along the strike of the orebody, adits driven along the dip of the orebody, and adits with blind shafts at the lowest horizon for very deep seated orebodies.

Various observations to be made in an adit with proforma for keeping records are given in Table 3.8. Aditing has been successfully adopted in many iron ore deposits and in some bauxite deposits.

Drifting

Drifting or driving is the process of making a sub-surface opening into the orebody along the strike. A drive may be along the footwall or hanging wall or both, or entirely through the orebody only depending upon the size and distribution of ore and the nature of the hanging and footwall contacts. Where a footwall or hanging wall contact is not clearly definable, the drives may be planned along that wall to define the orebody clearly. When the orebody is narrow but with well-defined contacts, a drive along the orebody may be more appropriate. The drive may start from the bottom of a shaft or other opening from the surface and may continue till the end of mineralisation is in sight. Drives are generally planned in such a way that they can be made use of in exploitation at a future date. The number of such drives and their spacing will depend on a large number of variables and no guidelines are possible.

Cross-cutting

Cross-cutting is the process of driving an opening across an ore body exposed in an underground opening. A cross-cut may be made from a hanging wall drive to a footwall drive or vice versa. A number of cross-cuts might be necessary to study the ore in full width cross-section in a series of drives.

Raising and Winzing

Raises and winzes are vertical openings made to connect various levels. An opening made from a lower to a higher level is a raise and from a higher level to a lower level is a winze. All raises and winzes need not be in orebodies. But some are put in the orebody purely for exploratory purposes.

Sampling

Sampling is done to ascertain the grade of a mineral and metal values that vary in proportion from one place to another. One single sample taken from one part of the orebody generally does not provide a representative picture of the grade of the entire orebody. A large number of well-spaced samples are required for ascertaining the average grade with an acceptable amount of accuracy. Normally,

Table 3.8 : Presentation of Adit Data Suggested Proforma

Name of the investigation :
Adit No. :
Location in co-ordinates :
Recorded by :
Direction of adit and R.L. of the portal :
Whether it is strike adit, cross-cut adit or tangential :

Date of commencement :
Date of completion :
Total length of the adit :
No. of cross cuts, raise and winzes with their location and total length :

ADIT LOG (All measured at breast height)

From portal	To End	Lithology	Contact dip and strike	Planar dip and strike	In ore the true width and grade

Other details :

All the details should be accompanied by :

(1) One adit map showing geological and other features on scale 1:100 or 1:200 and

(2) an assay plan showing the -

(a) number and details of location and method of bulk samples collected,

(b) number and details of channel/other samples collected.

no amount of sampling will give a truly representative picture of the orebody. There is always some degree of error between the actual value and the value computed from the samples. The aim of sampling is only to reduce the error to the minimum possible level[9].

In addition to knowing the grade of the ore, sampling also reveals the pattern of mineralisation within the orebody. A systematic mine sampling programme can demarcate the richer and leaner ore portions. Similarly, the limits of mineralisation towards both the hanging and footwall contacts can also be precisely defined by careful sampling.

Sampling is also necessary to determine the processing and extractability characteristics of the ore. For this purpose, bulk representative/simulated samples representing the quality and type of material to be treated are collected.

Principles

A sample should be truly representative of the entire orebody. In order to attain this, it is necessary to choose proper places for sampling and it is always necessary to show the sample sites and the width on the plan of the property. Any sample representing a very rich ore portion or a lean portion of the orebody loses its representative character. Theoretically, different samples collected from various parts of the orebody can be combined into a single composite sample to give the most representative picture of the whole orebody. This is never done because it is also necessary to know the average grade of the rich and lean portions of the orebody separately[9].

Samples should generally be taken so that at least all the exposed portions of the orebody are sampled. For this, samples may be spaced at regular intervals. The actual intervals cannot be determined arbitrarily, but have to be arrived at based on the experience gained in similar deposits in the past. It is not unusual for a gold-bearing quartz to be sampled at every 50 cm in an underground drive. But an iron exposure of the type common in India need not be sampled at less than 50 m intervals. As a thumb rule, an assumption that any interval which minimises the error is justified in sampling may not be very much out of place. It is a good practice to have a fixed minimum width or their multiples for each sample, depending upon the complexity of value distribution visualised.

Sampling is subject to certain limitations due to sampling errors. The errors may be of two types: (i) random and (ii) systematic. Of these, the random errors tend to cancel out each other whereas the systematic error accumulates to create gross errors which are easily recognisable because of their magnitude. The errors accumulate due to four factors.

(i) when check samples are taken from the same spot, there will be a natural divergence between the value of the principal sample and the control sample. This cannot be overcome,

(ii) errors accumulated due to measurement errors, poor facilities and equipment, and poor eye judgment of the sampler,

(iii) errors due to mistakes of calculations, misprints and poor numbering, and

(iv) limitations of the assay technique itself.

Of these, the first two are random errors and the other two systematic[18]. In addition, errors may crop up because of intentional or unintentional salting of the sample itself. All these errors have to be avoided to the extent possible to get a reliable estimate of the orebody. Check sampling and repeated sampling help in avoiding some of the mistakes whereas great care at every stage of sampling alone can offset the other mistakes like salting.

Various types of sampling

In exploration, four types of sampling are of recognised value. They are chip sampling, grab sampling, channel sampling and bulk sampling[20]. Occasionally, a geologist may have to resort to some special sampling techniques like car sampling, R.O.M. sampling, stack sampling, muck sampling, etc[9]. But these are of use only in specific situations. Sampling may be done for the determination of specific gravity, physical properties, petrological, and mineralogical characteristics of the ore.

Chip sampling

When values are regularly distributed as in an iron ore outcrop, chip sampling can be very useful. In chip sampling, first the outcrop or face to be sampled is cleaned properly and a regular, rectangular or square pattern is made by drawing lines and along and across the outcrop at fixed intervals. Then, small pieces of ore are broken loose either from the centre of the grid or rectangle or at the intersection points of the lines. The ore pieces should have approximately the same shape, size and weight. After collecting a piece from each centre or intersection point of the grid, the rock pieces are mixed together to form the sample[18]. In case of highly unpredictable values, the practice of shifting the grid by half the width or length of the grid is adopted to get another set of samples which may be mixed with the first set of chip samples and tested separately.

Grab sampling

This is done from different blasts at the faces or small stacks of ore or dumps at random for information of a very general nature. Care should be taken to see that material of varying sizes is collected according to its proportion by weight in the blasted material or the stacks or dumps as the case may be. Several such grabs are mixed together to form a sample. In sampling by this method, the quantity of material to be collected depends on the size of the largest pieces present in the material to be sampled and the degree of heterogeneity of the material.[18] The sample size is governed by the Richards - Chechette formula[18]

$$Q = K d^2$$

where Q = the reliable weight of the worked down (also initial) sample in kg.,

d = the diameter of the largest particle in the sample in mm, and

K = a factor depending on the homogeneity of the mineral.

The values of K which may be used in most cases are given below :

Ore type	Value of K
Homogeneous	0.05
Non-homogeneous	0.10
Very non-homogeneous	0.20-0.30
Extremely non-homogeneous	0.40-0.50

The K factor is determined on the basis of the irregularity of distribution of the principal constituent of the ore.

Channel sampling

In this sampling, a channel is cut across the face of the exposed ore, and the resultant cuttings and chips are collected as a sample. The surface to be sampled is first cleaned to remove the dust, soluble particle, etc. A thin layer of the exposed ore may be removed to avoid cutting the weathered ore. Then a channel outline 5-10 cm in width and extending from the footwall to the hanging wall of the ore-body is drawn by chalk or paint. Then the channel is cut by a moil and hammer to a depth which should be equal to the width. The resultant pieces are collected carefully on a clean sheet of canvas or any other convenient receptacle. The sides and the floor of the channel should be smooth and uniform so that overcutting (and overrepresentation) is effectively minimised[18]. The channel may be divided into 1 to 2 m sections or their multiples in the case of massive and more homogeneous ore bodies or sections of 30 to 50 cm in the case of more heterogeneous distributions and may be separated as per the physical characteristics of the ore, say hard ore and laminated ore in the case of iron ores.

Bulk sampling

Bulk sampling is done in two specific cases. One situation is when a pilot plant test is to be done on an ore. The other is when the constituents of the ore have to be determined accurately.

Bulk samples may be made by collecting a portion from every blast continuously, or from shovels or cars in the case of mines[18]. Bulk samples may be collected from a series of pits or a number of trenches, adits or underground drives in the case of prospects.

For technological studies covering laboratory scale beneficiation tests, the bulk sample may be 100 to 250 kg. in weight. In some complex ores, upto 1000 kg. may be necessary whereas for pilot plant tests 50 tons of material would be usually required.

Dump sampling

Dump sampling can be done by systematically driving auger into the dumps and collecting the augered material. Benches may be prepared on the dumps and, from the benches, pits can be drived to collect samples. If a shovel is available, shovels can be deployed to take out representative bulk samples.

Criteria for the selection of a sampling procedure for a particular mineral type

The usual mineral sampling methods have been discussed above. Each method has its advantage and disadvantage. Therefore, some methods are very well-suited to some type of deposits. The process of matching a deposit with the best sampling procedure suited for it requires certain criteria which are discussed below. Essentially, the criteria centre around the shape and type of mineralisation of the deposit[18].

(i) When the orebody is thick and the values of mineralisation are uniformly distributed, sampling can be done by chip or grab sampling.

(ii) When the orebody is of medium size and mineralisation is uniform, a combined chip and channel sampling will give the best results.

(iii) Where the orebody is too thin but occurs in benches or layers, sampling of various layers can be done by chip sampling[17].

(iv) When a deposit is of very large dimensions, it becomes necessary to collect a large number of samples. In such cases, a large number of chip samples would give reliable results. Here, the quicker and not necessarily the most accurate method should be preferred[9].

(v) With minerals like gold, rare metals, etc. where values are too spotty and irregular, bulk sampling would give the best results.

(vi) Wherever the ore is banded, channel sampling would give the best results, and

(vii) Very hard ore, particularly massive types of iron ore, would require to be sampled by blasthole cuttings[18].

Spacing of sample channels

There are no rigid rules regarding spacing of sample channels in any type of deposit. However, spacing can be controlled by mathematical analysis, which are discussed in Chapter 6. Notably, the formula using the standard error of statistical mean and the confidence interval is eminently suited for predetermining the channel spacing and the number of samples required for specific precision limit.

Collection of samples

The collection of samples is a job requiring skill and experience. All chips, blocks and powder coming from a groove should be gathered irrespective of the size of concentration of mineral value. No extraneous material should get mixed up with the sample. The sample should be collected in a clean canvas bag. After the completion of a groove, the collected chips/blocks, etc. should be put in a bag and properly labelled by marking on the outside of the bag and also putting a reference tag inside the bag. A field book of sample records containing serially numbered-sheets with a proforma for descriptions, and arrangement to retain the counterfoil of description in the book, and a similarly numbered label part going into the sample bag will be desirable. A proper register showing the location of the sample co-ordinates, channel logs, sample weight, time taken for sampling, etc. should be maintained by the sampler. The register should show the serial numbers of the samples. It is always preferable to complete the register as soon as a sample is collected. Table 3.9 gives a proforma for the maintenance of a register.

Preparation of samples

A geological sample is generally of a size which is not readily handled by a laboratory for chemical analysis. Besides, the individual chips and blocks range in such sizes that they do not mix easily. In order to overcome these, it is necessary to reduce the bulk of the sample to a convenient size ensuring at the same time a proper admixture of the various fractions. The operations are achieved by the processes of sizing, coning, and quartering. Sizing should be done on the basis of sample weight to particle size ratio which can be determined by the formula $Q = Kd^2$ which has been explained earlier. The procedure for the preparation of samples is as follows :

Suppose in a homogeneous orebody the sample as collected weighs 125 kg. and contains material of varying sizes up to 50 mm. First, the whole sample is crushed till all the fragments are of size less than 25 mm and the sample mixed thoroughly by heaping the mix. Then, by coning and quartering, the sample is reduced to 31 or 32 kg. Then, it is crushed down to -12 mm size and again coned and quartered. Then, progressively the particle size is reduced to -3 mm and by coning and quartering a laboratory size sample of less than 0.45 kg is obtained. This can be further handled in the laboratory. A worked-out table showing the relationship between the size of largest particle to the quantity of sample to be collected based on Richards - Chechette formula $Q = Kd^2$ for the four categories of homogeneity is given in Table 3.10 This is found to be very handy in all sampling programmes.

Coning and quartering is done as follows. First, the material is thoroughly mixed. Then, it is heaped by pouring the material at one single point which will ultimately be the centre of the heap. For this, it will be helpful if a tall peg is fixed in to the plate on which sampling is done so that the material is always poured down all round the top of the peg to obtain uniform distribution. When all the material is heaped the top of the cone in flattened gently by a plate. Then, the top is divided into four quarters as shown in Fig. 3.8. Now, two opposite quarters are scooped out and rejected. The remaining portion represents approximately one-half of the original samples.

A flow-sheet for the treatment of samples as suggested by Krieter[18] is given in Fig. 3.9. A list of ISI standards in respect of sampling for a few important minerals is given below :

IS 1405 - 1966	Methods of sampling iron ore.
IS 1449 - 1961	Methods of sampling manganese ore.

Table 3.9 : Suggested Proforma for Assay Register

Name of the Mine

Sample location : Level No. : X cut No./Drive with direction and co-ordinate values or other reference points

Sample No.	From	To	Assay width	True width	Assay value X	Geological information				Remarks
						Lithology	Type of minera-lisation	Strike	Dip	
	------ in metres ------				in % metals					

Weighted avarage grade from X_1 to X_n width ____________

Table 3.10 : Showing the Quantity of Sample Required at Different sizes of the Largest Particles in the Sample (Worked out Based on the Formula $Q = kd^2$)

If the size of the largest piece (d) is		Then the quantity of sample in kg. to be collected for material of various homogeneity will be			
(d) in mm	(d^2) in mm	Homogeneous (K = 0.05)	Non-Homogeneous (K = 0.10)	Very Non-Homogeneous (K = 0.20 to 0.30)	Extremely Non-Homogeneous (K = 0.40 to 0.50)
200	40,000	2,000.00	4,000.0	8,000.0 - 12,000.0	16,000.0 - 20,000.0
150	22,500	1,125.00	2,250.0	4,500.0 - 6,750.0	9,000.0 - 11,250.0
125	15,625	781.25	1,562.5	3,125.0 - 4,687.5	6,250.0 - 7,812.5
100	10,000	500.00	1,000.0	2,000.0 - 3,000.0	4,000.0 - 5,000.0
75	5,625	281.25	562.5	1,125.0 - 1,687.5	2,250.0 - 2,812.5
50	2,500	125.00	250.0	500.0 - 750.0	1,000.0 - 1,250.0
25	625	31.25	62.5	125.0 - 187.5	250.0 - 312.5
12	144	7.20	14.4	28.8 - 43.2	57.6 - 72.0
6	36	1.80	3.6	7.2 - 10.8	14.4 - 18.0
3	9	0.45	0.9	1.8 - 2.7	3.6 - 4.5

NOTE : If the final quantity of sample is as shown in the above table (i.e. two opposite quarters from the final core) remember that the last core will be double the above quantity and that much material should get broken to the required size.

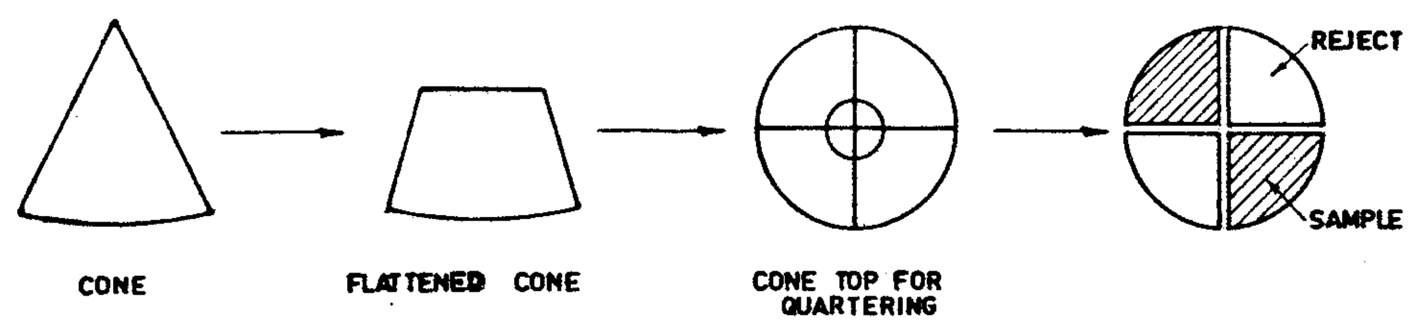

FIG: 3·8 METHOD OF CONING AND QUARTERING

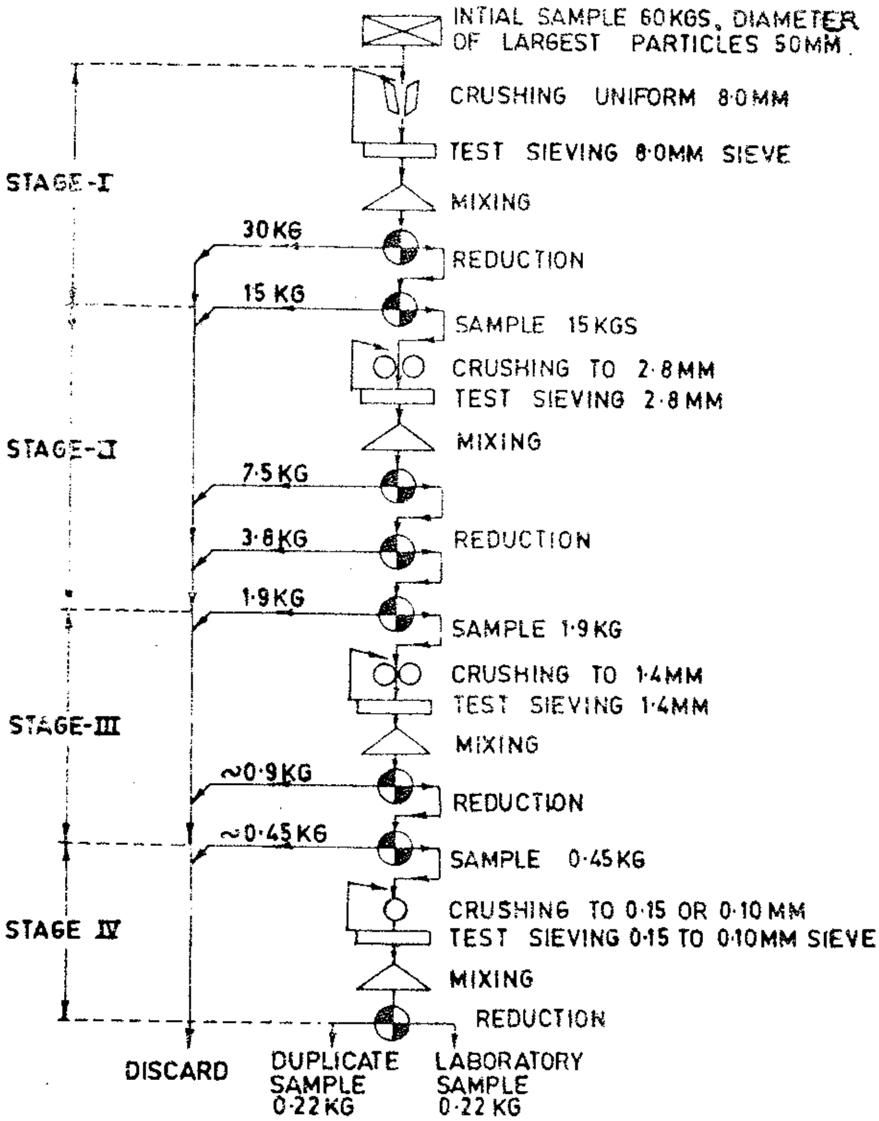

FIG: 3·9 FLOW SHEET FOR TREATMENT OF SAMPLES

IS 1528 - 1968	Methods of sampling and physical tests for refractory minerals.
IS 1817 - 1961	Sampling non-ferrous metals for chemical analysis.
IS 1999 - 1962	Methods of sampling bauxite.
IS 2109 - 1962	Sampling dolomite, limestone and other minerals.
IS 2246 - 1963	Methods of sampling fluorspar.
IS 4156 - 1967	Methods of sampling barytes.

A more comprehensive list of Indian Standards for various minerals is given in Appendix - 3.6.

Testing of samples

Samples collected during exploration are generally subjected to the following tests :

Assay of useful constituents and harmful ingredients.

Mineralogical investigations to ascertain mineral composition, grain size, texture and structure.

Semi-quantitative spectral analysis to determine all the elements present in the ore.

Technological tests to establish the most efficient method for treating the mineral.

Tests to determine certain physical properties of the mineral to establish the grade and mining methods and to estimate the reserves[18].

Of these, in most cases, only the first test is done to establish the grade of the ore. The others are done as and when a special necessity for such tests arises. A few important tests which find application in both exploration and ore beneficiation are given below.

Laboratory-scale examination

Certain laboratory investigations are conducted as a part of mineral exploration and beneficiation. The laboratory-scale investigations are listed below :

1. Testing physical characteristics
2. Petrological tests
3. Chemical analysis
4. X-ray and spectroscopic and other methods.

Testing of physical characteristics

The aim of these tests is to establish the hardness, specific gravity, brittleness and toughness of the sample. Determination of grain sizes also may be involved in certain cases.

Petrological tests

These may involve a quick examination of the minerals in a powdered form for identifying the major minerals. Detailed petrological studies are done by obtaining thin sections of samples and examining them under a petrological microscope. The details studied are the mineral assemblaye, ore and gangue minerals, texture, grain size, types of bonds between the various ore minerals and between ore and gangue minerals, etc. Besides, studies can be carried out for establishing the possible sequence of mineralisation or paragenesis. In complex cases, it may become necessary to carry out modal analyses, grain counting etc. which can be only on a microscope with a mechanical stage. Correlation on the basis of mineralogical composition and textural features can be done by these studies[34]. Petrological studies are followed by ore-microscopic studies where the polished ore surfaces are examined in an ore microscope. Ore microscopic studies can establish ore texture, grain size, and shape and the relationship between the various ore minerals and gangues. Minerals are recognised in this case by their colour, brightness, anisotropism, hardness, internal reflection, etch effects, cleavage, polishing, characteristic behaviour under oil immersion, etc.[35].

Chemical analysis

Conventional chemical analysis aims at establishing the chemical composition of the ore minerals and gangue. The valuable mineral is determined by chemical analysis and its percentage availability with respect to the whole minerals is expressed which helps in determining whether an ore can be commercially mined or not. A list showing the various chemical constituents required to be determined by conventional chemical analysis is given in Appendix - 3.7.

X-ray, spectroscopic and other methods

X-ray analysis helps in determining the mineral composition of certain ores which are otherwise difficult of determination. The mineralogy of bauxite for example can be reliably determined only by x-ray studies. X-ray fluorescence tests are helpful in identifying the rare elements.

Minerals and ores are known to possess certain special characteristics which show out conspicuously in the presence of activators. This principle has been made use of in the neutron activation analysis which is the most reliable and sensitive method for trace element determination. This method involves high cost though up to 55 elements can be detected by it[36]. From the data so obtained, the geochemical history can be inferred which in turn may lead to the discovery of valuable mineral deposits.

Diffraction spectroscopy (mass spectroscopy) : The finely-ground samples of minerals, down to 100 microns are analysed by x-ray diffraction which reveals not only the crystal structure of a mineral but also the inclusions and other related aspects.

Radiometric dating : Radiometric dating technique is gaining increasing importance in the field of mineral exploration. Even a very well-executed geological mapping may not leave the time correlation free from doubts. This can be overcome to a great extent by radiometric dating. The stratigraphic sequence which can be reasonably well established will greatly help the exploration geologist.

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Chapter 4

4.0 Survey in Exploration

Survey is a pre-requisite for geological mapping on the surface as well as underground. Surveying methods are used not only for preparing a topographical map, underground plan or vertical section on which geological details are plotted but also for locating such details on the map, plan or section. Surveying methods are also used for measuring the volumes of prospecting pits and trenches and the minerals or ores recovered from them for determining the recovery, swell and tonnage factors. The location and orientation of exploratory boreholes and drivages are also computed on the basis of surveying procedures. As most of these surveying procedures call for a high degree of skill, the work is invariably entrusted to a qualified and experienced surveyor. However a knowledge of the basic principles of the different methods of surveying and their advantages and limitations is essential for the exploration geologist so that he can effectively plan and coordinate the survey work during exploration.

4.1 Aims and objects of surveying

The primary object of surveying is to carry out such measurements as are necessary for representing a point or set of points on the surface of the earth, in their correct horizontal and vertical relationship, to the desired scale, on a map, plan or section. The measurements may be wholly linear or a combination of linear and angular, depending upon the methods of surveying adopted. For purposes of limiting and localising minor errors and to prevent their accumulation, surveying is always carried out from the whole to the part. In a survey carried out for the geological mapping of a mineral project for example, a set of main control points is established at the periphery of the prospect and connected with one or more permanent reference stations like Survey of India triangulation stations or state boundary pillars or revenue trijunction posts. If the area is large, another set of control points is set up within the prospecting lease and connected to the main set of control points. Topographic and geological details are plotted with reference to the second set of control points. Thus, the operation will involve three stages, viz. main, subsidiary and detailed survey.

4.2 Methods of surveying

Horizontal control, i.e. relative distances between the control points as measured on a horizontal plane, is established by triangulation and closed theodolite traversing for the main surveys. Traversing, tacheometry, plane tabling, and compass and tape surveying are used to establish horizontal control for the subsidiary surveys and detailed surveys carried out within the triangulation network or closed theodolite traverse.

4.2.1 Triangulation

In triangulation, horizontal control is established by a system of interconnected triangles in which the length of only one side, called the base line, and all the angles of the triangles are measured precisely, the lengths of the remaining lines (sides of the triangles) being computed by 'sine rule'. Apices of triangles are known as triangulation stations and the network of triangles is called a triangulation system or triangulation figure. Depending on the purpose of the survey, the area covered and the accuracy of the measurement desired, the triangulation systems[1] are classified as shown in Table 4.1.

The maximum area being statutorily limited to less than 25 sq.km. for a prospecting lease, and 10 sq.km. for a mining lease, triangulations, carried out for surveying such areas will belong to the tertiary category of triangulations. Hence, precise surveying procedures normally used for primary/secondary triangulations need not be adopted for the purpose.

Principles of Triangulation : In planning a triangulation survey in exploration the overall pattern of network of triangles may be decided depending on the shape of the property. As the areas are likely to be small, a well connected polygonal shape of the network with a central station known as a "Hub station", will be preferable to an open-chain network of triangles. The Triangles selected should be well conditioned i.e. the angles are not less than 30° and more than 120°. Such triangles are known to keep the errors in measurement to the minimum. The triangulation stations should be located on firm ground and should be intervisible as far as possible.

Triangulation involves measurement of all angles of the triangles. First the measurement of only one line, known as "Base Line" is done. The selection of the base line is to be done very carefully. Another line in the network is also selected and measured accurately as check on the accuracy of the base-line and is therefore called "Check-Base". Both "Base" and "Check-Base" should be on flat and level ground; straight stretch of rail-track or highway is ideal. The check-base should be as far away from the base line as possible and nearly at right angle to the direction of the base line. The base line may be 500 to 1000 m in length. The check base need not be as long as the base line.

Table 4.1 Classification of Triangulation Systems and Accuracy desired

System	Primary Triangulation	Secondary Triangulation	Tertiary Triangulation
1. Average triangle closure	Less than 1 second	3 seconds	6 seconds
2. Maximum triangle closure	Not more than 3 seconds	8 seconds	12 seconds
3. Length of base line	5 to 15 km	1.5 to 5 km	0.5 to 3 km
4. Length of the sides of triangles	30 to 150 km	8 to 65 km	1.5 to 10 km
5. Actual error of base	1 in 300,000	1 in 150,000	1 in 75,000
6. Probable error of base	1 in 1,000,000	1 in 500,000	1 in 250,000
7. Discrepancy between two measures of a section	10 mm/km	20 mm/km	25 mm/km
8. Probable error of computed distance	1 in 60,000 to 1 in 250,000	1 in 20,000 to 1 in 50,000	1 in 5,000 to 1 in 20,000
9. Probable error in astronomical azimuth	0.5 second	2 seconds	5 seconds
10. Applicability	Geodetic surveying, i.e. for mapping a whole country or to furnish most precise control points to which secondary triangulation may be connected.	Establishing closer control points within a primary network or main system of control for smaller areas.	For precise control network within the primary and secondary networks from which subsidary surveys for location details can be carried out.

Triangulation Procedure : A triangulation survey involves the following operations :

(1) Reconnaissance for selection of Triangulation stations, base-line, and check-base.

(2) Measurement of "Base" and "Check-Base".

(3) Measurement of horizontal angles.

(4) Computations and plotting.

(1) Reconnaissance : Assistance of Survey of India Toposheets may be taken if possible for selection of scheme of triangles. Where this is not feasible reconnaissance may be carried out for the purpose. Rough sketches of the location of stations with land-marks, base and check base may be drawn in the field book. Triangulation stations finally selected are marked permanently on the ground by concrete marker as shown in Fig. 4.1. The G.I.pipe in the concrete serves the purpose of holding a ranging rod. Theodolite is normally centred over a triangulation station by plumbing on the approximate centre of the G.I.pipe.

(2) Base-line measurement : Base line measurement is best carried out in the early morning hours, not only because the temperature then is likely to be low, but also because the environment will be pleasant and therefore conducive to a better quality of work.

The theodolite is set over the triangulation station at one end of the base-line and the telescope directed at the other end where a pencil point is held over the intersection of the weighted threads, marking precise position of the triangulation station. Wooden pegs (4 x 5 x 60 cm for soft ground and 2.5 x 2.5 and 15 cm for hard ground) are driven in at intervals of less than 30 m after their positions have been correctly aligned with the help of the theodolite. The wooden pegs are either capped with a zinc plate or a layer of plasticine so that a straight line aligned with the direction of the line of sight of the telescope can be drawn on the top of each peg. This is done by drawing a line to join two pencil marks made on the peg top in line with the telescope's line of sight.

The reduced levels of the peg tops are then determined by levelling. The distance between the wooden pegs is then accurately measured in drafts or bays of approximately 30 m starting from one end of the base-line. For this purpose, a pair of straining poles (Fig. 4.2) are used for stretching the tape with an appropriate tension during the measurement[2]. The starting end of the tape is attached by a leather hoop to the straining pole. The other end of the tape is attached to the

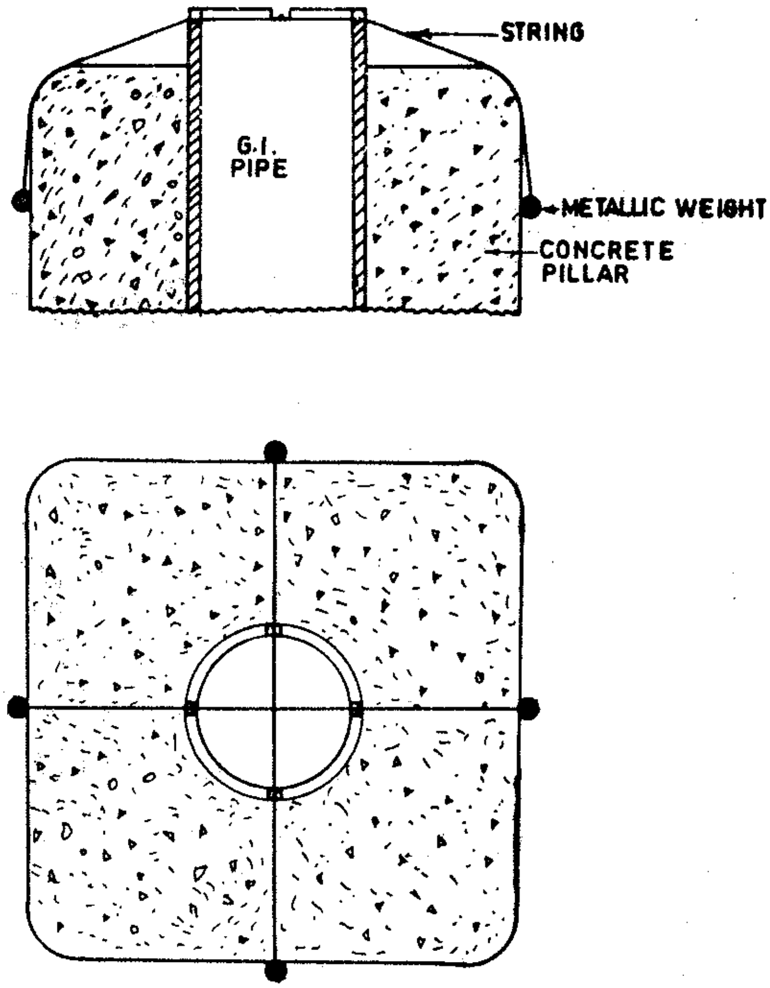

FIG. 4·1 MARKING OF TRIANGULATION STATION

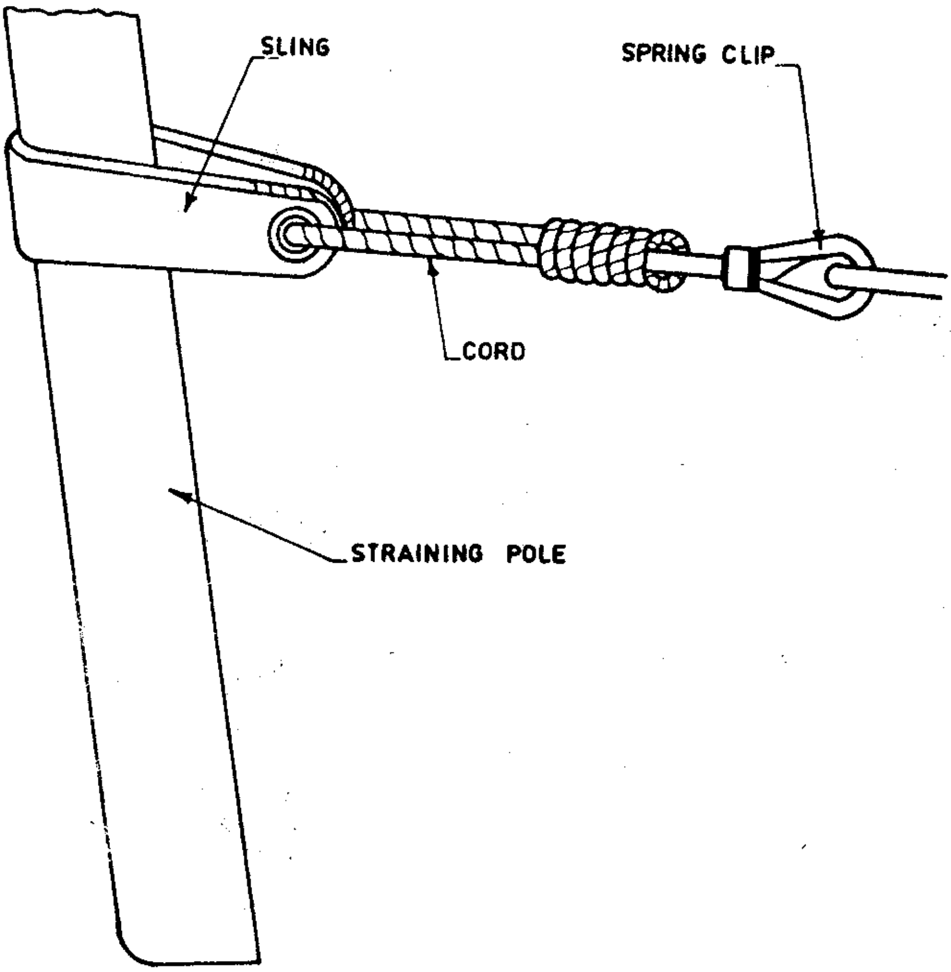

FIG: 4·2 STRAINING POLE

hook of the spring balance the handle of which is secured to the second straining pole. Supporting pegs are fixed at every 3 m or so under the tape to prevent excessive sag. The temperature of the steel tape is measured by means of base-line thermometer. The exact length of the bay is measured to the nearest millimetre by using a finely graduated straight edge to measure the gap between the index marks on the tape and transverse marks made on the tops of the pegs either end while correct tension is being applied to the tape. This procedure is repeated till the entire base-line is measured. The measurement is repeated five to six times for each bay and the mean of the measurements taken as the length of the base. The readings of the tape, temperature, and level difference of each draft are recorded in a proper table.

Each bay or draft of the base-line should be corrected as follows :

(i) Correction for standardization of the tape : The graduated steel tape stretches with use, and should be standardised against an invar tape under correct tension after taking the effect of temperature into consideration. This correction is applied as a direct proportion.

(ii) Temperature correction : The length of tape will be affected by expansion or contraction depending upon the temperature prevailing at the time of measurement. So, an appropriate correction is applied by calculating the increase or decrease in length (i.e. coefficient of expansion X difference of the ambient temperature and standard temperature) adding or subtracting it from the measured length.

(iii) Correction for slope : Horizontal length of each draft or bay is calculated from the difference between the squares of the measured distance and the vertical height as determined by levelling.

(iv) Correction of sag : Sag is negligible when the tape is supported. On an undulating ground, it is not always possible to support the tape. In such cases, correction has to be applied.

(3) <u>Measurement of horizontal angles</u> : Measurement of horizontal angles is preferably done by reiteration method using a theodolite with a least count of not greater than 20"/30" by direct reading and 10"/15" by eye estimation. In reiteration, different parts of the circle are used for each observation and the result is obtained as a mean of the observations. When several stations are to be observed from the same instrument station, reiteration is quicker than repetition in which the

angle being measured is multiplied a fixed number of times on the horizontal circle and the result obtained by dividing the multiple angle by the number of repetitions. In both cases, readings are alternately taken witn the telescope in face-right and face-left positions. Both methods compensate for the uneven graduation of the circle. However, repetition compensates for error due to tilt of the transit axis when taking steep sights.

(4) Computation and plotting :

(a) Adjustment of angular observations : After the measurement of all the horizontal angles has been made, the following corrections are applied to the measured angles in the office, in the sequence shown :

(i) 180° adjustment for triangles : The measured values of the angles of each triangle are corrected so that they add up to 180°.

The magnitude of the correction applied to each angle is roughly proportional to its magnitude.

(ii) Hub Correction : The hub angles are added, and if they do not add up to 360°, the difference is appropriately distributed. Corresponding adjustments are simultaneously made in the peripheral angles to ensure that the 180° condition for triangles remains undisturbed. It may be noted here that subsequent corrections are applied to the peripheral angles only. The hub angles are left alone.

(iii) Polygon adjustment (log sine correction) : After making the angles of every triangle total 180° and every hub total 360°, a true balance between the peripheral angles and lengths of the triangles is ensured by making the sum of the logs of sines of the odd angles equal to the logs of even angles. If the correction required is very large, or exceeds the sum of 10-seconds differences for the logs of sines of the angles, the accuracy of the angular measurements becomes suspect and must be checked[3].

(b) Lengths of sides : The lengths of the sides of triangles are computed from the corrected length of the baseline, and the adjusted angles of the system, by using the sine rule.

(c) Co-ordinates : From the measurement of bearing of one side in the triangulation network in the field, and measured horizontal angles, bearings of all the other sides of the triangles are calculated. These bearings may be "whole-circle bearings" or "quadrant bearings". Coordinates of each of the points are then calculated from the length and bearing of the sides of triangles. The first step is to compute "latitudes" and "departures" of the lines which are obtained from L sin α and L cos α where L is the length and α is quadrant bearing of the line. From these, total coordinates are obtained for each point by adding algebraically the latitudes and departures successively from one point, which may be termed as origin. The coordinates of the origin are chosen so as to keep the values of all coordinates positive.

4.2.2 Traversing

In traversing, horizontal control is established by measuring the lengths and directions of the lines joining the traverse stations. Traverses are of two types :

1. Closed traverses.
2. Open traverses.

Closed traverses : A closed traverse closes upon the starting station (usually a triangulation station, a trijunction point, or other permanent control point) from which the traverse commenced. It is called a polygonally closed traverse to distinguish it from one which is closed between two previously established control points. The accuracy of work in the case of polygonally closed traverse can be judged by comparing the initial and final bearings of the closing line, and the initial and closing coordinates of the survey. In the case of a traverse which is closed between two previously established control points, the accuracy of the traverse can be checked by the agreement between the bearings and the coordinates of the line joining them obtained from the traversing, with the corresponding values obtained from the more accurate original survey.

In exploration surveys, closed traversing is adopted for establishing the main horizontal control points when the area to be covered is flat or when it is not very large, and the distances between the stations can be measured without much difficulty. It is also used for establishing additional or subsidiary horizontal control points for detailed surveys between the permanent reference points established earlier by triangulation.

Traversing procedure : Traversing involves the following operations :

(a) Reconnaissance and setting up traverse stations.

(b) Measurement of angles and distances between the stations.

(c) Calculation of bearings and coordinates and plotting the traverse.

(a) Reconnaissance and setting up traverse stations : The object of reconnaissance is to select the shortest traverse route which offers best ground for taping and at the same time avoids short legs. The site at which traverse stations are located must be stable and unlikely to be affected by mining or natural agencies. At this stage, a sketch is made of the route to be followed, the location of the stations and the places where distinct changes of slope occur along each leg. The permanent stations are marked in the same way at triangulation stations.

(b) Measurement of angles and distances : A theodolite is used for measuring the angles. A microptic theodolite with optical plumbing will make for rapid progress without sacrificing accuracy. The instrument is accurately levelled and centered on the traverse stations with telescope in the face-left position. The telescope is directed towards the back station and is sighted, and plates are clamped. Accurate bisection is effected by tangent screws. Initial reading of the horizontal circle is recorded. The horizontal circle may be set to read zero. Now, the upper plate clamp is released and the telescope directed towards the forestation and the clamp tightened. The station is accurately bisected with the help of upper plate tangent screw, and the reading taken. The differenceof the initial and the final reading will give the horizontal angle between back and forestation. The process is repeated in the face-right position also for the sake of accuracy, two sets of readings are taken at each setting. The angle of elevation or depression (i.e. vertical angles) is also measured and recorded. The method of booking is shown in Table 4.2.

Calculation of bearings and coordinates : The azimuth (i.e. the clock-wise angle of a line with the true north) of the first line is either already known or determined. The external angle of each of the subsequent traverse lines is converted into a whole circle or azimuth bearing. In a closed traverse, initial and closing azimuths of the first line should agree. If there is a difference, it is equally distributed between the observed angles. This also applies to a traverse which opens from a line of known azimuth and closes on a line of known azimuth.

Open traverses : Open traverses are used for providing subsidiary horizontal control points, from which details can be filled up. Open traverses normally do not require the same refinement or care as the closed traverses which partly replace triangulation. Horizontal angles are measured only once or rarely twice on each face.

In prospecting and exploration, open traverses are carried out for fixing the position of the tacheometer or plane-table stations for filling in details. The traverse

Table 4.2 Method of Booking-Measurement of Angles in Traversing

Traverse : From $T-T_1$ to No. 1 Shaft   Observer : P.Q.   Booker : M.N.   Instrument : Microptic Theodolite with optical plumbing Inst. No. Th-2

To Station	Horizontal angles at station 6					Vertical angles from 6 to 7				Changes of slopes
	F.L.	Included angle	F.R.	Included angle	Mean angle	Face	Reading	Vertical angle	Mean	
							6 to a			
5	273-55-55		93-27-31			L	359-32-32	00-27-28		
7	84-17-35	170-22-40	263-50-05	170-22-34		R	180-28-10	00-28-10	00-27-49	
					170-22-36		b to a			
5	07-37-30		190-07-56			L	3-28-10	3-28-10		
7	178-00-08	170-22-38	00-30-28	170-22-32		R	176-31-36	3-28-24	3-28-17	
							b to 7			
						L	357-24-05	2-35-55		
						R	182-36-28	2-36-28	2-36-12	
	Horizontal angles at station 7					Vertical angles from 7 to 8				
							7 to a			
6	318-41-10		297-10-31			L	358-41-16	01-18-44		
8	163-06-50	204-25-40	141-36-05	204-25-34		R	181-19-03	01-19-03	01-18-54	
					204-25-35		b to a			
6	36-21-58		02-05-48			L	357-12-24	02-47-36		
8	240-47-31	204-25-30	206-31-21	204-25-33		R	182-47-44	02-47-44	02-47-40	
							b to 8			
						L	355-14-42	04-45-18		
						R	184-45-40	04-45-40	04-45-29	

stations may also be used as end points for tape and compass traverses from which offsets are taken to the various surface and geological features.

4.2.3 Levelling

Primary vertical control points to which different kinds of surveys are normally referred to are the "primary protected bench marks" established by the Survey of India on the basis of precision levelling. The mean sea level determined on the basis of tidal observations at selected sea ports forms the datum for these bench marks. The central and state public works or civil engineering departments, railways, city and town planning authorities establish local bench marks connected to these via secondary and tertiary bench marks[4].

Spirit levelling : Spirit levelling consists of taking measurements with a levelling instrument and a graduated staff. Usually a dumpy level is used for this purpose.

The Survey of India toposheets show the heights fixed by spirit level in upright type preceded by the letters B.M. Data on primary and secondary bench marks are also contained in levelling pamphlets issued by the Survey of India.

In surveys carried out for exploration, one or more bench-marks are established within the area being explored, by carrying fly-levelling from the nearest Survey of India bench-mark or local bench-mark. If such a bench-mark is not available within a reasonable distance, an assumed datum is used for the purpose. The bench-marks so established should be sited on firm rock not likely to be disturbed by natural or human agencies. Bench-marks established in unconsolidated ground are unreliable, especially when subjected to vibrations due to mining operations, movement of heavy vehicles or railways, etc.

The modern Engineer's level has replaced the dumpy level which was earlier used for ordinary levelling jobs. However, as the sturdy dumpy level is still used in some mines, it is briefly described here. It consists of a telescope whose barrel is cast solid with a vertical spindle carried on a triangular plate (Tribrach). The Tribrach is supported on a bottom plate or trivet stage by means of three levelling screws. A sensitive spirit level is mounted on the telescope by means of a hinge at one end and a Capstan Screw at the other end. The Capstan Screw is meant for making the axis of the spirit level parallel to the optical axis of the telescope. A smaller spirit level is mounted at right angles to the main spirit level near the eye piece of the telescope. The trivet stage incorporates a quick levelling device, and can be readily mounted on a telescopic tripod.

When properly adjusted, the axis of the spirit level must be parallel to the optical axis of the telescope and both axes must be perpendicular to the vertical axis. The line of sight is horizontal for all positions of the telescope if the main spirit level remains centralised in all positions. This is achieved by centralising the main spirit level in two directions at right angles to each other. In practice, however, wind pressure, a slight sinking of the tripod or movement caused by the activities of the observer can disturb the verticality of the axis of rotation of the dumpy level and the bubble may not be quite central for a given sight. The bubble can be recentralised by means of one of the foot-screws.

In the modern Engineer's tilting levels, the disadvantages of the dumpy level have been overcome by pivoting the telescope at its junction with the vertical axis, so that it can be relevelled for each line of sight by means of a fine levelling screw, without affecting the height of the line of sight. A small circular spirit level is provided for quick preliminary levelling at each setting. The images of the two ends of the main spirit bubble are brought together by a specially designed optical system placed along side the eyepiece of the telescope. This makes it possible for the surveyor to centralise the bubble by coincidence of the images, and at the same time read the staff without walking around the tripod. Further, he can check the coincidence of the bubble as he takes the staff reading.

A modern tilting level must satisfy the following conditions if it is correctly adjusted : (a) the axis of rotation must be approximately vertical when the circular spirit level is central, (b) the main spirit level must be central when the line of collimation is horizontal, and (c) the fine-levelling screw should be at zero when the main spirit level bubble is central and the axis of rotation truly vertical. Procedures for testing and correcting these adjustments can be found in the textbooks on surveying listed in the references given at the end of this chapter.

The levelling stavesconsist of 3 or 4 sections, either hinged or telescopically connected, and made of seasoned wood. The staves are graduated in metres, decimetres and centimetres.

Levelling procedure

The method of levelling is illustrated in Fig. 4.3. The instrument is first set up at a convenient point from which the bench-mark or another station (A) the reduced level of which is known, is clearly visible. The telescope is properly levelled and pointed to a staff held on A and the reading of the levelling hair entered in the level book under the column headed back sight (B.S.). The level bubble should then be checked to

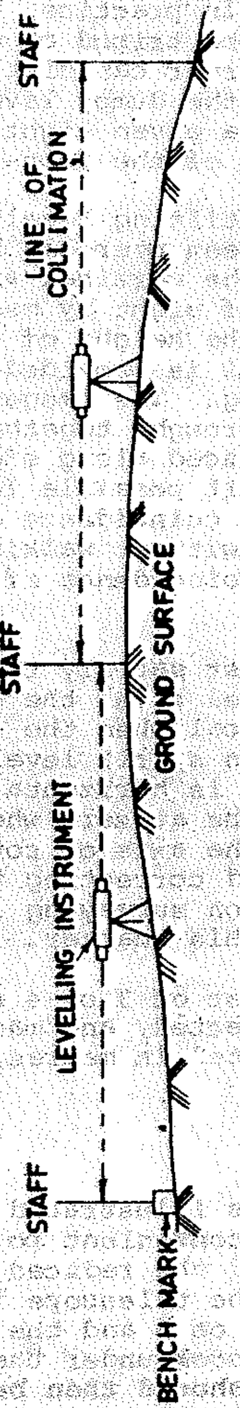

FIG: 4·3 METHOD OF LEVELLING

ensure that it is centralised. The staff is then moved to point(B), and sighted through the telescope. The staff is read and the reading entered under column foresight. Read- ings for any number of intermediate stations between the Back-station and Forestation may be taken as per requirement in which case the readings are recorded as intermediate sights. A forward sight is the most forward station sighted from an instrument setting. The setting of the levelling instrument is selected taking into account clarity of vision, weather effect on the image, topography, etc. In order to minimise the errors due to curvature, refraction, etc. the instrument is set up approximately equidistant from the back and fore- stations. The instrument is then shifted to a position between the forward station of the last setting and the next forward station. The procedure of sighting and recording staff-readings is repeated for this setting.

Two methods of obtaining the reduced levels from the field observations, viz. (a) the rise and fall method, and (b) the height of collimation method are shown[5] in Tables 4.3 and 4.4. The former method permits an arithmetical check to be made before the reduced levels are calculated. The latter method makes the setting out of points of specified level easy since the staff reading necessary to obtain a par- ticular level can be readily calculated from the height of collimation.

Levelling may be classified as fly levelling and sectional levelling according to their purpose. Fly levell- ing is done for determining the relative levels of two or more isolated points. It, therefore, does not normally involve taking intermediate sights and measuring distances between staff stations. Sectional levelling is done for plotting the profile of the ground along a predetermined route. It involves, in addition to levelling, the continuous measurement of distances from a fixed point to each of the staff stations. These distances are entered in the field- book under the column : distances.

<u>Trigonometrical levelling</u> : Trigonometrical levell- ing is used for determining relative differences in elevation in steep ground or steep underground workings, especially when considerable distances are involved. It involves the measure- ment of the vertical angle and inclined distance between the instrument station and the staff station. The vertical dis- tance between the instrument station and the staff station is given by inclined distance X sine Ø (vertical angle). A theodolite is used for measuring the vertical angle and a vertical staff sighted.

The accuracy of the method depends on the accuracy of linear measurement, the angular measurement and the paralle- lism between the line of sight and the ground profile. The

Table 4.3: Method of Booking for Rise and Fall Method

Station	Backsight ft.	Intermediate sight ft.	Foresight ft.	Rise ft.	Fall ft.	Reduced level ft.	Total distance ft.
1	4.68					5,502.80	00.00
2		6.74			2.06	5,500.74	121.60
3		10.82			4.08	5,496.66	237.80
4		7.56		3.26		5,499.92	356.50
5	3.78		13.88		6.32	5,493.60	472.50
6		2.98		0.80		5,494.40	587.70
7		7.76			4.78	5,489.62	695.80
8			11.73		3.97	5,485.65	789.50
Check	8.46		25.61 8.46	4.06	21.21 4.06	5,485.65 5,502.80	
Calculation			17.15		17.15	17.15	Fall

Table 4.4: Method of Booking Height of Collimation

Station	Backsight ft.	Intermediate sight ft.	Foresight ft.	Height of collimation ft.	Reduced level ft.	Total distance ft.
1	4.68			5,507.48	5,502.80	00.00
2		6.74			5,500.74	121.60
3		10.82			5,496.66	237.80
4		7.56			5,499.92	356.50
5	3.78		13.88	5,497.38	5,493.60	472.50
6		2.98			5,494.40	587.00
7		7.75			5,489.62	695.80
8			11.73		5,485.65	789.50
Check	8.46		25.61 8.46		5,485.65 5,502.80	
Calculation			17.15	-- Fall --	17.15	

linear measurement is carried out with a steel band. The vertical angle is measured on the face-left and the face-right positions at each instrument station. The accuracy in trigonometric levelling is inferior to spirit levelling.

The method is also applied to finding the approximate elevation of stations in triangulation and traversing. Vertical angles are normally measured along with the horizontal angles.

4.2.4 Contouring

Of the different methods of showing relief (i.e. surface features) in a map, the most convenient method is by contours. A contour line can best be defined as the intersection of a level plane and the ground surface. Every point on a contour is, therefore, at the same elevation. The difference between the elevations of points on two successive contours is called the contour interval. The contour interval for any particular plan is selected by taking into account the purpose of the survey, the extent of the survey, the nature of the country and the scale of the plan.

The advantages of showing contours on a geological/ mine map are :

(a) Changes in level are clearly depicted.

(b) Strike and dip of a formation can be easily marked.

(c) The amount and direction of dip of an outcrop can be readily calculated.

(d) Structures like anticlines and synclines can be readily deciphered.

(e) Gradients of roads can be found.

(f) Profile sections can be drawn.

(g) Drainage pattern of the area can be readily visualised.

Methods of contouring : Contouring involves two separate tasks, viz. (i) determining the elevation of selected points (i.e. vertical control) and (ii) fixing the position of these points on the map (i.e. horizontal control). The tasks may be carried out independently using a dumpy level or tilting level and a staff for vertical control and a theodolite and tape, a compass (dial) and tape or a chain or tape, for horizontal control. The vertical and horizontal controls can be simultaneously and quickly established by tacheometry or plane table equipped with a telescopic alidade or an Indian pattern clinometer. A plane table with a simple alidade can be used in conjunction with a theodolite (with stadia lines on the diaphragm) for rapid contouring. Levelling for this purpose can be carried out by three methods, which are described below.

(a) Method of cross-sections : In this method, elevations of points located on straight lines set off at right angles to traverse lines or radiating from the instrument station are determined. The section lines are spaced so that abrupt changes in gradients, like spurs, streams, etc. can be picked. The section lines selected for determining the elevations are surveyed and plotted. The spot levels are shown on the map. Contours are interpolated from the spot levels[6] (Fig. 4.4). This method is suitable for contouring a narrow strip of ground.

(b) Method of Gridding : In this method, spot levels of the corners of grids or squares formed by a system of mutually perpendicular straight lines are determined. The grid interval depends upon the area, the steepness of the ground and the contour interval. If the ground is of a varying character, the grid interval may be changed to suit the ground covered. This method is suitable for contouring small areas with a gently or moderately sloping ground. The procedure[6] is shown in (Fig. 4.5).

(c) Method of pegging out the contours : In this method, each contour line is directly demarcated on the ground by means of pegs. Fly-levelling is carried out from the Survey of India permanent bench-mark or a local bench-mark to a point within the area being contoured, using the height of collimation method. The levelling staff is moved up or down along the line of sight till the staff reading is equal to the difference between the height of collimation and the elevation of the contour. A peg is driven into the ground. The procedure is repeated along the other lines of sight radiating from the instrument station. Several contour lines around each instrument station can be pegged out if appropriate care is taken to identify the pegs of one contour from those of another. The contours as marked out by the pegs are plotted by plane tabling or other suitable method of detail filling. This method, also known as direct contouring, is accurate but time consuming. So, its use is limited to close contouring of small areas. The procedure is illustrated[6] in (Fig. 4.6).

4.2.5 Tacheometry

Tacheometry is a method of rapidly measuring horizontal and vertical distances exclusively by instrumental observations. It does not involve any linear measurement, and in most cases, it is possible to make the observations for a number of points from one fixed station. It is used for expeditiously plotting contours, topographical details and geological features within the horizontal control framework, provided by the principal and subsidiary surveys. It is particularly suited for detailed mapping of rough country where linear measurement by chain or tape is slow and inaccurate and ordinary levelling is tedious.

The basic principle on which different systems of tacheometry are based is that the horizontal distance between an instrument station A and a point B, as well as the elevation of B relative to the instrument, can be deduced from (1) the angle subtended at A by a known distance (e.g. a staff intercept) at B and (2) the vertical angle from A to B. Methods of tacheometry can be broadly classified into (a) the stadia system, and (b) the tangential system[7].

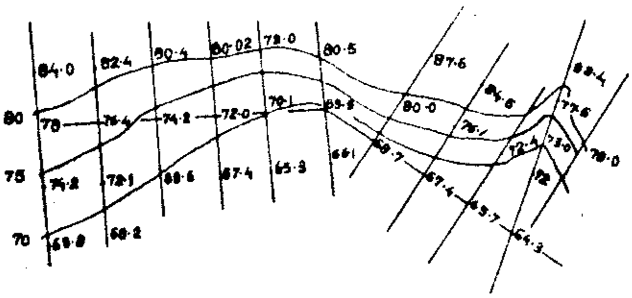

FIG: 4·4 CONTOURING BY METHOD OF CROSS SECTIONS

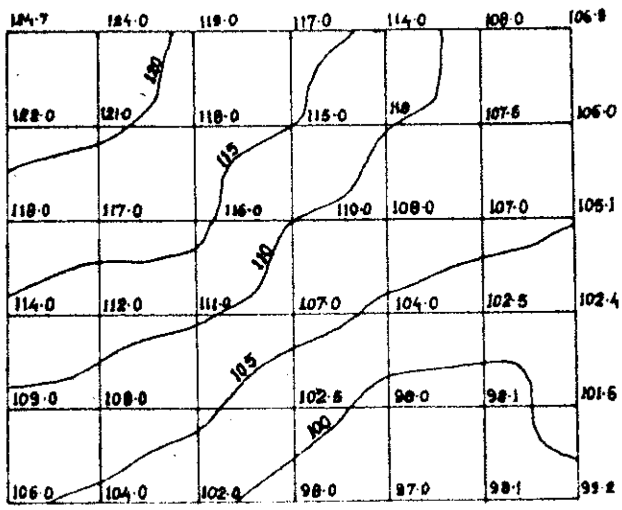

FIG: 4·5 GRIDDING METHOD OF CONTOURING

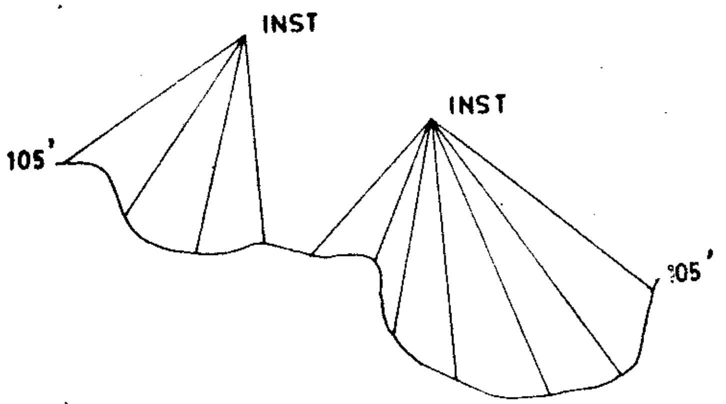

FIG: 4·6 METHOD OF PEGGING CONTOURS

The stadia system is the most common practical system adopted in field work. In the stadia system, only one sighting of the telescope is needed for making three observations at any particular point. In the tangential system, two manipulations and two sightings are needed for making a complete observation. So, more time is required in the tangential system. Further, there is always a risk that the instrument may be disturbed or the atmospheric refraction may change during the interval. The stadia system is, therefore, generally preferred.

Two additional horizontal hairs or rulings, known as stadia hairs or lines, are provided on most of the modern surveying telescopes; one is above and the other below the central horizontal hair or line. The stadia wires are so located that the staff readings in vertical plane give corresponding horizontal distances directly by simple multiplication by a factor. In the fixed hair method of stadia system of tacheometry, a staff is held over the point to be located with respect to the instrument station, and the reading of the top, middle and bottom horizontal lines on the diaphragm are read through the telescope. The line of sight may be horizontal or inclined depending upon the elevation. In case of inclined line of sight, the graduated staff on the point of sight may be either vertical or normal to the line of sight.

Horizontal sights : If the horizontal distance between the instrument station and the point to be located is H, length of staff intercept, i.e. the difference between top and bottom stadia hair readings = S, then H = S x K + C, K being the multiplying constant and C the additive constant for the telescope. K and C are normally given by the manufacturer. Modern telescopes are designed so that the horizontal distance can be obtained with an accuracy of 1 in 1000 for distances ranging from 6 m to infinity, by merely multiplying the staff intercept by 100. The elevation of the staff station is computed from the reading of the central horizontal line and the height of the instrument in a manner similar to that used in levelling.

Simple formulae can either be derived or obtained from textbooks for computing horizontal distances and elevations in cases where the line of sight is inclined, and the staff is either vertical or normal to the line of sight.

4.2.6 Plane Tabling

Plane tabling provides the easiest and only method of plotting of topographical and geological details directly in the field. The plane table is a rectangular (65 x 45 cm) or square (65 x 65 cm) drawing board made of well-seasoned wood. It is attached to a tripod with a quick levelling head by means of a vertical spindle fixed at the geometric centre of the lower side of the board. Its accessories are (1) an alidade, (2) a spirit level, (3) a trough compass, (4) plumbing fork with plumbline and bob, and (5) clamps for mounting cloth-backed paper on the board.

The plain alidade consists of a straight edge with folding sight vanes. It permits the determination of horizontal positions of points but does not permit vertical heights to be shown unless a dumpy level or an Engineer's level is used in conjunction with the plane-table. The Indian pattern clinometer is also a type of alidade. It carries a peep-sight at one end and a slit-sight with angles of elevation and depression etched on one side of the slot and the tangential values of the angles marked on the other side. A sliding frame carrying a horizontal hair which can be clamped in any desired position with a thumb screw is provided on the slit sight to facilitate reading. The sight-vanes are hinged to an upper plate which can be levelled in relation to the base plate by means of a levelling screw and a small spirit level. When levelled correctly, the zero on the slit-sight is at the same level as the peep-hole. The difference of level between the point being sighted and the plane table is found by multiplying the tangent scale reading by the distance of the point. A telescopic alidade consists of a tacheometric telescope aligned with the straight edge. It carries a graduated vertical circle for taking inclined sights. It is used in conjunction with a stadia rod or levelling staff. A spirit level is used for levelling the table. A compass is used in some surveys for aligning the plane table with the magnetic meridian with the help of a north line drawn on the paper. The plumbing fork is used for marking a point corresponding to the instrument station on the paper mounted on the plane table.

<u>Methods of Surveying with plane table</u> :

(1) <u>Radiation</u> : In this method, the plane table is set up on a control point from which the points to be plotted are visible. The table is clamped and the control point or station is transferred to the paper by the plumbing fork. Rays or sights are then taken to the points to be plotted and lines are drawn to represent them[2] (Fig. 4.7). Distance from the station to each point is carefully measured and scaled off on the corresponding ray. The method is used only for large-scale work.

(2) <u>Traversing</u> : It is similar in principle to close traversing with a theodolite. The plane table is successively set up over previously selected traverse stations, and back and forward sights taken and lines are drawn at each setting. The distances are measured by tape and plotted to scale to locate the stations[2] (Fig. 4.8). Accuracy of the traverse is checked by the coincidence of the starting station as initially plotted with the intersection of the forward sight from the last station. This method is useful for surveying roads, rivers, boundaries, etc.

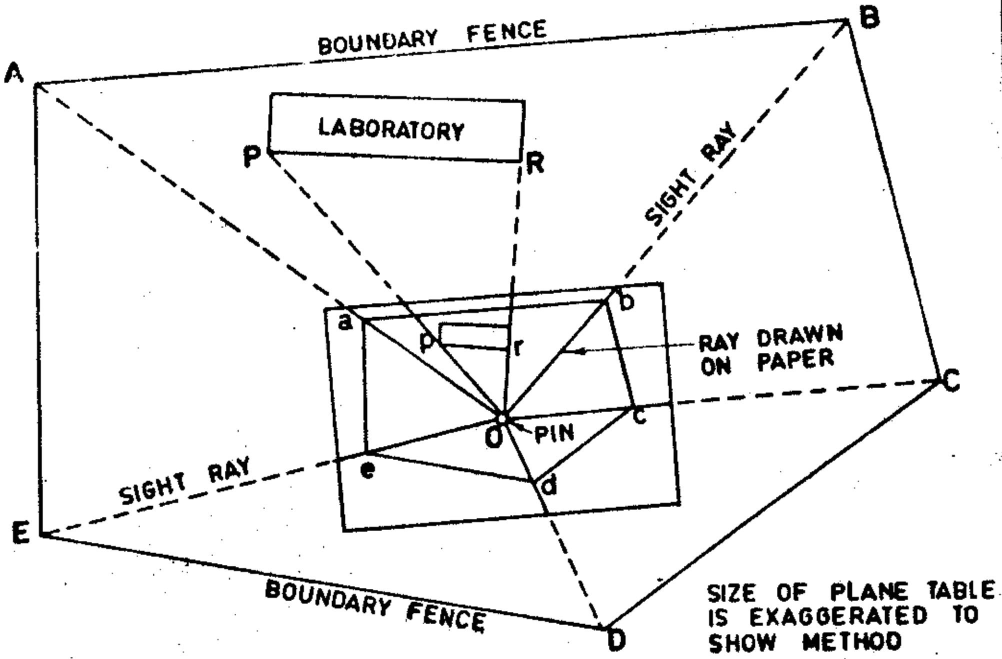

FIG. : 4·7 RADIATION METHOD OF PLANE TABLING

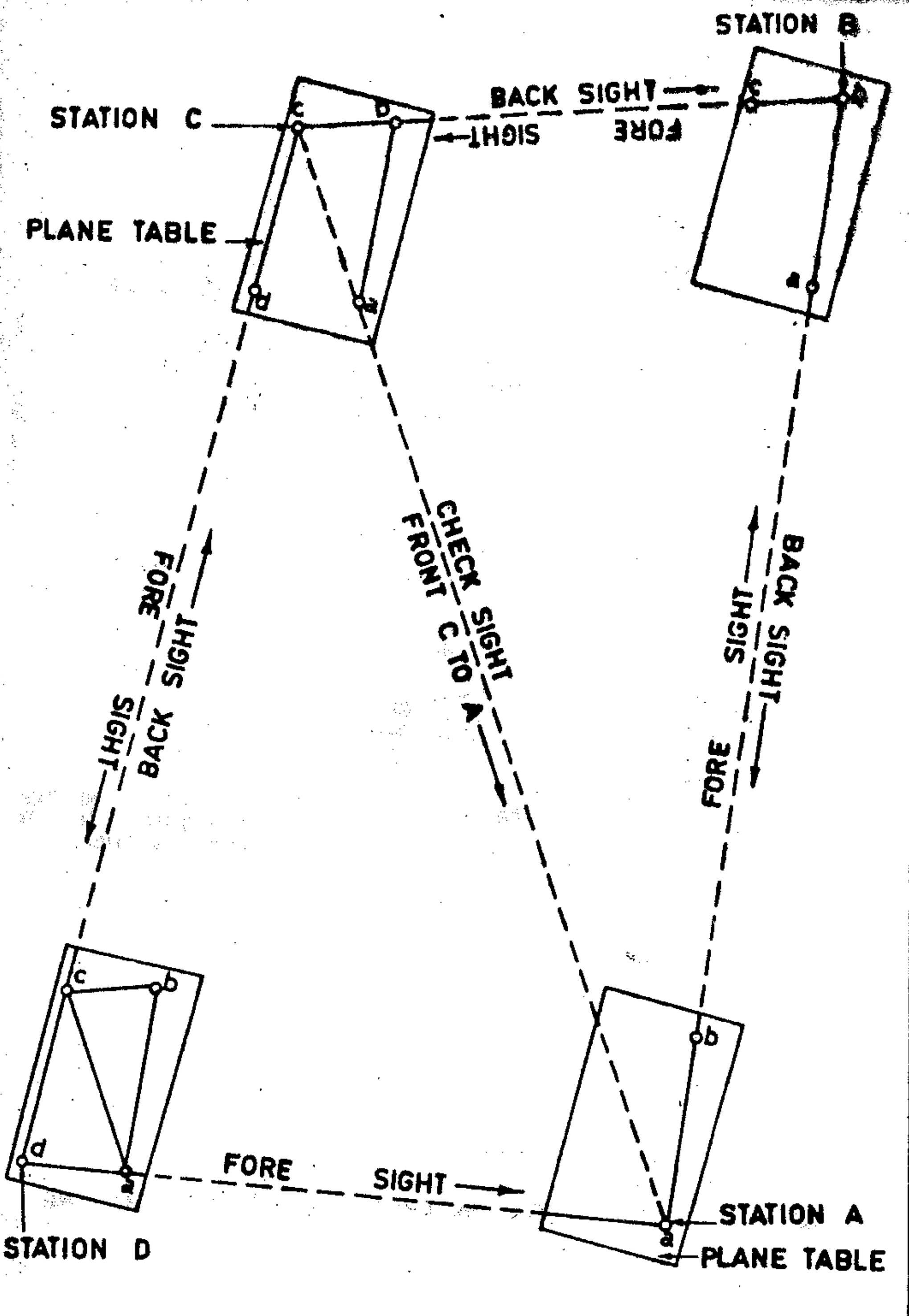

FIG: 4·8 TRAVERSING METHOD OF PLANE TABLING

(3) Intersection : Intersection is the method commonly used for plotting the details. The method consists of setting up the plane table first at one end of a base line of known length. The base line is drawn to scale on the map sheet after transferring the instrument station to the paper by the plumb bob and sighting the other end of the base line with the alidade. Rays are then drawn to the points to be plotted. The plane table is then shifted to the other end of the base line and clamped after being aligned by taking a back sight along the plotted base line. Rays are now drawn to the points to be plotted intersecting the corresponding rays drawn from the previous plane table setting. Topographical and geological details can be sketched with the help of these intersection points[2] (Fig. 4.9).

The main advantage of this method is that the plane tabler can see before him the features he is plotting. The intersection method of plotting is well-suited for detail filling from theodolite traverse stations.

4.2.7 Chain or Linear Surveying

This form of surveying is carried out by linear measurements over small areas by using a chain or a tape. This does not involve measurement of angles. Usually offsets are taken at right angles to principal lines laid down on the field by means of alignment and chain or tape. Occasionally the property is covered by triangles which is done by reconnaissance.

Considerations guiding the selection of provisional stations during reconnaissance are :

(a) As far as possible, the survey framework should be erected on a base line running through the middle of the area.

(b) Triangles should be well-conditioned and placed so that "check lines" or "tie lines" can be run from the vertices to the mid-points on the opposite sides.

(c) As far as possible, the chain lines should be free from any obstacles.

(d) Survey lines from which offsets are taken should run as close to the surface details being picked up as possible.

Details are picked up by measuring offsets to the points from the chainline. At each offset, the distance along the chain line to the offset and the length of the offset are

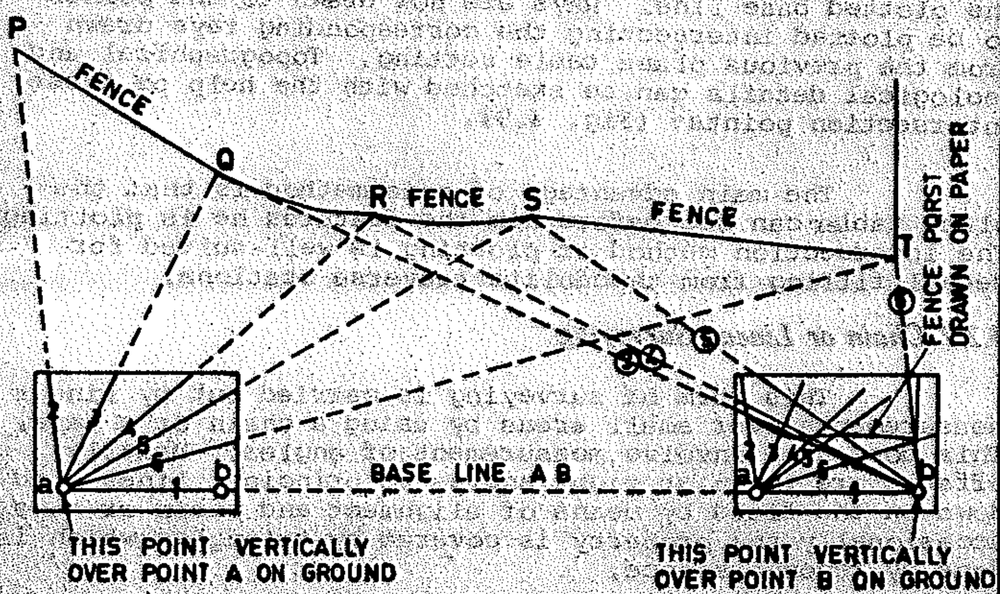

FIG: 4·9 INTERSECTION METHOD OF PLANE TABLING noted in the field book. The next tape length is ranged and measured in the same way. Steel wire marker, known as arrow are used to mark the tape lengths, measured as the survey progresses. The survey is plotted to scale in the office, and hence unlike plane tabling, omissions in the field work cannot be readily detected and rectified.

4.2.8 Traversing with Compass

A fairly accurate map can be drawn by using a Brunton Compass, miner's dial or prismatic compass to fill in topographic and geological details within the horizontal control established by traversing. A traverse line or a road or footpath, the position of which has already been located, can form the reference line for the compass survey. Magnetic bearings of details or objects are taken from the reference line, and the respective distances are measured by pacing, taping,etc. Care is taken to ensure that at least two rays are taken to each point of the detail so that it can be plotted by intersection. This method is faster than chain surveying. Further, points which are at a distance can be picked up by intersection. The date of traverse should be noted, in order to check magnetic variations. Care also is to be taken to see that no local attractions are existing in the vicinity of the survey lines.

4.3 Underground surveys

The principles of surveying in underground workings are basically the same as those of surface surveys but the methods used are dictated by the constraints imposed by poor lighting conditions, low height, limited space, steep slopes, constant activity connected with mining operations, etc. Traversing by theodolite, and rarely by a miner's dial, is the most common method of underground survey. Special techniques and accessories are available for dealing with the difficulties encountered in carrying out a theodolite-traverse underground.

(1) Traverse stations : The traverse stations are usually fixed on the roof of the underground workings as pegs or markers fixed on the floor are liable to be dislodged by the movement of men and machines. The station is marked by driving a dry wooden plug into a hole drilled in the roof and a special brass spud is fixed in the plug so that it projects only slightly below the roof.

(2) Centering of the theodolite is done by suspending a plumb bob from a hole in the spud. The theodolites used underground have a centering pin on top of the telescope for this purpose.

(3) For sighting the plumb line, it is necessary to place an illuminated cloth or paper screen behind it. A cap lamp or torch can be used for this purpose.

(4) For surveying steep workings in which the tripod cannot be set up, it may be necessary to mount the theodolite on a stretcher bar. It consists of two light strong alloy-steel telescopic tubes which can be clamped by screw action between walls. The telescope is carried at one end of a bar, with counter-weight at the other end. This bar is mounted on the stretcher bar in such a way that it can be moved or turned in any direction and clamped in any desired position.

(5) Accessories for the theodolite in underground surveys :

(i) diagonal eye piece - It is used for taking steep upward sights in which the target cannot be conveniently viewed through the eye piece of the telescope.

(ii) auxiliary telescope - This is a smaller telescope mounted above or on the side of the normal telescope. It is used for taking steep downward sights.

(iii) Strident level - This is a level which can be mounted on the trunion axis and is used for ensuring that this axis is truly horizontal.

(iv) modern theodolites are equipped with battery powered illumination systems for lighting up the vertical and horizontal circles if necessary.

(6) In levelling work underground, the staff is generally held in an inverted position with its base on the roof, so that height of the station in roof above the line of collimation is measured, in order to keep the reduced levels always positive. The datum to which the underground levels are referred is assumed and is marked on a bench-mark at the lowest point within the mine.

(7) In steep workings, trigonometric levelling is used.

(8) Correlation or orientation of underground survey with the surface surveys is essential. The methods used for this purpose are :

(a) direct traversing via mine entry : This is possible when the underground workings are accessible through an adit or incline.

(b) shaft plumbing : The methods listed below are used where one or more vertical shafts provide access to the underground workings.

(1) One wire in each shaft : This method is used when two shafts connected by the underground workings are available. At the surface, the true bearing of the line joining the plumb wires suspended in the two shafts is determined by connecting the wires directly or indirectly to triangulation stations. An underground traverse is run between the wires and their coordinates calculated by reference to an assumed meridian. The bearing of the plumb plane calculated from these coordinates is compared with the true bearing observed on the surface. If there is variation between the true bearing and the computed bearing, correction has to be applied to the computed bearing and also to all the computed bearing and also to all the underground bearings by the amount of variation.

(2) Two or more wires in a single shaft : In this method, two wires are vertically suspended in the shaft to form a plumb plane. The azimuth of this plumb plane is determined and transferred on the reference base below ground. Two or more plumb planes may be formed by suspending a number of pairs of plumb wires.

The three principal methods of observing the azimuth of the plumb plane are :

(i) Exact coplaning or alignment in which the theodolite is set up exactly in line with the plumb-bobs. This is a time consuming procedure and requires much patience and manipulation.

(ii) Weisbach Triangle method : In this method, the theodolite is set up in an approximate alignment with the plumb wires. A triangle is formed with the theodolite section and the two plumb wires which is known as the Weisbach triangle. The small angle subtended at the theodolite station by the plumb-wires, and the length of all the three sides of the triangle are measured very accurately. Measurement of other angles and distance to connect the three points with surface survey are also taken carefully. On the basis of these readings the coordinates of the plumb wires are computed, which form the base for transferring the bearing to underground station.

(iii) Method of Weiss quadrilateral : A quadrilateral (known as Weiss quadrilateral) is formed by the plumb wires and the two stations in the shaft inset. Angles are measured from these two shaft stations to the plumb wires, and also the distance between the shaft station. From these observations it is possible to calculate all the polygonal angles and sides of the quadrilateral without any linear measurements, from which the bearing of plumb wires is computed and transmitted to another underground station.

(c) Precise magnetic corelation : The method involves the determination of the correct magnetic bearing of both surface and underground reference lines and the application of the difference between them to the azimuth of the surface line to give the azimuth of the underground line. A common coordinate is obtained by suspending a single wire in a shaft and running a traverse from it to the underground reference line. The method is prone to errors due to the presence of local magnetic disturbances, diurnal variations, magnetic storms, magnetic declination, instrumental peculiarities, etc.

(d) Gyroscopic Theodolite : Of late, a gyroscopic theodolite has become available. In this a gyroscope driven by an electric power-pack whose axis is aligned to the true maridian forms the reference direction for the theodolite. The horizontal angles measured will then be able to give bearings directly.

4.4 Accuracy of various types of surveying methods

The following limits of error for surveying and plotting work carried out in mining areas are compiled from the circulars issued by the Directorate-General of Mines Safety, India.

Type of work	Limit of error permissible
1. Surface Surveys	
(a) Triangulation : Position of triangulation stations as determined from initial and check bases.	1:5000 in linear distance from the local point or origin.
(b) Traverses	
Total angular error.	30 x $\sqrt{n}$ seconds, where n = number of angles measured.
Error of closure.	1:3000 in the horizontal length of the traverse.
2. Subsidiary Surveys	
Error of closure.	1:500 in horizontal length of traverse.
3. Levelling	
Surface bench mark at the mine	50 mm (i.e. 5 cm) per kilometre.

Inset bench mark	Two or more shaft measurements to establish inset bench marks should agree within 1:5000.

4. Underground Surveys

(a) Traverse closed polygonally Total angular error.	30 x $\sqrt{n}$ sec. where n = number of angles measured.
Error of closure.	1 : 2500 in horizontal length of traverse.
(b) Traverse closed upon reference points.	1 : 1500 in horizontal length of traverse.

4.5 Equipment and personnel requirement

The requirement of equipment for carrying out a survey for mineral exploration will depend upon the area to be covered, the time available for the work, topography of the area, the methods of surveying selected for use, and the money available for buying the equipment. For carrying out triangulation, traversing, levelling, tacheometry, plane tabling and linear surveys on the surface, the following equipment is suggested:

A. Field Equipment

Sl. No.	Name of instrument and description	Number of units required
1.	Theodolite, Microptic with stadia diaphragm, telescopic metal tripod and optical plumbing device.	1
2.	Engineer's Tilting level with split bubble optical system.	1
3.	Plane Table approximately 65 cm x 65 cm with quick levelling head and telescopic metal tripod, a spirit level, compass and preferably a telescopic alidade.	1
4.	(a) Steel tapes, graduated in metres and centimetres, of 30 metres length.	2
	(b) Metallic or Linen Tapes	2

5.	Levelling staves of telescopic or folding type graduated in Metric system.	4
6.	Trestles (wooden)	4
7.	Ranging rods	6
8.	Brunton compass with tripod	1
9.	Surveyor's umbrella	1
10.	Axe, wood chopper or bush knife, shovel, pick axe, hacksaw trowel, cement, galvanised 25 mm dia pipe etc. for clearing lines of sight and for levelling ground and marking permanent stations.	
11.	Wooden pegs 50 mm x 500 mm for base line measurement and 25 mm for marking temporary stations.	
12.	Hammer	
13.	Plumb bobs and thread.	
14.	Field books, pencils and eraser.	
15.	Set of scales, protractor, set squares and drawing instruments.	
16.	Torch light (3 cells).	

B. Office Equipment

1. Drawing table or drafting table and seat.
2. Drawing board (Elephant size). A drafting board can be used instead of (1) and (2).
3. T-squares (wooden).
4. Steel straight edge.
5. Parallel ruler (Brass).
6. Good quality drawing instrument box.
7. Protractor circular (large).
8. Set squares.
9. Best quality handmade drawing paper.

10. Tracing paper.
11. Pencils 4H, 2H and H.
12. Synthetic eraser.
13. Lettering pens, stencils, crow quills, and line pens.
14. Indian ink and water colours.
15. Drawing pins.
16. Cellotape.
17. Ferroprinting/ammonia printing equipment.
18. Glare free lighting fittings.

Personnel

The minimum personnel requirement for one survey field party is as follows[1]:

Surveyor	...	1
Assistant Surveyor	...	1
Chainman	...	1
Labourers	...	6

4.6 Norms for various surveying jobs

Norms for various types of survey work based on the experience by Indian Bureau of Mines are listed below with the equipment and personnel specified in para 4.5.

	Description of work	Norm Average progress per day	Nature of terrain
1.	Boundary traverse with central and check-line which have been chained.	330 m	Medium terrain
2.	Boundary levelling	1200 m	Medium terrain
3.	Boundary traverse by plane tabling	400 m	Medium terrain
4.	Detail filling and contouring by tacheometry, etc.	2 hectares	Medium terrain

Medium Terrain = Terrain which is neither too flat nor too rugged.

The average daily progress for surveying jobs will depend, apart from the nature of the terrain and the weather conditions, upon the skill of the surveyor and the persons assisting him and the type and condition of surveying equipment used. The above norms are, therefore, offered merely as a guide and may not represent the standard.

4.7 References

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Chapter 5

5.0 Evaluation

Evaluation is one of the most important aspects of mineral exploration. The aim of evaluation may be the assessment of the progress of exploration, or the determination of the commercial value of a mineral deposit. In both the cases, the methodology is essentially the same, although the precision of evaluation may have to be of a higher order in the latter case. Exploration may be carried out in various stages and it may become necessary to check periodically the progress at each stage so that those deposits which are not of immediate economic value can be eliminated. Incidentally, when such an evaluation is made the areas of poor information become evident. Such gaps in exploration are filled up systematically and thus planning is also dependent on evaluation. However the major evaluation of a deposit is made at the stage of taking it up as a commercial prospect for mining. Evaluation of a deposit for this purpose is made in two stages -

(i) interpretation of data, and
(ii) computation and classification of reserves and grades.

5.1 Interpretation of data

Exploratory data have to be evaluated continuously while the operations are on and finally after the whole of them are over. The former is done stage by stage as the data are built up while the latter is done after all the data are assembled. In either case, the organisation and processing of the data are very essential. Various types of data which come out of an exploration operation are briefly listed below :

Survey data

Surface and sub-surface geological data

Surface and sub-surface drilling data

Trench and pit data

Exploratory mining data

For purposes of data interpretation, various types of plans and sections are necessary the most important of which are the structure contour plan, isopach (isochore) plan, isograd plan, assay plan, ore distribution plan, cross section of ore-bodies, isometric projection and slice plan.

5.1.1 Structure contour plans

Structure contour plans may be of two types, floor contour plans and roof contour plans. They depict the configuration of the roof or floor surfaces by contour lines by joining points of equal elevation[1]. These plans are of great use in interpreting the structure of sedimentary rocks. Generally, some key ore bed is chosen for drawing the contours. The principle involved in constructing the plan is the same as in surface contouring. The only difference is that the points of elevation of a particular horizon (roof or floor) will have to be computed from exploratory data.

Structural contour plans have good interpretative qualities which can be made use of in reserves estimation, particularly in opencast operations.

5.1.2 Isopach (Isochore) map

Isopach maps show the variation in the true thickness of a formation by contour lines drawn through points at which the formations are of equal thickness. Isopachs can be prepared for deposits of any shape provided sufficient data are available. An isochore map is basically an isopach map drawn on the drilled thickness of the strata without referring to its true thickness and is drawn for formations with gentle dips[1]. The principle involved is the same as in preparing the structual contours except that the actual contours are drawn on thickness rather than a reference horizon. The isopach maps alone or in combination with other plans have considerable interpretative value particularly for estimating depthwise reserves and for planning opencast mines.

5.1.3 Isograd plans

These are the plans which depict the grade (quality) details of a mineral deposit and, like the isopach plan can be prepared for ore bodies of any shape. The principles involved are the same as in preparing isopachs, but in this case the thickness values are substituted by grade, individual metal value, and combined metal value (quality values). Like isopachs, these plans also have a tremendous interpretative value. Such plans are of considerable use in estimating gradewise reserves, and can be used in combination with isopachs or floor contours or with slice plans and face plans.

5.1.4 Assay plans

Assay plans are plans which show the results of sampling and generally show the underground openings with full assay details. This plan should be prepared on very large scales (1:500 or even larger, 1:200 is the most common in vein type deposits). Alongwith the assay plan there should be a plan on similar scale showing the geological and structural details of the concerned area, in addition to the positions of boreholes and other exploratory openings[2]. This assay plan helps in delineating the ore bodies based on different assay cut offs and in drawing up mining plans and quality and grade controlled production programmes. This is the most important plan always referred to while evaluating and mining (see Fig.5.1.).

5.1.5 Ore distribution plan

This is a composite plan showing the mining face. Various mining details like the positions of benches, faces, etc., are shown in addition to the exploration details. The various grades and types of ores are shown with their thickness, tonnages and average grades. Such a plan may be formed on a slice projection or bench plan in the case of opencast mines or in the case of face or stope plans in the case of underground mines

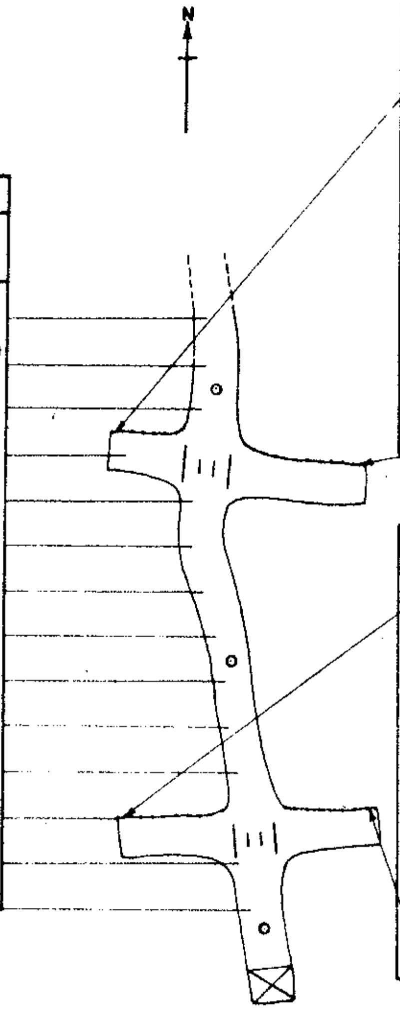
5.1.6 Cross-section

An earlier discussion dealt with the preparation of geological cross-sections. For the purpose of constructing cross-sections of ore bodies, the principles involved are almost the same. However greater precision is called for and hence more data are required. Usually the cross-sections may be along the dip of the ore body in which case they are called transverse sections.(see Fig.5.2) Cross-sections may be along the strike in which case they are called longitudinal vertical sections. Transverse sections are used for a variety of interpretational purposes. They depict the underground structure and ore distribution of the deposit. By projecting bore hole data the quality and grade information can be shown on cross-sections. In addition the depth of mineralisation can be shown graphically and in bench position projected, opencast mines and economic quarry limit fixed. Cross-sections can also be used for computing the reserves. A problem which is common in the construction of cross-sections is the determination of the correct dip along the section line. When the line of section is at right angles to the line of strike the true dips can be used. Normally the line of section makes an angle with the line of strike and the section should be constructed with the apparent dip component along the line of the section. For this it is necessary to convert the true dip into the apparent dip. A chart showing this conversion[3] is given in Table 5.1.

5.1.7 Longitudinal vertical projection

Longitudinal vertical projections are drawn along the strike of the orebody. For this, a common surface reference point is chosen along the strike of the orebody. The

HANGING WALL				MIDDLE WALL				FOOT WALL			
WIDTH IN CM	Cu %	Pb %	Zn %	WIDTH IN CM	Cu %	Pb %	Zn %	WIDTH IN CM	Cu %	Pb %	Zn %
50	0·38	1·53	2·04	50	0·73	1·00	2·90	50	0·60	1·40	1·36
50	0·65	1·47	2·14	50	0·55	1·88	2·76	50	0·32	1·00	2·00
50	0·38	1·53	2·04	50	0·43	1·70	2·01	50	0·58	1·05	1·68
50	0·47	1·02	1·89	50	0·56	1·78	1·96	50	0·40	1·11	1·60
50	0·70	1·22	2·03	50	0·80	1·21	2·60	50	0·84	1·27	2·88
50	0·50	0·98	2·56	50	0·48	1·08	2·55	50	0·81	1·43	2·16
50	0·90	1·38	2·92	50	0·37	1·57	2·03	50	0·52	1·60	1·80
50	1·00	1·07	1·60	50	0·45	1·14	2·81	50	0·44	1·83	1·74
50	0·97	0·87	1·87	50	0·40	1·63	2·37	50	0·57	1·79	1·98
50	0·77	1·51	2·10	50	0·54	1·71	2·41	50	0·62	1·65	2·11
50	0·80	1·39	2·32	50	0·44	1·57	1·73	50	0·71	1·47	2·40
50	0·56	1·43	2·72	50	0·68	1·41	2·08	50	0·59	1·52	1·89
50	0·85	1·65	1·82	50	0·50	1·78	2·15	50	0·83	1·70	1·96
50	0·72	1·71	2·07	50	0·61	1·51	1·98	50	0·69	1·68	2·09



WIDTH IN CM	Cu %	Pb %	Zn %
50	0·42	1·82	2·24
50	0·51	1·90	2·08
50	0·46	1·99	1·44
50	0·38	1·60	1·57
50	0·41	1·57	1·60
50	0·37	1·98	2·09
50	0·60	1·46	2·00
50	0·50	1·52	1·97
50	0·59	1·87	1·78
50	0·64	1·79	1·81
50	0·69	1·68	1·90
50	0·58	1·49	2·10
50	0·36	1·73	1·87
50	0·39	1·51	2·01
50	0·41	1·68	1·91
50	0·38	1·72	2·00
50	0·65	1·47	2·05
50	0·70	1·59	1·79

WIDTH IN CM	Cu %	Pb %	Zn %
50	0·83	1·80	2·12
50	[illegible]·69	1·68	1·57
50	0·72	1·77	1·77
50	0·59	1·61	1·66
50	0·81	1·90	2·07
50	0·52	1·83	1·99
50	0·73	1·71	1·90
50	0·68	1·64	1·69
50	0·49	1·69	2·10
50	0·37	1·78	1·77
50	0·82	1·53	1·81
50	0·72	1·50	1·73
50	0·57	1·72	1·97
50	0·37	1·57	2·01
50	0·45	1·60	1·93
50	0·34	2·00	1·70
50	0·59	1·89	1·59
50	0·77	1·75	2·02

INDEX

SHAFT

UNDERGROUND SURVEY STATION

DRIVE UNDER PROGRESS

X - CUT

FIG. 5·1 ASSAY PLAN OF UNDERGROUND DEVELOPMENT

Table 5.1 Conversion of True Dip to Component in the Line Section

LINE OF SECTION

Angle between line of section & strike of strata	Apparent Dips in the Line of Section																
5	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.5	10.0	13.0	18.0	26.0	44.0
10	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.5	10.0	12.0	13.0	16.5	20.0	25.0	32.0	44.0	62.0
15	1.5	3.0	4.0	5.5	7.0	8.5	10.5	12.0	15.0	17.5	20.0	24.0	29.5	35.0	43.0	55.0	70.0
20	1.5	3.5	5.5	7.0	9.0	11.0	13.5	16.0	19.0	22.5	26.0	31.0	36.0	42.5	51.0	62.0	75.0
25	2.0	4.5	6.5	9.0	11.0	13.5	17.0	19.5	22.5	27.0	31.0	36.5	42.0	48.5	57.0	67.0	78.0
30	2.5	5.0	8.0	10.5	13.0	16.0	19.0	23.0	26.0	31.0	35.5	41.0	46.5	53.0	61.0	70.5	80.0
35	3.0	6.0	9.0	12.0	15.0	18.0	23.0	26.0	29.0	34.5	39.5	45.0	50.5	57.5	65.0	73.0	82.0
40	3.0	6.5	10.0	13.5	16.5	20.5	24.0	28.0	32.0	37.5	43.0	48.0	54.0	61.0	67.0	75.0	83.0
45	3.5	7.0	11.0	14.5	18.0	20.0	26.5	31.0	35.5	40.0	45.5	51.0	56.5	63.0	69.0	76.5	83.5
50	3.5	7.5	11.5	16.0	19.5	24.0	28.0	33.0	37.5	42.5	47.5	53.0	59.0	65.0	71.0	77.5	84.0
55	4.0	8.0	12.0	17.0	21.0	25.0	30.0	35.0	39.5	44.5	49.5	55.0	60.5	66.5	72.0	78.0	84.0
60	4.5	9.0	13.0	18.0	22.0	27.0	31.5	36.5	41.0	46.0	51.0	56.5	61.5	67.5	73.0	79.0	84.0
65	4.5	9.0	13.5	18.5	23.0	28.0	32.5	37.5	42.0	47.0	52.0	57.5	62.5	68.5	73.5	79.5	84.5
70	4.5	9.0	14.0	19.0	23.5	28.5	33.5	38.0	43.0	48.0	53.0	58.5	63.5	69.0	74.0	79.5	85.0
75	5.0	9.5	14.5	19.5	24.0	29.0	34.0	39.0	44.0	49.0	54.0	59.0	64.0	69.5	74.5	80.0	85.0
80	5.0	10.0	15.0	20.0	24.5	29.5	34.5	39.5	44.5	49.5	54.5	59.5	64.5	69.5	74.5	80.0	85.0
85	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	44.5	49.5	54.5	59.5	64.5	69.5	75.0	80.0	85.0
Degree	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
	True Dips at 90° to the strike																

Example 1 :- Strike N 10° E - Dip 30° SE, line of section N 50° E, Find apparent dip along line of section. Angle between strike and line of section 50° - 10° = 40° in left column, 30° on bottom row; dip component in line of section is 20.5°.

Example 2 :- Strike of strata N 15° E, component of dip along a line bearing N 40° E is 20°. Find true dip. Angle between strike and line of component is 40° - 15° = 25°. From left column at 25° find 20° to the right (19.5 is nearest point). From 19.5, read true dip at bottom, 40°, approximate.

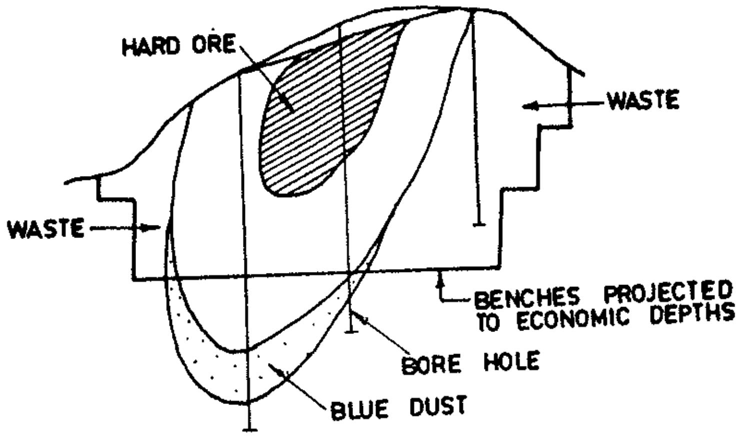


FIG 5.2 FOLDED IRON ORE BODY IN PROFILE SECTION

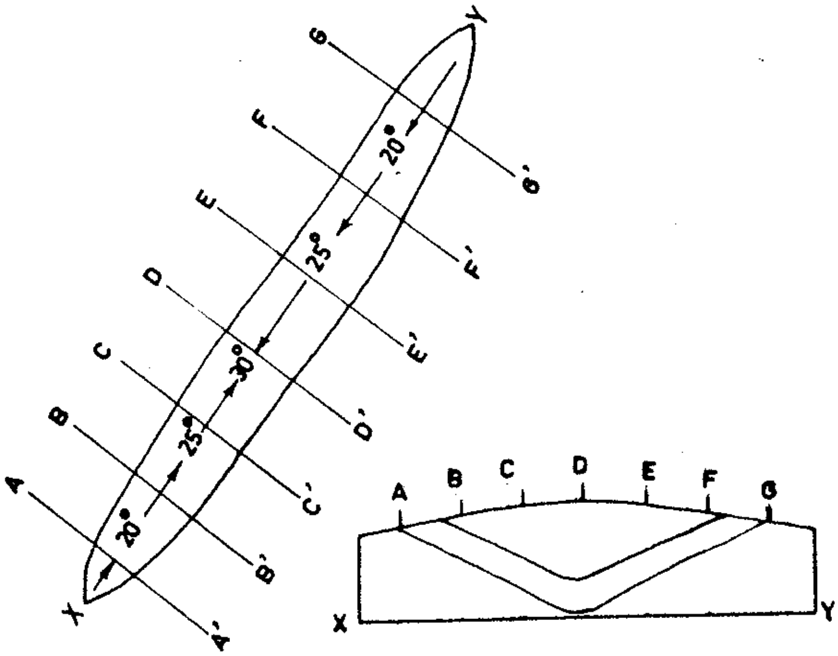


FIG: 5.3 HYPOTHETICAL SECTION OF FOLDED ORE BODY X-Y LONG: SECTION line may pass along the footwall or hanging wall contact or the centre of the orebody depending upon the purpose for which the sections are chosen. All boreholes, pits trenches and subsurface details are brought on to the longitudinal vertical section by suitable projections so that all these details can be viewed in one plane. This along with the transverse sections help in depicting the orebody in three dimensions and can be of great help in studying the geometry of the deposit, see Fig. 5.3.

5.1.8 Isometric projection

Isometric projections are used to depict the structure and disposition of complex ore bodies. Such projections afford a three dimensional display of the orebody underground. The isometric projections are made on a cube which is also represented by a single projection[4], the direction of projection running north-south. The idea is to bring out a perspective of a solid body as observed from one angle where only three sides of any figure can be seen instead of all the six sides. Such projections can be made only after all data both from the surface and from underground are plotted accurately in the geological plan[1].

5.1.9 Slice plan

These plans show the outline of various slices in an open cast mine, indicating in each slice various geological and mining details. The geological details may be structural features, ore types, quantities, etc., determined on the basis of exploration and face sampling. It will show the position of benches as they advance, ore and waste, and other details. Fig 5.4 shows a hypothetical slice plan. It is natural to keep the height of each slice equivalent to the height of the proposed benches in mining.

In addition to the plans and sections described above, there may be geophysical and geochemical maps if such surveys are undertaken. All the plans, sections and projections discussed above are very essential for the correlation and interpretation of the exploratory data. Obviously, all the exploratory data cannot be depicted in one plan. Therefore, it would be necessary to subdivide the plans according to convenience. Each of the plans may be made on a copy of the base map keeping common grids for an easy tally or traced on tracing cloth so that one can be superimposed on another. Even after doing a great deal of sampling and exploration, there would still be points in the orebody where specific information will be lacking. To make reliable estimates about the shape, size, grade and tonnage of the ore-body, it is necessary to bridge this information

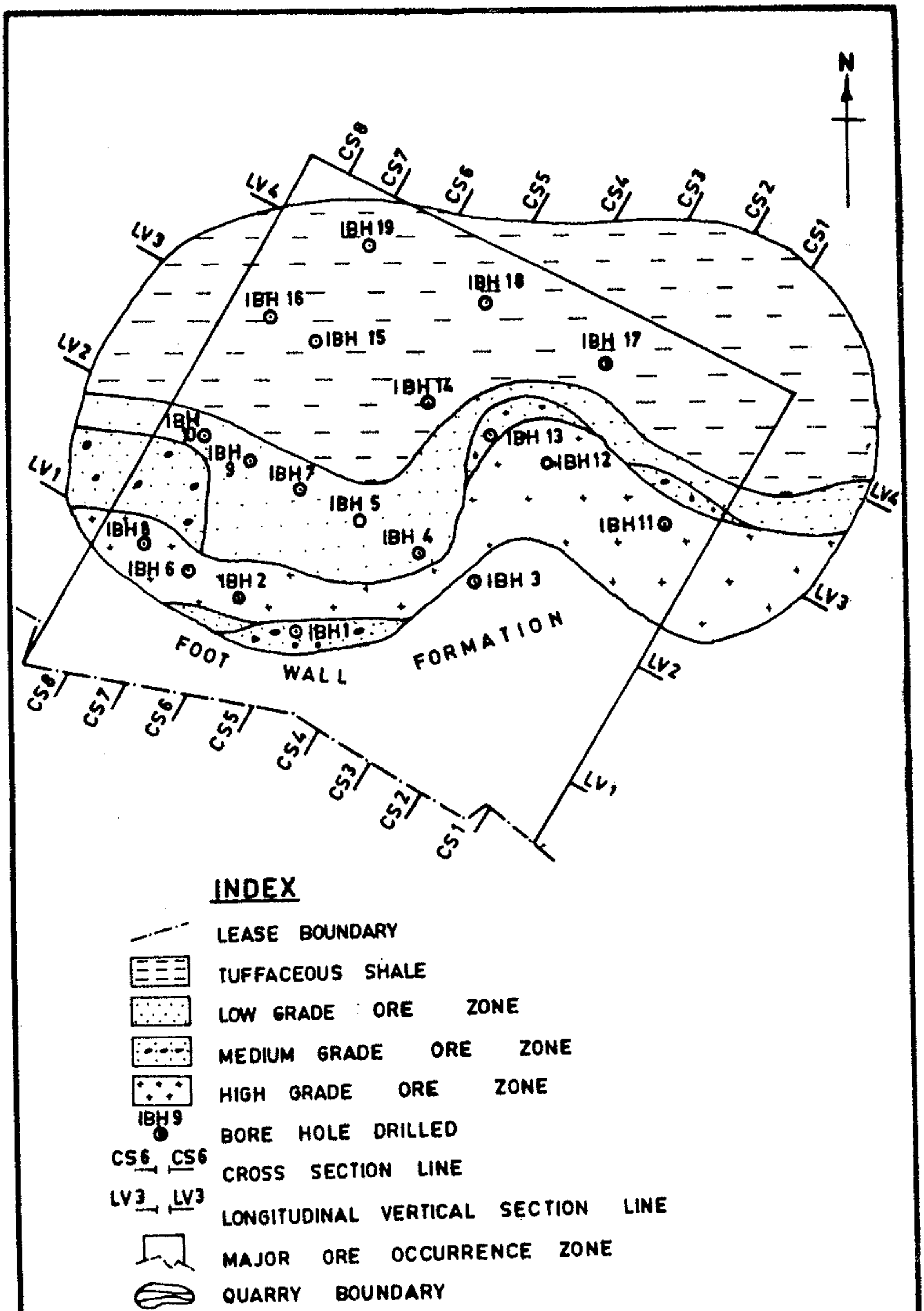


FIG: 5·4 SLICE PLAN

gap. This is done by correlation and interpretation. For example, there may be two points where outcrops are clearly visible but, in between, the outcrop is not seen. By interpreting the strike, dip and structure of the ore-body, the missing outcrop can be placed on the map by interpolation. This principle can be adopted to various situations where specific data gaps will have to be bridged up.

The preparation of the plans in itself is a part of the process of interpretation. By representing the ore-body in three dimensions, a type of interpretative correlation is automatically established. For example, a transverse section which meets with the outcrops in a series of repetitions due to folding can reconstruct the actual fold which establishes the correlation and interpretation in one action. These interpretations ultimately lead to certain concrete conclusions regarding the reserves and disposition of the deposit.

5.2 Computation and classification of reserves and grades

Once a deposit has been proved by exploration, it becomes more or less a commercial proposition. The deposit is now viewed in terms of investments, return on capital, daily rate of production, etc. In effect, the deposit has to support a mine which will yield ore in enough quantity and in appropriate grades to amortise the invested capital whithin a fixed period of time at a projected rate of production and also yield a profit which is acceptable to the investor. In order to take investment decisions of this magnitude, an accurate estimate of the ore reserves together with their grade is essential. All exploration activities lead ultimately to such an estimate. The more precise the exploration the more accurate will be reserve estimate. In very simple terms the reserve can be estimated by computing the volume of the ore and converting that volume into tonnage.

Tonnage = Volume X Sp. gravity (Bulk Density)

i.e. $Q = V D$

Q = tonnage

V = volume of the orebody

and D = specific gravity or density of raw mineral materials (bulk density)

The computation of the volume of the deposit is, however, complicated by factors like geology, size and shape of the deposit and pattern of mineralisation which are inherent in all deposits. Within these broad limitations, a large number of methods are available for the computation of volume. They are discussed below.

Some assumptions regarding the behaviour of the orebody and the nature of exploratory data are necessary for any reserve computation. They are as follows :

(1) Any basic character of an orebody, established at one point by exploration, changes or extends to an adjoining point in accordance with certain principles. Two such principles are recognised. These are : (a) the rule of gradual change or the law of linear function. According to this rule, all parameters (such as thickness and grade) of an orebody expressed numerically change gradually and continuously along a straight line connecting two stations within the orebody. Accordingly, if at two stations A and B in fig.5.5 the thicknesses of the orebody are t_1 and t_2 then at point C in between A and B the thickness will be t_3, which will have a numerical value between t_1 and t_2 and will be nearer to t_1 when C is near A; and closer to t_2 as the point C shifts gradually towards B. (b) the rule of the nearest points or equal influence. According to this rule the value (mineralisation parameter like thickness and grade) at any point between two adjacent stations is constant and equal to the value of the nearest station. Between A and B, the value of A will be valid up to C the midpoint between A and B and the value of B will be valid up to C from B. This is the underlying principle behind the area of influence method in reserve computation[5].

(2) Observations are made in conformity with the nature of the deposit and samples are taken with equal precision everywhere; such samples represent the ore within the zone of influence they control.

(3) That the physical continuity projected on the basis of exploration is a geological possibility in a given set up.

(4) An orebody of complex shape can be represented by drawing hypothetical figures, plans and sections.

5.2.1 *Methods of reserve computation*

According to the United States Bureau of Mines, there are four major methods available for computing the reserves[5]. These are :

(i) average factors and area method,
(ii) mining block method,
(iii) cross-section method, and
(iv) analytical method.

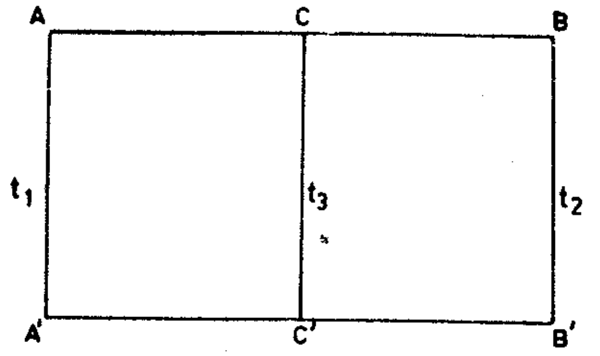


FIG 5·5 THE RULE OF LINEAR FUNCTION

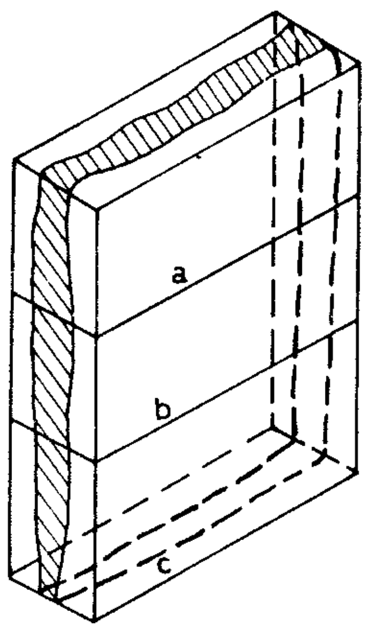


FIG 5·6 ISOMETRIC PROJECTION OF AN ORE BLOCK DEVELOPED ON ALL FOUR SIDES

(i) Average factors and area method

The method has been described by various authorities as arithmetic average, weighted average, average depth and area, statistical, analogous, geological block methods, etc. For purposes of this discussion, the methods will be referred to as geological block and analogous block methods[5]. The basic assumptions in these methods are that certain areas/blocks of areas have geological and technical features similar to certain other blocks which have been explored or mined out and their results known. The result of the known block is now taken as valid for an unknown block of similar dimensions. The blocks in such cases may be constructed on the basis of geology, structure, thickness, depth, grade, value, overburden, etc.[5].

(a) Analogous block method

The method is based on the principle that a quantitative similarity exists between a given block and another block which is better known (mined out). The variables such as thickness and grade (the area of the block is defined on the basis of the parameters mentioned earlier) may be the arithmetic or weighted average of a number of observations like drill core data and pit data. A single observation in the given block of these parameters is also acceptable[5].

The method is accurate in uniform deposits, the accuracy decreasing with the irregular deposits. This method is ideal for computing districtwise reserves particularly on the basis of very approximate parameters like tonnage/sq.km. Where an orebody is inadequately explored, this method is very effective[5].

(b) Geological block method

A geological block may be an entire mineral deposit or a small portion of it outlined in a map on the basis of exploratory data. The block can be defined by fixing boundaries on the basis of geological and structural features (fold, fault) or on the basis of variation in grade and thickness[5].

Variables like grades and thickness are computed from production figures, exploratory data, sampling data or data from another part of the orebody. The average grade, thickness, etc. are determined by arithmetic or weighted average or by statistical analysis. This method is very effective in the early stages of exploration, the accuracy increasing with the increasing availability of exploratory data. Bedded and placer deposits are particularly amenable to this method. The major advantage of both the methods is their simplicity, ease of direct application and relative accuracy in circumstances of insufficient data[5].

(2) The mining block method

This method is also known as longitudinal section method and mine exploration method. A mining block may be defined as an ore block bounded on four sides by openings/workings or bounded on three or less sides by openings/workings and other sides by arbitrary lines. Such blocking can be done on the basis of exploration (borehole sampling, etc.), geological features, and technical and economic considerations. Mining blocks may be rectangular in shape with their base lying in the plane or inclined or vertical longitudinal section (see fig. 5.6).

(a) Block exposed on all four sides

The area is computed by the length and breadth of an individual block and the thickness determined as the arithmetic average of the assay width. When the ore thickness is less than the underground openings and uniform, the variables are found by calculating the simple arithmetic average. In irregular orebodies, the average grade of a working is computed by the weighted average method. The weight factor can be area, volume or tonnage. When the interval of sampling on all sides is equal, a simple arithmetic averaging will be sufficient for obtaining the average thickness and grades. When the interval of sampling or the lengths of the sides are unequal, then the thickness and grades are not directly computed, it will be necessary to find the weighted average thickness and grade. The weight factor may be the lengths of the individual blocks. When the lengths of the sides are unequal and there are wide variations in grades and thickness, the average factors should be found by working out the weighted averages, the weight in this case being the area of influence of the sample points.

When the ore thickness is more than the width of underground openings and the blocks are developed by cross-cuts on two levels, the cross-cut data may be used for reserve computation particularly when mineralisation is continuous. In an irregular or discontinuous orebody, the blocks should be subdivided and the areas of influence should be computed[5] separately for each subdivided block.

(b) Block exposed on three sides

In this case, the methods discussed below can be used effectively; arithmetic average of three sides;

weighing the variables against the length of workings on each side of the block; computing the factors for the fourth side by end samples (A and B in fig.5.7) and then averaging the variables on all sides; and, weighing the areas of influence of the three existing workings.

In the case of an area blocked out by an adit and surface workings also, the above methods can be used. Geological evidences such as the degree of ore alteration, thickness, grade, zoning or the number of observations as shown in fig.5.8 help in demarcating the ore boundaries, particularly when the ore is extensively exposed on the surface.

(c) Block exposed on two sides

When a block of ore is defined only by two levels as shown in the fig.5.9, the average factors for both the levels are computed separately. Then the block averages are worked out as the average of both the levels in uniformly mineralised orebodies. If the ore is not uniform, the area weights are used for computing the weighted averages.

When two openings meet as in fig.5.10 to form a triangular ore block, the length weighted averages of both the sides will have to be worked out. The block can also be subdivided into two by the area of influence and area weighted averages of the blocks can be determined to find the block values[5].

(d) Block exposed on one level and intersected by borehole at depth

In this case, from the drill hole intersection levels perpendiculars are drawn to the working levels as shown in fig.5.11. The plan containing a, b and c is intersected by the boreholes and the perpendiculars aa', bb' and cc', are drawn from the point of the intersection of the orebody by the borehole to the working level. Blocking of boundaries can also be done by geological criteria or by economic considerations.

Average thickness $T_{av} = \dfrac{t_1 L_1 + t_2 L_2}{L_1 + L_2}$

Average grade $C_{av} = \dfrac{C_1 L_1 + C_2 L_2}{L_1 + L_2}$

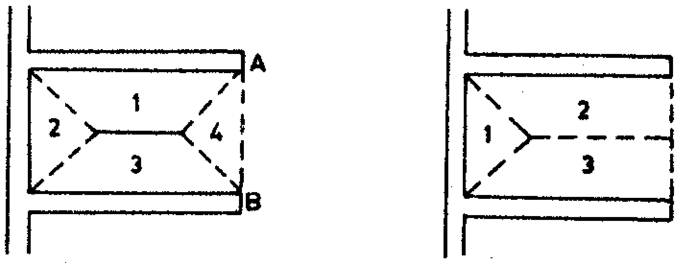


FIG:5·7 VARIOUS TYPES OF OREBLOCKS WHEN THREE SIDES ARE EXPOSED

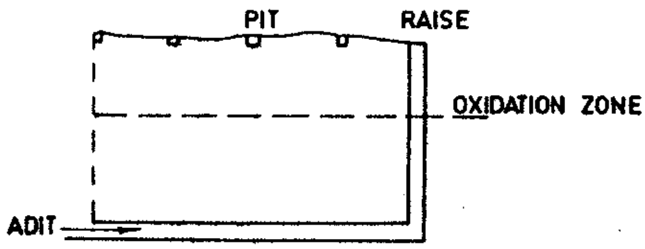


FIG: 5·8 OREBLOCK EXPLORED BY ADIT AND SURFACE WORKINGS

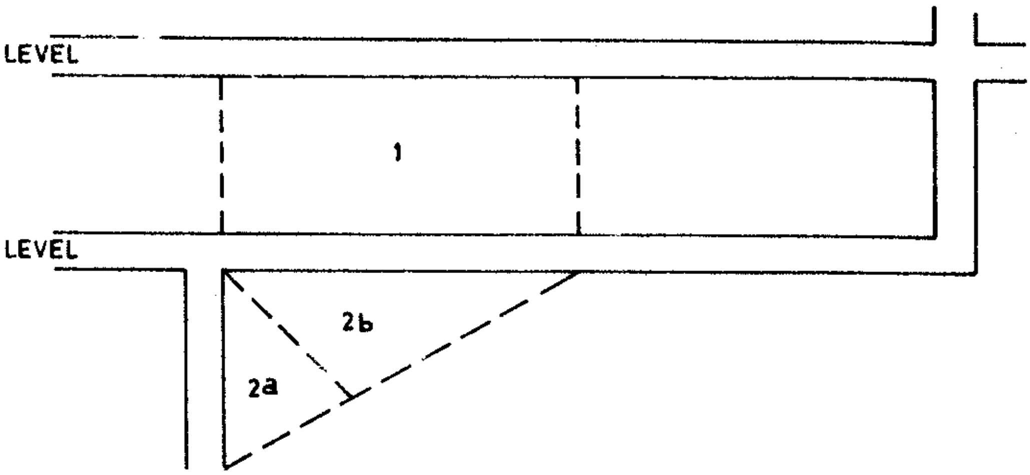


FIG: 5·9 BLOCK EXPOSED ON TWO SIDES

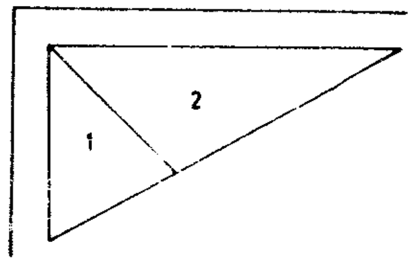


FIG: 5·10 TRIANGULAR ORE BLOCK

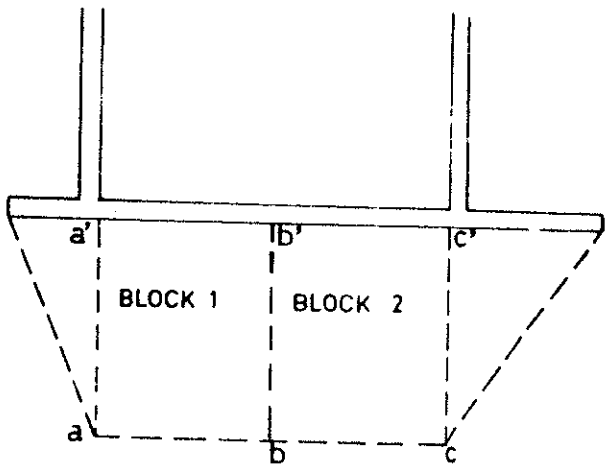


FIG: 5·11 BLOCK EXPOSED ON ONE LEVEL AND INTERSECTED BY BORE HOLE AT DEPTH

Where ,

t_1 = average thickness of ore in each block in the level,

t_2 = average thickness of borehole intersections of adjoining boreholes,

C_1 = average grade of ore in each block in the level corresponding to t_1,

C_2 = average grade of ore in borehole intersection of adjoining boreholes corresponding to t_2,

L_1 and L_2 block length on both the levels,

T_{av} = average block thickness, and

C_{av} = average block grade.

When a large number of levels and boreholes are available the average grades and thicknesses are computed by using the following formulae[5].

$$T_{av} = \frac{t_1 + t_2 + \ldots\ldots + t_n + t_1' + t_2' + \ldots + t_m'}{n + m}$$

$$C_{av} = \frac{c_1 + c_2 + \ldots\ldots + c_n + c_1' + c_2' + \ldots + c_m'}{n + m}$$

and when there is only one borehole apart from drift samples, etc.

$$T_{av} = \frac{t_1 + t_2 + \ldots + t_n + t_1'}{n + 1}, \text{ and}$$

$$C_{av} = \frac{c_1 + c_2 + \ldots + c_n + c_1'}{n + 1}$$

Where,

$t_1, t_2 \ldots t_n$ = thickness observed in the drift,

$c_1, c_2 \ldots c_n$ = corresponding assay values,

$t_1', t_2' \ldots t_m'$ = thicknesses of drill hole intersections,

$c_1', c_2' \ldots c_m'$ = corresponding assay values,

n = number of samples in the drift, and

m = number of drill holes

In order to make use of this method, the orebody is blocked out by a network of openings and the block reserves may be computed on the basis of factors like thickness, grade and mining costs, etc. The degree of error in this method depends on the genetic type of the ore. Except in highly irregular pockety deposits this method is highly effective[5].

(3) Cross-section method

In this method the orebody is divided into various segments by transverse cross-section lines spaced at equal intervals or in some cases at unequal intervals. The orebody can be divided by such lines in different levels including underground workings. Three methods have been recognised.

(a) Standard method

Each internal block is confined by two section lines and an irregular lateral end. The end sections are controlled by one cross-section line and one irregular end surface (See fig. 5.12.) Sections may be parallel or nonparallel, as well as vertical, horizontal or inclined.

The reserves are computed as follows :

The areas of all sections are determined first. The average thickness and grade for each section are computed next. Thus, the volume of a block confined by two adjoining sections is

$$\text{Volume of ore } V = \frac{(S_1 + S_2) \times L}{2},$$

where S_1 and S_2 are areas of two adjacent blocks of nearly equal size and L is the perpendicular distance between them. The volume is multiplied by the specific gravity for computing the tonnage. Sample points can be as close to the section lines as feasible.

The end area of an orebody may occupy a number of irregular shapes, the areas of which cannot be determined easily. In such special cases different formulae are necessary to compute the volume of the end area. There are also cases when S_1 and S_2 vary in size but are similar in shape. Some of the simple cases and formulae are briefly listed below:

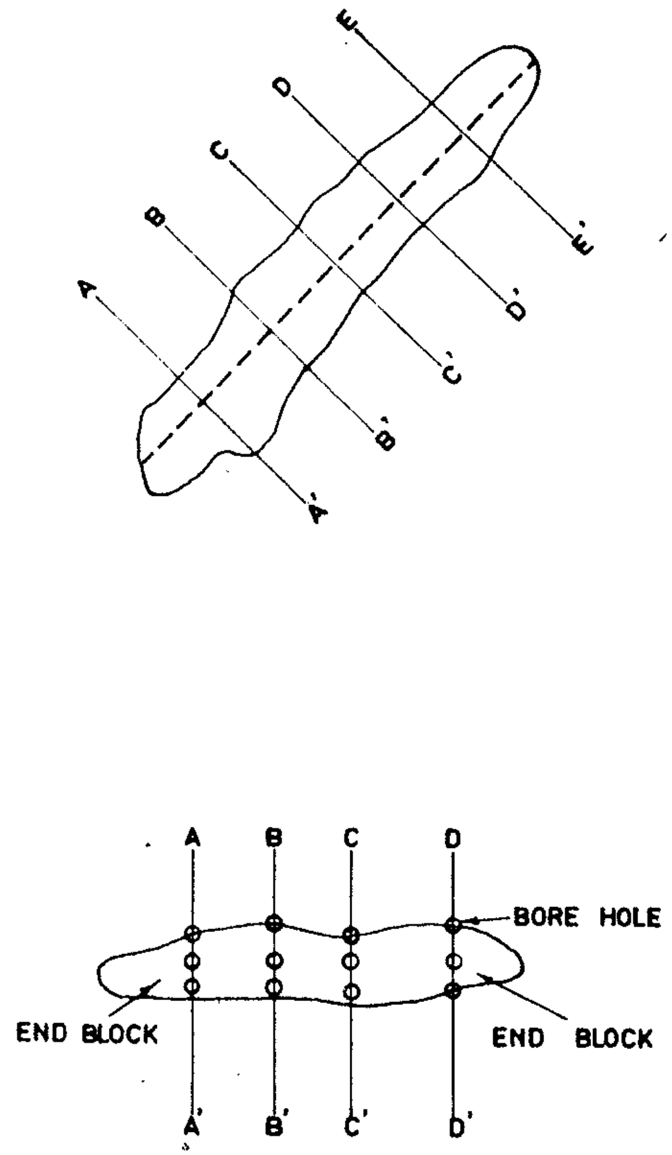
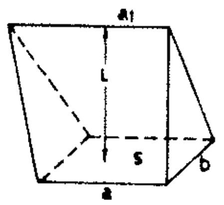


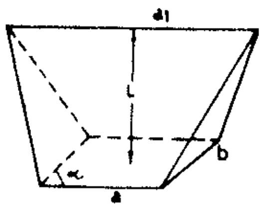
FIG: 5·12 CROSS SECTION METHODS



WEDGE SHAPED END AREA:

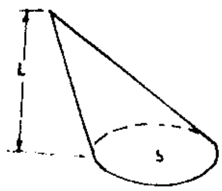
(1) $V = \frac{S}{2} \times L$, WHEN THE BASE IS RECTANGULAR AND THE LATERAL FACES FORM ISOSCELES TRIANGLES

FIG: 5·13 AREA OF A WEDGESHAPED BLOCK



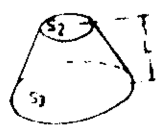
(2) $V = \frac{L}{6}(2a + a_1)b \sin\alpha$, WHERE a AND b ARE THE LENGTH OF THE SIDES OF THE BASE, α IS THE ANGLE BETWEEN a AND b, AND a IS THE LARGER SIDE OF THE TRAPEZOID.

FIG: 5·14 AREA OF A TRAPEZOID BLOCK



(3) $V = \frac{S}{3} L$, WHEN THE AREA TAPERS TO A CONE.

FIG: 5·15 AREA OF A CONE



(4) $V = \frac{L}{3}(S_1 + S_2 + \sqrt{S_1 S_2})$ WHEN S_1 AND S_2 VARY IN SIZE BUT ARE SIMILAR IN SHAPE.

FIG: 5·16 AREA OF A FLATTENED CONE

More complex shapes and sized will also be available in some cases which will have to be tackled on the basis of more sophisticated formulae.

(b) Non-parallel sections

Because of the change in the strike of the ore-body some of the transverse sections may show a tendency to diverge or converge. In essence they are not parallel and reserve computation becomes complex. If the sections are AA', BB' and the areas of cross-sections involved are S_1 and S_2 and the angle between AA' & BB' is less than 10^o the volume is defined as

$$V = \frac{(S_1 + S_2)}{2} \frac{(h_1 + h_2)}{2}$$

where h_1 and h_2 are two perpendiculars drawn from the centre of gravity of the cross-section to the adjacent section line. The centre of gravity of the section is determined by plotting out the area on a piece of card-board and locating the point where the cardboard hangs in balance from a thread.(see Fig. 5.17.)

When the angle is more than 10^o, the above formula is modified to

$$V = \frac{\alpha}{\sin\alpha} \frac{(S_1+S_2)}{2} \frac{(h_1+h_2)}{2}$$

(α to be expressed in radians)

The method has been criticised as being too cumbersome and of limited accuracy. When angle α is less than 10^o it is better to regard the sections as parallel[5].

(c) Linear method

In this, each block is defined by a section and a length equal to half the distance between the adjoining sections. Volume is determined by the formula $V = S_1 \times L$.

In the case of parallel cross-sections no computing is involved. In non-parallel sections the procedure is as follows. Let A,B,C be the section lines. Block ee, e_1 e_1 is the ore block (fig. 5.18.). The area of influence between B and A is determined by ee, a line which bisects angle α which is the angle between section lines A and B. Similarly e_1e_1 bisects the angle which is the angle (β) between B and C cross-section lines. The areas, volumes etc., are now determined by the usual methods and tabulated.

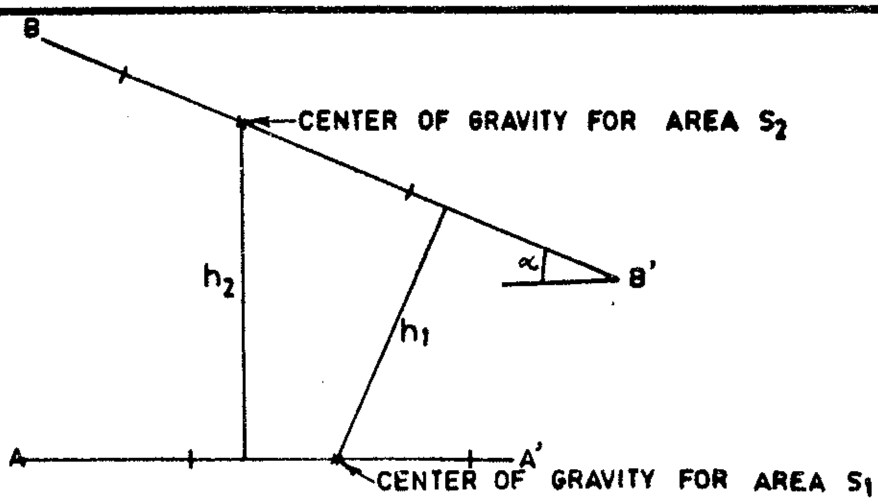


FIG: 5·17 NON-PARALLEL SECTIONS ANGLE < 10°

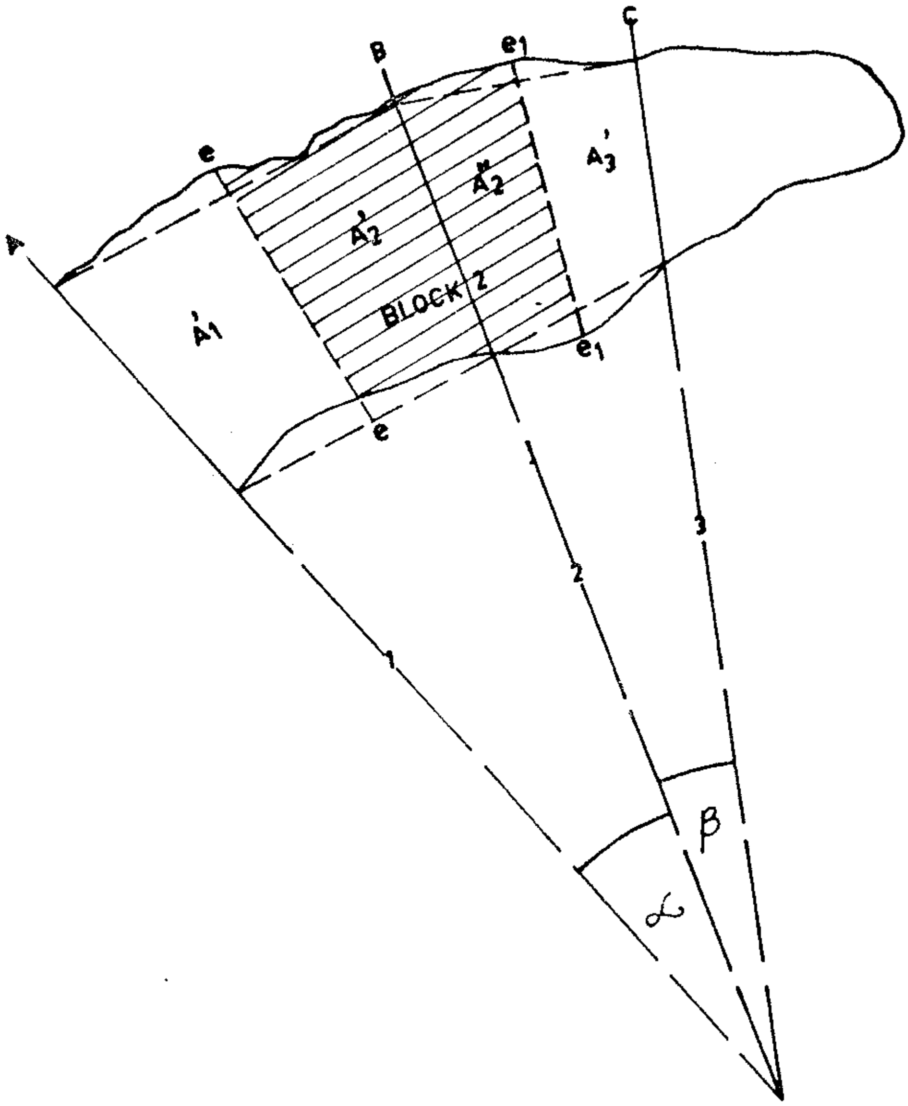


FIG: 5·18 BLOCK BETWEEN NONPARALLEL SECTIONS ANGLE > 10°

Well defined, large orebodies with uniform thickness and grade generally give accurate results in cross-sectional methods. Where the ore distribution is highly erratic and the orebody has a highly irregular shape, the method may not give satisfactory results[5].

This is particularly useful in evaluating boreholes drilled on tabular orebody and obtaining intersections at different levels in a vertical plane.

(d) Method of isolines

Isolines (isopachs, isochores and isograds) can be used for reserves computation by combining the plan with the principle of cross-sections. The formula

$$\frac{(S_1 + S_2)}{2} \times L = V$$

can be used for finding the volume between any two cross-sections when the orebody is regular. (Please see **Fig. 5.19.**) More sophisticated formulae are required for complex situations where the value distribution is in two parts of the cross-section.

If as shown in Fig.5.20 the area corresponding to thickness 'h' is in two parts (S_2' and S_2''), the volume of the slice between h_1 and h_2 will be given by the formula

$$V_2 = h \left[\frac{S_1 + (S_2' + S_2'')}{2} \right]$$

In a case where the ore thickness, say h_2 is missing in one section and h_1 is available then the slice between h_2 and h_3 is given by the formula:

$$V_3 = \frac{h}{2} \left[(S_2' + S_2'') + (S_3' - S_3'') \right]$$

In both the formulae,

V = volume,

h = a constant thickness interval between the two isolines,

So = area enclosed by ho contour line, and S_1, S_2, etc. are areas corresponding to the thickness h_1, h_2 contour lines.

Isograd maps can be used for computing the average grades by the following formula:

$$C_{av} = \frac{C_o A_o + \frac{C}{2} (A_o + 2A_1 + 2A_2 + \ldots\ldots + A_n),}{Ao}$$

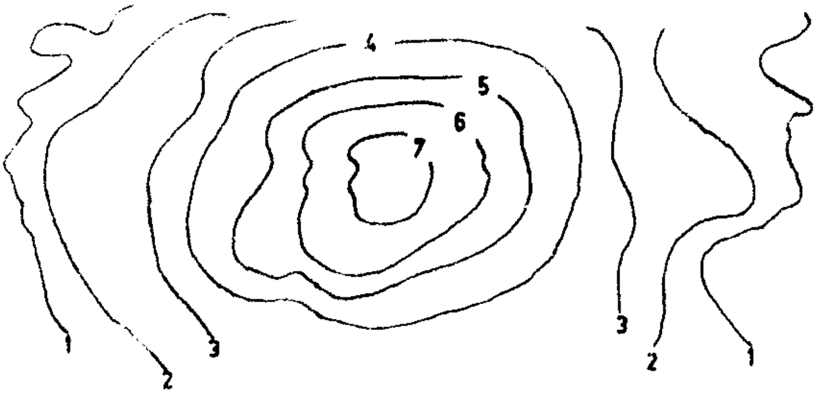


FIG: 5·19

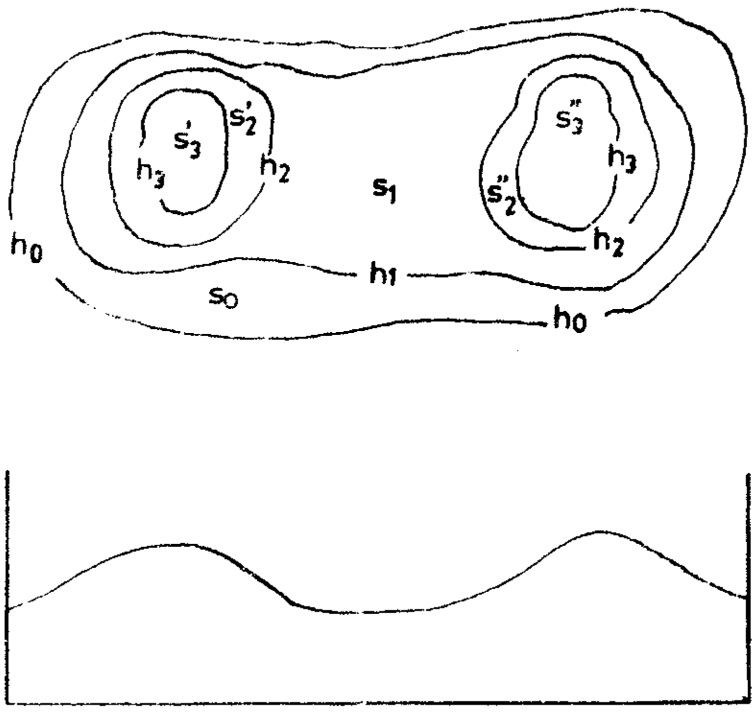


FIG: 5·20

METHOD OF ISOLINES (ISOPACHS AND ISOGRADE) where

C_o = minimum grade of ore,

C = constant grade interval between the isolines,

A_o = area of the orebody with grade C_o and higher,

A_1 = area of the orebody with grade C_o plus C and higher, and

A_2 = area of the orebody with grade C_o plus 2C and higher, etc.

Isoline maps have some advantages over other plans. They depict the orebody quite faithfully showing the distribution of poor and rich ore value. They are easy to read, measure and interpolate and in computation the total calculations are not very large as there are fewer blocks unlike other cross-section methods. These plans also help in a better mine planning[5].

However, it suffers from certain drawbacks. From the same set of data, two persons may construct isolines with different configurations. Also, where the data are scattered, isolines may give a very erroneous impression of value distribution. In case of abundant data, the process of construction of the isoline maps becomes cumbersome[5].

(4) Analytical methods

(a) Method of triangles

In this method, all workings, pits or boreholes or any other exploratory openings are connected to one another by a series of straight lines, thus dividing the orebody into a series of triangles. For computational accuracy, equilateral triangles are preferable, but in practice the construction of such triangles is not feasible. Each triangle rests on the plane of the map but represents an imaginary prism with edges t_1, t_2, t_3 with a thickness equal to the vertical thickness of the orebody (please see fig. 5.21). The upper base of the prism is conceptually truncated (smoothened to an even shape) because of the irregularity of the orebody. The volume of a truncated triangular prism with uneven height is found out by the formula.

$$V = \frac{1}{3} (t_1 + t_2 + t_3) S,$$

where S is the area of the base.

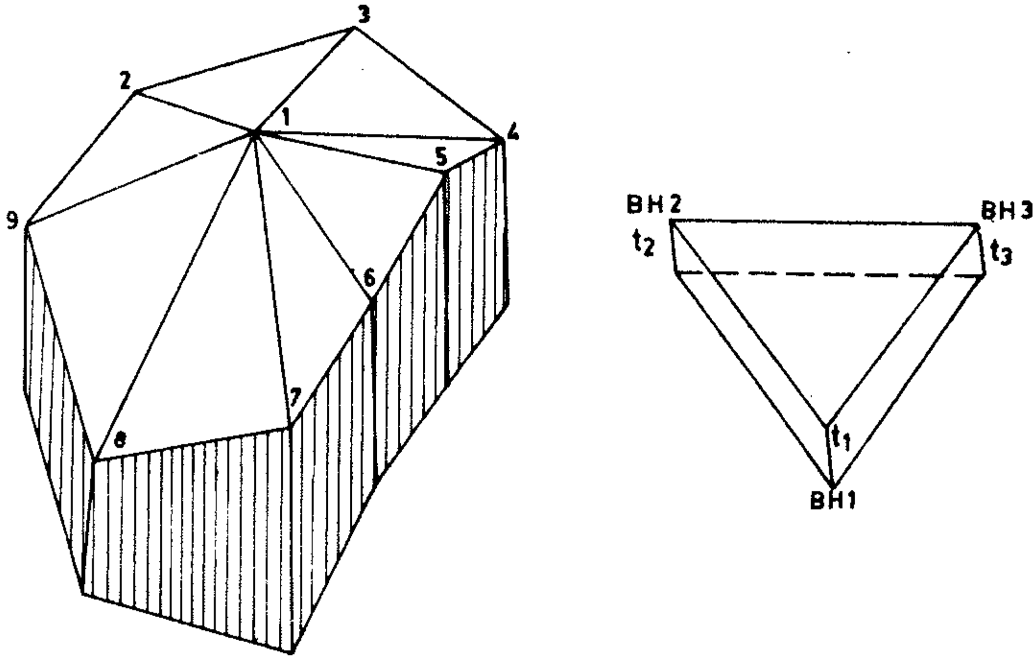


FIG: 5·21 METHOD OF TRIANGLES

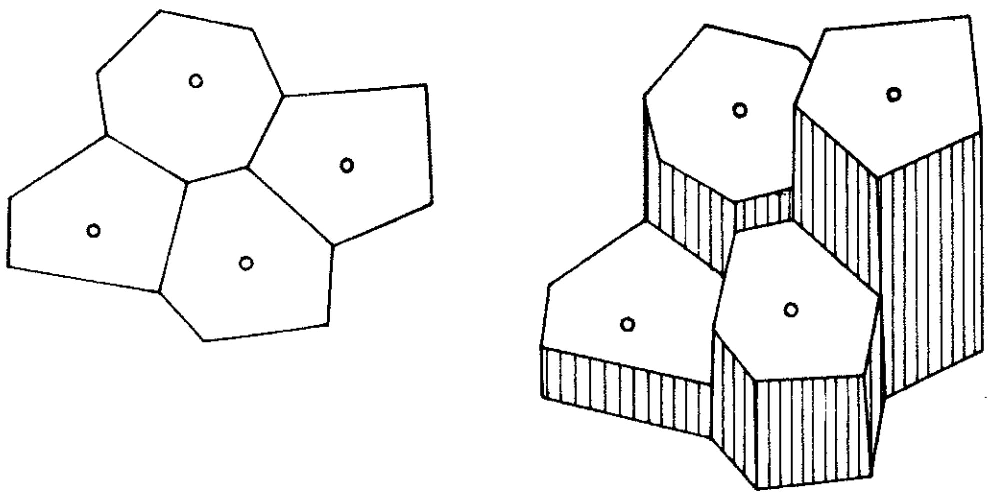


FIG: 5·22 METHOD OF POLYGONS

The area S is computed by using the standard formula ½ base x height. It is preferable to use a common base line for a pair of adjacent triangles. The average grade of each prism is determined by the formula.

$$C_{av} = \frac{c_1 + c_2 + c_3}{3}$$ when the ore distribution is uniform. In case the ore distribution is erratic, weighted averages are found and the formula becomes,

$$C_{av} = \frac{c_1 t_1 + c_2 t_2 + c_3 t_3}{t_1 + t_2 + t_3}$$

From the volume, the reserves are computed by multiplying it by specific gravity. This method finds maximum use in deposits of sedimentary types, particularly the simple bedded types and large disseminated types explored by a good network of boreholes or pits.

The method suffers from various disadvantages. The triangles do not permit delineation of the physical ore types. They may also camouflage value distributions. The method requires the subdivision of the orebody into a large number of triangles as a result of which the calculations become cumbersome. It is believed that in lenticular orebodies this method will tend to underestimate the total reserves[5].

(b) Method of Polygons

This is also known as the area of influence method. The procedure is to determine the area of influence of each exploratory point (pit, borehole, etc.) and construct polygonal blocks with the pit or borehole in the centre of each polygon. The area of influence is determined by joining two adjoining pits and finding out the midpoint between them. A perpendicular is dropped at this point of division. The process is repeated for all sets of boreholes or pits. The perpendiculars intersect and the polygonal forms automatically result. A correctly constructed polygon will have angles less than 180 between any two sides[5]. (see Fig. 5.22.)

Some difficulties crop up in the case of linear workings, horizontal boreholes, trenches, etc.. In such cases the linear workings have to be divided into four areas of influence or four elementary prisms each characterised by appropriate workings. This is comparable to the mining block method[5].

For computing the reserves, the area of the polygon is determined and is multiplied by the thickness of the ore within the polygon and the specific gravity of the ore.

This method is ideally applicable when there are a large number of workings/exploratory openings arranged in a regular grid. Reserves of tabular bodies, large lenses and stocks are effectively computed by this method.

The advantages and disadvantages discussed in the case of the triangular method apply for this method also. An added disadvantage in this case is that the construction of proper polygons is a job which requires skill and experience[5].

Determination of area

Areas in most cases can be measured by planimetering. The other methods involve the use of special templates and geometrical calculations.

In planimetering, the measurement should be done once in each of the opposite directions and if the difference between the readings is less than 2% the average of the two is acceptable.

Templates may be of three types. They may be squares with a measured unit area (Fig.5.23) or dots wherein each dot is the centre of a unit of equal area (Fig.5.24), or parallel lines drawn equivalent and to scale (Fig. 5.25). In the case of the lined template the area is determined by adding the length of all the lines occupying an area and then multiplying this by the unit value of the scale.

In geometric computations, there are two important methods. One is the trapezoid method in which the standard formula of a trapezoid is used. Any irregular area may be divided into a number of trapezoidal figures by equidistant parallel lines, and assuming that the boundaries of the strips between the ordinates are straight-lines the whole area can be computed by the trapezoidal rule.

The standard formula for the area of a trapezoid is:

$$S = \frac{(a + b)}{2} h$$

The same can be applied to any figure like the one shown in Fig.5.26 by extending the formula suitably[5]:

$$S = h \left(\frac{a_1 + a_n}{2} + \sum a_{n-1} \right)$$

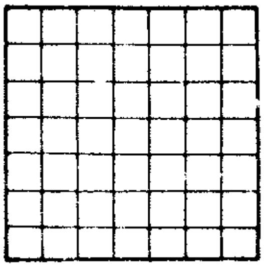


FIG: 5 23 SQUARE TEMPLATES

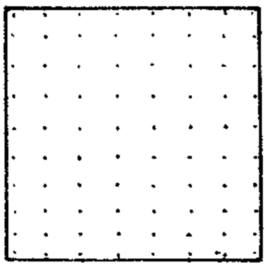


FIG: 5·24 DOTTED TEMPLATES

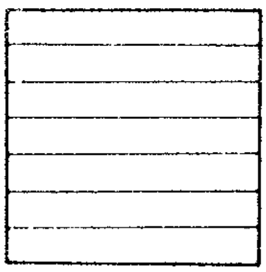


FIG: 5·25 LINED TEMPLATES

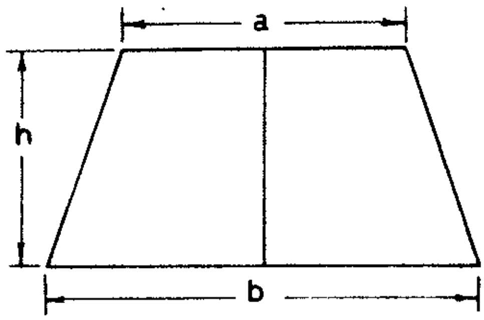


FIG: 5·26 AREA OF TRAPEZOID

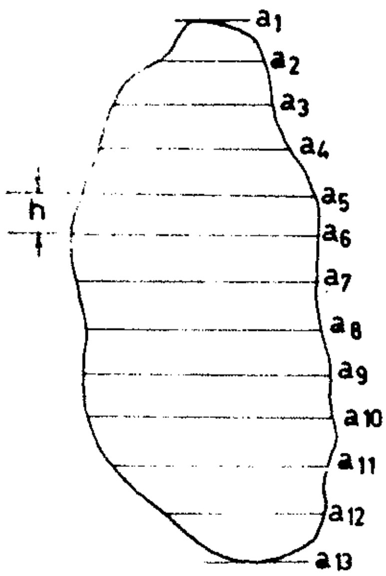


FIG: 5·27 SIMPSON'S RULE

where h = the distance between parallel lines,

$a_1..a_n$ = end-ordinates (offsets) dividing the irregular figure into trapezoidal shapes and

Σa = Sum of intermediate offsets.

By applying Simpson's rule, the area of irregular shapes can be determined. The fig.5.27 shown here explains the procedure. The assumption is that the uneven ends of each strip are parabolic and pass through consecutive points.

The formula[5] is :

$$S = \frac{1}{3} h \left(a_1 + 2 \Sigma a_{odd} + 4 \Sigma a_{even} + a_n \right)$$

where h = a constant interval between the ordinates and $a_1 ... a_n$ = ordinates dividing the irregular area.

Determination of bulk density

Bulk density is determined as follows. A measured volume of in situ ore is mined out and weighed. The weight is divided by the in situ volume and the quotient so obtained is the bulk density of the in situ ore. Thus,

$$D = \frac{W}{V}$$

where D = bulk density of ore
V = volume of the in situ ore, and
W = weight of the ore corresponding to volume V.

In this method the ore is dried. Ore in the wet condition may have to be separately treated for bulk density and an average of the two figures may be accepted.

Another method is by applying the formula[5].

$$Dnat = \frac{Dm\ (1 - P_o)}{(1 - M_o)},$$

where Dnat = the bulk density in situ,
Dm= the specific gravity of the ore,
P_o= Porosity of the ore in per cent, pore space to unit of volume, and
M_o= Moisture in per cent weight loss of the ore on drying.

5.2.2 Criteria for the choice of a reserve computation method

The choice depends upon the geology of the deposit, exploration method used, availability of data, reliability, purpose of calculation and the required precision. In the case of preliminary estimates, any simple method can be used. But when the reserves have to be categorised for mine planning, a method compatible with the extraction technique will have to be used. In open cast operations of large uniform orebodies, any simple method will give reliable results. But if the mineral is of low bulk and the values are erratic and the ore has to be extracted by underground mining very precise methods should be chosen. The type and extent of exploratory openings also influence the method selection[5].

5.2.3 Classification of reserves

No reserve estimate is likely to be completely fool-proof. Within the inherent and well known limitations involved in the work, the estimate should, however, provide certain understandable precision. The accuracy of an estimate depends largely on the quantum and quality of the exploratory data. The more the exploratory data the better is the precision of the estimate. Ore reserves should be classified according to a decreasing order of precision. The classification suggested by the Geological Survey of India is quite adequate in most cases.

According to this classification, there may be 4 types of reserves[6], viz., developed reserves, proved reserves, probable reserves and possible reserves.

Developed Reserves : These are reserves blocked out and ready for immediate extraction; their quantity and grade are estimated on the basis of data from mine development carried out as preparatory to production.

Proved Reserves : These include such reserves where the orebody limits and average characteristics are sufficiently assured and chances of failure of these estimations are so remote that a decision for mine development can be taken.

Probable Reserves : This category of reserves includes either extensions around the proved ore panels or such zones where the orebody limits and average characteristics are known with reasonable certainty.

Possible Reserves : This category assumes the continuity of the orebody purely on geological grounds, past mining activity, comparison with similar deposits nearby, smallscale regional mapping with widespaced drilling or geophysical and geochemical evidences.

Another category of reserves known as 'Potential Ore' is also recognised[7]. Such ore is essentially sub-marginal and becomes exploitable due to change in technology or minability etc.

Reserves can also be classified in different contexts gradewise, depthwise, thicknesswise, etc., in specific mining situations. However, the classification into 'developed', 'proved', 'probable' and 'possible' categories alone is helpful in making investment decisions.

Gradewise classification is a rather flexible concept and is used to define ores already classified into developed, proved, etc. grades. In the present context, size specifications are also used along with grade, so that one refers to, say, developed reserves of +64% Fe and +10 mm size, in the case of some iron ores.

In addition to the classifications discussed so far, there could be others. The meaning of the term "reserves" differs from one person to another i.e., geologist, miner, metallurgists and economist. While a miner works with a property for immediate returns, the economist likes to keep an eye on the future also but not forgetting the current needs. Irrespective of the long or short term economic considerations, the computed reserves are usually geological reserves, computed by geologists. Such a geological appraisal contains many indeterminates.

Secondly, the geological appraisals vary from organisation to organisation. It might also be said that no agreement can be envisaged between any two methods or any two organisations. In other words, there are neither standard classifications nor norms of reserves calculation for any deposit. Consequently, an element of doubt will always be present, more so when the economic indeterminates are associated with the geological indeterminates.

Keeping this in view, authorities all over the world have been actively engaged in evolving proper terms with suitable definitions for expressing reserves and fixing certain boundaries beyond which these terms become invalid. From such attempts have emerged various sets of classifications like positive, probable, possible;[2], A, B, C, C_2; (I.V. Denokhindal 1969); A, B, C, D, E; proved, probable and possible; measured, indicated and inferred, etc. The Indian Bureau of Mines some time ago had suggested the recognition of 9 types of reserves in the appraisal of specific properties and 4 types in the appraisal of national resources[8]. These classifications are as follows :

Appraisal of specific mining properties

(i) Minable proved reserves

(ii) Marginal proved reserves

(iii) Sub-marginal proved reserves

(iv) Minable probable reserves

(v) Marginal probable reserves

(vi) Sub-marginal probable reserves

(vii) Minable possible reserves

(viii) Marginal possible reserves

(ix) Sub-marginal possible reserves.

Appraisal of national resources

(i) Minable measured resources

(ii) Marginal measured resources

(iii) Sub-marginal measured resources

(iv) Inferred resources

The general classification of reserves as measured, indicated and inferred,as given by United States Bureau of Mines is currently under wide use. However, it has been suggested that the terms "measured" and "indicated" should be given up and in their place a single term "demonstrated ore" should be used[8].

It is obvious from the above that the classification of reserves is as complicated as the definition of "Ore". Besides, the work of reserve estimation does not end just in calculating the amount and grade of certain ore for any particular time but it must also show the amount of ore available, even of a lesser grade, which could be used at a later date when technology may have improved. Hence, the total quantity of ore falling in the various categories, viz. reserves, marginal resources, sub-marginal resources, and latent resources which together constitute "resources" should also be estimated. It can only be said that the parameters employed by various exploration organisations may vary according to the objectives and the necessity of the assignment but there should be a close comparison of the data and results.

The United States Bureau of Mines and the United States Geological Survey have recently suggested a more comprehensive categorisation of reserves[9]. According to this, any mineral property is considered broadly as a "Resource". The whole concept is shown diagrammatically in Fig.5.28. Resources may be of two types[9]:

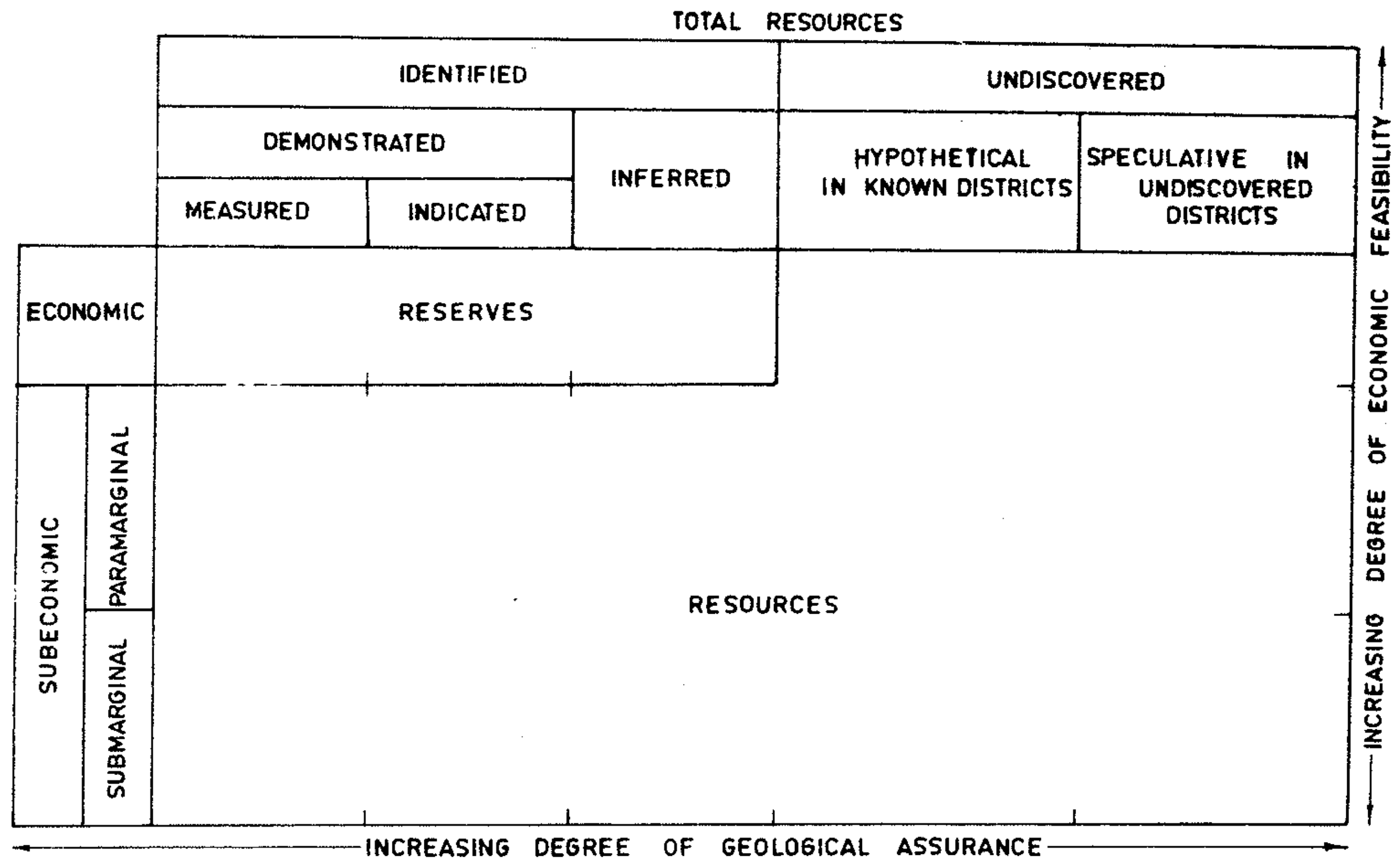


FIG: 5·28 CLASSIFICATION OF RESERVES BY USBM & USGS[9]

"Identified resources - specific bodies of mineral bearing material whose location, quality and quantity are known from geologic evidence supported by engineering measurements with respect to the demonstrated category".

"Undiscovered resources - unspecific bodies of mineral bearing material surmised to exist on the basis of broad geologic knowledge and theory".

In addition, they recognise "Reserves" as follows :

"That portion of the identified resource from which a usable mineral and energy commodity can be economically and legally extracted at the time of determination. The term ore is used for reserves of some minerals".

The reserves may be of the following types[9].

(1) Measured (Proved). Material for which estimates of the quality and quantity have been computed, within a margin of error of less than 20 per cent, from sample analysis and measurements from closely spaced and geologically wellknown sample sites.

(2) Indicated (Probable): Material for which estimate of the quality and quantity has been computed partly from sample analyses and measurements and partly from reasonable geologic projections.

(3) Demonstrated; A collective term for the sum of materials in both measured and indicated resources.

(4) Inferred (Possible): Material in unexplored extensions of demonstrated resources for which estimates of the quality and size are supported by geologic evidence and projection.

(5) Identified (Sub-economic resources): materials that are not Reserves, but may become so as a result of changes in economic and legal conditions

(6) Para marginal: the portion of sub-economic Resources that (a) borders on being capable of production economically or (b) is not commercially available solely because of legal or political circumstances.

(7) Submarginal: The portion of subeconomic resources which would require a substantially higher price (more than 1.5 times the price at the time of determinations) or a major cost reducing advance in technology.

(8) Hypothetical Resources: Undiscovered materials that may reasonably be expected to exist in a known mining district under known geologic conditions. Exploration that confirms their existence and reveals quantity and quality will permit their reclassification as a reserve or identified sub-economic resource.

(9) Speculative Resources: Undiscovered materials that may occur either in known types of deposits in a favourable geologic setting where no discoveries have been made, or in as yet unknown types of deposits that remain to be recognised. Exploration that confirms their existence and reveals quantity and quality will permit their reclassification as Reserves or Identified-sub-economic resources.

The classification of reserves followed in the U.S.S.R. is as follows[10]:-

Class A Production planning and mine projecting

Class B Estimating mining investment and for planning the development of deposits,

Class C_1 Long-term development plans of industry and for projecting detailed exploration,

Class C_2 For planning further prospecting. see Fig.5.29.

5.2.4 Methods of Grade Computation

The grade of the ore defines the quality of the ore or in short the quantity of the valuable product within the ore expressed in terms of percentage availability. Four types of grades are usually recognised[2].

(i) Sample grade : The quality of the ore in situ as determined by underground, surface, or drill hole sampling.

(ii) Mill-head grade : The grade of the ore as it comes out of the mine and sent to the mill.

(iii) Recoverable grade : This is the quantity of ore that can be recovered by the metallurgical process at mill after due losses. Some amount of ore is usually lost during the extraction. To account for this, the concept of recoverable grade is essential.

(iv) Liquidation grade : This is the grade of ore on which a purchaser or smelter fixes the price.

In addition, there are terms like cut-off grades, average grade, etc., which define certain specific conditions of the ore quality. The cut-off grade can be roughly defined as the lowest grade of ore which can be mined economically[2]. Sometimes a given cut-off limit may coincide with some geological boundary. In such cases, the term geological cut-off can be used. Pay value is defined as the grade of ore that can be mined in any given technoeconomic set up. In computing reserves and average grades, the data should be assembled on the basis of cut-off grades. In borehole intersections, pit sections, channels, etc. the assay value will be distributed in such a way that some will be below the cut-off grade and some will be above. Those which are below the cut-off have to be eliminated before the average grade is computed. This omission is very easy when values lower than the cut-off are at the two ends of the ore column as shown in Fig 5.30. However, when the lower than cut-off values are within an ore column as in Fig 5.31, the rejections should be done with a great deal of caution. The following procedure is advocated. The average grade with all the values is calculated. Then the average grade is computed after eliminating the low values. If the difference is not appreciable, then, the lower values can be included. If they bring in a sharp dilution so that the average grade is near the cut-off grade, then the low values will have to be omitted. In case, the low value portions form a column of ore which is recognisable during mining, then that portion should be omitted from calculation in any case. It is easy to reject a leaner section only when manual mining and hand sorting operations are used.

The grade worked at any time is commensurate with the then current economics and technical knowledge. With improved technology, low grade ores might be used later. This point should also be kept in view while computing the grades.

The average grade defines the quality of the ore of a well defined block of ore. The computation of average grade is essential for classifying the reserves. Some of the methods for calculating the average grades are discussed below. Some concepts about the precision of grade estimates are also discussed.

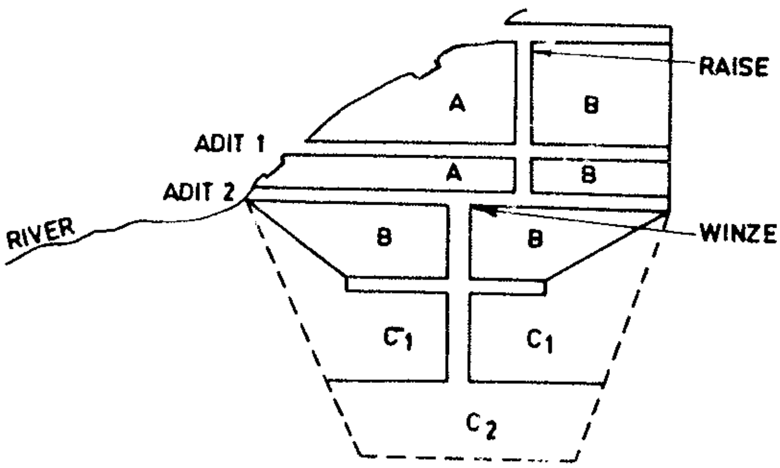


FIG: 5·29 RUSSIAN CLASSIFICATION OF RESERVES

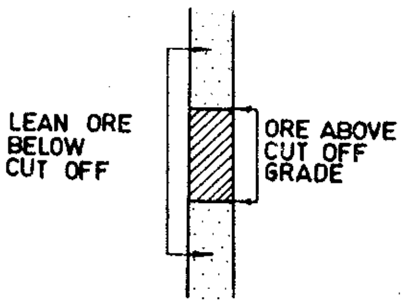


FIG: 5·30

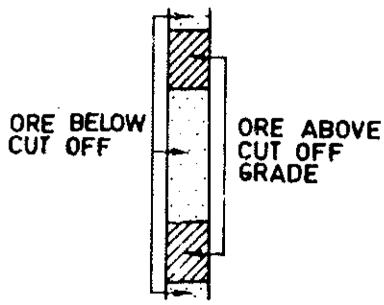


FIG: 5·31

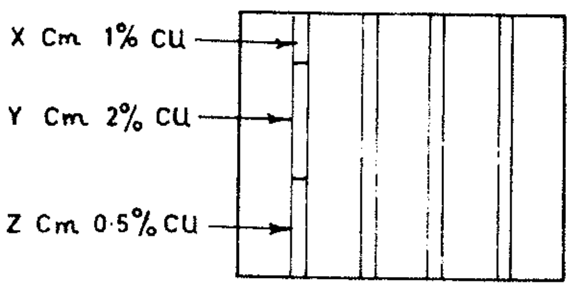


FIG: 5·32 SAMPLE CHANNELS

The average grade should be computed on the basis of assay plans or isograd maps. In the simplest form, the average grade can be calculated by arithmetic averaging.

$$G_{av} = \frac{\sum a_1 + a_2 + a_3 + \ldots\ldots a_n}{n}$$

where a_1 a_2......a_n are grades of individual samples in a block and n is the number of samples. However, the situation described above is extremely simplified and is applicable only when the ore is uniform in every respect which is seldom the case. Some non-uniformity is always present and to account for the influence of non-uniformity, the concept of weightage is introduced. Here, the grade is weighted against various factors like assay width, ore thickness intersected by a hole/pit, area of influence of a sample or the tonnage over the influence of the sample.

In cases where there is a question of minimum stoping width the weight will always be the stoping width with allowances for dilution. In such cases, the principle of weightagehas to be employed even in the individual channel samples, (see Fig.5.32.) The minimum stoping width is x + y + z where x =1.0%Cu, and y=2.0%Cu and z=0.5%Cu. In finding out the average grade, the stope calculation will be as follows

$$G_{av} = \frac{x \times 1.0 + y \times 2.0 + z \times 0.5}{x + y + z}$$

The x, y and z are the weighting factors which in this case, are widths. The weighting factor can be area or tonnage, also, as indicated earlier.

The concept of weighting, however, does not smoothen out some of the special cases of erratically high and low values which are frequent in gold and platinum. The erratically high values may be as follows

	Assay in gm/ton	Width mm	Assay x width	Av: Assay
(1)	4	1.5	6	
(2)	6	2.0	12	
(3)	100	1.5	150	
(4)	7	2.0	14	
		7.0	182 / 7.0	= 26 gm/ton

The third assay value, it will be seen, exerts a disproportionate influence on the average assay value. Values which are very low can also lead to such unreliable results. In such cases the ordinary weighted average method fails and such high values have to be discarded. But this will also lead to an erratic value of the average grade as some deposits acquire their commercial value purely on such erratically high assays. In order to get a fair estimate in such circumstances a frequency weighting method can be used[2]. In this a statistical frequency table is made of the assay values of a level or block or any other convenient area. The frequency of each group of values is converted into a percentage of the whole. Then the average grade is calculated from the following formula.

$$G_{av} = \frac{\Sigma A \times W \times F}{\Sigma W \times F}$$

where A = assay value,
W = width,
F = frequency percentage of 'A' assay value in the whole.

The methods of grade computation by statistical methods have been dealt with elsewhere in greater detail.

Sometimes the assay values may show a very high value not falling within the range of other values. Such erratically high values can be peaked out by having the average of a set of 5 immediate values each on either sides of the erratic high value.

5.2.5 Precision of grade computation

The average grade of ore is generally expressed as say x %, Al_2O_3, Fe or any other valuable mineral content, or as 2% Cu, 4 gm of gold, etc. The value of 'x' is determined by either arithmetical average or weighted average. The expression that 'x' is the average grade of ore is known as a point estimate. Such an estimate generally implies an accuracy unattainable in most mineral deposits. Hence, the grade of ore should be expressed within a range of values, say 64 to 66 per cent Fe. With this a statistical confidence interval is also defined and the estimate becomes more acceptable in the light of fluctuations easily noticed in the grade values. The methodology is described in the chapter on statistics. Confidence interval defines the lower limit and upper limits within which most values will fall in a sample from a panel, level, mine or a set of boreholes. The confidence interval generally in use is 95% or $t_{0.05}$ which means that in 95 cases out of a hundred the values will be within a set of values defined by the confidence interval[11]. For an estimate of lesser precision a 90% confidence limit is also used[12]. The calculation of the confidence limit for one set of data is shown in the case of a bauxite deposit in the chapter on statistical methods. An estimate with confidence intervals achieves many objectives which help in decision making. These are :

(1) The risk inherent is known quantitatively.

(2) The fluctuation in grade can be understood.

(3) By increasing the sampling the precision of estimate can be improved. Confidence interval helps in knowing the improvement in the accuracy of estimate quantitatively[13].

(4) Cut-off can be determined more realistically.

Similarly the precision of reserve computation can also be defined statistically.

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Chapter 6

6.0 Statistical Methods in Mineral Exploration

Statistical methods offer excellent grade computation procedures. Besides grade computations, these methods also help in studying the error involved in grade and tonnage computations. Since the parameters involved in these computations have wide applications in exploration, the subject will be dealt with at some length in the following paragraphs.

6.1 Definitions

In order to understand the procedures involved in statistical analysis, some terms need definition.

6.1.1 Universe

In the case of mineral deposits, the universe may consist of various measurable characteristics of the mineral deposit such as assay from samples, thickness, width of mineralised zone, width x assay products (accumulations) results of chemical analysis, etc. The universe can be physically defined as a whole deposit, part of a deposit, level, stope, section, etc. with definite dimensions[1].

6.1.2 Population

The population is defined as a family of measurements of specific characteristics, obtained from all possible sampling units that could be selected from the universe. In the case of mineral deposits, populations are measurements of a single attribute of a universe such as assays, thickness, product of assay x width, etc.[1].

6.1.3 Frequency distribution

If the measurements of source population characteristics such as assay values of any mineral deposits were to be classified into various grade intervals and the intervals tabulated with the frequency of occurrence of assays within those intervals (grade intervals on abscissa and frequency on ordinate) a histogram would be produced. A curve fitted on this histogram will show the frequency distribution of the assay data. Assay frequency assumes many shapes, each indicating a separate law of frequency distribution[1].

6.1.4 Normal distribution and skewness

The most common distribution which is useful in mineral deposit data analysis is the normal distribution. This is indicated by a bellshaped curve when a curve is fitted to the histogram. However, in many cases the distribution is uneven and the curve shows steepness towards a lower or higher grade range. This phenomenon is called skewness. When the steepness is towards the higher value range, the distribution is said to be negatively skewed. When the steepness is towards the lower value range, the distribution is positively skewed[1]. See Fig. 6.1.

6.1.5 Arithmetic mean

Arithmetic mean is the value obtained by dividing the various items by the number of items. Suppose there are assay values a_1, a_2, $a_3 \ldots a_n$, where 'n' is the total number of values and a_1, a_2, etc. are the individual assays, the arithmetic mean is

$$\bar{X} = \frac{\sum a_1 + a_2 \ldots a_n}{n}$$

where $\bar{X}$ = arithmetic mean.

When a_1, $a_2 \ldots a_n$ are rearranged in a frequency distribution, the arithmetic mean is determined by a different method. The midpoint of the grade interval (if the grade interval is 40 to 41, then the midpoint is 40.5) is multiplied by the frequency (number of data in each grade interval) and then added up. This sum is divided by the total number of items (say assays[1]).

Arithmetic mean $$\bar{x} = \frac{\Sigma f(mp)}{n}$$

where f = number of samples in each grade interval,

(mp) = midpoint of the grade interval, and

n = total number of items (assays).

6.1.6 Geometric mean

When the law of distribution approximates binomial instead of the arithmetic mean, the geometric mean is used. The geometric mean of 'n' items (assay values a_1, $a_2 \ldots a_n$) is the 'n'th root of the product of the items. Thus, for data

a_1, $a_2 \ldots \ldots a_n$

the geometric mean $M_g = \sqrt[n]{a_1 \times a_2 \ldots \ldots a_n}$

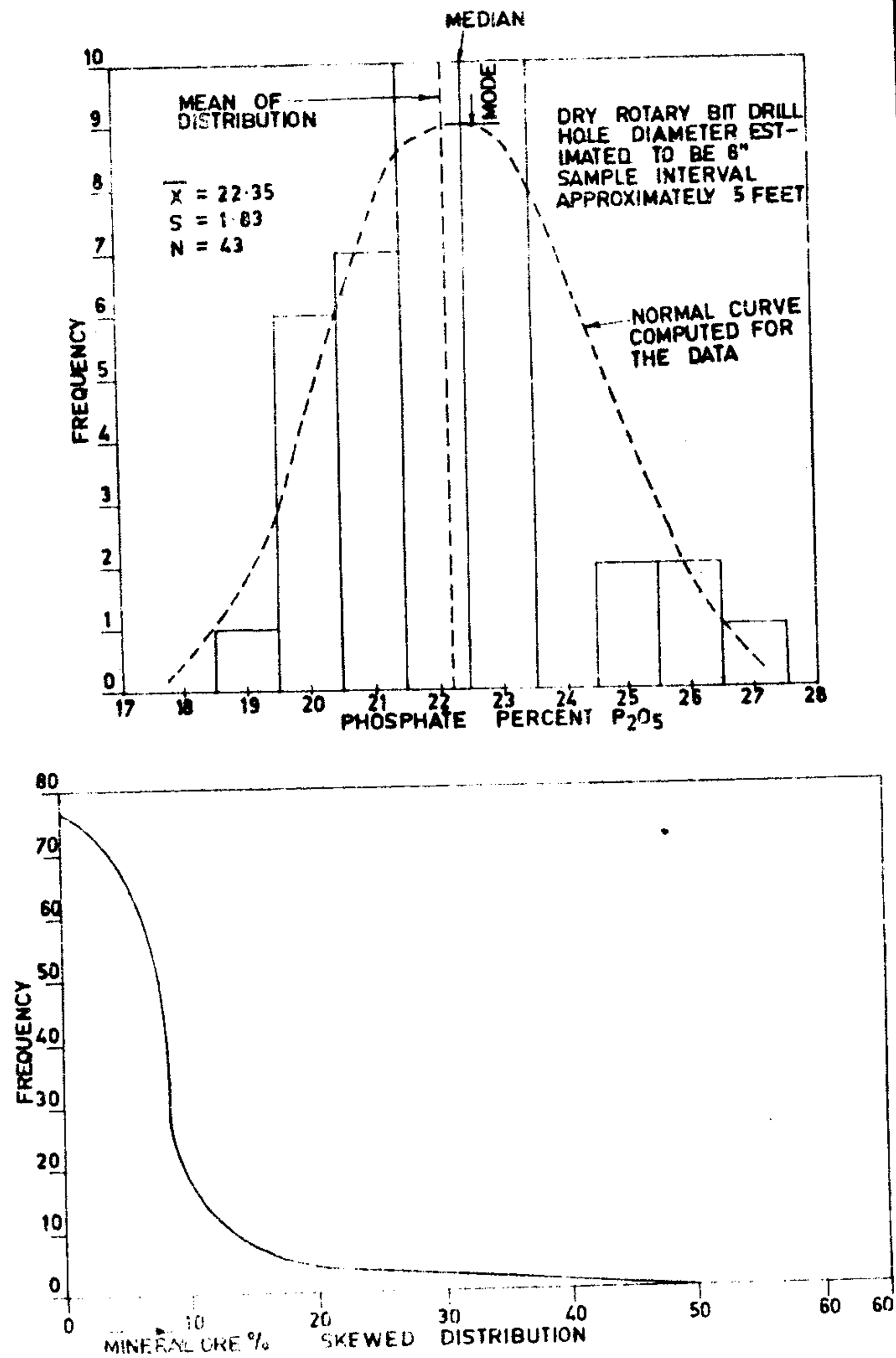

FIG. 5·1 NORMAL DISTRIBUTION AND SKEWNESS

This may be converted to logarithmic values for ease in computation.

6.1.7 Variance

Variance is a measure of the dispersion of values around the mean. This is also called dispersion. Variance is defined as the sum of squares of the deviations of the items from the mean divided by one less than the total number of items[1] (assays). Variance is designated by

$$S^2 = \frac{\sum[a_{1-n} - \bar{x}]^2}{n-1}$$

6.1.8 Median

Median is the midpoint value of a frequency distribution[1].

6.1.9 Mode

The mode is the most frequently occurring value in a smooth frequency distribution. It is an average of position and is independent of extreme values. The value of the mode is indicated by the highest point in a frequency distribution curve[1].

6.1.10 Standard deviation

Standard deviation is the square root of variance. It is designated as[1]

$$\sigma = \sqrt{s^2}$$

6.1.11 Co-efficient of variability

The coefficient of variability is a quantity determined by dividing the standard deviation by the mean and multiplying the result by 100. It is expressed as

$$V = \frac{\sigma}{\bar{x}} \times 100$$

6.1.12 Standard error of the mean

The standard error of the mean $s_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$

where σ = standard deviation, and

n = number of items (assays).

The standard error of the mean is used for estimating the precision of grade computation.

6.1.13 *Confidence interval*

From the standard error of the mean, the precision of sampling (grade estimate in practical terms) can be estimated in the form of a confidence interval by the following formula :

$$\frac{CI}{2} = S_{\bar{x}}(t_{0.05})$$

Where $t_{0.05}$ has a table value depending on the size of the sample (n), at various confidence levels. For 95 per cent confidence level, this value is about 1.97 (2 for all practical purposes[1]). However, the values are available in standard textbooks on statistics.

6.1.14 *Regression*

Regression is a statistical technique by which a mathematical expression can be developed to express the relationship between variables[2].

6.1.15 *Correlation*

Correlation is a means by which the degree of inter-relationship between variables can be established[2].

All mineral exploration data are not amenable to statistical analysis. Before starting any analysis, it is necessary to ascertain whether the behaviour of the data is statistical. For this, a number of tests involving random data, density contrast, etc. are available. These are briefly described below.

6.1.16 *Random data*

Statistics is based on the theory of mathematical probability which can be applied only to random data. Random data can be generated from a deposit by random sampling. Due to circumstantial constraints, this is not possible except in rare cases. Alternatively, it may generally be assumed that all mineral occurrences show randomness in their distribution. However, such an assumption alone is insufficient. In specific cases, a test can be performed to confirm the randomness of data. This test is based on the relationship existing between sample volume and variance[2].

$$S^2 \lambda = \text{constant},$$

where S^2 = variance, and

λ = sample volume.

In conditions of randomness, when two sets of data of different sample volumes are considered the relationship should be

$$S_1^2 \ \lambda_1 = S_2^2 \ \lambda_2 ,$$

where S_1^2 and S_2^2 are the variance of samples of n_1 and n_2 sizes from the same deposit (say NX and BX core samples) and λ_1 and λ_2 are the corresponding sample volumes.

The relationship can be studied by plotting variance against the reciprocal of sample volume. In random data, a straightline relationship will be established as shown in the hypothetical Fig. 6.2.

Automatically therefore, by controlling the sample volume, the data become random.

6.1.17 Trend

Trend may be defined as the change in the average grade of ore over some area or distance which has been sampled. Trend may be a sharp change in grade across an ore boundary or it may be a gradual change, either increasing or decreasing in assay value. The change must be persistent or continuous over some distance in contrast to the rapid changes over short distances which are random.

All deposits show trends from commercial to non-commercial ore, and from one commercial grade range to another. However, these trends do not influence the deposit parameters. But they do influence subpopulation parameters - parameters affecting certain high grade zones. When such trends are present in a deposit, stratified sampling should be done in minimum trend blocks of subpopulations[1].

6.1.18 Density contrast

The distribution characteristics of a mineral deposit are related to its structure and size, mineral size and sample size. The most commonly analysed data are assay values in weight percentage of the valuable metal content. If the conversion from fractional volume to element weight is linear, then the shape of the distribution will not change. In such cases, there is no density contrast[2].

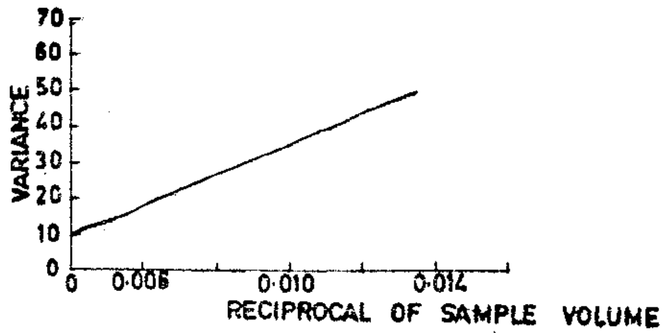

FIG: 6·2

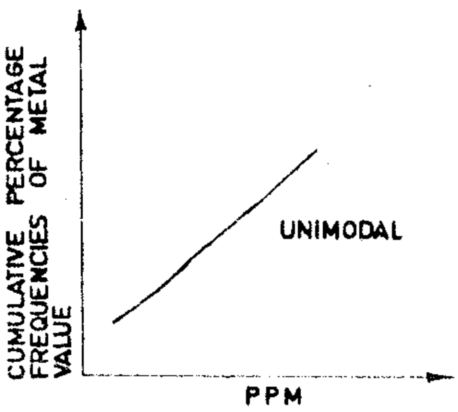

FIG: 6·3 INTERPRETATION OF GEOCHEMICAL DATA

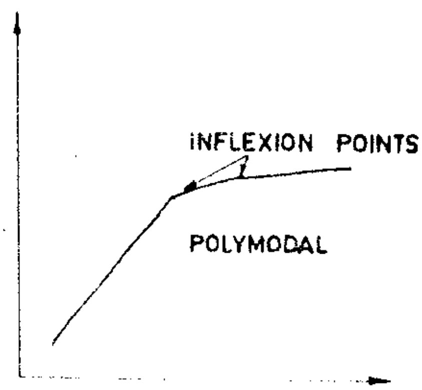

FIG: 6·4 INTERPRETATION OF GEOCHEMICAL DATA

A set of data may be interpreted on the basis of two statistical concepts. One is the mathematical statistical concept and the other the geostatistical concept. Although some of the fundamental parameters are the same for both, the methodology and procedures differ. Both methods will be discussed in the following section.

6.2 Mathematical statistical methods and their applications

The mathematical statistical methods do not take into account the degree of continuity of mineralisation (sample correlation in a statistical sense) and are concerned only with random, minimum trend data without any density contrasts. The steps invovled in mathematical statistics are given[3] in Table 6.1.

The important applications of mathemetical statistical analyses are given below :

(1) computing the mean grade of ore,

(2) determination of the precision of grade estimate,

(3) determining the number of samples for specific precision levels of estimate, and computing the number of exploratory openings in mineral exploration,

(4) calculating the distance between two exploratory openings,

(5) calculating the number of exploratory openings,

(6) determining the sample volumes,

(7) regression and correlation, and

(8) use of lognormal distributions.

6.2.1 Computing the mean grade of the ore

See earlier description under definitions, 6.1.5 and 6.1.6.

6.2.2 Determination of the precision of grade estimate

If the sample standard deviation is a good estimate of the population standard deviation, then the standard error of the mean $S_{\bar{x}}$ can be used to establish the precision of grade estimate[2].

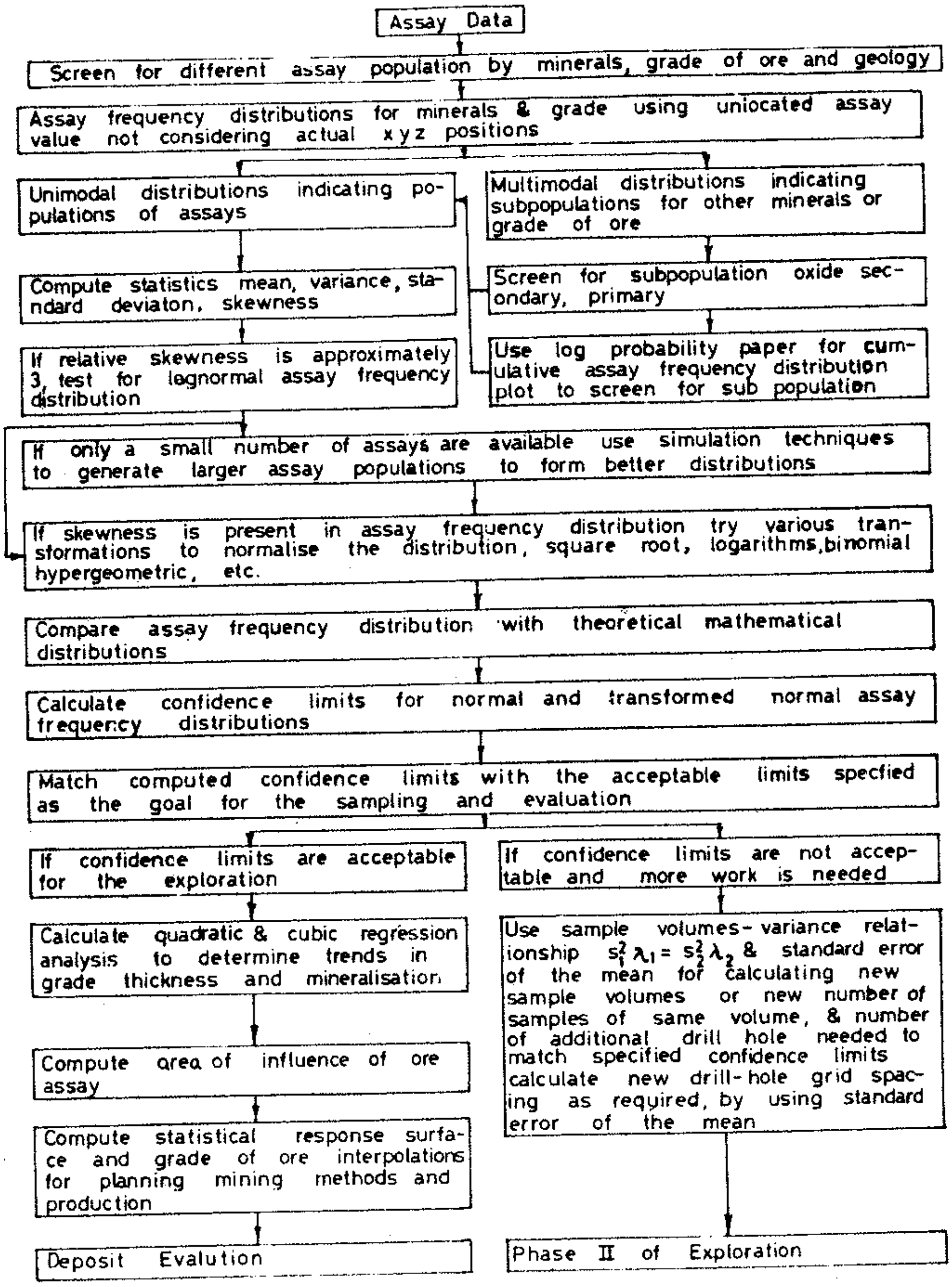

TABLE : 6·1 FLOWCHART FOR STATISTICAL ANALYSIS

$$S_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

where $S_{\bar{x}}$ = standard error of the mean,

σ = standard deviation, and

n = number of assays.

Such estimates are expressed in terms of confidence interval at the 95 per cent level (or other appropriate levels) of confidence, as shown below :

$$\bar{X} \pm t_{0.05} \times S_{\bar{x}}$$

where $\bar{X}$ = average grade of the ore (mean)

$t_{0.05}$ = a table value for the sample size n at the relevent confidence level[2].

The confidence interval is a function of the standard deviation and the number of samples. The narrower the confidence interval, the better the precision of the estimate.

6.2.3 *Determining the number of samples for specific precision levels of estimate and computing the number of exploratory openings in mineral exploration*

The confidence interval is a measure of the degree of confidence in the results of a sampling programme. When no data are available, a preliminary sampling programme is undertaken to generate some data to establish various factors like $\bar{X}$, σ, S^2, $S_{\bar{X}}$, etc. Then the necessary sample volume for various confidence intervals can be calculated. This method can also be used for determining the number of boreholes/ exploratory openings in an exploration programme. The method is shown in the following worked out example.

The sample chosen is from a bauxite exploration programme. The initial sample is of size n = 61, assays of alumina (Al_2O_3). The example is purely illustrative.

Al_2O_3 Assay data in frequency chart

Al_2O_3 in grade interval of 3	Frequency f	Midpoint mp	f(mp)	$f(mp)^2$
37.50-40.49	1	39	39	1521
40.50-43.49	6	42	252	10584
43.50-46.49	11	45	495	22275
46.50-49.49	10	48	480	23040
49.50-52.49	10	51	510	26010
52.50-55.49	12	54	648	34992
55.50-58.49	8	57	456	25992
58.50-61.49	3	60	180	10800
	61		3060	155,214

n = 61

Mean $\bar{x}$ $= \frac{f(mp)}{n} = \frac{3060}{61} = 50.16\%\ Al_2O_3$

Sample variance $s^2 = \frac{\sum f(mp)^2}{n} - \left[\frac{\sum f(mp)}{n}\right]^2 = \frac{155214}{61} - 50.16^2 = 28.47$

Standard deviation $= \sigma = \sqrt{s^2} = \sqrt{28.47} = 5.34$

Corrected (for population) $\sigma = \sqrt{s^2} \times \frac{n}{n-1} = 5.34 \times \frac{61}{60} = 5.43$

Standard error of the mean $s_{\bar{x}} = \frac{s}{\sqrt{n}} = \frac{5.34}{\sqrt{61}} = 0.68$

$\frac{CI}{2} = \pm s_{\bar{x}} \times t_{0.05}$

$= 0.68 \times$ table value of $t_{0.05} = \pm 1.34$

At 95 per cent confidence, the estimate of the average (mean) grade of the ore is 50.16 ± 1.34 or 48.82 - 51.50% Al_2O_3.

The value of confidence interval is 2.68 = 1.34 x 2. Here, it may be seen that the grade estimate is in terms of a range of values, rather than a single value of 50.16 which is called a point estimate. The point estimate of 50.16 implies an estimate of precision which is not attainable in grade computation because of grade fluctuations commonly seen in any group of assay values. The computation of a grade range with a known level of precision is one of the most important contributions of statistics to mineral exploration.

In this sample, instead of ± 1.34, suppose a precision of say ± 0.40 is desired. The number of samples (n) required for this can be determined by the formula[4]

$$S_{\bar{x}} = \frac{CI/2}{t_{0.05}}$$

$$S_1\bar{x} = \frac{0.80}{2} / t_{0.05} = 0.20$$

now $$n_1 = \frac{\sigma^2}{S_1\bar{x}^2} = \frac{5.33}{(0.20)^2} = 711$$

Therefore, the total number of samples required for a precision of ± 0.40 is 711.

If the original assay data had come from 61 boreholes, the total number of n samples computed above would have represented 711 boreholes. Similarly, the number of pits, trenches, etc. also can be computed.

In this method, a certain quantum of data is required before starting the computation. Such data may come from strategically placed boreholes, pits, trenches or any opening which can give a sample of 50 to 100 assay readings. Samples may also be chosen from blocks of ore which have already been proved/mined out.

The above formula does not take into account the dimensions of the deposit. The formula[5] given below incorporates the dimensions of the deposit also:

$$S_{\bar{x}} = \frac{\sigma}{\sqrt{(APDH)(NN)\left(\frac{DW}{GS} + 1\right)\left(\frac{DL}{GS} + 1\right)}}$$

where

$S_{\bar{x}}$ = standard error of the mean of a sample,

σ = standard deviation of the sample consisting of assays above cut off, APDH = average assay per drill hole,

NN = ratio of the number of assays above cut-off grade, to total number of assays, i.e.

$$\frac{\text{Number of assays above cut off}}{\text{Total number of assays}},$$

DW = width of the deposit,

DL = length of the deposit, and

GS = grid spacing.

Here, instead of the n number of holes, the actual distance between borehole or grid spacing is calculated.

There are various other methods and procedures which can be used for determining the number of exploratory openings or the grid spacing, which make use of parameters like variance, coefficient of variability, etc. Some of these formulae are described below.

6.2.4 Calculation of the distance between two exploratory openings (Boreholes/Pits, etc.)

$$l = \frac{P^2}{W^2} \times L \quad \text{or} \quad \frac{P^2}{W^2} \times A,$$

where l = the average distance between two boreholes,

P = accuracy of the relative mean error in the percentage of the arithmetic average,

W = variance of the deposit calculated by the formula

$$W = \sqrt{W_m^2 + W_c^2 + W_d^2}$$

Where W_m = variance with regard to the thickness of the orebody,

W_c = variance with regard to the assay value,

W_d = variance with regard to the bulk weight,

L = length of the sector/bench/block/deposit to be explored, and

A = area of the sector/bench/block/deposit to be explored[6].

Here the main problem is to calculate the value of 'P' from a known deposit or a block or ore, and then to substitute this value for various similar deposits/blocks of ore. The value of '1' will vary according to the value of 'W'. In a wholly unknown block, in order to determine the value of 'W', certain strategically placed boreholes/trenches/pits would be necessary in the initial stages.

6.2.5 *Calculating the number of exploratorv openings*

Formula 1

The number of boreholes/pits/trenches required can be computed by using the following formula[6] :

$$N = \frac{W^2}{P^2},$$

where W and P are as described above and

N = number of boreholes/pits/trenches, etc.

Formula 2

Here N is calculated on a different basis[7] :

$$N = \left(\frac{Q}{a}\right)^2 \times P,$$

where N = number of boreholes/pits/trenches required for a specific precision of estimate,

a = precision of estimate,

P = probability factor which is 2 for normal distributions, and

Q = Coefficient of complication of the deposit determined by the formula

$$Q = \frac{V}{K \times M}$$

Where V = coefficient of variation of the thickness of the deposit (coefficient of variability described earlier),

K = coefficient of variation of impurities in the deposit determined by the formula

K = CC - (F1, F2, Fn etc.),

where OC = total surface area of the deposit,

F1, F2, etc. = surface areas of impurities within the deposit,

M = modulus of complication of the ore waste contact determined by the formula

$$M = \frac{PE}{PC},$$

where PE = perimeter for theoretical ellipse of the deposit outline, determined by the formula

$$PE = 2\pi\sqrt{\tfrac{1}{2}(a^2 + b^2)}$$

where 'a' and 'b' are the maximum length and width of the deposit, and

PC = circumference of the deposit contact with waste (actual perimeter as measured).

For computing this formula also, an initial sample is required which may be obtained from an initial set of strategically placed boreholes. Data from a known similar deposit can also be used .

6.2.6 *Calculation of sample volume*

Statistical methods can be used for predicting the desired sample volume in producing a pre-required sampling precision. For this, the relationship existing between the sample volume and variance can be made use of[5].

The formula is $S^2\ \lambda_1 = S^2\ \lambda_2$

Since S^2 (variance) is related to the standard deviation $\sigma = \sqrt{S^2}$ and to the standard error of the mean and confidence interval ($S_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$ and $\frac{C.I.}{2} = S_{\bar{x}} \times t_{0.05}$), it is easy to calculate the values of λ (sample volume).

For various values of confidence interval, new values of $S_{\bar{x}}$, σ and finally S^2 are determined and the value of S^2 is substituted in the relationship $S_1{}^2\ \lambda_1 = S_2^2\ \lambda_2$ to arrive at new sample volumes.

6.2.7 *Regression and correlation*

By studying the relationship between the various variables, it is easy to predict in a mineral deposit new information from a set of exploration data. The techniques used are regression and correlation analyses. The variables whose interrelationship is to be studied may be grade or assay values, or specific gravity, thickness, width, mineralogy of the ore, micro or macrostructures, etc. Any variable/variables showing predictable relationship can be used to generate reliable new data. The variables may be independent or interdependent. Various regression techniques which are needed in such cases are dealt with below.

For initiating such studies, it is ideal to plot the information on a graph sheet and find out the equation best suited to express the relationship between any two plotted variables. These relationships may be expressed by the regression line[2].

Suppose the relationship between the grade (x) and bulk density (y) of an iron ore deposit is being studied.

After plotting the information, the relationship has been found to be in the form of equation

$$y - (a + bx) = 0,$$

where x = grade of ore,

y = bulk density,

a and b are the coefficients of linear regression.

For purposes of prediction, it is necessary to find the values of 'a' and 'b' by using the following formulae[2] :

$$a = \frac{\Sigma x^2 \Sigma y - \Sigma x \Sigma xy}{n\Sigma x^2 - [\Sigma(x)]^2}$$

where n is the number of pairs of observations, and

$$b = \frac{n\Sigma xy - \Sigma x \Sigma y}{n\Sigma x^2 - (\Sigma x)^2}$$

The method was used to forecast the price of lead, zinc, copper, etc. from London Metal Exchange data for an ongoing feasibility study undertaken by the I.B.M.[8].

The equation of the line of regression of y on x is

$$y = \left[\frac{\Sigma x^2 \Sigma y - \Sigma x \Sigma xy}{n\Sigma x^2 - (\Sigma x)^2}\right] + \left[\frac{n\Sigma xy - \Sigma x \Sigma y}{n\Sigma x^2 - (\Sigma x)^2}\right] x$$

After establishing this formula, new values of 'y' such as y_1, y_2, ... y_n etc. can be computed by knowing only the value of x_1, x_2 .... x_n etc.

In the case of mineral deposits, the relationship between various variables is seldom independent. When various variables show a correlation, the formulae used are more complex. A typical equation showing the relationship between 'y' dependent variable to various independent variables, like x_1, x_2, x_3 .....x_n is given here :

$$y = bo + b_1x_1 + b_2x_2 + \ldots\ldots b_nx_n$$

where bo is a constant and b_1, b_2, ... b_n are partial regression coefficients.

The values of bo, b1, b_2 .... bn are found by solving the basic equations. The number of basic equations increases with the number of coefficients in the type equation.

The basic equations are :

$$\sum y = nbo + b_1\sum x_1 + b_2\sum x_2$$

$$\sum x_1 y = bo\sum x_1 + b_1\sum x_1^2 + b_2\sum x_1 x_2$$

$$\sum x_2 y = bo\sum x_2 + b_1\sum x_1 x_2 + b_2\sum x_2^2$$

Such equations are most amenable to standard computer treatment.

After finding out the numerical values of bo, b_1, b_2 ..... b_n etc., it is possible to generate the values of y_1, y_2, y_3 .... y_n on the basis of various sets of x_1, x_2, x_3 .... x_n values.

This can be applied in the following way. Let 'y' be the gibbsite content of a bauxite sample. 'y' shows correlations to say four variables $X_1 = Al_2O_3$ content, X_2 = L.O.I., $X_3 = Fe_2O_3$, and $X_4 = TiO_2$ + minor minerals content, Gibbsite = $y = bo + b_1\ Al_2O_3 + b_2\ LOI + b_3\ Fe_2O_3 + b_4\ TiO_2$.

By solving the basic equation for bo, b_1, b2, b3 and b4, the gibbsite content can be predicted without costly and time-taking X-ray analysis which is normally required.

When the data are in three dimensions, as is often the case with mineral exploration data, a procedure known as the 'Three Dimensional Regression Analysis' is resorted to. Here, the cartesian (graph) coordinate values (values of X, Y and Z cartesian coordinates) are introduced into the regression equation[2].

The equation may take the following form :

$$\bar{x} = a_1 + a_2x + a_3y + a_4z$$

where $\bar{x}$ = mean value at any point, x, y, z.

a_1, a_2...... etc. = regression coefficients the values of which are a function of the strike, dip and plunge of the linear surface.

The equation is re-written for ease in mathematical treatment, as :

$$\bar{x} = a_1 + a_2 (x - \bar{x}) + a_3 (y - \bar{y}) + a_4 (z - \bar{z}) + E,$$

where, E = error term associated with any value of X.

This formula is used in a variety of forms in mineral exploration.

Coefficient of Correlation

In all the above mathematical considerations, the underlying principle is the degree of inter-relationship between the variables. This relationship can be expressed by a mathematical expression, the correlation coefficient. The formula for this is

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

where X and Y are variables,

n is the number of observations, and

r is the linear correlation coefficient.

The coefficient of correlation r may have positive or negative values, ranging from -1to+1. When no correlation exists, the 'r' value may come close to zero. As the degree of correlation improves, the 'r' values may approach one. When the value is positive, the variables vary directly. If the value is negative, the variation is in inverse proportion.

When interdependent data are made use of, a multiple correlation coefficient is determined. It is designated as 'R'.

These methods are extremely useful when studying core losses in drilling and choosing regional exploration targets[9,10].

Linear programming is a statistical tool which has grown out of the principle discussed above and has some limited application in grade control operations in producing mines. The method was used by the Indian Bureau of Mines for finding out the optimum product mix from a number of manganese mines of M/s MOIL, Nagpur. The work involved the formulation of 36 linear equations of 33 quantity (tonnage) and 3 grade restrictions, Mn, P and SiO_2 with 70 variables and was resolved in an electronic computer[11].

6.2.8 *Use of lognormal distributions*

It was mentioned earlier that some data on being arranged in a frequency distribution show skewness. The degree of skewness can be tested by a formula[2].

$$\text{Coefficient of skewness} = \frac{\text{mean-mode}}{\text{standard deviation}}$$

When the numerical value of the coefficient of skewness is less than 0.3, the distribution is lognormal. The condition of lognormality can be tested by other methods also like plotting the histogram (high degree of positive skewness indicates lognormal distribution) and plotting cumulative frequency (if the cumulative frequencies are plotted on a log probability paper, the lognormal data will form a straight-line).

In the latter case, there are a few points to be observed :

(a) A change of slope of the line indicates a bimodal distribution.

(b) The accuracy at the top end of the curve is usually poor, because accuracy of assaying high values is poor.

(c) This plot can be utilised to determine sample parameters such as geometric mean, variance and confidence limit.

The lognormal distributions can be converted to normal distribution by transforming the assay readings to their natural logarithmic value. After this conversion, all equations applicable to normal distribution become valid.

However, in the case of lognormal distribution, the arithmetic mean is a poor estimator. In its place, the geometric mean should be determined and the standard deviation, standard error of the mean, etc. determined on the geometric mean[1].

In the case of true lognormal distributions, the best mean grade estimator is a quantity known as the Sichel's 't' estimator.

This is expressed as

$$t = e^{\bar{x}} \; r(v),$$

where $\bar{x}$ = mean of the natural logarithms of the assays,

v = natural variance of the natural logarithms of assay, and

$r(v)$ = a complex mathematical function.

The complete formula is

$$t = e^{\bar{x}} \left[1 + \frac{1}{2} V + \frac{N-1}{2^2 \, 2!(N+1)} V^2 + \frac{(N-1)^2}{2^3 \, 3!(N+1)(N+3)} V^3 + \ldots \right]$$

However, the application of this formula is subject to serious practical difficulties. To be used effectively, N, the sample size, should be around 100, which limits its application.

Interpretation of geochemical data

The lognormal distribution has applications in geochemical exploration. An earlier section dealt with the geochemical exploration methods. The data resulting from a geochemical exploration are arranged in a cumulative frequency curve. The cumulative percentage frequencies of metal values are plotted against their real metal values in ppm. The resulting curve may be a strightline if the data are unimodal (only one population). The line may show various inflexion points in which case the population may be biomodal or polymodal (many populations). as shown in Fig. 6.3.

The curves can also be used to find out the geometric mean and the coefficient of deviation. These are used in a formula to find the threshold value :

$$t = bS'^2,$$

where t = threshold value,

b = background value (geometric mean), and

S' = log of the coefficient of deviation.

The values which are above 't' may be considered as anomalous and can be determined at three probability levels 68%, 95% and 99%; 95% being preferred in most geochemical cases[12].

Unimodal curves are easy to interpret and polymodal curves difficult. The separation of various populations requires the use of a computer.

6.3 Geo statistical methods and their applications

Geostatistical methods are also utilised in grade estimation. The basic tool in geostatistical studies is the variogram. In this, the spatial correlation between the various sample values is studied by means of a variogram which is a mathematical function defining the natural (intrinsic) dispersion of assay values[13,14].

6.3.1 The Variogram

The variogram is constructed as follows[15] :

Suppose there is a set of copper assay values as shown below :

Cu%
1
1
2
1
2
2
1
2

The values are rearranged by pushing out the last assay value. This is the one lag position.

Set A	Set A'	A - A' and ignoring sign	$(A - A')^2$
1	:		
1	2	1	0
2	1	1	1
1	2	1	1
2	2	0	1
2	1	1	1
1	2	1	1
2			
			5

This value is divided by

$$\frac{1}{2\ (L - h)}\ ,$$

where L = length of the data string - 8 in this case, and

h = lag value which is one.

This division produces the value denoted as $\gamma\ (h)$

$$\gamma\ (h_1) = \frac{5}{2\ (8-1)} = \frac{5}{14}$$

Now we rearrange the data to two-lag position :

A_1	$A_1{}^1$	$A_1 - A_1{}^1$	$(A_1 - A_1{}^1)^2$
2	1	1	1
1	2	1	1
2	2	0	0
2	1	1	1
1			
			3

$$\frac{1}{2\ (L - h)} = \frac{3}{2(5-2)} = \frac{3}{6} = \frac{1}{2} = \gamma\ (h_2)$$

The process is continued till the data are exhausted. Now we get various values of γ (h) (variance) for various lags. This is plotted with lag values on the 'X' axis and γ (h) values on the Y axis. The resulting curve is called a variogram.

The variogram yields a statistical parameter called the semi-variogram function expressed as γ (h) and defined by the equation.

$$\gamma(h) = \frac{1}{2(L-h)} \int_0^{L-h} \left[f(x+h) - f(x) \right]^2 dx$$

where

f(x) and f(x+h) are assay values at distance 'h' and L is the total distance of the plot.

The equation defined above is that of a unidimensional variogram which is applicable in most cases. Five major types of variograms are recognised. They are

(1) Continuous type (Fig. 6.5)

(2) Linear type (Fig. 6.6)

(3) Nugget type (Fig. 6.7)

(4) Random type (Fig. 6.8)

(5) Transitive type. (Fig. 6.9)

By constructing the variogram, the law of dispersion of the variable under study (assay value, thickness, etc.) within the deposit can be understood. And once this law of dispersion is understood, the mathematical law and statistical parameters can be worked out and used for various grade computation purposes[13].

The statistical parameters to be determined are -

<u>Variance</u> : Variance is a measure of the dispersion of values xi of the random variable (tenor values, assay values, assay x width values, thickness, etc.) about its mean $\bar{x}$. It is the expected value[13] $(x_i - x)^2$.

The variance $= \sigma^2 = \frac{1}{n}\left[\sum(xi)^2 - \frac{\sum(xi)^2}{n}\right]$

The procedure for determining the variance is slightly different from the one shown in the earlier section on mathematical statistics.

<u>Logarithmic variance</u> : When the random variable shows lognormal distribution, the variance is found by converting the values to their natural logs. The logarithmic variance $\sigma^2 LN$ in such cases is expressed as follows[13] :

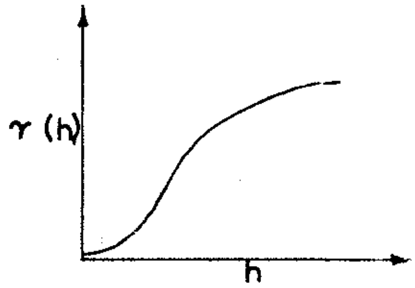

FIG: 6·5 CONTINUOUS TYPE

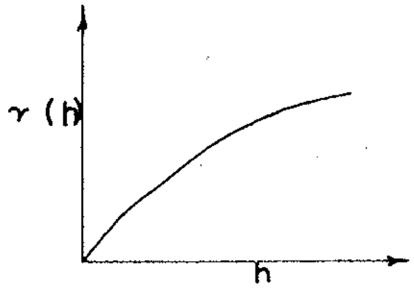

FIG: 6·6 LINEAR TYPE

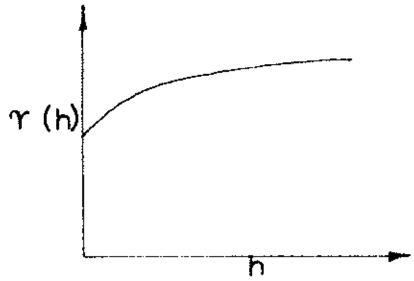

FIG: 6·7 NUGGET TYPE

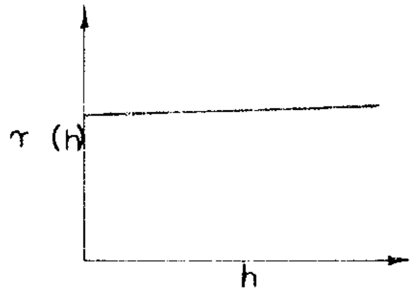

FIG: 6·8 RANDOM TYPE

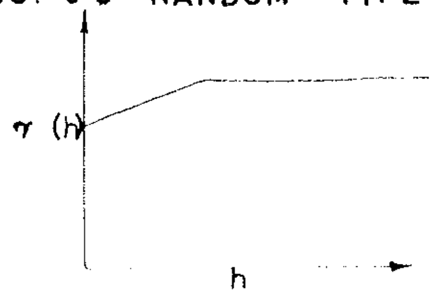

FIG: 6·9 TRANSITIVE TYPE

$$\sigma^2_{LN} = \frac{5.302}{n}\left[\sum_{i=1}^{k} fi(\log xi)^2 - \left(\frac{\sum_{i=1}^{k} fi \log xi}{n}\right)^2\right]$$

Standard deviation : The standard deviation is the square root of the variance and is expressed by 'σ'

Standard error of the mean : The standard error of the mean is defined by the formula as shown in an earlier section.

$$\sigma(\bar{x}) = \frac{\sigma}{\sqrt{n}}$$

These parameters can be used for determining the error involved in various types of grade, tenor and tonnage estimates by analysing the relevant exploratory data. The procedures for making the estimates are described below.

As mentioned earlier, the dispersion laws of various deposits are different. Two very common types of dispersion laws are represented by the De Wijsian model and the Transitive model.

6.3.2 The De Wijsian Model

The general De Wijsian law is stated as follows :

$$\sigma^2_{LN}(t) = \alpha \, Ln\left(\frac{V}{v}\right),$$

where

$\sigma^2_{LN}(t)$ = logarithmic variance of tenors,

α = a geostatistical factor of dispersion of mineralisation,

V = volume of the ore block, and

v = volume of the samples taken in this block the shape of which is the same as that of the block, i.e. the samples are homothetic to the block[13].

The quantity α can be determined by three methods.

(1) From the slope of the variogram.

(2) From Matheron - De Wijs formula given below :

$$\sigma^2_{LN}(t) = 3\alpha \, Ln\left(\frac{D}{d}\right),$$

where

$\sigma^2 LN\ (t)$ = logarithmic variance of the samples (obtained from statistics),

α = absolute coefficient of dispersion,

D = linear equivalent of the block of ore considered,

D = A + B + 0.7 C, where A, B, and C are the three dimensions of the ore block, and

d = a + b + 0.7 c, where a, b, and c are the dimensions of the diamond drill hole, (used for computing $\sigma^2 LN\ (t)$).

(3) From the variance - variogram chart prepared by Matheron[15]. Of these, the Matheron De Wijs formula described above appears most useful for practical purposes.

The formulae described above can be used for calculating the total error involved in any ore estimate based on the exploration data. The calculation is done on the principle of "Extension Geovariance".

6.3.3 Extension geovariance

It is the normal procedure to extrapolate the ore value of a diamond drill hole, channel sample, etc. to its natural zone of influence. However, unless the mineralisation is very uniform, an error is introduced in such extrapolation. This error is related to three factors, viz.

(i) variability of mineralisation,

(ii) geometry of the sample, and

(iii) zone of influence of the sample.

Extension geovariance measures the error involved in this extrapolation quantitatively taking into account the three factors described above. In actual terms, extension geovariance has three error components, which are :

(a) Line geovariance : Error committed when the values of a series of points are extended to a line, e.g. the assays of a linear series of grab samples on an ore face.

(b) Section geovariance : Error committed when extending the value of a line to its rectangle of influence, e.g. weighted average grade of a drill hole intersection.

(c) Block geovariance : Error committed when extending the average grade of a section to its volume of influence, e.g. the weighted average grade of a series of drill holes in a section.

In addition, the sampling variance which indicates the error committed in various sampling practices also contributes to the total error in the estimate. For finding the extension geovariance, the formula is[13]

$$\sigma LN\ (E) = \sqrt{\frac{\sigma^2(s)}{\bar{x}^2} + \sigma^2 LN\ (L) + \sigma^2 LN\ (X) + \sigma^2 LN\ (B)}$$

where σ LN (E) = extension geovariance (total error in the estimation)

$\frac{\sigma^2 (S)}{\bar{X}^2}$ = sampling variance,

σ^2LN (L) = **line geovariance,**

σ^2LN (X) = section geovariance, and

σ^2LN (B) = block geovariance.

Since grab sampling is seldom used, $LN^2(L)$ does not usually figure in the computations.

$\frac{\sigma^2 (S)}{\bar{x}^2}$ is determined by dividing the variance by square of the sample mean $\bar{x}$.

σ^2 LN (X) is found by using the formula :

$$\sigma^2 LN\ (X) = \frac{\pi}{2} \propto \frac{h}{p} \cdot \frac{1}{N}$$

where N = is the number of drill holes intersecting the relevant section,

h = interval between the drill holes,

p = average length of ore intersection, and

$\propto$ = absolute coefficient of dispersion.

LN (B) is found by using the formula :

$$\sigma^2 LN\ (B) = \frac{\pi}{2} \propto \frac{H}{L^1} \cdot \frac{1}{N^1} = \frac{\pi}{2} \propto \frac{H}{L} \cdot \frac{L}{L} = \frac{\pi}{2} \propto \frac{S}{L^2}$$

where N' = number of sections - say levels in a block of ore,

L' = average strike length of the deposit in horizontal section,

L = total length of ore recognised in various levels,

H = level interval, and

S = surface of the ore body in a longitudinal section.

6.3.4 The Transitive Model

In this model the variogram will have a shape shown in Fig. 6.10.

The intrinsic dispersion conforms to the following law :

$$\gamma(r) = C_o + C_T(r, a)$$

where r = distance,

a = range of correlation,

Co = nugget effect, i.e. value of $\gamma(r)$ at $\gamma = o$

C = a constant equal to the difference between the variance of assay values and the nugget effect, and

$T(r,a)$ = pure transition function which is equal to r/a for $r \leq a$ and equal to one when $r > a$

In practical terms, this law describes the geometrical fragmentation of various grades of mineralisation in a deposit. When two samples M and M' are close to each other, they are likely to be in the same grade range (grade microbasins). When the distance r between these two increases, the two samples are likely to be in different grade ranges (grade microbasins). This formula can also be used for calculating the extension geovariance (total error of estimation).

For calculation of the geovariance, the following sequence is adopted. In an estimate of an ore block, the value of length 'f' of intersection is extended to its rectangle of influence o width 'h' the intrinsic law T(r, a) is replaced by F (h, f) which is an auxiliary function representing the geometrical equivalent of the block. The numerical value of this is determined from Serra's graph[13].

The earlier formula now becomes

$\sigma^2(t)$ = Co + CF (h, L), where

$\sigma^2(t)$ = relative arithmetic variance of assay values (obtained from statistics),

Co = nugget effect,

C = pitch of the transitive variogram, and

F(h,L) = value from charts for h/a and l/a, 'a' being the range of correlation of values as shown by the transitive variogram;

The total/error of estimate = $\sqrt{\text{Section geovariance + block geovariance}}$

Section geovariance is determined by the following formula :

$$\text{Section geovariance} = \frac{1}{NP}\ \sigma^2(e)\ \left(\frac{L'}{N}\right),$$

where N = average number of ore intersections in each level,

L' = average length of ore in each level, and

P = number of levels intersected by diamond drill holes.

$\sigma^2(e)\,h$ which is an elementary estimation of variance of a segment of length 'h' and assumes three values depending on 'h' the length of the segment for which the estimation is made.

Thus, $\sigma^2(e)h$ when $h < a$ $= \frac{1}{6}\ \frac{h}{a}$

when $a < h < 2a$ $= \frac{1}{2}\ \frac{h}{a} + \frac{a}{h} - 1 - \frac{1}{3}\ \frac{a^2}{h^2}$

when $h > 2a$ $= 1 - \frac{a}{h} - \frac{1}{3}\ \frac{a^2}{h^2}$ and

value of F(h) $= \frac{1}{3}\ \frac{h}{a}$ when $h < a$ and

$1 - \frac{a}{h} + \frac{1}{3}\ \frac{a^2}{h^2}$, when $h > a$.

Block geovariance = $\frac{1}{p}\ \sigma^2(e)\ (H, L)$

where H is the standard vertical interval between the levels. When H is smaller than a (range) then

$$\sigma^2(e)\ (H,\ L) = 0.07385\ \frac{h^2}{aL} - \frac{h^2}{40\ aL^2}$$

$\sigma^2(e)\ (H, L)$ is the value of the function read from Serra's chart[13] when H > a.

6.3.5 Kriging and its application in grade estimation

In certain special cases, it is difficult to make a reliable estimate of the grade of ore in small blocks in working mines for absence or inadequacy of data within the block. In such cases a procedure known as continuous Krigging is needed for estimating the grade.

The case dealt with here is that of a block of ore which has little data of its own but is surrounded by levels and drives which have data. The usual procedure in such cases is to find out the weighted panel averages around the block and interpolate the results. To increase the efficiency, the following procedure (continuous Krigging) is adopted[13].

The ore block (square) is assigned additional weighting factors (calculated and standardised) as shown in the Fig. 6.11 in such a way that the weight for the square block does not exceed 1000 (250 for each side). Grade computation from the surrounding blocks is now given in additional weighting factor, the nearest factor of each reading. Now, the weighted mean is found out. This yields the best weighted average of the square block of ore[13].

Another procedure known as discontinuous Krigging is used when the block of ore in question has been explored by boreholes put in a square grid. The problem is to ascertain the influence of each borehole.

In the case shown in Fig. 6.12 the central borehole has an average grade of u, the first ring of boreholes an average weighted grade of v and the outermost ring of boreholes an average weighted grade of w[13].

Here, an estimator z = u is made use of to predict the grade of the central block. The estimator z is known as the Krigged estimator and is considered to be the most efficient under the circumstances[13].

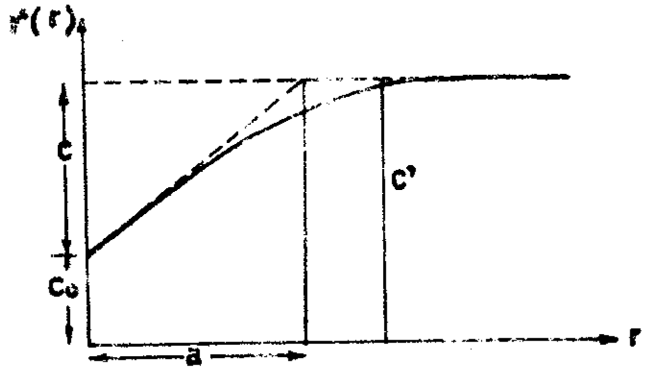

FIG: 6·10 TRANSITIVE MODEL

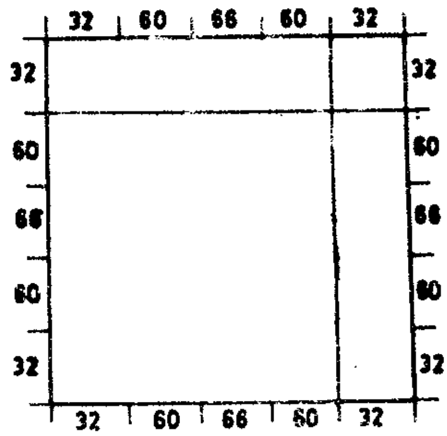

FIG: 6·11 KRIGGING AND ITS APPLICATION IN GRADE ESTIMATION

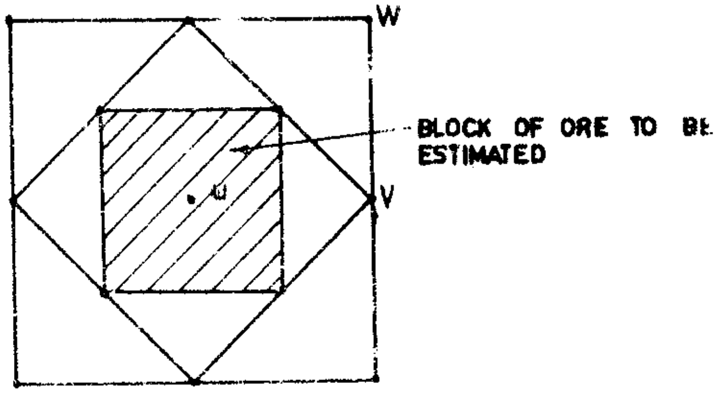

FIG: 6·12 KRIGGING AND ITS APPLICATION IN GRADE ESTIMATION

The formula for Krigged estimator

$$z = (1 - \lambda - \mu) u + \lambda v + \mu w$$

Here z = Krigged estimator of the panel considered,

u = weighted average grade of the central hole,

v = weighted average grade of the first ring of holes,

w = weighted average grade of the second ring of holes, and

λ & μ = geometric coefficient the values of which are read off from a standard chart, see Fig. 6.13.

$$x = \frac{h}{a} = \frac{\text{average thickness of ore (holes u, v, and w)}}{\text{cell edge of basic square drilling grid}}$$

The chart is prepared by putting the values of $x = \frac{h}{a}$ on the 'x' axis and the values $\frac{1}{3\alpha} \sigma^2 k$ on the 'y' axis.

Here α = value of absolute coefficient of dispersion determined from the variogram, and

$\sigma^2 k$ = variance of each intersection plotted on 'x' axis. The corresponding value of $\frac{h}{a}$.

Geostatistical methods described above are of use in certain types of mineral deposits like gold, copper, lead-zinc, etc. The use of this method for other mineral deposits is under experimentation. The methods find the best application in producing mines where grade control has to be done continuously.

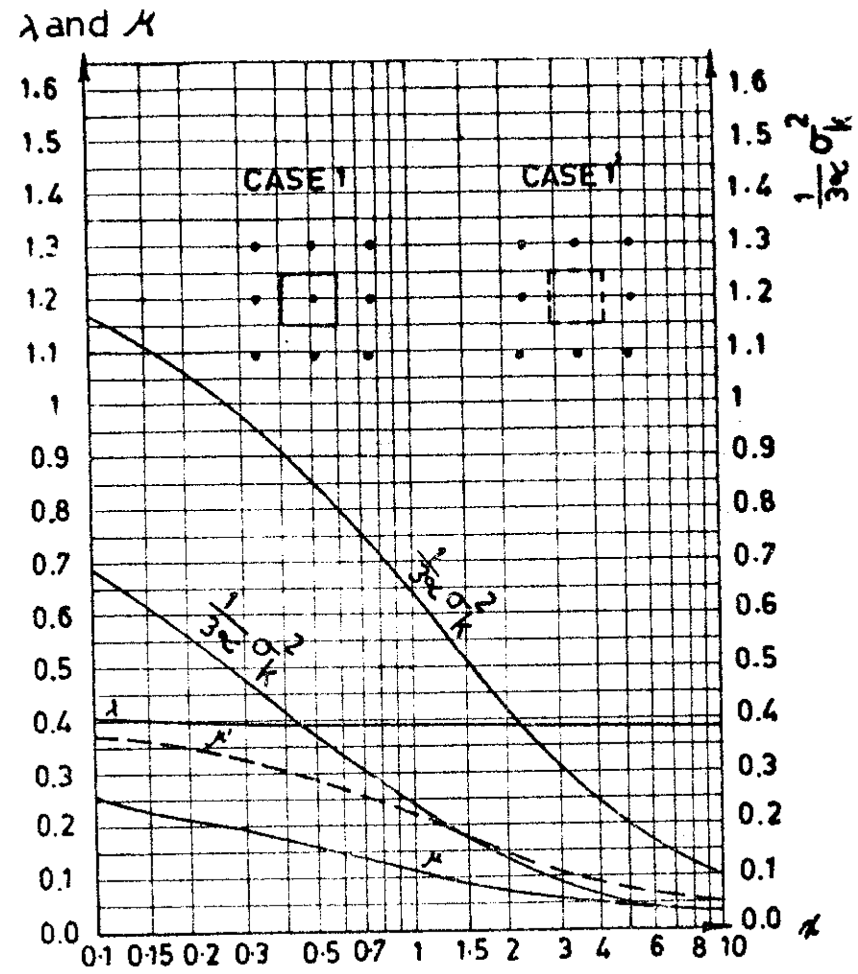

Fig: 6.13. Chart giving the geometrical coefficients to be used in krigging the D.D.H. which have been drilled following the two drilling patterns illustrated above. Note that in the drilling grid shown on the right, there is no central hole in the ore panel considered. The chart gives the coefficients λ and μ, to be used in the krigging equation. These coefficients are read from the value of x on the abscissa, where x is the ratio of the average length of ore intersection in the drill holes to the size of the drilling grid (in this case, the cell edge of the unit drilling square). The precision of the kriged estimator of the ore panel considered is read directly from the chart, using the absolute coefficient of dispersion(read from the variogram) & the statistical variance of the D.D.H. sample values. This chart is for the De Wijsian model.

6.4 References

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Chapter 7

7.0 Geology of the Mineral Belts of India

7.1 A broad outline of the geology of India

A broad knowledge of the geology of India as well as a knowledge of the occurrence, distribution and the geological background of the major mineral deposits is very essential for an exploration geologist intending to prospect and explore for mineral deposits. It should be recognised that a given mineral deposit has a specific place of its own in the geological setting in which it is found and the exploration geologist should first understand it if the exploration has to be well directed.

Physiographically, India has been divided into three units, viz.

(i) Peninsular region,
(ii) Indogangetic alluvial plains, and
(iii) Extrapeninsular India or the Himalayan region.

The peninsular part of India is a shield area which has been exposed to long and sustained denudation. This shield area contains some rocks which are geologically most ancient. Most of the major mineral deposits are located in this shield area. A large area of the western and middle parts of this shield is covered by the lava flows of the Deccan Traps. This trap-covered portion has remained unimportant from the point of view of finding economic mineral deposits.

The Indogangetic alluvial plain covers a vast stretch of land north of the peninsular shield. Like the Deccan Trap, large parts of this vast plain have also not offered any target for mineral exploration so far.

The Himalayan region represents geosynclinal formations extending from Cambrian to Tertiary which have been folded and overthrust. The core of the mountain contains granitic intrusions[1]. The true mineral potential of the Himalayas has not been properly assessed as yet although exploration in certain isolated areas has shown mineralisation of various types.

<u>Major Geological Formations</u>

The major Indian rock formations from the Precambrian to Recent Alluvium have been arranged in Table 7.1 in the descending order of their age.

Table 7.1: Major Geological formations of India

Recent	Recent Alluvia, Sand dunes, Soils
Pleistocene	Older Alluvia, Karewas of Kashmir, and Pleistocene river terraces, etc.
Mio-Pliocene	Siwalik, Irrawaddy and Manchhar Systems; Cuddalore, Warkilli and Rajamahendri Sandstones
Oligo-Miocene	Murree and Pegu Systems; Nari and Gaj Series
Eocene	Ranikot-Laki-Kirthar-Chharat Series; Eocene of Burma
Lower Eocene: Upper Cretaceous	Deccan Traps and Inter-trappeans
Cretaceous	Cretaceous of Trichinopoly, Assam and Narmada Valley; Giumal and Chikkim Series ; Umia beds
Jurassic	Kioto Limestone and Spiti Shales; Kota-Rajmahal and Jabalpur Series
Triassic	Lilang System including Kioto Limestone; Mahadeva and Panchet Series
Permian	Kuling System; Damuda System
Carboniferous	Lipak and Po Series; Talchir Series
Devonian	Muth quartzite
Silurian	Silurian of Burma and Himalayas
Ordovician	Ordovician of Burma and Himalayas
Cambrian	Haimanta System; Garbyang Series
Pre-Cambrian and	Cuddapah and Vindhyan Systems; Dogra and Simla Slates; Martoli Series
Archaean	Dharwar and Aravalli Systems; Salkhala, Jutogh and Daling Series, various gneisses, etc.

7.2 Tectono- metallogenic units

All geological formations, however, do not contain mineral deposits. It has been found that there is a relationship between tectonic phenomena, formation of major rock units and oregenesis.

In the Indian context, 3 major tectonic units which include all the structural metallogenic zones have been identified. They are: (i) shield areas, (ii) mobile belts, and (iii) platform areas[2]. In addition to these three units, there are two other areas of interest from the mineral exploration stand point. They are: (1) the lateritic belts and (2) the area of Quaternary formations like alluvium, loess, beach sands, etc.

Formations like the Gondwanas, Deccan Traps, Cretaceous, Triassic, Jurassic, and the whole of Tertiaries have so far not revealed any significant endogenetic mineralisation. Limestone, phosphatic nodules, building stones, chinaclay, fireclay, gypsum, etc. are present in some of these formations. But such deposits are present in most formations and a tectono-metallogenic approach is not necessary to understand them. The sedimentary and evaporative type of deposits are dealt with individually in another section. Coal, oil, etc. which are present in some of these formations are not dealt with in this publication.

7.2.1 <u>Shield areas</u> : A shield is described as a part of the earth's crust which obviously has not been seriously disturbed since the Precambrian time. Of course, this apparent stability is only relative. The most typical characteristics by which the Precambrian shields are recognised are migmatisation and granitisation, indicating a high degree of metamorphism undergone by the rocks of the shield area[3].

The shield areas naturally contain the oldest geological formations starting with Archaeans which has so far provided to be the largest repository of mineral wealth. The other formations which contain mineral deposits are Delhis, Cuddapahs, Vindhyans, etc., of the Pre-Cambrian and Cambrians.

(i) The Archaean : The major rock units in the Archaeans are the ancient gneisses, metavolcanics and metasediments. Five principal belts of these rocks can be identified in the shield area[2]. These are :

(a) Dharwar system of Karnataka and adjoining States- South India.

(b) Eastern ghat belt-South-East India.

(c) Singhbhum-Gangpur-Bijawar belt East and East-Central Peninsular India.

(d) Sausar-Sakoli systems of Central India, and

(e) Aravalli system North-Western Peninsular India.

Dharwar system of Karnataka and adjoining States South India

The major rock units of the Dharwar system are metavolcanics, metasediments, intrusives of various types (ultra-basic to acidic) orthoquartzite-carbonate rocks, ironstone bands, etc.[1] The **metavolcanics, metasediments and** the orthoquartzite-carbonate rocks broadly form schist belts, or greenstone belts. Various greenstone belts are recognisable. Presently, it is thought that these greenstone belts form part of a huge geosyncline[4]. These rocks have been affected by three phases of acidic intrusives and granitisation together with an early and late basic phase. The earlier basic and ultrabasic rocks have been responsible for magmatic deposits of chromium and iron. The first phase of gneissic intrusion has been co-related to many hydrothermal deposits, principally gold, copper, lead and zinc, These may also have been caused by later intrusions like the peninsular gneiss or Closepet granite. The second phase of ultrabasic intrusive gave rise to more chromium and iron deposits[2]. The major rock units of the Dharwars are shown[1] in Table 7.2.

The metavolcanic and metasedimentary rocks referred to above were formed in the mobile belts. A mobile belt is described[4] as a portion of the earth's crust, generally long compared to its width and many scores of miles wide, that is more mobile as evidenced by geosynclines, folds and faults, than the adjoining stable blocks of the crust[5]. The major endogenic mineralisation which occurred within the Dharwar and its equivalents is considered to have resulted from different phases of magmatism corresponding to the different stages of the development of a mobile belt in this particular case, one geosyncline or several geosynclines. Four major stages of development of a mobile belt are **recognised**. They are[2]:

(1) Initial stage - This stage of development is characterised by the presence of basic and ultrabasic intrusives.

(2) Intermediate stage - The intermediate stage is characterised by granodioritic complexes and the formation of granitic rocks of intermediate composition by various processes.

(3) Late stage - In this stage, the major intrusive and extrusive rocks are acid-granites.

(4) Final stage - This stage is characterised by the intrusion and extrusion of granitoids and aplites.

* Table 7.2 The Dharwarian Succession in the Shimoga Belt

Smeeth (1915)		B. Rama Rao (1940): Original formations		Probable alterations
Pre-Cambrian -- Basic dykes		Basic dykes, chiefly dolerites		
Eparchaean interval Felsite and porphyry dukes Closepet Granite (coarse pink or grey biotite-granite rarely slightly foliated)		Felsites and Porphyry dykes Closepet granite.		slightly foliated
Charnockite massife and later dykes		Recrystallisation and reconstitution of older rocks into complex types of the charnockite series Norite dykes Hornblendic dykes		slightly crushed and
Hornblende and pyroxene granulite dykes				
Peninsular Gneiss (Biotite-granite and gneiss with inclusions of schists)		Peninsular Gneiss : Complex granite gneisses		
Champion Gneiss (crushed granitic gneiss with zones of autoclastic conglomerate)		Eruptive unconformity		
Eruptive unconformity	Dharwar System: Upper	Some cherty and ferruginous silts, clays, calcareous site and clays, impure quartzites and conglomerates forming in part the G.R.formation (Local)		Somewhat altered but easily recognisable
Dharwar System: Upper Dharwars (Chloritic Division), Chloritic schists and greenstones, mica-schists, conglomerates, quartzites, crystalling limestones and banded ferruginous quartzites. Also schists with kyanite, staurolite, etc.	Dharwar System: Middle	Granite perphyry and granitic rocks, fine and coarse.		Micaceous granitic gneisses and crushed and foliated gneissic granites.
Lower Dharwars (Hornblandic Division) schistose hornblendic rocks with sub-ordinate magnetite- and hematite-quartzites, some calc-granulites etc.	Dharwar System: Middle	Basic and ultrabasic intrusives Ironstones, limestones, argillites quartzites and conglomerates; also ashee, tuffs and other volcanic products.		Banded ironstones with amphibole, etc., granular crystalline limestones, micaceous gneisses with cordierite, sillimanite etc. schistose conglomerates - all highly crushed and crystalline.
	Dharwar System: Lower	Phyolites, felsites and quartz-porphyry and other acid volcanics with opalescent quartz.		Quartz-schists, micaceous quartz schists and gneisses with opalescent quartz - highly crushed
	Dharwar System: Lower	Basic volcanic dykes and flows		Greenstones, hronblende-schists, etc.
		Original basement not recognised		

All stages may or may not be present in a given belt. Cyclic repetition of one or more stages is also recognised. Clear-cut distinctions into the four stages may not be easy in many cases.

In the Dharwars of South India, two stages of the development of a mobile belt are recognised: an initial stage of two cycles, and an intermediate and late stage[2]. Each stage has given rise to typical mineral deposits genetically associated with the intrusive or extrusive rock typical of that stage.

(1) Initial Stage :

Magmatic deposits : In the Dharwars of South India, the early stage of development is seen in two cycles. The first basic and ultrabasic magmatic invasion gave rise to magmatic deposits of chromium and iron ore. A second magmatic invasion took place subsequently which also produced chromium and iron deposits. Due to complex metamorphism, the cycles are not easily recognisable although the Salem ultrabasic complex belonging to these cycles is considered to be the younger of the two[2]. The resulting mineralisation is that of chromium and iron and is seen in the Shimoga-Tumkur-Arsikere-Mysore-Salem zone[2].

Mineralisation occurs in refolded regional synform in the eastern part of the belt, while, in the western part, the mineralisation is in a cross-folded synform.

Sedimentary metamorphic deposits : In the initial stage, a sedimentary metamorphic mineralisation episode is also recognised. This episode gave rise to iron mineralisation. Economic deposits associated with this structuro-metallogenic event are the iron ore deposits of Sandur area[2]. Manganese mineralisation seen in close association with the iron ore also may belong to the same structuro-metallogenic epoch.

(2) Intermediate-late stage :

The two stages cannot be separated owing to the high grade metamorphism undergone by the rocks. This intermediate and late stages have been typified by the development of gneisses (Champion gneiss) which gave rise to hydrothermal mineralisation of gold, copper, lead and zinc. Hydrothermal mineralisation was caused by granitic invasion also (Closepet granite). This structuro-metallogenic epoch has produced five zones of mineralisation[2]. These are :

(i) Gadag-Chitradurga-Mysore zone. Economic mineral deposits - gold (Gadag gold-field) and copper (Chitradurga).

(ii) Bensimalai - Hadhanate - Kowdali zone.

(iii) Ramagiri - east Bangalore zone - gold (Ramagiri).

(iv) Hutti, Chityala - Kolar - Mamandur - Kondadu - Vellore-Tirupathi zone. The mineralisation seen is of Au (As, Fe, Cu, Pb, W) and Pb (Ag, Zn, Cu, Fe). Economic mineral deposits : gold (Kolar - Hutti) copper, lead, zinc, silver, etc. (Mamandur and Kolar).

(v) Garimanapenta - Nellore zone - mica deposits.

With minor elements like Be, Nb, Ta, Y, etc. Of these, the belts i-iv occupy folded synformal structures flanked by antiforms with associated granitic cores. Belt v occupies a refolded synform of metasediments and gneiss[2].

Apart from the endogenetic mineralisation explained above, the Dharwars contain chemico-sedimentary deposits like limestone, dolomite, clay, etc.

Eastern Ghats

This belt consists of high grade metamorphic products of predominantly calcareous aluminous rocks. Various stages of hybridisation and granitisation are also recognised. Metavolcanics and metabasics are rare[2]. The geological succession is best represented by the Jeypore-Bastar section[1] which is shown in Table 7.3.

The mineralised belts of the eastern ghats do not clearly show the development of the various stages of the mobile belt. The eastern ghats rocks occur in the linear belts of high grade metamorphites, predominantly calcareous and aluminous, in various stages of granitisation and hybridisation. Matavolcanics and metabasic rocks are rare and the mineralisation may have taken place in the exterior and shelf-shore areas of the mobile belt. Thus, the iron ore deposits of this belt are considered to be of exogenic origin associated with banded hematite quartzite[2].

Table 7.3 Geological Succession in Jeypore-Bastar

PURANA	Upper :	Limestones, purple shales and slates
	Lower :	Pale sandstones and shales, purple shales quartzites, grits, conglomerates
	Unconformity	
IGNEOUS ROCKS	Dolerite dykes Granite and pegmatite Charnockites Greenstones and Granite-gneiss	
	Unconformity	
KHONDALITES	(Position uncertain)	
	Unconformity	
BAILADILA IRON ORE SERIES	Banded hematite-quartzites, grunerite-quartzites and white quartzites, etc.	
	Unconformity	
BENGPAL SERIES	Ferruginous schists, schistose conglomerates, biotite-hornblende-quartzites, shales, slates. Slates, schists, phyllites, grunerite-garnet-schists, magnetite-quartzites, garnet-biotite-gneiss, with basaltic flows and tuffs. Sericite-quartzites, andalustite-gneiss, banded magnetite-quartzites, grunerite-schists and quartzites with intercalated basalt flows	
	Line of division uncertain	
SUKMA SERIES	Sillimanite-quartzites, grunerite-schists magnetite and diopside-quartzites, hornblende-schists, biotite-cordierite gneiss, etc.	

The zones of mineralisation are :

(1) Pipalgaon-Lohara-Asola-Dewalgaon zone,
(2) Dhalli-Rajhara-Perrerkaro zone, and
(3) Bailadila-Kondpal-Parowada-Taki zone.

These zones give economic deposits of iron ore.

Endogenic mineralisation may have taken place in the other exterior areas belonging to the eastern ghats resulting in manganese formation. The resulting economic mineralisation is seen in the Srikakulam-Kalahandi-Raigada zone[2].

Singhbhum-Ganpur-Bijawar belt - east and east-central Peninsular India

The belt contains various types of rocks belonging to the Archaeans. The rock succession in these areas is as shown in Table 7.4.

Table 7.4: Succession in Singhbhum

Newer dolerite
Soda granite and Cu-U mineralisation
Chota Nagpur Granite-Gneiss
Dhanjori Orogeny (Singhbhum Orogeny of Sarkar and Saha)
Dalma and Dhanjori lavas
Dhanjori stage (? Kolhan series)
Singhbhum granite
Singhbhum Orogeny (Iron-ore Orogeny of Sarkar and Saha)
Iron-ore Series
Older Metamorphics

The northern and eastern portions of the Singhbhum craton are considered to show the development of a geosyncline. The basal conglomerate sequence is followed by black carbonaceous shales and turbidites intercalated with volcanic flows and tuffs. Gabbro-anorthosite intrusions took place in the marginal fractured zones of the geosyncline. Vanadiferous magnetite lenses were emplaced after these intrusions. The geosyncline was then subjected to folding and granitic intrusions. The granites are recognised as the Romapahari granite, Chakradharpur granite and the Singhbhum soda-granite associated with the shear zone and copper-uranium mineralisation[1].

*** Table 7.5: The Gangpur Series**

Iron-ore Series (?)	Phyllites, slates and lavas Raghunathpali conglomerate
------------ Shear zone ------------	
Gangpur Series	Phyllites and mica-schists Upper carbonaceous phyllites Calcitic marbles Dolomitic marbles Mica-schists and phyllites Lower carbonaceous quartzites and phyllites Gondites with associated phyllites (Base not seen)

Gangpur series occurring to the west of Singhbhum forms a geanticline with a closure in the east and granitic intrusions in the west[1].

The core of the geanticline shows gondites. They are followed by carbonaceous quartzites, phyllites, dolomitic and calcitic marbles, carbonaceous phyllites, mica schists, etc. At the top of this sequence is a shear zone. This is overlain by phyllites and mica-schists of the Iron-Ore Series. The Gangpur series has been intruded into by basic sills and Chota-Nagpur granites[1].

In the Singhbhum-Gangpur succession, two stages of development of the mobile belt are recognised. They are (i) initial stage and (ii) intermediate-late-final stage[2].

(i) Initial stage : The initial stage shows the development of metavolcanics and metasediments. Thus, there are magmatic mineral deposits and sedimentary metamorphic deposits[2].

> Magmatic deposits - The mineral deposits were formed as a result of ultrabasic and basic volcanic invasions of the initial stages of the mobile belt. The resulting structuro-metallogenic zone is the Cuttack-Keonjhar-Singhbhum-Dhalbhum-Mayurbhanj zone. In this zone, the important mineral deposits are chromite, nickel, titaniferous and vanadiferous magnetites, etc.
>
> Sedimentary-metamorphic deposits - The structuro-metallogenic zones of sedimentary-metamorphic deposits are the (i) Singhbhum-Keonjhar zone and (ii) Mayurbhanj-Sambalpur-Sundergarh zone.

The economic mineral deposits in this belt are iron and manganese ores.

The Gangpur manganese ore mineralisation also may belong to this group but may be an older endogenic development[2].

(ii) Intermediate-late-final stage : This stage shows the invasion of various granites like the Chota-Nagpur and Singhbhum granites. The structuro-metallogenic epoch is represented by the Benkakocha-Lawa-Kumar-Singhbhum copper zone and Pahardia-Monoharpur-Beldih-Kulad zone. The mineralisation seen is Au, Cu, (Fe, Ni, U), Pb (Cu, Au, Fe, Zn), U, Th, and Ca (Ca, Pr, Rd, Sm, Be). The important economic mineral deposits are of copper (Mosaboni, Rakha, etc.) nickel, (Mosaboni), uranium (Jaduguda), etc.

Sausar-Sakoli System - Central India

The rock formations of this belt (Sausar-Sakoli belt) are extensions of the Chipli Ghat series of the Chattisgarh basin.

The succession of the Sausar series is shown in Table 7.6.

Table 7.6: The Sausar Series

Minor intrusions	- Leucocratic granite, granite-pegmatite and quartz veins.
Granitic intrusives	- Gneissic granite and ortho-gneiss.
SAUSAR SERIES:	
BICHUA STAGE	- Dolomitic marble, serpentine marble, diopsidites, actinolite-schists, calc-silicate granulites with tremolite, anthophyllite, wollastonite and grossularite. Occurs in all areas except in the south and east.
JUNEWANI STAGE	- Muscovite-biotite-schists, quartz-biotite-granulite, locally biotite-gneiss, often garnetiferous; in places staurolite, kyanite and sillimanite; sometimes interdigitating with Bichua stage. Widespread but lenticular.
CHORBAOLI STAGE	- Quartzites, quartz-muscovite and felspathic quartz-schists, occasionally garnetiferous; sillimanite and kyanite in places; also autoclastic quartz conglomerates. Widespread except in the Central part of the belt.
Manganese ore and Gondite Horizon :	
MANSAR STAGE	- Muscovite and biotite schists, phyllite, often garnetiferous, become gneissic where feldspathised. Generally highly argillaceous. Two or three Manganese horizons in the schists. Most widespread stage of the Series.
Manganese ore and Gondite Horizon :	
LOHANGI STAGE :-	
(a) LOHANGI	- Pink and white calcitic marbles (locally dolomitic) and calciphyres, etc. Occurs mainly in the northern part of the belt.

(b) UTEKATA - Calc-granulite and calc-gneiss with silicates; contains microcline-bearing bands. Extensively distributed but thin and impersistent.

(c) KADBIKHERA - Quartz-biotite granulite with epidote and magnetite intercalated with quartz-biotite-gneiss. Occurs only in the western part but thin and lenticular.

SITASAONGI STAGE - Quartz-muscovite-schist, feldspar-muscovite-schist and intercalated quartzites; locally a gneiss with kyanite and garnet. Well developed in Bhandara, extending to the east as a schistose feldspathic grit. Passes laterally into the Lohangi Stage to the west.

Unconformity

TIRODI GNEISS - Biotite gneiss with subordinate intercalations of amphibolite, hornblende-schist, calc-gneiss, feldspar-muscovite-schist, biotite-granulite; commonly garnetiferous, locally porphyroblastic; varies from arkose-grit to gneiss according to metamorphic grade. Occupies the middle strip of the belt mainly but found also in other parts extensively.

Unconformity

METAMORPHIC GROUP - Hypersthene-granite gneiss, biotite-gneiss, hornblende-gneiss, amphibolite, etc.

(Note : The members of the substages of Lohangi tend to grade into each other laterally. They pinch out in the eastern and south-eastern part of the belt where they are replaced by the Sitasaongi Stage.)

The succession of the Sakoli series is shown in Table 7.7.

Table 7.7: The Sakoli Series

		Quartz-dolerite Tourmaline-muscovite granite and pegmatite
Sausar Series	Sakoli Series	Crushed albite-microcline-quartzite
		Phyllite and slate
		Hematite-sericite-quartzite
		Chlorite-muscovite schist with chloritoid, epidote-chlorite-schist, jaspilite, phyllite, chloritic horn-blende-schist
		Amphibolite and garnet-amphibolite
		Dolomites, crystalline limestone calciphyre and chlorite-tremolite-schist
		Microcline-muscovite-quartzite

Although the rocks belong to a mobile belt, the manganese and iron ore mineralisations are thought to be earlier than the development of the typical geosynclinal conditions represented by greywackes, etc. They are considered to be part of a suits of sedimentary rocks which were pre-orogenic[2].

The important mineral deposits of this belt are manganese ore (Mansar, Kandri, etc.), chromite (Pauni) and copper (Malanjkhand).

<u>Aravalli system - north-western Peninsular India</u>

The Aravallis are predominantly argillaceous in nature and are highly folded and metamorphosed. The succession of rocks is shown in Table 7.8.

* Table 7.8: Previndhyan formations of Rajasthan (After A. M. Heron)

Jodhpur		Mewar; Ajmer-Merwara (Main syncline)	Chitor; Nimbahera; Sadri (unmetamorphosed)		Jaipur	Alwar
Vindhyans Malani Volcanic series	Delhi System	Calc-gneisses Calc-schists Phyllites and biotite-schists Quartzites Basal arkose-grits	Upper Vindhyans (Semri series) Lower Vindhyans Sawa grits	Jiran Sandstone	Ajabgarh series Alwar series	Ajabgarh series Hornstone breccia Kushalgarh limestones Alwar series
Raialo (Makrana) Marble; Limestones of Ras	Raialo	Garnetiferous biotite-schists Raialo (Rajnagar) marble Basal grit - local	Raialo (Bhagwanpura) limestone			Raialo limestone Raialo quartzite
Shales (Sojat) Schists of Godwar	Aravalli System	Phyllites, cherty limestones, quartzites and composite gneisses Basal quartzites, grits and local conglomerates Thick volcanics (local)	Khardsola grits Badesar quartzites Ranthambhor quartzites Shales and cherty limestones Basal quartzites and grits	Great Boundary Fault Binota shales	Quartzites and schists of Baonli Awan ridge and Bechum, Biana and Lalsot hills, Volcanics of Basi, Schists of Rajmahal	Limestones and schists of Rajgarh. Conglomerates and quartzites of Rewasa
Grey, homogeneous gneiss		Banded gneissic complex	Bundelkhand Gneiss		Gneissic granite of Kerala and Ganor	

The rocks represented in the Aravalli system are considered to be a group of flysch and metavolcanics of the interior part of mobile belt. Mineralisation of the early stages of the mobile belt are rare. Acid magmatism of the intermediate stage has produced hydrothermal and pegmatitic mineralisation.

Two structural metallogenic units are recognised in the Aravalli system.

(1) Rewara-Betumi-Pahari-Dariba belt showing mineralisation of Pb, Zn, and mica. Economic mineral deposit - Lead & Zinc (Dariba).

(2) Zawar-Debari-Rikhabdeo belt showing the mineralisation of Pb, (Cu, Zn, Ag, Cd). Economic mineral deposit - Zawar.

The manganese deposits of Jhabua belong to the shelf-shore areas and are formed exogenetically with quartzite and limestone sedimentation.

The Precambrians and Cambrians (Proterozoic) : The Precambrian and Cambrian, or more precisely, Proterozoic formations are the next in importance to Archaeans from the point of view of mineral occurrence. Three formations belonging to the fairly easily recognisable structural metallogenic zones are grouped in this. The three units are :

(i) The Cuddapahs,

(ii) The Delhis, and

(iii) The Vindhyans.

(i) The Cuddapahs : The Cuddapah formations consist of a series of sedimentary rocks which have been metamorphosed to varying degrees. The main Cuddapah basin located in Andhra Pradesh is crescent shaped and the rocks rest on the irregular surface of the gneisses and schists of Archaean age. The Cuddapahs have been folded and also overthrust in the eastern margin. The major folds are parallel to the basinal margins. The main basin shows the following (Table 7.9) succession[1].

*** Table 7.9: The Cuddapah System**

Kurnool System		Various Sedimentary Rocks
Kistna Series (600 m)		Srisailam Quartzites Kolamnala Shales Irlakonda Quartzites
	Unconformity	
Nallamalai Series (1000 m)		Cumbum Shales Bairenkonda Quartzites
	Unconformity	
Cheyair (Cheyyeru) Series (3,300 m)		Tadpatri (Pullampet) Shales Cumbum Shales
	Unconformity	
Papaghni Series (1,400 m)		Vempalle Shales and Limestones Gulcheru Quartzites
	Unconformity	
	Archaeans ----	Gneisses and schists

In the structural and metallogenic context, the Cuddapahs are thought to show an incomplete development of a mobile belt. The western part of the basin probably shows the exterior of a mobile belt. Mineralisation associated with the early stage of development of the mobile belt is not seen. The intermediate stage of development of the mobile belt is physically represented by two mineralised belts :

(1) Cuddapah zone - Pb, Zn

(2) Agnigundala-Belapalle-zone - Cr, (Fe), Pb, Zn, (Cu).

Important mineral deposits are copper, lead-zinc, asbestos, barytes, limestone and diamond.

(ii) The Delhis

The Delhis occur along the main axis of the fold of the Aravallis in a major synclinorium. The rocks lie over the gneisses and the Raialos separated by an unconformity. The Delhi System is broadly comparable to the Cuddapah although the latter is less severely folded. The succession of the Delhi is shown below[1] (Table 7.10).

*** Table 7.10: The Delhi System**

Jodhpur	Main Synclinorium, Mewar and Ajmer-Merwara	Chitor and Nimbahera	Jaipur	Alwar
Vindhyans of Western Rajasthan				
Malani igneous suite	'Calc-gneisses' 'Calc-schists' Phyllites and biotite-schists	Lower Vindhyans Boundary Fault	Ajabgarh Series	Ajabgarh Series Hornstone breccia Kushalgarh limestone
Delhi System (not present)		Sawa shales and grits : Jiran sandstones	Alwar Series	Alwar Series
	Quartzites Arkose-grits			
Raialo Series (Makrana Marbles)	Raialo Series	Raialo Series : ...	...	Raialo Series

Metallogenically, the Delhis shows the development of the exterior and interior areas of a mobile belt. Basic volcanism of the early stage of the mobile belt and acid magmatism of the late stage are present. However, mineralisation is confined to the late stage of acidic magmatism. Three major structural metallogenic belts are recognised in the Delhis.

(i) Singhana-Khetri-Babai belt shows mineralisation of Cu, (Fe, As, Cp). Economic mineral deposits : Copper (Khetri, etc.).

(ii) Anjari-Dariba-Banrat-Gudkishordas Jodhawas belt shows mineralisation of Cu, (Fe, Ni, Co), Pb, (Zn, Sb). Economic mineral deposits : Copper, Lead, Zinc (Dariba).

(iii) Kishangarh-Ajitgarh-Taragarh-Ambamata belt shows mineralisation of Pb, (Cu, Ti), Cu. Economic mineral deposits : Copper, Lead-Zinc (Ambamata).

All these belts show a complex degree of folding and occupy synclinoriums[2].

The Vindhyans

The Vindhyans show extensive development in central India and consist of arenaceous and calcareous rocks with very small argillaceous bands. The Vindhyan succession is shown in Tables 7.11 and 7.12[1].

Table 7.11: Upper Vindhyan Succession

Bhander Series		Upper Bhander Sandstones Sirbu Shales Lower Bhander Sandstones Bhander Limestone (Nagode) Ganurgarh Shales
----------Diamond-bearing Conglomerate----------		
Rewa Series		Upper Rewa Sandstones Jhiri Shales Lower Rewa Sandstones Panna Shales
----------Diamond-bearing Conglomerate----------		
Kaimur Series	Upper	Dhandraul Quartzite Scarp Sandstone and Conglomerate
	Lower	Bijaigarh Shales Upper Quartzites and Sandstones Susnai Breccia Lower Quartzites and Shales

* Table 7.12 The Semri Series and its Equivalents

	Sone Valley	Karauli	Chitor
Rohtas Stage	Alternating limestones and shales	Tirohan Breccia .. Tirohan Limestone	Suket Shales .. Nimbahera Limestone
Kheinjua Stage	Glauconite beds Fawn limestone Olive shales	Glauconite-bearing beds	Nimbahera Shales
Porecellanite Stage	Porcellanites and silicified rocks	Sandstones and conglomerates	Grits and Conglomerates
Basal Stage	Kajrahat Limestone Basal Conglomerate		

The Vindhyans represent typical platform/shelf facies. No major folding or metallogenic epochs are recognisable in the Vindhyans[2].

7.2.2 The Himalayan Mobile Belts

In the Himalayan region, two structural metallogenic episodes are recognized rather broadly. One belongs to the Hercynian mobile belt which is essentially older than the development of the Himalayan, latter mobile belt. The Hercynian mobile belts were intruded by granites and gneisses. During the development of the Himalayan mobile belt, these granites and gneisses were reworked. In the eugeosynclinal areas of Himalaya-Naga-Lushai belt, ultrabasic and basic intrusives are present. They belong to the lower, middle and upper stages of the development of the mobile belt. Important mineralisation, both of magmatic and magmatic metamorphic types, is recognised concomitant with the intrusives. The resulting deposits are of chromium, iron and copper[2].

The important structural metallogenic belts of the pre-Himalayan era are as follows :

Dharampur-Bajila-Shishkhani belt,
Totan-Dakoti-Basantapur-Aiyur-Pindki belt,
Subathu-Ser-Kakag-Kondo belt,
Jari-Manikaram-Uchich-Kotkandi-Jaorinala belt,
Rampur-Benali-Lari-Kammarli, Kara Kunjan
Narkasi Forest - Prankutiran belt,
Kistwar-Shumahal-Dul belt,
Benihal-Khabrel-belt, and
Najawan-Kulam-Lashteal (?) belt,
Pb, (Zn, Fe, Cu, Ag, Au, Sb, Ba);
Cu, (Pb, Fe, As).

These zones occupy the axial portions of the regional folds and are associated with metamorphosed Palaeozoic and Precambrian sediments. Mineralisation has been correlated to the granites which occur nearby[2].

In the Himalayan mobile belt itself, the following structural-metallogenic belts are identified:

Hanle - chu belt,
Dras - Tashgam belt,
Kohima - Ninghthi-Kongal-Nungon belt,
Chakkargaon - Rutland Island belt, and
Cu, (Fe); Cu, (Co, Ni, Fe, Zn, As)[2].

7.2.3 The Platform Areas

The platform areas contain various sedimentary rocks with little of endogenetic mineralisation. The Ironstone-Shale-Barren Measure zone of the Gondwanas is not economically significant[2]. However, the clays of Gondwanas, especially the fireclay which occurs along with coal seams, are being commercially exploited today. Numerous occurrences of good grade clays belonging to the Tertiary period are also known.

Cambrian to Recent geological times are represented by various groups of rock formations typically developed in the peninsular and extra-peninsular regions. These formations have not so far given any indication of major endogenic mineralisation. The deposits seen in these formations are limestone, salt, gypsum, building stones, occasionally phosphatic nodules, etc.

A large number of mineral deposits are associated with the lateritic formations and the Quaternaries in many countries. In India, the lateritic terrain has been explored in some details, but not quite extensively, and the Quaternaries remain yet to be explored. These formations are of great interest to exploration geologists and are briefly discussed below.

7.2.4 Areas of Secondary Mineralisation

The areas described hitherto are mainly zones and belts of primary mineralisation and represent areas in which secondary processes have produced economic mineral deposits. The processes responsible for these accumulations are weathering, transportation, etc. The two groups of formations of interest are (i) laterites and (ii) Quaternaries.

(i) The lateritic areas

The peninsular part of India shows widespread occurrence of laterite. Laterite is a product of subaerial weathering of a wide variety of rocks. It contains hydrous iron oxides, aluminium oxides, quartz, titanium, and a variety of other minerals[6].

Laterites have been rather broadly grouped within and also above the Tertiary formations on the geological scale. They occur as cappings and also occasionally as boulders over rocks which have undergone lateritisation. The process of lateritisation affects the mineral constituents of host rocks in such a way as to concentrate them into economic mineral deposits, bauxite being a typical example[7].

Many laterites have yielded valuable mineral deposits like iron ore, manganese ore, nickel, ore, etc. The important lateritic zones of India and the associated mineral deposits are listed below[2]:

Ranchi-Palamau zone - Al, Fe

Bonai-Keonjhar-Singhbhum - Mn, Fe

Bolangir-Patna zone - Mn, Fe

Balaghat-Mandla zone - Al, Fe

Bilaspur-Shahdol zone - Al, Fe

Jabalpur-zone - Al, Mn, Fe

North Kanara-Belgaum zone - Al, Mn

Kolhapur zone - Al

Salem zone - Al

Bababudan zone - Al, Fe

Sambalpur-Kalahandi zone - Al Fe

Chitaldurga-Chickmagalur-Shimoga-Tumkur zone - Mn

Sandur-Bellary zone - Mn, Fe

Goa zone - Fe

Jammu and Poonch zone - Al, Fe

Sukinda zone - Cr, Ni, Co

Although lateritisation is not always an ore forming process, the widespread occurrence of important mineral concentrations within lateritic cappings makes it an important area of interest for the exploration geologist. The economic mineral deposits are bauxite, clay, manganese and nickel.

(ii) Quarternary areas

Quarternary system is recognised as a time stratigraphic unit and consists of the youngest sequence of strata including sediments which are being deposited presently[8]. The Quarternary formations of India may include glacial deposits, river deposits, desert deposits like sand dunes, loesses, beach deposits, and various alluvial terrances and formations. These formations present everywhere, are very interesting from the point of view of mineral exploration. It is in these formations that diamonds (riverine-accumulation - Panna), tin (deposits of Bastar), iron ore, gold (Ranchi), monazite (Kerala), etc. are found in the form of floats and fine particles. These formations have not yet been fully studied and classified in India.

7.3 Other mineralised formations

From Cambrian to Pleistocene Age, a large number of formations are recorded in the peninsular and extra-peninsular India. These formations, along with the mineral deposits associated with them, are summarised in Table 7.13.

Table 7.13: Other Geological formations and Mineral Deposits Associated with them

Age of the formation	Name of the formation	Mineral deposits
1) Cambrian	Salt range of Himalayas	Rock-salt, gypsum and dolomite, oil
2) Ordovician	Part of Haimanta system of Himalayas	No mineral deposit recorded
3) Silurian	-	-do-
4) Devonian	Muth Quartzites	-do-
5) Carboniferous to Permian	Gondwanas	Coal, fireclay, iron ore
6) Triassic	-	Limestones
7) Jurassic	-	No mineral deposit recorded
8) Cretaceous	-	Phosphates
9) Upper Cretaceous to Lower Eocene	Deccan Traps	Quartz, amethyst, chalcedony, etc. of gem quality

7.4 References

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Chapter 8

8.0 Exploration for Various Mineral Deposits

8.1 Field Guides

Each mineral deposit will have typical characteristics of its own and even deposits of the same mineral occurring close together exhibit some diverse characteristics. However, broad similarities of certain characteristics are also noticeable which make it possible to draw general inferences. In the case of Indian mineral deposits also, vast diversities between any two deposits of the same mineral in a particular type and broad similarities in a particular type are noticeable. Based on these, it is necessary to recognise certain field guides which help in the search for a given mineral deposit. Such guides are presented in Table 8.1.

The salient characteristics and some criteria by which the important ore forming minerals may be identified easily in the field have been tabulated in Appendix 8.1.. For further description of characteristics of various minerals, standard books on mineralogy may be referred to.

8.2 Preliminary observations

It has been generally mentioned that no two deposits, even though of the same mineral or ore, bear absolute comparison with each other. Naturally, an exploration strategy which has proved successful in one deposit may not meet with the same success in another. In formulating an exploration strategy therefore, some basic geological knowledge and other data of each deposit are necessary. In order to collect data systematically, the following check list of observations to be made and recorded is recommended :

Check list of preliminary observations

(1) Status of the area :

(a) developed area with good communications, or

(b) undeveloped area.

(2) Topography of the terrain

(a) plain/wooded/barren

(b) hilly/wooded/barren

(c) mountainous/wooded/barren

Table-8.1 : Field guides for recognising some important mineral deposits

SL. NO.	MINERAL DEPOSIT	STRATIGRAPHIC GUIDE	LITHOLOGICAL GUIDE	MINERALOGICAL GUIDE	PHYSIOGRAPHICAL GUIDE	STRUCTURAL GUIDE	FLOAT/PLACER GUIDE	OTHER GUIDES
1.	CHROMITE	INTRUSIVES IN DHARWAR AND EQUIVALENT META-SEDIMENTS	ULTRABASIC ROCKS, DUNITE, PYROXENITES, SAXONITES AND PERIDOTITES. ORE OCCURS IN SERPENTINISED TALC ZONE.	CHROMITE GENERALLY SHOWS GENETIC ASSOCIATION WITH NICKEL, COBALT, MAGNESITE, ETC.	ULTRABASIC ROCKS TEND TO OCCUPY AREAS OF SUBDUED TOPOGRAPHY. SHOW RUGGED TROPICAL WEATHERED SURFACE.	MANY CHROMITE ORE BODIES OCCUR WITHIN PROMINENT SHEAR ZONES AND ZONES OF MYLONITISATION.	QUITE COMMON AS BLACK SAND	(1) ULTRABASIC HOST ROCKS ARE LINEAR AND PARALLEL TO THE LINEATIONS OF THE HOST ROCK. (2) THE MAJOR MINERALISATION IS PARALLEL TO THE LONG AXIS OF THE INDIVIDUAL ULTRABASIC BODY.
2.	ASBESTOS							
	(1) CHRYSOTILE	MOSTLY IN CUDDAPAHS, ALSO PRESENT IN DHARWARS AND THEIR EQUIVALENTS	(1) SERPENTINISED ULTRABASIC ROCKS LIKE DUNITE AND PERIDOTITE. (2) SERPENTINISED DOLOMITE AND MAGNESIAN LIMESTONE	(1) SERPENTINISED ZONES (2) MAGNESITE, MAGNETITE, STEATITE, TALC, CALCITE, ETC.	SUBDUED TOPOGRAPHY	(1) SHEAR ZONES (2) FRACTURE AND FAULT ZONES (3) CHILLED CONTACTS OF INTRUSIVES		
	(2) TREMOLITE	—	(1) TALC-CHLORITE SCHIST (2) ACTINOLITE TREMOLITE SCHIST (3) ALTERED PYROXENITES				ASBESTOS AND ASBESTOS BEARING ROCKS.	AFTER RAINS, ASBESTOS SHOWS UP AS A COTTON LIKE FLUFF IN THE FRESH SOIL.
	(3) AMOSITE CROCIDOLITE	PRECAMBRIANS	IRONSTONE ROCKS	(1) GRUNERITE AND RIEBECKITE				
3.	NICKEL (LATERITIC)	INTRUSIVES IN DHARWAR AND THEIR EQUIVALENTS	ULTRABASIC ROCKS WHICH HAVE BEEN DEEPLY LATERITISED. LATERITE CAPPINGS FROM THE HOST ROCK.	(1) NICKELLIFEROUS MONTMORILLONITE WITH CHLORITE (2) SERPENTINE WITH GOETHITE	SUBDUED TOPOGRAPHY	—	NICKEL IN TRACES IS FOUND IN THE SOIL, DETECTABLE ONLY BY [illegible] CHEMICAL SAMPLING.	NICKEL DEPOSITS OF THE LATERITIC TYPE SHOW AFFINITY TO OCHREOUS MATERIAL FOUND IN THE LATERITE, CAPPING THE ULTRABASICS.
4.	MAGNESITE							
	(1) VEINS	INTRUSIVE IN PRECAMBRIANS	ULTRABASIC ROCKS, MAINLY DUNITE	CARBONATE	SUBDUED TOPOGRAPHY, VERY RUGGED.	INTERCONNECTED NET-WORKS OF SHEAR ZONES	[illegible]	INTRICATE WHITE [illegible] VEINS IN GREENISH GREY EARTHY DUNITES.
	(2) REPLACEMENT	KROL BEDS	ANY DOLOMITIC LIMESTONE IS A POTENTIAL HOST	CARBONATE	—	—	NOT [illegible]	MASSIVE FORM.
5.	DIAMOND	INTRUSIVE OF KURNOOL-VINDHYAN AGE	(1) KIMBERLITE-PIPE ROCKS (2) PLACER GRAVELS (3) OLD CONSOLIDATED CONGLOMERATES AND STRATA-BOUND CONGLOMERATE	JASPER PEBBLES, QUARTZITE, ETC.	CIRCULAR OR OVAL WATER-FILLED DEPRESSIONS FOR PIPES. VERY TYPICALLY RECOGNISED IN AERIAL PHOTOGRAPHS.		RESIDUAL DIAMOND IN GRAVEL IS [illegible] INDICATOR	CALCAREOUS TUFFA IS A TYPICAL ASSOCIATE OF KIMBERLITE ROCK.

Table-8.1: Field guides for recognising some important mineral deposits (Contd.)

SL. NO.	MINERAL DEPOSIT	STRATIGRAPHIC GUIDE	LITHOLOGICAL GUIDE	MINERALOGICAL GUIDE	PHYSIOGRAPHICAL GUIDE	STRUCTURAL GUIDE	FLOAT/PLACER GUIDE	OTHER GUIDES
6.	BARYTES	CUDDAPAHS, DHARWAR AND EQUIVALENT OF KROLS	DOLOMITIC LIMESTONE; AND QUARTZITE INTRUDED INTO BY DOLERITE BODY. ANY MAGNESIAN LIMESTONE IS A GOOD POTENTIAL HOST ROCK. STRATA BOUND TUFFACEOUS DEPOSITS	GALENA, PYRITE, SPHALERITE, QUARTZ, FLUORITE, SIDERITE, CALCITE, ETC. AS INDICATORS.	SOLUTION CREEP IS TYPICAL AND GENERALLY LEADS TO OUTCROPS	VEIN DEPOSITS OCCUR IN SHEAR ZONES	PRESENT IN MANY CASES AS GIANT BOULDERS	AREAS OF QUARTZ-GRANODIORITE INTRUSIVES HAVE BEEN KNOWN TO RICH BARYTE DEPOSITS. AREAS OF UPLIFT AND MAGMATIC ACTIVITY OF THE ABOVE TYPES ARE GOOD POTENTIAL TARGETS. PRESENCE OF TUFFACEOUS ROCK SHOULD BE INVESTIGATED.
7.	FLUORITE	(1) HYDROTHERMAL VEIN (2) VOLCANIC CARBONATITE	— CERTAIN CALCAREOUS ROCKS, CARBONATITES, ETC.	INTRUSIVE GRANITE	QUARTZ, CALCITE VEINS, GOSSANS AND CAPPING SHOW TRACES OF CaF_2. RADIOACTIVE MINERALS, VEINS, ETC.	VEINS OCCUR IN SHEAR ZONES. BEDDING/JOINT PLANE CONTROLS ALSO COMMON.	FLUORITE DEPOSITS ARE TYPICALLY SEEN ALONG DEEP SEATED RIFT TYPE FAULT ZONES	(1) GROUNDWATER RICH IN FLUORINE (2) AREAS OF EXPLOSIVE, ACIDIC VOLCANISM, VOLCANIC NECK (3) CARBONATITE INTRUSIVES
8.	COPPER	PRECAMBRIAN GREEN-STONE SCHIST	GOSSANS AND CAPPINGS. LIMONITIC CAPPINGS WITH TRACES OF COPPER, ETC.	SULPHIDE MINERALS LIKE PYRITE, PYRRHOTITE, CHALCOPYRITE, OXIDES LIKE MALACHITE, AZURITE, AND NATIVE COPPER.	HOST ROCKS GENERALLY OCCUPY PROMINENCES IN OTHERWISE FLAT COUNTRY. NARROW ELONGATED SCHIST BELTS.	SHEAR ZONES, FAULT AND FRACTURE PLANES	PRESENT PARTICULARLY AS NATIVE COPPER	THE MOST TYPICAL GUIDE FOR COPPER IN INDIA ARE THE OLD WORKINGS, SLAG HEAPS, WASTE DUMPS, CHARCOAL DUMPS, FRESH SOILS, LUXURIANT GROWTH OF TREES IN AN-ALIGNMENT, OLD WATER-FILLED DEPRESSIONS, ETC.
9.	LEAD-ZINC	PRECAMBRIAN GREEN-STONE SCHIST	LIMESTONE, DOLOMITIC LIMESTONES AND OTHER CALCAREOUS ROCKS. CAPPINGS AND GOSSANS WITH CARBONATE MINERALS	SULPHIDE MINERALS, GALENA MARCASITE, ETC.	HOST ROCKS OCCUPY GENERALLY ELEVATED GROUND. NARROW ELONGATED SCHIST BELTS	SHEAR ZONES AND FAULT PLANES	PRESENT	OLD WORKINGS AS DESCRIBED ABOVE. TYPICAL SMELTER POTS OF OVAL SHAPE MADE OF CLAY ARE COMMON NEAR OLD WORKING.
10.	GOLD	PRECAMBRIAN GREEN-STONE AND ACIDIC LAVA-FLOWS	GOLD-BEARING QUARTZ VEINS, OCCASIONALLY BLUE QUARTZ	NATIVE GOLD AND SULPHIDE MINERALS, BARITES, FLUORITE, STIBNITE, REALGER, CINNABAR, ETC., ARE INDICATORS.	NARROW ELONGATED BELTS OF GREENSTONE SCHIST BELTS	REGIONALLY FOLDED, SYNCLINES, AND DRAG FOLDS, CROSS FOLDS, SHOW MORE MINERALISATION.	ALWAYS PRESENT IN THE FORM OF FLAKES, SMALL GRAINS AND OCCASIONALLY IN LARGE BONANZA SIZES	ANCIENT WORKINGS, OLD WATER-FILLED DEPRESSIONS, SLAG HEAPS, WASTE DUMPS, LUXURIANT GROWTH OF TREES ALONG CERTAIN ALIGNMENTS, ETC.
11.	TIN	PRECAMBRIAN	ZONED PEGMATITES	LEPIDOLITE IN PEGMATITE	TYPICAL PATTERN OF PEGMATITE OCCURRENCE, RECOGNISABLE IN AERIAL PHOTOGRAPHS	THE INTRUSION OF PEGMATITE IS CONFINED TO CONTACTS AND IS PARALLEL TO THE HOST ROCK FOLIATION	PRESENT	TIN DEPOSITS ARE MOSTLY ECONOMIC WHEN OCCURRING AS A PLACER

Table-8.1 : Field guides for recognising some important mineral deposits(Contd.)

SL. NO.	MINERAL DEPOSIT	STRATIGRAPHIC GUIDE	LITHOLOGICAL GUIDE	MINERALOGICAL GUIDE	PHYSIOGRAPHICAL GUIDE	STRUCTURAL GUIDE	FLOAT/PLACER GUIDE	OTHER GUIDES
12.	TUNGSTEN	ARCHAEAN INTRUSIVE GRANITE	QUARTZ VEINS, QUARTZ-RICH PEGMATITE VEINS. DISSEMINATION IN GRANITE.	—	—	INTRUSIVE GRANITE BASE AND CHILLED CONTACT WITH COUNTRY ROCKS	PRESENT AND FORMS IMPORTANT PLACER DEPOSITS	SCHEELITE IS FLUORESCENT AND RECOGNISABLE UNDER ULTRAVIOLET LIGHT.
13.	MICA	ARCHAEAN INTRUSIVE GRANITE PLUTONS AND ASSOCIATED PEGMATITES	MICA PEGMATITES OCCUR MOSTLY IN MICA SCHISTS, AND MICACEOUS QUARTZITES	(1) PLAGIOCLASE IN OUTER CHILLED CONTACT OF PEGMATITE WITH MICA SCHIST (2) KAOLINISED OCHRE-COLOURED FELSPAR AND INCLUSIONS OF MUSCOVITE IN FELSPAR (3) POORLY CRYSTALLISED FELSPAR (4) SMOKY QUARTZ IN ZONED PEGMATITES (5) RADIOACTIVE MINERALS (6) TRACE ELEMENTS Nb (300–500 ppm) Cs (50–150 ppm) Li (5–45 ppm) ARE GOOD INDICATORS (7) DECREASING Pb and AND INCREASING Ba AND Sr CONTENTS IN UNDEFORMED PEGMATITES (8) HIGH AND INTERMEDIATE VALUES OF TRICLINICITY OF POTASH FELSPARS	TYPICAL PATTERNS OF PEGMATITE OCCURRENCES. RECOGNISABLE ONLY IN AIRPHOTOS.	PEGMATITES INTRUDE ALONG BEDDING AND FOLIATION PLANES, AND TENSION JOINTS OF MICA SCHISTS. REGIONAL FOLD PLUNGES INFLUENCE DEPTH OF MICA BEARING PEGMATITES	MICA FLAKES AND BOOKS IN ALLUVIUM AND ALONE	(1) MICA OCCURS IN ZONES 0-5.2 KM AWAY FROM MAJOR ADAMALITE GRANITE PLUTONS (2) UNDEFORMED PEGMATITES CONTAIN MICA BOOKS (3) DISCORDANT PEGMATITES ARE GOOD ORE CARRIERS (4) WHEN THE CONTACT OF THE PEGMATITE AND HOST ROCK IS SHIFTING, MICA BOOKS ARE MORE COMMON
14.	LIMESTONE AND DOLOMITE	NO SPECIFIC GUIDE AS LIMESTONE AND DOLOMITE OCCUR IN ALL GEOLOGICAL FORMATIONS	—	PRESENCE OF KANKAR (LIME CONCRETIONS IN THE SOIL)	GENERALLY SUBDUED TOPOGRAPHY	—	PRESENT	THE BEST TEST FOR LIMESTONE/ DOLOMITE IS THE ACID TEST, WHEN EFFERVESCENCE IS NOTICED. LIMESTONE COUNTRY RECOGNISED BY SINK HOLES, KARSTS AND SUBSOIL MOISTURE AND DRAINAGE PHENOMENA IN AERIAL PHOTOGRAPHS. HARD WATER IS A USUAL FEATURE IN LIMESTONE/DOLOMITE TERRAIN.
15.	GYPSUM	NO SPECIFIC GUIDE	MOST LIMESTONE AREAS ARE POTENTIAL HOSTS FOR GYPSUM	DESERT AND SEMIARID REGIONS OF PRESENT OR PAST GEOLOGICAL ERA	SUBDUED TOPOGRAPHY	—	PRESENT	PRESENCE OF HARD WATER

Table - 8.1 : Field guides for recognising some important mineral deposits (Concld.)

SL. NO.	MINERAL DEPOSIT	STRATIGRAPHIC GUIDE	LITHOLOGICAL GUIDE	MINERALOGICAL GUIDE	PHYSIOGRAPHICAL GUIDE	STRUCTURAL GUIDES	FLOAT/PLACER GUIDE	OTHER GUIDES
16.	PHOSPHORITE	NO SPECIFIC GUIDE	LIMESTONE, CALCAREOUS PHYLLITES, ORTHOQUARTZITES, BLACK SHALES, AND CHERTS.	RADIOACTIVE MINERAL AND RADIOACTIVITY	—	—	—	PHOSPHORITE OCCURS IN MIOGEOSYNCLINES SURROUNDING ANCIENT CRATONS. ALGAL STROMATOLITES INDICATE THE PRESENCE OF PHOSPHORITE. BEDS OF FORAMINIFERA ECHINOIDS, CRABS, ETC. IN FOSSIL BED ARE FAVOURABLE INDICATORS.
17.	IRON ORE (HEMATITE)	PRECAMBRIAN IRON ORE FORMATIONS	BANDED HEMATITE, QUARTZITE, JASPER, ETC. AT THE BASE. LATERITIC CAPS WITH IRON ORE PIECES, PINK FERRUGINOUS PHYLLITES AT THE BASE	HEMATITE AND LIMONITIC MINERALS	ALWAYS OCCUPY TOPOGRAPHICALLY PROMINENT PLACES LIKE HILL TOPS, RIDGE TOPS, PLATEAU TOPS, ETC.	PRESERVED IN REGIONALLY FOLDED STRUCTURES.ANTICLINES SHOW POOR DEPTH. SYNCLINAL FOLDS SHOW THICK ORE BODIES	INVARIABLY PRESENT	- -
18.	MANGANESE ORE	PRECAMBRIAN METASEDIMENTS	QUARTZ-SPESSARTITE (GONDITE) ROCK, MANGANIFEROUS PHYLLITES AND LOOSE CHERTY QUARTZITES	PRESENCE OF WAD	THOSE ASSOCIATED WITH IRON ORE OCCUPY TOPOGRAPHIC FEATURES LIKE PLATEAU AND RIDGE EDGES, SOMETIMES PLATEAU TOPS.	PRESERVED IN SYNCLINAL TROUGHS. CROSS FOLDS SHOW BEST ORE CONCENTRATION	INVARIABLY PRESENT	(1) MANGANIFEROUS LATERITIC CAPPINGS. (2) COLOUR DIFFERENCES IN SOIL. DARK GREY TO BLACK COLOUR FOR MANGANESE (3) MANGANESE BEARING SOIL LEAVES AN OILY FILAMENT ON WATER (4) PLANTS LIKE NAMA, KUNDEL, JAMBA ARE THOUGHT TO HAVE AFFINITY FOR MANGANESE DEPOSITS BUT NOT ESTABLISHED.
19.	KYANITE-SILLIMANITE	HIGHLY METAMORPHOSED ARGILLACEOUS SEDIMENTS OF PRECAMBRIAN	SILLIMANITE-KYANITE, ANDALUSITE ROCK	KYANITE, SILLIMANITE	—	—	ALWAYS PRESENT AND FORMS THE MOST ECONOMIC DEPOSITS	THESE MINERALS ARE ALWAYS PRESENT IN VERY HIGH METAMORPHIC TERRAIN
20.	GRAPHITE	HIGHLY METAMORPHOSED PRECAMBRIAN	—	GRAPHITE, RADIOACTIVE MINERALS	—	CONFINED TO ZONES OF INTENSE SHEARING MIGMATISATION AND FELSPATHISATION. CONTACTS OF HIGH GRADE METAMORPHIC ROCKS	PRESENT	PRESENT IN HIGHLY METAMORPHOSED AREAS
21.	BAUXITE	RECENT FORMATIONS	LATERITES AND SOME TERTIARY LIMESTONE AND CLAY BEDS	LIMONITIC MINERALS OF LATERITE. GIBBSITE IN NODULAR AND PISOLITIC FORM	PRIMARY DEPOSITS CONFINED TO PLATEAU TOPS, MOSTLY FLAT	—	PRESENT AS SCREES AND BURRIED FLOAT	BAUXITE IS EASILY RECOGNISED BY THE PHENOMENA OF SCRAP RETREAT. IN AIR PHOTOS,AREAS OF SPARSE BUSH IN AN AREA OF LUXURIANT VEGETATION.
22.	TALC-PYROPHYLLITE	HIGHLY METAMORPHOSED PRECAMBRIAN	MAGNESIUM BEARING CARBONATE AND SILICATE ROCKS	—	—	—	PRESENT	VERY SOFT ORE IN HIGHLY METAMORPHOSED AREAS
23.	CLAY	—	RESIDUAL FORM IN WEATHERED GRANITES	—	--	—	—	RECOGNISABLE BY THEIR TYPICAL PHYSICAL APPEARANCE

(3) Regional geology and structure of the terrain

(a) igneous,
(b) sedimentary,
(c) metamorphic,
(d) residual,
(e) alluvial terrain,
(f) structure and tectonics-simple or complicated

(4) Size of the ore body

(a) length,
(b) width, and
(c) depth

(5) Outline of the ore body

(a) simple,
(b) irregular, or
(c) complex

(6) Types of ore bodies

(a) capping,
(b) reef,
(c) veins (various types of veins),
(d) disseminations,
(e) lenses and pockets and other irregular bodies, or
(f) stratified sedimentary beds.

(7) Nature of the enclosing rock

(a) lithology,
(b) hard, medium, soft, friable, etc.

(8) Wall rock alteration

(a) pronounced,
(b) prominent,
(c) not prominent or
(d) totally absent

(9) Mineralogy

(a) monomineralic,
(b) polymineralic, and
(c) nature of gangue minerals

(10) Structure

(a) simple,

(b) fairly complex,

(c) complex, or

(d) very complex

(11) Disposition

(a) extent of overburden

(i) no overburden,

(ii) partially covered by overburden, or

(iii) fully covered by overburden

(b) depth extension

(i) confined to the surface,

(ii) partially confined to the surface, or

(iii) fully extending underground

(12) Ground/surface water

(a) present, but not likely to cause any trouble,

(b) present and likely to interfere with drilling, pitting, trenching, aditing, etc. or

(c) not present at all

(13) Field evidence about ore genesis

(a) clear, or

(b) not clear

(14) Climate of the area with records of rainfall and temperature variations

(a) desert,

(b) arid,

(c) semiarid,

(d) humid, etc.

The various factors mentioned above influence the choice of exploration methods and also the quantum of exploration in many cases. The latter is also dependent on the required degree of precision of the exploration data.

After a promising mineral deposit has been located, and its broad characteristics studied, the next step is to choose a particular scheme for detailed exploration based on specific needs and other guiding factors like cost, time, etc.

There are many factors which go a long way in helping the exploration geologist in his choice of an exploration method. The factors discussed below may be made use of either individually or in varying combinations.

i. Capacity of exploration method to give reliable type of samples in sufficient quantity

The prime objective of any exploration programme is to collect samples of desired quantum and type and to prove the quality and extent of the deposit. Hence, it is important to choose a method which yields such samples laterally and in depth. Samples should be available continuously at regular intervals. In the surfacial deposits (also shallow), pitting yields most reliable samples. But, as mineralisation extends downwards, most of the observations have to come from diamond-core drilling which can later be substantiated by samples obtained from exploratory mining.

2. Efficiency of the method in operation

This depends on a host of conditions like the organisation of the team, nature of the country rock, stratigraphic sequence, nature of mineralisation, structural features, etc. Pitting in hard rock like quartzite is time-consuming and costly, and it can be resorted to only under compelling circumstances. In such cases, core drilling will yield equally reliable data.

3. Cost bearability

The total cost of operations should not become unbearably high. The geologist should remember that the money sunk in exploration cannot be recovered in any form except in the sale value of the ore to be proved. The amount expended on this account should be such as to be easily absorbed by the sale price later.

4. Maintenance of required speed of operations

The exploration programmes are mostly time bound. Sometimes, either due to breakdown of machinery or any other reason, the programme may get stalled. Hence, the method chosen should be quite flexible with either spare machinery or manpower or by opting for substitution of the programme with another suitable method.

5. Conformity with the shape, size and pattern of mineralisation

This factor almost totally controls any exploration operation. For deposits of large aerial extent and surfacial nature, pitting and trenching are adopted. Asbestos, bauxite, magnesite, and diamond are explored by these methods. However, spacing of the pits or trenches is of vital consideration as it influences the total cost of operation. Care should, however, be exercised in exploring some minerals like mica either by pitting or by drilling. For deep seated deposits such as chromite, copper, lead, and zinc ores, drilling will have to be done. Drilling in such deposits is often controlled by the structure and stratigraphic sequence.

6. Topography of the area

Some areas remain inaccessible due to their altitude, thick vegetation, poor ground condition like marshy terrain and lack of communication. Though man can reach these areas, it would be very difficult to take material and machinery. This particular situation has been faced in the case of bauxite deposits. Even many iron ore deposits had been inaccessible in India until recently. The exploration geologist will have to choose such a method which entails easy transportation of man and material, availability of firm ground for setting up camps and drilling machines, availability of other facilities, etc.

7. Marketability of the ore at the exploratory stage

In some exploration programmes, it may be necessary to sell the ore raised during the operation. In such cases, the choice may be in favour of a method which may yield large quantities of ore. This is generally the case in the exploration of copper ore which is sent to smelters even far removed from the deposit. Similar is the situation with mica, asbestos, etc.

8.3 Important Mineral Deposits and their Exploration

India possesses a large number of metallic and non-metallic mineral deposits which are found scattered throughout the length and breadth of the country. Of these, the most important deposits are chromite, asbestos, nickel, magnesite, diamond, barytes, fluorite, copper, lead-zinc, gold, tin, tungsten, mica, limestone and dolomite, gypsum, phosphorite, iron-ore, manganese ore, kyanite, sillimanite, graphite, talc, pyrophyllite, bauxite and clay.

For convenience of discussion, these mineral deposits have been grouped on the basis of their host rock associations as below :

(1) Mineral deposits associated with igneous ultrabasic and basic rocks.

(2) Mineral deposits associated with igneous intermediate rocks.

(3) Mineral deposits associated with igneous acidic rocks.

(4) Mineral deposits associated with sedimentary evaporite rocks.

(5) Mineral deposits associated with metamorphic rocks.

(6) Mineral deposits associated with residual rocks.

(7) Mineral deposits associated with placers.

8.3.1 Mineral deposits associated with igneous ultrabasic and basic rocks

The major ultrabasic and basic rocks are peridotite, dunite, saxonite, pyroxenite, enstatite, norite, dolerite, basalt, gabbro, etc. These rocks may be extrusive or intrusive in nature. The important mineral deposits associated with these rocks are chromite, asbestos, magnesite, platinum, titaniferous magnetite, corundum, nickel-copper sulphides, silver, cobalt, etc. Of these, the most important deposits are chromite, asbestos, nickel, magnesite, diamond, barytes and fluorite. The geology, prospecting and exploration of these deposits are dealt with below. Guidelines evolved by the Geological Survey of India[1] have been used in this Bulletin wherever available.

Chromite

Geology

Chromite deposits occur mostly in the Precambrian ultrabasic intrusives. Five types of commercially important deposits are recognised. They are[2]

(1) evenly scattered,
(2) schlieren banded,
(3) stratiform (with bedded appearance),
(4) sackform (pockety), and
(5) fissure form (vein-like).

These may occur independently or in various combinations. The usual host rocks are dunite, saxonite, leherzolite, pyroxenite, enstatite, norite, etc. Some details about the major commercial chromite deposits of India are given in Table 8.2.

Table 3.2 : Geological distribution of chromite deposits in India

State	District	Geological formation	Host rock
Bihar	Singhbhum (Roro-Jojohatu)	Intrusive in Iron Ore Series[3]	Serpentinized dunite and enstatite saxonite[4]
Maharashtra	Bhandara (Pauni)	Sakoli Series	Steatitised-silicified serpentinites[3]
Karnataka	i) Hassan (Byrapur)	Dharwars	Serpentinised peridotites with lenses of pyroxenites, amphibolites, etc.[5]
	ii) Mysore	-do-	Serpentine-talc-chlorite rock and amphibolites[6]
Orissa	Keonjhar, Cuttack Dhenkanal (Sukinda, Boula, Nousahi)	Iron Ore Series	Talc-serpentine rock altered from ultrabasics[3]

Chromite is a product of magmatic segregation and is invariably associated with intrusive ultrabasic igneous rocks. All the Indian deposits are considered as primary differentiates of ultrabasic magmas which intruded successively, producing several generations of chromite deposits. The earliest phase of the intrusion gave rise to coarse-grained chromite. This was followed by medium-and fine-grained deposits[7]. Many ultrabasic intrusives, particularly in Orissa, show extensive lateritisation which has remobilized the disseminated chromite, producing extensive lateritic deposits.

Some chromite ore bodies show signs of genetic association with shear zones. This is particularly evident in Orissa and Karnataka deposits where they occur very close to zones of mylonitisation. Some ore bodies, particularly those of Keonjhar area, show signs of having been folded along with their host rocks, producing complexly folded ore bodies. The ore bearing ultrabasic rocks of Bhandara district have shown some genetic association with regional synclinal troughs[4].

Many chromite ore bodies exhibit lensoid shapes and the ore is traceable for long distances. Some ore bodies of Sukinda in Orissa[8] have shown a continuity of about 1.8 km. In depth persistence, some ore bodies have been traced[9] down to 200 m. Dips of foliation generally show high variation, from flat lying lenses to vertical veins.

Prospecting and Exploration

The important field guides for locating chromite ore bodies are shown in Table 8.1. Since chromite deposit occur exclusively in ultrabasic rocks, the primary aim of prospecting is to locate such targets. Chromite-bearing ultrabasic rocks are easily recognised in the field. The target area may be mapped on a scale of 1 : 25000 to separate out promising ultrabasic rocks which show obvious evidence of chromite mineralisation. Outcrops of chromite may be usually present and may be of mappable dimensions. In case mineralisation is suspected but outcrops are not visible, geochemical and geophysical prospecting may be carried out to locate specific deposits. Geophysical prospecting by gravity and electrical methods have helped in locating chromite ore bodies in Maharashtra and Orissa. When the densitites of the ore body and the host rock differ sharply, the gravity method is successful. The ultrabasic bodies generally show contrastable magnetic characteristics which help in mapping them from their host country rocks. Electrical methods are useful in locating chromite ore bodies in serpentine zones because the electrical resistivity of chromite is 2-3 times that of serpentine[10]. Various guidelines for the exploration of chromite deposits are given in Table 8.3.

Asbestos

Geology

Asbestos is a name applied to a group of minerals of varying compositions. Asbestos has been classified mineralogically as follows[11]:

(1) Amphibole group

- (a) Orthorhombic
  - (i) anthophyllite
  - (ii) amosite-rich in iron than anthophyllite, and
  - (iii) tremolite
- (b) Monoclinic
  - (i) actinolite, and
  - (ii) crocidolite

(2) Chrysotile group

- (a) chrysotile, and
- (b) picrolite

Table 8.3 : General guidelines for exploration work for chromite (methods for stratiform chromite generally satisfy barytes, excepting bedded deposits), fluorite, etc.

Method	Stratiform deposits		Podiform bodies		Remarks
	Regional exploration stage	Intensive exploration stage	Regional exploration stage	Intensive exploration stage	
1. Mapping	1: 2000 to 1:5000	1:1000 to 1:2000	1:2000 to 1:5000	1:1000	To isolate ultrabasics and mappable chromite bodies, sheer zones, zones of serpentinisation, etc.
2. Drilling	200-500 m intervals	100 m intervals	100-200 m section intervals; 1 to 2 boreholes in each section	50-100 m section intervals at 3/4 levels down to a workable depth	Also study core recovery in the ore zone, lithology, occurrence of unsuspected ore-bodies, etc.
3. Trenching	As necessary to expose the concealed extensions	Not recommended	As necessary to explore the concealed sections along strike	Not recommended	—
4. Pitting	1-3 numbers across each representative ore type	3-5 numbers for every mass/body	2-4 numbers across for every representative ore type	3-5 numbers for every mass/body	More helpful in vein and lens-like bodies. Recovery with depth should also be studied.
5. Sampling	Core and sludge, bulk and chips from pits, etc.	Core and sludge bulk samples for grade analysis and beneficiation	Core and sludge, separate analysis for gangue-free ore, bulk samples from pits according to ore types	Core and sludge samples from pits for grade analysis for beneficiation.	—

(Based on Manual of Mineral Exploration, Geol. Sur. India, Misc. Pub. No.33)

The major commercial asbestos deposits of India are listed in Table 8.4.

Table 8.4 : Geological distribution of major asbestos deposits in India

State	District (area)	Geological formation	Host rock
Andhra Pradesh	Cuddapah (Brahmanapalle and Chinnakudala)	Cuddapahs	Chilled contact of magnesian limestone intrusive dolerite sill[12].
Bihar	Singhbhum	Iron Ore Series	Contact between serpentinised perido-tite intrusives and shales of Iron Ore series[13].
Karnataka	Hassan (Holenarssipur)	Dharwars	Dunite intrusives[14].
Orissa	Mayurbhanj	Iron Ore Series	Contact between ultra-basic intrusives and Iron Ore Series.
Rajasthan	Ajmer (Khotra, Manpura) Bhilwara (Daulatgarh) Dongarpur Jhunjhunu Pali Udaipur (Dhelana, Abbasi, Sapod)	Precambrians (Aravallis)	Contacts between intrusives and various schistose country rocks, limestones and dolomites.

Indian asbestos deposits are associated with rocks of two geological ages: (i) Precambrians, particularly Dharwars and equivalent formations, and (ii) Cuddapahs. In both cases, the mineralisation is confined to chilled borders of ultrabasic intrusives. The chilled borders, serpentinisation and development of asbestos deposits are very intimately connected and can be used as guides to search for ore deposits. The most important deposits are of chrysotile and amphibole types.

Chrysotile asbestos is essentially a fibrous type of serpentine. Serpentinisation is a type of autometamorphism which occurs in ultrabasic bodies like dunite. This autometamorphism is accompanied by emanations of hot residual solutions from the rock body itself. In the first stage, some 40 to 60 per cent of the rock is serpentinised. In the second stage, the serpentinisation takes place along fractures and openings. The fibre of asbestos is considered to be developed within the fracture zone[7].

Amphibole asbestos is thought to have originated due to deep seated metamorphism. Molecular reorganisation of the host rock without transfer of its constituents is thought to be the process responsible for the formation[7].

Geological structures have played a major role in the control and localisation of some important asbestos deposits. Field evidences supporting this hypothesis are shown below[15]:

(1) Mineralisation is richer within the synclinal folds, the secondary synclines showing the richest deposits.

(2) The noses of anticlines are devoid of asbestos mineralisation.

(3) Where folding is not intense, mineralisation is poor.

(4) The major ore shoots show pitches parallel to the enclosing structure.

(5) When the synclines are shallow, yellow and light asbestos are seen in greyish serpentine. Black serpentine is absent.

(6) In shallow synclines, the veins occur over a wider range of serpentinised zone, and do not remain localised as in the case of deep troughs.

Regional-scale folds also may influence asbestos mineralisation. The asbestos deposits of Hassan district are preferentially concentrated along the major regional anticlinal axis. Some of these features can be used as guides to locating new ore bodies.

Asbestos occurs in the form of very narrow seams and mass fibres. Individual veins may have lengths varying between 0.3 and 30 m and width ranging between 0.005 and 0.3 m. Individual fibre length may vary[12] between a few mm and some 50 cm.

Prospecting and Exploration

Asbestos deposits of tremolite and chrysotile varieties are found only in ultrabasic rocks, their weathered derivatives, chilled contacts and magnesian limestones near the ultrabasic intrusives. Therefore, the area of initial search is exclusively confined to the terrain where ultrabasic rocks occur. As in the case of chromite, the ultrabasic rocks should be mapped out on suitable scales initially. The asbestos bearing shear zones, or chilled contacts, can be mapped only if they are of large mappable dimensions.

Airborne as well as ground magnetic surveys help in locating ultrabasic bodies which may be potentially asbestos bearing[11]. Although asbestos is nonmagnetic, it is associated with magnetite and this association makes magnetic methods effective. For aeromagnetic surveys flights are arranged at 4 km. intervals at a flight elevation of 150 m. In case the terrain is very rugged, the flight height is reduced to 90 m. Ground magnetic traverses are spaced at 60 or 90 m and readings are taken at every 15 or 30 metres[12]. Such surveys also can discriminate asbestos-bearing serpentinous horizons although actual ore zones cannot be distinguished this way.

The exploratory sequence[16,17] followed in asbestos and other relevant details are shown in Table 8.5.

Table 8.5 : Exploration Guides—Asbestos

Method	Details
1. Mapping	1 : 200 to 1 : 600 in ideal host rocks.
2. Pitting	Random trial pits followed by systematic pits in 3-15 m. grid and size varying from 1.5 m X 1.5 m to 2.5 m X 2.5 m with variable depths, to ascertain grade and structure of the deposits.
3. Trenches	Shallow to deep, depending on the need but usually at 15 m intervals.
4. Drilling	15 - 30 m interval or at larger intervals, for regional exploration.
5. Exploratory mining	Drives, crosscuts, winzes and raises to explore the contacts, and bulk sampling.
6. Sampling	Visual sampling to get ideas on fibre content.

Visual sampling is a technique used in cross fibre asbestos deposits, and gives reliable results about the fibre content within the ore zone without the aid of mining and milling tests. In this, all visible fibre exposed in stopes, drives and other openings, drill cores, etc., are counted and measured in terms of 1.59 mm fibre lengths as being useful and those below as unusable. The widths of all individual veins encountered are totalled up and the percentage of fibre to the width of ore is computed for each section. In a drive, the average value is calculated by the weighted average method. The values so obtained can be converted into percentage fibre per tonne also. The length ranges of the fibres and their individual percentage availability for every tonne are also calculated[12]. For conducting visual sampling, the fibres from individual veins, seams, etc. should be systematically and carefully scooped out by a pocket-knife and measured by a scale. In case of partings within seams, fibres up to each partings should be scooped out separately. The widths of the individual seams are automatically fixed by their fibre lengths and this makes it easy for the weighted average computation for a certain drive length, stope or sample width.

Nickel

Geology

Nickel deposits are known in two commercial forms. They are :

(1) residual concentration of nickel silicate formed by the weathering of ultrabasic igneous rocks, and

(2) nickel - copper sulphides formed by magmatic concentration and hydrothermal action.

The important nickel deposits of India are listed in Table 8.6.

Table 8.6 : Geological distribution of important nickel deposits in India

State	District (area)	Geological formation	Host rock
Orissa	Cuttack (Sukinda)	Ultrabasic intrusive in Iron Ore Series	Nickeliferous laterite and serpentinous ultrabasic rocks[18].
Bihar	Singhbhum (Mosaboni Copper deposit)	Iron Ore Series	Mica schists, quartz-schist, hornblende schists[19]. Occurs along with copper ore.

Both the mineralisations are Precambrian in age although the Cuttack deposits have become economically valuable only due to lateritisation of a later geological age.

Many ultramafic layered intrusive rocks contain nickel in a highly disseminated form. In Sukinda, Cuttack district, the original host rock is an enstatite dunite. Nickel deposits occur as thin bands within the laterite covering the original host rocks. Sometimes, nickel occurs along with lateritic chromite deposits also (nickel percentage ranging from 0.5 to 1.5 per cent). Two nickelbearing minerals are recognised in the Sukinda deposits (1) nickelliferous montmorillonite associated with chromite and (2) serpentine associated with goethite. These minerals are found grading into one another[18]. Lateritic nickel ore bodies tend to occur as a regular residual horizon just beneath the laterite cap, and just above the fresh unaltered ultrabasic rock. The contacts are wavy and irregular. Lensing is common although ore pockets are uncommon. Colour and compositional banding are uncommon in the Sukinda nickel deposits[18].

Magmatic deposits of nickel are not known in India. Nickel sulphide occurrence along with copper mineralisation in Mosaboni, etc., is considered to be hydrothermal in origin and shows structural influence in localisation.

Prospecting and Exploration

Prospecting for nickel in lateritic terrain is usually done by geochemical sampling. Nickel bearing laterites do not have any typical diagnostic characteristics which are different from any other laterite. Therefore, it is not possible to detect the presence of nickel in the laterite by mere physical examination. The persence of nickel in Sukinda went unrecognised for many years although nickelliferous laterites were being stripped off for mining chromite. Grab samples taken rather casually from an yellow ochreous zone below the chromite deposit showed the presence of nickel for the first time. This discovery was followed up by a systematic channel sampling effort in all exposed ochreous zones. All the samples indicated nickel in commercially viable quantities and the presence of a deposit was confirmed[18].

Geochemical subsoil and suboutcrop samples are ideally suited for nickel prospecting and have been successfully employed in a few instances. In a nickel prospect in Orissa, the geochemical samples just below the topsoil showed the best nickel concentration[20]. A similar experience is reported from Jamaica from a similar geological terrain[21]. This is rather suggestive that the top layers of soil, laterites, etc., may not show the presence of nickel in recognisable and geochemically anomalous quantities. Geophysical prospecting may help in locating potential ore bearing ultrabasic rocks.

The exploration for lateritic deposits is summarised in the section dealing with bauxite.

Magnesite

Geology

Three types of economic deposits of magnesite are known. They are[7]:

(1) replacement in dolomite and limestone,

(2) as veins, and

(3) sedimentary beds.

Of these, only the first two types are known in India. The distribution of the important Indian deposits is shown in Table 8.7.

Table 8.7 : Geological distribution of important magnesite deposits in India

State	District (area)	Geological formation	Host rock
Tamil Nadu	Salem (Subramangalam belt)	Precambrian intrusives	Dunite[7]
Karnataka	Mysore (Kadakola)	Precambrian intrusives	Serpentinite Dunite
Uttar Pradesh	Almora (Dewaldhar)	Krol beds-Permian	Dolomite[7]

It is seen that magnesite mineralisation occurred in two geological ages, Precambrian and Permian. The Precambrian mineralisation is within dunites and the Permian mineralisation within dolomite.

The Salem and Mysore deposits are of Precambrian age and occur within dunites as veins, stringers, etc. These deposits are considered to have resulted from the action of carbonic acid on olivine mineral present in dunite rock, under conditions of high temperature and pressure[19]. The mineralising solutions may have originated from within the dunite itself. The deposits occur as an irregular network of veins. The individual veins vary in length from a few metres to a few hundreds of metres, and show thickness ranging from a few mm to about a metre or so. Vein networks extend over great distances and coalesce and branch off frequently[7]. The available evidences tend to support the view that the individual veins and lenses may have been formed within fracture zones, shear and joint planes.

The replacement deposits formed in dolomite occur in a massive form, as in the case of Almora deposits. Mineralisation is considered to have taken place along the bedding planes of the host rock-dolomite in this case. Magnesite bands show a bedded appearance and are interbanded with unreplaced rock. The ore bodies tend to be massive, showing a great strike continuity (2.9 km at Almora) and thickness (5-20 m at Almora)[22].

Prospecting and Exploration

The vein type of deposits are exclusively associated with ultrabasic rocks, particularly dunite. The area of preliminary search is narrowed down to areas of ultrabasic intrusives. Field guides for locating magnesite deposits are given in Table 8.1.

The ultrabasic body suspected to contain magnesite may be mapped on scale 1:25,000 or 1:10,000. Individual mineralised patches are mapped if exposed and large enough. The presence of magnesite is fairly easy to recognise in ultrabasic rocks. The vein network usually shows bright grey to white colour in a greenish, dull grey background. Test for effervescence by acid on the white veins confirms the presence of magnesite. A few chip samples collected from important exposures may be analysed chemically and studied in thin sections for confirmation. Trenches may be put to study the extension of veins in depth. Scout boreholes to test the extent of mineralisation and the continuity of the ultrabasic body in depth would be quite useful.

Prospecting for replacement deposits is rather difficult because dolomitic limestone and limestone which form the host rock and magnesite shows similar physical appearance. However, such deposits invariably occur in dolomitic terrain and the initial target can be confined to areas of dolomitic limestone. The initial mapping of the target area should be on a fairly large scale, 1:5,000 to 1:10,000. Systematic channel samples are collected at 50-100 m intervals. Their sections are prepared for samples at very close intervals, for every separate channel. From the microslides, the presence and percentage of dolomite is determined. The samples are subjected to chemical analysis in sections, corresponding to the channel sections from which microslides were made. A relationship between the magnesite availability shown by chemical analysis and the corresponding microslide is established. With the help of the microslide and chemical analysis data, the bands of magnesite and dolomite are marked out and mapped. Gradually, the prospecting geologist should acquire the necessary skill to separate dolomite and magnesite bands without difficulty. This method was used with success in the Almora magnesite investigation by a party of IBM geologists[23].

Exploration for vein type magnesite ore bodies similar to Salem deposits may be done on the lines suggested for asbestos in Table 8.5. However, for a deposit of the type occurring at Almora, the exploration guides may be as follows :

	Method	Details
(1)	Mapping	1:2,000, 1:1,000
(2)	Trenching	50 m intervals along the strike
(3)	Drilling	50 m and 100 m grid intervals
(4)	Sampling	Channel and drill core samples

Diamond

Geology

Three types of diamond deposits are known in India. They are :

(1) primary deposits in Kimberlite and other ultrabasic pipelike intrusives,

(2) conglomerates, and

(3) alluvium of stream and riverine origin.

The occurrence and distribution of the important diamond deposits of India are shown in Table 8.8.

Table 8.8 : Geological distribution of important deposits in India

State	District	Geological formation	Host rock
Andhra Pradesh	Anantapur Bellary Cuddapah Kurnool Krishna Godavari	Recent alluvium and Kurnool Series (Cuddapah/Vindhyan)	Gravels. Ultrabasic pipelike intrusives and conglomerates
Madhya Pradesh	Panna	Recent alluvium and Rewa Series	Gravels, conglomeratic and ultrabasic intrusive pipes.
Orissa	Sambalpur	Recent alluvium	Gravels.

The original source of diamond is the ultrabasic rock of peridotitic composition known as kimberlite. These bodies occur in the form of pipelike intrusives and diamonds occur disseminated in this rock in a discrete crystalline form. The conglomerates and gravels which yield diamonds in India have preserved diamonds derived from these pipelike rocks. Within the pipelike intrusive, the diamond may have been formed by ***insitu*** crystallisation or originally formed in the eclogite layers and brought up by the upwelling kimberlites or originally crystallised in the magma chamber and brought up by kimberlite magma. This suggests that an explosion of magma may have marked the beginning of the process of kimberlite intrusion. The fragments of rocks presumably fell into the cavity through which the pipe later intruded. The magma at this stage is considered to be of low temperature so that the host rocks were not affected[24].

The Majhgawan pipe rock, the best known in India so far, looks like a breccia with profuse calcite veinlets. It is a greenish, tuffaceous and agglomeratic rock of serpentinuous composition[25]. Along the walls, the pipe is fine-grained, vesicular and barren. The coarse-grained unweathered central core zone is diamond bearing[7]. The conglomeratic and alluvial diamonds are of secondary origin. Diamond occurs as discrete crystals in the case of pipes, conglomerates and alluvium. In India, all types of deposits have shown a tendency to occur in close proximity, making the task of exploration fairly easy.

In the Vindhyan conglomeratic deposit, diamonds occur along with pebbles of jasper, quartzite, vein quartz, chert, hematite, limonite and clay, set in an arenaceous, shaly and ferruginous matrix. The pebbles are of highly varying sizes and shapes[25].

Alluvial diamonds occur as irregular patches in the various river valleys draining the pipe-bearing terrain. Alluvium of minor river valleys and nala beds shows diamonds whereas the alluvium of large river systems seldom contains any diamonds.

Prospecting and Exploration

As mentioned earlier, all the three types of deposits occur in close proximity and the discovery of one often leads to the other two. The target area should generally be one which has yielded diamonds at some time and should be known to contain kimberlite intrusives.

The area may be mapped on large scale, 1:20,000 - 1:10,000, aerial photographs. The preferred targets are circular or elliptical water-filled depressions which may cover hidden kimberlite bodies and minor drainage channels and their alluvial accumulations for alluvial diamonds. The pipekike kimberlite bodies generally weather easily and circular water-filled depressions are formed which are easily recognised in aerial photographs. Having chosen a large number of such targets, each water-filled depression is subjected to deep test pitting to check the presence of weathered remnants of pipe or calcareous tuffa. This method was followed successfully by the Geological Survey of India in its Panna diamond prospecting[26].

Aeromagnetic, ground magnetic and electrical resistivity methods can be used for the prospecting of kimberlite pipes. The Hinota and Angora pipes of Panna area were discovered by these methods[27].

For placer diamonds, the preferred targets are minor confluences, alluvial fans and cones, river terraces, abandoned river courses, etc.

During ground verification, the targets selected on aerial photographs are checked by panning surveys. It, is, however, seldom that diamonds can be directly located by this method, because of their extreme rarity even within the pipe rocks. Diamonds are associated genetically with a number of satellite minerals. They are pyrope, picroilmenite, chrome-diopside and olivine. Since these satellite minerals occur in much larger quantities even within the pipe, their dispersion within the stream and alluvial accumulations is also proportionately more. Hence, the occurrence and concentration of these minerals along alluvial accumulations should be carefully examined by panning survey. The panning points can be chosen from favourable targets located on the basis of photogeological studies. The points should be chosen systematically at regular grid intervals along current and ancient drainage channels till their source of origin or a source of origin of diamond is reached[28].

If diamond is located or any of the satellite minerals are seen in unusual concentrations during panwashing, the next step is to collect bulk samples of the gravel by deep pitting. This sample is subjected to washing and jigging to ascertain the presence of diamond. Here the fractions which are above 4 mm in size are straightaway rejected, and -4 mm + 1 mm material is concentrated. The details of these investigations are systematically recorded in the geological map for choosing promising sites for detailed exploration[28]. It may, however, be noted that, in the Indian context, the satellite minerals may be olivine, magnetite, hematite, ilmenite, perovskite, and rutile.

The presence or absence of diamond in any terrain can be established only by bulk sampling and beneficiation of the samples, and forms the most important prospecting operation. In order to confirm that the beneficiation is complete and proper in every respect it is customary to add 2-8 marked diamonds to the sample. If during the beneficiation these diamonds are not recovered the process of concentration is considered incomplete. The concentration is carried out till the marked diamonds are recovered[28].

In India, diamond has been mined since a very long time and it is not unusual to find ancient workings. These workings can be found by ground reconnaissance and photogeological studies and form good field guides.

Alluvial diamonds may be found in two types of alluvium :

(1) placer deposits associated with the present drainage, and

(2) placer deposits which show no relationship with the present drainage.

In the first case, the deposit may be arranged linearly along drainage channels and therefore pitting, drilling etc., may be done along lines. In the second case, deposits tend to be irregular and a square grid system may be more effective in drilling and pitting[29].

Exploration guides for diamond is summarised in Table 8.9.

Table 8.9 : Guides to the exploration of diamond

	Methods	Details
1.	Mapping	1:10,000 to 1: 20,000
2.	Pitting	Widely adopted. No defined intervals.
3.	Drilling	Useful in exploring vertical depth of pipes. No specific grid intervals are suggested.
4.	Expl. mining	Short levels with connecting raises and winzes.
5.	Sampling	Pits and bulk samples from Mines

Barytes

Geology

Three types of baryte deposits are known in India. They are[30]:

(1) vein deposits,

(2) bedded deposits, and

(3) replacement deposits.

The geology and distribution of the important Indian baryte deposits are listed below in Table 8.10.

Table 8.10 : Geological distribution of important barytes deposits in India

State	District	Geological formation	Host rock
Andhra Pradesh	Anantapur Cuddapah (Pulivendla) Kurnool Khammam	Cuddapahs	(1) Vempalle limestone (2) Doleritic traps
Rajasthan	Alwar	Delhi Series	Alwar quartzites
Himachal Pradesh	Sirmur	N.A.	N.A.
Maharashtra	Chanda	Precambrian	Granites[31]
Madhya Pradesh	Sidhi	Precambrian	Talc chlorite schist[32]
Karnataka	Chitradurga	Precambrian	Fuchsite quartzite[33]

The occurrences associated with the Cuddapahs are in vein replacements and beds. The veins occur in dolerite whereas bedded bodies occur in limestone and shale. The occurrences in Alwar quartzite are reported to be in fissure veins.

The Cuddapah deposits are thought to have formed from the mineralising solutions originating from the dolerites which have intruded into the Vempalle limestones. Sulphur is believed to have been leached out of the limestone which on reaction with barium solution produces the barytes deposits.

It has been observed recently that extensive deposits of barytes occur within shales with thin dolomitic limestone and quartzite in a bedded form in Mangampet area. These deposits are considered to be volcanogenetic sedimentary in origin[30].

Alwar deposits are considered to be of hydrothermal origin although no clear source of hydrothermal solution has so far been recognised.

Mineralised veins in the Cuddapah area have shown preferential concentration within faults and slickensided fissures hading 20-30° south-southeast[34]. The vein type ore bodies are generally confined to shear zones. The orebodies show irregular pinch and swell structures along the strike and dip. They also coalesce and separate forming intricate patterns. These patterns are well developed in the barytes deposit of Cuddapah district[35]. In the granitic and schistose terrain also the vein deposits show intricate patterns and are traceable in depth. The bedded types occur in complete conformity with the host rock showing all sedimentary features. A typical example is the Mangampet deposit where the host rock is a tuffaceous shale within which baryte occurs as large lenses.

Prospecting and Exploration

Some field guides which would be useful in barytes prospecting are given in Table 8.1. Barytes mineralisation tends to be associated with areas of uplift and magmatic activity of the granodiorite and admalite type. In the regional search for target, such areas should be given priority attention. Veins and beds of barytes, when exposed, usually leave a solution creep because the outcropped material is dissolved away in water. This is a very important field evidence to look for. Float ores are not common although in some cases they may be found.

In order to define ground targets, geophysical methods are useful. In an investigation for vein barytes in a granitic terrain, magnetic and resistivity measurements were used which indicated clear anomalies in areas of vein quartz with barytes mineralisation. This was followed by gravity surveys in which readings were taken at 5 m grid intervals which gave further definition to the ore zones[36].

Bedded deposits usually show genetic association with tuffaceous beds which may be useful as a field guide during prospecting.

The exploration guides for vein type barytes are summarised in Table 8.3. For bedded and replacement deposits the exploration guides are similar to bedded limestone deposits described elsewhere.

The stringers form a network coalescing and separating frequently. The individual ore lenses are of very small strike lengths. The Chandidongri deposit which is typically lensoid has a strike length of only 192 m. whereas the shear zone is traceable for a distance of 20 km. The deposits at Ambadongar also occur in the form of lenses of extremely small dimensions[41].

Prospecting and Exploration

Field guides for locating fluorite deposits are given in Table 8.1. In order to choose broad targets, photo-geological studies of regional rift structures may help, as most fluorite deposits show genetic relationship with regional rifts. Areas of carbonatite intrusions, volcanism, radioactive mineralisation, etc., are excellent targets. The presence of fluorine in ground water is a confirmatory evidence indicating the presence of fluorite mineralisation nearby. Float ores are seldom seen. In a favourable target area, regional shear zones with quartz and calcite vein intrusives form favourable host rocks. For confirming the presence of fluorite, chip samples may be collected and analysed from outcrops. Goassans and cappings are usually present particularly with CaF_2 and are good indicators for the presence of fluorite mineralisation[37]. Geophysical prospecting has not been successful in locating ore bodies so far in India[40].

The exploration guides for hydrothermal vein type deposits of fluorite are given in Table 8.3. However for deposits found in carbonatite no specific guidelines are possible.

8.3.2 Mineral deposits associated with igneous intermediate rocks

The intermediate rocks are diorites, monozonites, granodiorites, syenites and nepheline syenites. The mineral deposits are essentially sulphides of copper, lead, zinc, gold, silver and iron. A large number of minor minerals are also recognised within this group of rocks. The important ones are molybdenum, nickel, cobalt, cadmium, selenium, tellurium, mercury, arsenic, etc. These may occur in complex sulphide form with several minerals or in single sulphide form with only one dominant mineral. In India, copper, lead, zinc, gold and pyrites are the most important ones.

Copper

Geology

Copper deposits of many types are known, some of which are listed below[24]:

Fluorite

Geology

Two types of fluorite deposits are recognised in India. They are (i) hydrothermal deposits associated with acid igneous rocks, and (ii) deposits formed in carbonate rocks, following the emplacement of alkaline igneous rocks, and associated explosive volcanic action.

The geology and distribution of Indian fluorite deposits are given in Table 8.11.

Table 8.11 : Geological distribution of important fluorite deposits in India

State	District	Geological formation	Host rock
Madhya Pradesh	Durg and Rajnandgaon (Chandi Dongri)	Archaean	Quartz veins in granites and epidiorite intrusive[37]
Gujarat	Baroda (Amba Dungar)	Tertiary	Carbonate rock[38]
Rajasthan	Dungarpur (Mando-ki-Pal)	Archaean(?)	Cavity fillings, joint and fracture fillings in granite[39].

The fluorite deposits of Madhya Pradesh and Rajasthan may be of hydrothermal origin whereas the deposits of Gujarat are in carbonatites and associated with explosive volcanism. The mineralising solutions in this case are thought to have originated from the Deccan Lavas[39].

Major fluorite deposits all over the world occur along major continental rift zones and lineaments. The mineralising solutions are thought to have come up from the lower crust through the rift zone to form the mineral deposits. Some of the Indian fluorite deposits also occur along the Narmada rift zone of Tertiary age and may have a similar origin[40]. The structural association in such cases is quite clear, the mineralisation being broadly influenced by fault planes, as seen in the case of fluorite deposits of Gujarat and Madhya Pradesh.

Fluorite deposits occur generally in the form of veins and stringers within shear zones, and show considerable depth persistence, narrow outcrops, and steep to vertical dips.

(1) Magmatic

(2) Contact metasomatic

(3) Hydrothermal

  (a) cavity filling

  (b) replacement

(4) Sedimentary

(5) Surficial oxidation

(6) Supergene enrichment.

Of these, in India, the hydrothermal deposits are most common. Many hydrothermal deposits show signs of oxidation and enrichment.

Some of the important Indian deposits are listed in Table 8.12.

All the Indian copper deposits are considered to be of hydrothermal origin with replacement as the dominant process. Structure has played a dominant role in localising many important deposits. A detailed structural analysis of Singhbhum copper belt has shown that the mineralising sulphide bearing solutions have passed through certain prominent slip planes (strain slip cleavage S_5) of the host rocks which existed prior to the mineralisation. This resulted in the development of sulphide stringers along the slip cleavages. A set of axial plane schistosity (S2 planes) has been recognised as the next preferred site of mineralisation, where streaks and stringers of sulphide are seen. In addition, the intersections of the planes of S2 and S5 and zones of intense crushing have also acted as sites of mineralisation[50].

The major ore shoots in the Mosaboni area follow the general strike direction of the strain slip cleavage S_5 giving rise to massive, rich ore. Ore shoots striking parallel to S_2 are thicker with massive and braided ore. It has also been observed that where the angle between S2 and S5 is steeper, the ore shoots are thicker. The ore shoots have definite axes and plunge probably under the influence of locally developed crossfolds[50].

In the case of Khetri Copper Belt also, structural controls are noticeable. There, mineralisation is controlled by a set of reverse dip faults and shear zones developed parallel to them. Wherever the shear zones have developed parallel to the bedding plane schistosity, mineralisation has been intense. Structural controls are noticeable in many of the other copper deposits also.

Copper deposits generally show complex geometrical shapes. The mineralisation is generally in the form of stringers, disseminations, veins and massive lenses[51]. These occur in conformity with the formation and bedding of the host rocks. Wide zones of low-grade mineralisation are sometimes

Table 8.12 : Geological distribution of imoortant copper deposits in India

State	District	Geological formation	Host rock	Important Mminerals
Bihar	Singhbhum, Mosaboni, Surda, Rakha, Roam-Siddeshwar Tamapahar	Iron ore series	Chlorite-biotite schist, quartz-schist, etc.	Chalcopyrite, pyrrhotite with pyrite[42]
Rajasthan	Jhunjhunu Khetri group Madhan-Khudan etc.	Delhis	Garnetiferous chlorite, quartz schists and phyllite	Pyrrhotite, pyrite and chalcopyrite[43]
Madhya Pradesh	Balaghat (Malanjkhand)	Archean basement complex	Quartz reef[44]	Chalcopyrite, pyrite[45]
Andhra Pradesh	Guntur Bandalamothu Nallakonda Dhukonda	Cuddapah	Quartzites and phyllites	Chalcopyrite, monor malachite[46]
	Khammam (Mailaram)	Pakhal Series Cuddapah (?)	Quartz veins within phyllites, schists, limestones and quartzite[47]	---
Karnataka	Chitradurga (Ingaldhal) Gulbarga (Thinthini)	Dharwar	Ferruginous chert bands Gabbroic rocks	Chalcopyrite cupriform form Pyrite[19] chalcopyrite
	Hasan (Kalyadi)	-do-	Quartzite and quartz schists	Malachite, azurite and chalcopyrite[48]
Tamil Nadu	S.Arcot (Mamandur) Multimetal lodes	Dharwar (?)	Contact of garnetiferous gneiss and biotite granite[49]	Chalcopyrite Malachite
Gujarat	Banaskantha (Ambaji Multimetal lodes)	Delhis	Talc and calc schists	Chalcopyrite
Sikkim	Rangpo-Dikchu Bholang	Precambrian	Daling series Raulil schist (Quartz mica schist	Chalcopyrite and phyrotite

recognised although a majority of the lodes are very narrow in width. Strike and depth continuity of mineralisation are traceable along shear zones as in the case of Singhbhum copper deposits.

Prospecting and Exploration

Copper occurs in a variety of rocks, but most of the important commercial deposits in India are confined to the Archaean and Precambrian formations. All important copper mineralisations in India are associated with prominent narrow, linear greenstone belts and most of the deposits are either within the belts or in granites and gneisses in close proximity. These greenstone terrains therefore form the most important initial target area for search.

Copper has been mined in India since ancient times and old workings, which are very common, form the most important field guide. Old tailings, slagheaps, water filled depressions with luxuriant growth of vegetation around should attract attention as a possible copper target. Such old workings can be easily located by photogeological studies and ground verification. Other field guides for copper are given in Table 8.1.

Geochemical sampling is very effective in defining areas of copper mineralisation. The methods used are soil, bed rock and stream sediment sampling. For this, traverse lines are laid across the suspected area of mineralisation and samples collected at every few metres on a regular grid pattern. Traverse lines at 100 m interval and sampling points at every 25 m along the line gave very promising results in prospecting for a copper deposit near Jabalpur[52].

Geophysical prospecting may be undertaken in areas where sulphide bodies are to be located. The methods may be air-borne magnetometric surveys (for large regional targets), electromagnetic surveys and electrical methods (for specific small areas). In the Malanjkhand sulphide deposit, induced polarisation (chargeability) gave very good results, particularly in pinpointing the area of mineralisation. The prospect was earlier surveyed by self-potential and electro-magnetic methods which also demarcated the area of sulphide mineralisation. However, the anomaly was better defined by the use of induced polarisation method[53].

Exploration methods for copper are summarised in Table 8.13.

Lead-Zinc

Geology

Lead and zinc deposits tend to occur together. The following types of lead-zinc deposits are recognised.

Table 8.13: General guidelines for exploration for sulphides (Copper, Lead, Zinc, Pyrites, Nickel (in sulphide) and multimetal combination)

Method	Thin, low dipping strata-bound body with a little structural formation		Large lenticular replacement body		Low to moderately dipping large bodies with simple structure		Steep dipping small ore bodies structurally complicated		Remarks
	Regional exploration stage	Intensive exploration stage	Regional exploration stage	Intensive exploration stage	Regional Exploration stage	Intensive exploration stage	Regional exploration stage	Intensive exploration stage	
1 Mapping	1:2000 to 1:5000	1:1000 to 1:2000	1:2000 to 1:5000	1:1000	1:2000 to 1:5000	1:1000 to 1:2000	1:2000 to 1:5000	1:1000	To establish foot-wall hanging wall contacts, extension along strike, individual leases and vein assay boundaries etc., lithological units, old workings abandoned mines dumps, etc.
Underground mapping	1:100 to 1:200	1:100 to 1:200	1:100 to 1:200	1:100 to 1:200	1:100 to 1:200	1:100 to 1:200		1:100 to 1:200	
2. Drilling	200-500 m section intervals with 50-100mm grid drilling in test strips	50-120 m grid drilling with underground drilling if necessary	200-240 m intervals in 2 levels within ore zone with 50-100 m grid intervals in test strips	50-120 m section interval with intersection at 3/4 levels at 50-60 m vertical interval with underground drilling if necessary	240 m section interval, 50 m down depth within orebody to be explored	100-120 m section interval. Intersection at 3 to 4 levels with 50-60 m intervals, underground drilling if necessary	50-100 m section interval, intersection at 25 m vertical depth in ore body	50 m section interval, intersection at 4 to 5 levels at vertical intervals of 30 m.	For establishing depth continuity, strike extension, width of mineralisation and depth of oxidation.
3. Exploratory mining	Not recommended	1 km. strike length of the deposit by driving cross-cutting etc.	Not recommended	The entire strike length in two levels by drives, winzes cross-cuts	Not recommended	Entire strike length in two levels by drive with cross-cuts at 30 m intervals and winzes and raises	Not recommended	Entire strike length in two levels by driving with cross cuts at 15 m intervals, with raises and cross-cuts	
4. Sampling	Core and sludge also for laboratory scale beneficiation	Core and sludge underground channel samples, bulk samples for beneficiation test	Core and sludge also for laboratory tests	Core and sludge, channel sample, bulk samples, etc.	Core and sludge for laboratory tests	Core and sludge, channel samples, bulk samples	Core and sludge, core sample for laboratory tests	Core and sludge underground channel sampling, bulk sampling, etc.	

Based on Manual of Mineral Exploration, Geol. Sur. India Misc. Pub. No. 33)

(1) contact metasomatic

(2) hydrothermal

(a) cavity filling

(b) replacement

(c) disseminated[24]

The known Indian deposits have been generally considered as hydrothermal, the mineralisation being controlled by limestone and other calcareous host rocks. The geology and distribution of some important lead-zinc deposits are listed in Table 8.14.

Table 8.14 : Geological distribution of important lead-zinc deposits in India

State	District	Geological formation	Host rock	Important minerals
Rajasthan	Udaipur (Zawar)	Aravallis	Impure dolomitic limestone and dolomite[54]	Sphalerite and galena[51]
	Aguchha	Gneissic-complex?	Biotite gneiss?	Sphalerite and galena
Gujarat	Banaskantna (Ambamata multimetal lodes)	Delhis	Talc and talc schists	Sphalerite, galena and chalcopyrite[55]
Orissa	Sundergarh (Sargipalle)	Gangpur series	Quartzwacke, quartzose clay and calcareous rocks	Galena, sphalerite and chalcopyrite
Tamil Nadu	South Arcot (Mamandur multimetal lodes)	Dharwar(?)	Contact of garnetiferous gneiss and biotite granite	Galena, sphalerite
Andhra Pradesh	Cuddapah (Zangamarajupalle)	--	--	--

Some lead-zinc deposits show evidence of having been controlled by lithology and structure in their genesis. The Zawar deposits occur within impure limestone (lithological control) and are also within a shear zone (structural control). The Sargipalle deposits also occur in an impure clacareous rock.

All lead-zinc deposits have been grouped as hydrothermal, although of late this assumption has been questioned. Some authorities[55,56] point out that the deposits at Ambamata, Zawar and Sargipalle occur within geosynclinal sequences, as indicated by the presence of ophiolites and greywackes in the sequence which contain the deposits. The absence of wall rock alteration at Zawar has been observed by the proponents of the hydrothermal theory also. The general conformity of the ore bodies with the host rock, parallelism with bedding planes, and the absence of any relationship with intrusives tend to support the view that mineralisation in these deposits is syngenetic. Some recent work has indicated that some parts of the Zawar deposits show rhythmic lamination, load cast, slump structures and graded bedding which are all sedimentary structures. This suggests that at least a part of the Zawar deposit may be sedimentogenetic, later remobilised under favourable tectonic and hydrothermal conditions[57]. The Sargipalle deposit has been considered as sedimentary on the basis of the following field evidence[56].

(1) mineralisation is confined to one stratigraphic horizon,

(2) cross cutting veins are absent,

(3) variation in mineralisation is correlatable with the variation in sedimentary facies,

(4) metamorphism is isofacial in the ore and host rock,

(5) itense shearing or faulting along the ore zone is absent, and

(6) wall rock alteration is absent.

Lead-zinc ore bodies generally show lenticular shapes, although some of the deposits may be banded. Thus, the lead-zinc prospects at Sargipalle occur in the form of bands and lodes[58]. The Zawar deposits show clear strike continuity and considerable depth extension.

Prospecting and Exploration

The association of lead-zinc deposits with impure calcareous rocks gives a very good field guide in the prospecting operation. Old slag heaps, workings, etc., are equally helpful as in the case of copper. Geochemical and geophysical methods are also useful in the case of lead-zinc, just as in the case of copper. The lead-zinc deposits at Sargipalle were located and defined by self-potential survey[58].

Exploration

Exploration for lead-zinc deposits is summarised in Table 8.13.

Pyrites

Geology

Two pyrites deposits of commercial value are known in India. One is located at Amjhor in Shahabad district of Bihar, and the other at Saladipura in Sikar district of Rajasthan. The deposits of Amjhor are of sedimentary origin while Saladipura deposit may be hydrothermal.

Prospecting and Exploration

Prospecting for pyrites is done more or less in the same way as copper, lead, zinc, etc. Geophysical prospecting (gravity and magnetic methods) give very good response/ and may be used for locating and defining ore bodies.

The guides to exploration for vein type deposits of pyrites have been given in Table 8.13. In the bedded type, the Indian Bureau of Mines[59] has adopted the norms given in Table 8.15.

Table 8.15 : Guides to exploration of pyrites (bedded type)

	Method	Details
1.	Mapping	1 : 8,000
2.	Pitting	To be done near sca.. faces to expose thickness
3.	Drilling	500 m grid
4.	Exploratory Mining	Aditing

Gold

Geology

Five major types of gold deposits[24] are recognised. They are :

(1) magmatic deposits

(2) contact metasomatic deposits

(3) hydrothermal deposits

- (a) replacement
  - (i) massive
  - (ii) lode
- (b) cavity filling
  - (i) fissure vein
  - (ii) stock works
  - (iii) saddle reefs
  - (iv) breccia

(4) mechanical concentration

(5) placer deposits.

Of these, the only type recognised in India is the hydrothermal type. The geology and distribution of some important Indian gold deposits are given in Table 8.16.

Table 8.16 : Geological distribution of important gold deposits in India

State	District	Geological formation	Host rock	Important minerals
Karnataka	Kolar (Kolar Gold Fields)	Dharwar	Quartz vein in hornblende chlorite and mica schist[60] (metavolcanics)	Sulphide[60]
Andhra Pradesh	Raichur (Hutti)	Dharwar	Quartz vein in metavolcanics[60]	Sulphide and native form
	Anantha-pur (Ramagiri)	Dharwar	Quartz veins in serecite, chlorite phyllite	Native[60]
Kerala	Kozhikode (Wyanad)	Charnockites (Archaen)	Quartz vein in biotite granulite and hornblende granulite	Sulphide[60]

Gold occurrences are reported from practically every state in India, although only a few of them are of economic importance. Excepting the occurrence of gold in charnockites in Wayanad(Kozhikode), all deposits are found in suites of metavolcanics in Dharwarian greenschists[60].

All Indian deposits are considered to be of hydrothermal origin. The exact source of hydrothermal solutions is not clear. In Kolar, the mineralisation has been genetically correlated with a suite of rocks known as Champion Gneiss, although this view is not universally accepted.

In Ramagiri gold field, the host rocks of the gold deposits are andesitic lava flows. It is considered that the lava flows contained gold in a disseminated form originally. During metamorphism, the lava flows were reconstituted and mineralising solutions containing gold emanated from them, and deposits were emplaced in quartz reefs[61]. This hypothesis is more akin to the "Source Bed Concept" for sulphide mineralisation rather than to the hydrothermal concept[62]. The "Source Bed Concept" supports the view that sulphide mineralisation takes place syngenetically in sedimentary basins in particular horizons and they subsequently migrate to their present host rock during a rise in temperature (metamorphism?) of the enclosing rocks. Gold-bearing quartz veins occur within a suite of greenstones. In most cases, the veins remain parallel to the schistose host rocks. Cross-cutting veins are also seen. Sulphide-bearing lodes contain, in addition to gold, minerals like pyrite, pyrrhotite, galena, etc. The lodes generally form parallel fracture filled vein systems. These vein lode systems show great strike continuity, narrow outcrop widths and conspicuous depth persistence as in the case of the Kolar Gold Fields where mineralisation has been proved beyond a depth of 3,000 m. Most orebodies are characterised by steep dips. Dextral and sinistral cross-folds have affected the lodes and are considered to have influenced gold mineralisation along with en echelon drag folds[63]. Pinching and swelling along strike and dip are quite common in some of the reefs[64].

Prospecting and Exploration

Since gold mineralisation is generally associated with acidic metavolcanics of greenstone belts, the regional target areas should be selected in such areas.

Gold has been mined since ancient times in India, and it is usual to find old workings in many areas. These may include old pits, tailing dumps, slag heaps, etc. Kolar Gold Fields were located on the basis of old workings present all over the area. Trenching across old workings shows a compact clayey fill containing mined rock fragments and pieces of charcoal which were used presumably for 'fire setting' which was an ancient gold mining practice. It is said that in Kolar the ancient mining was so selective and systematic that outcrops are traceable only at the bottom of large slumped waste heaps in gold workings[65].

In favourable target areas, pan washing for gold is an excellent prospecting tool. Gold placers in the form of specks, flakes and pinheads are usually found in sediments of streams running through the auriferous reef terrain. Systematic pan washing at intervals of 50 m. from the confluence to the watershed of several streams gave promising results in a gold prospecting operation in the Chandil area of Singhbhum district[66]..

Since gold has a high specific gravity, even flakes and specks tend to concentrate at the bottom of the gravel bed. Hence, panning alone may not givé conclusive results in many cases. Pitting to reach the bottom of the gravel bed is as equally important as pan washing. Random scout drilling may also be successful in reaching the bottom of the gravel bed.

Geochemical and geophysical methods are not very effective except where gold occurs along with other sulphides, like copper, lead and zinc. Many gold-bearing quartz reefs show the presence of scheelite. Since scheelite is fluorescent, an ultraviolet lamp survey in the suspented reefs may reveal the presence of scheelite which may lead to the location of gold.

Exploration methods for gold are summarised in Table 8.17.

8.3.3 Mineral deposits associated with igneous acidic rocks

The major rock types in this group are granites and pegmatites. The associated mineral deposits are of tin, tungsten and mica. Various important minor minerals are quartz, felspar, beryl, tourmaline, sapphire, lithium, rubidium, cessium, etc. Of these, tin, tungsten and mica are important in the Indian context.

Tin-cassiterite

Geology

Three types[24] of cassiterite deposits are recognised. They are :

(1) Hydrothermal deposits
   (a) stock works
   (b) fissure veins, and
   (c) disseminated replacements

(2) Pegmatitic deposits

(3) Placer deposits.

Table 8.17 : General guidelines for exploration work for tin, tungsten and gold

	Method	Regional exploration stage	Intensive exploration stage	Remarks
1.	Mapping	1:2000 to 1:5000	1:2000 to 1:5000	Most gold deposits are however explored by the same methods as in sulphides. See guides for sulphides in Table No. 8.13
2.	Surface drilling	200-500 m section interval in two levels, 30 - 60 m vertically apart	100-200 m section interval in 2-3 levels, 30 - 60 - 90 m vertical interval to trace and intersect mineralised zones.	
3.	Underground drilling	Not recommended	As and where necessary	
4.	Trenching	200 - 500 m section intervals to trace old working	Not recommended	
5.	Exploratory mining	Not recommended	3 or more levels over the entire/part strike length of ore body at 30 m. level interval and winzes along suitable intervals.	
6.	Sampling	Core and sludge, blast and channel	Core and sludge, blast and channel, bulk sample from underground developments for beneficiation test.	

Based on Manual of Mineral Exploration, Geol. Sur: India Misc:Pub.No.33)

Of these, the last two types are known in India, although so far there has been only one major potentially economic find the tin fields of Bastar district in Madhya Pradesh. Here, the primary source of cassiterite is a zoned pegmatite. Some fossil placers are also considered promising[67].

The lepidolite pegmatites which show cassiterite mineralisation in Bastar have been emplaced in metabasic sills which have intruded the Bangpal group of metasediments. The Palim granite located closeby is thought to have given rise to the pegmatites. Cassiterite occurs as discrete crystals in a disseminated form within the pegmatites along with rich veins of solid cassiterite ore. Mineralisation took place by replacement. The pegmatites have intruded along the contact of metasediments with the metabasics. The joint planes of serecite-quartzites have also helped the pegmatitic intrusion[67]. Pegmatite bodies containing cassiterite occur as irregular lensoid concentrations within shear zones. They have highly irregular shapes. Placer deposits of cassiterite are derived from these pegmatites and show highly irregular concentrations.

Prospecting and Exploration

Tin-cassiterite deposits of pegmatitic and placer types usually occur together or in close proximity as is seen in the case of Bastar tin field. Most of the tin deposits are confined to Precambrian terrain where large granitic plutons have been emplaced[67]. Regional targets, therefore, should be selected from Precambrian areas showing granitic intrusions. Large target areas should be subjected to geochemical surveys. The methods generally in use are stream sediment and suboutcrop sampling. Stream sediment sampling was used by Geological Survey of India intensively in their investigations for tin in Bastar district of Madhya Pradesh and was mainly responsible for the initial discovery of the deposit. In a prospect in Hazaribagh district, the target, a granitic gneiss, was subjected to suboutcrop sampling which helped in confirming that the mineralisation was too spotty to be economical[68].

Any promising area should be selected for photogeological studies (1:30,000 or larger scale photography) to locate pegmatite occurrences and also to build up a geomorphological map of the area. The geomorphological approach is necessary because the level of erosion of the terrain has a profound influence on the formation of placers. Features which need to be specially studied are alluvial cones, fans, river terraces, meander bends, river confluences, abandoned river channels, etc. Various potential targets should be marked on the photographs and test pitting carried out in these targets. Bulk samples should be collected and the samples concentrated by jigging or pan washing to see whether cassiterite pebbles and fragments are present. Presence of cassiterite in any quantity warrants detailed exploration of the target. Geophysical prospecting is useful in locating buried river channels and certain types of riverine accumulations. Trenches and pits may become necessary during outcrop mapping.

Exploration procedures are summarised in Table 8.17

Tungsten - Wolframite - Scheelite

Geology

Four types of tungsten deposits are known. They are :

(1) Pegmatitic deposits

(2) Contact metasomatic deposits

(3) Hydrothermal deposits

  (a) replacement deposits

  (b) fissure vein

(4) Placers

In India, the known deposits are either contact metasomatic, hydrothermal or placers. The important Indian tungsten deposits are listed in Table 8.18.

Table 8.18 : Geological distribution of tungsten deposits in India

State	District	Geological formation	Host rock	Important mineral
Rajasthan	Nagaur (Degana)	Archaean	Granites and phyllites[19]	Wolframite
West Bengal	Bankura	Dhonjori[69] (Dharwars)	Quartz veins and alluvium	Wolframite[19]
Maharashtra	Nagpur	Archaeans	Veins of quartz interbedded with schists[19]	Wolframite
Karnataka	Kolar (Kolar Gold Fields)	Dharwars	With gold-bearing quartz veins	Scheelite[7]

None of the deposits has so far shown any economic promise, although the present known occurrences might lead to new discoveries in nearby areas.

All the known Indian deposits are genetically linked to nearby granitic intrusive bodies. At Degana (Nagaur), the mineralising quartz veins and lodes occur at the contact of the intrusive granite with phyllitic country rocks. The mineralisation is considered to be pneumatolytic[70]. Wolframite can be found in the alluvium nearby as placer deposits.

Scheelite has been reported from Kolar gold fields of Karnataka and Buruguranda in West Godavari district of Andhra Pradesh[71].

Wolframite occurs in the form of veins, stringers and lodes in highly irregular forms, sometimes forming stock-works. The individual lodes are usually within quartz veins of some 25 mm - 30 cm width as seen in Degana[70]. It may also occur within quartz-rich pegmatites of 5 to 15 cm width with lodes of 0.3 - 3 cm widths. In the Bankura area, the deposits occurs in the form of stockworks (Thamapahar and Chorradungri) and in the form of emanations in thin quartz veins (Purnapani)[69].

Prospecting and Exploration

Tungsten deposits of primary origin as well as their secondary derivatives tend to occur in the same terrain. Prospecting should aim at locating both types of deposits. As mineralisation occurs close to intrusive granitic bodies, the regional targets should be chosen from areas with a known history of granitisation. Geochemical sampling is useful in locating areas of mineralisation. Both soil and stream sediments should be sampled. In the Buruguranda area (West Godavari district, Andhra Pradesh), the Geological Survey of India conducted soil geochemical sampling for a wolframite-scheelite prospect. Samples were collected at 5 m intervals. The results showed anomalous values up to 1,000 ppm. tungsten against a background of 10 ppm[71].

Geophysical methods (magnetic and electrical resistivity) have proved ineffective in the case of wolframite.

Areas of scheelite mineralisation can be recognised by ultraviolet lamp surveys. Scheelite, being fluorescent, shows up in ultraviolet light. The method was successfully used in Buruguranda prospect by the G.S.I.[71].

Photogeological studies along the same lines suggested for tin prospecting may be useful in the case of tungsten deposits also[72].

Exploration methods for tungsten are summarised in Table 8.17.

Mica

Geology

Mica occurs in book form in pegmatites and is the only type of deposit of economic value. Several types of mica are known but in India only muscovite and phlogopire are of economic value. Of these, presently only muscovite is being mined. The various types of mica are listed below[73]:

(1) muscovite (potassium mica)
(2) paragonite (sodium mica)
(3) lepidolite (lithium mica)
(4) lepidomelane (iron mica)
(5) phlogopite (magnesium mica)
(6) **zinwaldite** (lithium-iron mica)
(7) biotite (magnesium-iron mica)

The important mica deposits of India are shown in Table 8.19.

Table 8.19 : Geological distribution of mica in india

State	District	Geological formation	Host rock
Bihar	Giridih Hazaribagh Monghyr Nawadah	Precambrian	Pegmatite in mica schist[74]
Andhra Pradesh	Nellore	Precambrian	Pegmatites in hornblende-biotite schist.
Rajasthan	Ajmer Bhilwara Sikar Jaipur Tonk Udaipur	Precambrian	Pegmatites in mica schist

There are other deposits reported from various parts of the country. Their economic value is not known.

Pegmatites are formed from fluids emanating from deep seated intrusive granitic plutons. Such intrusive bodies have been recognised in Rajasthan and Bihar fields. Similar intrusives have so far not been identified in the case of Nellore mica fields. It is thought that the mineralising solutions emanating from the intrusive granite are rich in volatiles and are channelised into voids where the hydrostatic pressure is presumably low and formed books of mica. The earlier solutions were silica rich with varying alkalies and alumina and possibly gave rise to the massive quartz core, a characteristic feature of all mica-bearing pegmatites. This theory contradicts the opinion held by most Indian geologists that mica crystallised out of the country rock and got concentrated along the wall rocks of pegmatites, the solutions from deep seated sources acting mostly as mobilising media[74]. A noteworthy feature of most Indian mica pegmatites is their general concordance with the plane of schistosity of the host rocks. Another feature which merits consideration is the concentration of mica along the contact zones of pegmatites with the country rocks. Mica-bearing pegmatites show a tendency to occur in clusters in specific localities. The emplacement of these has been along cleavages, foliations, fault planes or other natural openings. In many pegmatites of Nellore, mineralisation is intense along the fold noses[75]. These features suggest that mica mineralisation and localisation are controlled by the structure.

Mica-bearing pegmatites may be of three types viz., (i) fracture filling, (ii) replacement bodies and (iii) zoned pegmatites. Of these, the last two are of economic value[74].

Prospecting and Exploration

Prospecting for mica consists of two tasks. One is to locate pegmatite bodies and the other to locate mica deposits within the pegmatites. Field guides for locating mica deposits have been given in Table 8.1. Regional targets are chosen from areas where mica schists have been intruded into by granitic plutons. The presence of lit-par-lit injections within the country rock is a negative indicator and such areas should be rejected.

In locating areas of pegmatite intrusion, aerial photographs are very useful. Even concealed bodies can be recognised by studying the pattern of exposed pegmatites, by photogeological studies.

After locating pegmatite bodies, it is necessary to check whether they are mica-bearing or not. The presence of various indicator minerals, zoning, etc. generally indicates the likelihood of mica deposits. Laboratory scale studies to recognise the mineral assemblage also help in recognising potential mica-bearing pegmatites.

Exploration methods are shown in Table 8.20.

Table 8.20 : Guides to exploration of mica

	Method	Details
1.	Mapping[76]	
	(Surface)	1 : 1000
	(Underground)	1 : 500
		1 : 100 to 1 : 50
2.	Trenching[77]	30 m along strike
3.	Exploratory mining	8 m interval levels, winzes and raises, cross-cuts at close intervals.
4.	Drilling	Extension rods fitted to jackhammer and other methods in between cross-cuts and advancing faces

Simple deposits occur as large continuous beds showing low dips (5-15°), good outcrops of fairly uniform quality. Such deposits are usually seen in Vindhyan-Cuddapah basins.

Complex deposits show moderate to steep dips and may be folded, but are consistent. They may be medium to large in size. Such deposits are found in Lower Vindhyans, Upper Cuddapahs and Infrastrappeans, younger limestone occurs in Assam, Himalayas, and certain crystalline limestone of Tamil Nadu.

Intricate deposits are highly folded, faulted or dislocated. They may also be lenticular or interbedded with shales, etc. Such deposits belong to the Precambrians including the Dharwars of South India, Ajabgarhs and Raialos of Rajasthan and many other Archaean crystalline limestones.

Prospecting and Exploration

In selecting broad target areas of limestone and dolomite, photogeological mapping is of great help. The presence of sinkholes and karsts in a generally flat and subdued topography indicates the presence of limestone. Limestone terrains also encourage subsurface drainage due to the presence of solution cavities. These features are very easily recognised in aerial photographs. The ideal photographic scale for this type of work is 1:50,000.

Soils which develop on limestone tend to contain a high level of moisture which gives a dark tone to the soil and can be easily spotted in the aerial photographs and is another indication of the presence of limestone.

Some chip sampling and rapid analysis for CaO, MgO, etc., would help in confirming the presence of limestone and dolomite.

Exploration guidelines for limestone are shown in Table 8.21.

Gypsum

Geology

Four major types of gypsum deposits are recognised in India. They are :

(i) bedded evaporite sedimentary type,

(ii) crystalline gypsum in veins or disseminations in clays and shales,

(iii) as grains of gypsum in semiporous aggregates in desert salt pans, and

(iv) as bouldery disseminations in soil.

8.3.4 Mineral deposits associated with sedimentary evaporite rocks

The sedimentary evaporite environment encourages many types of deposition, like pure clastic accumulations, chemical precipitates, photosynthetic accumulations and evaporites. One common factor is the presence of water in circulation or stagnant water or both in all these processes. The most important mineral deposits in this group are limestone, dolomite, gypsum, phosphorite and rock salt.

Limestone and Dolomite

Geology

Limestone and dolomite are formed from solutions carrying calcium and magnesium carbonates. Minerals and rocks containing carbonates in major or minor quantities are the original source of all limestone and dolomites. Limestone may form by three processes, viz., inorganic, organic, and mechanical.

Carbonates are precipitated when carbon dioxide escapes from the solution. The amount of carbon dioxide contained in sea water is dependent upon the temperature of water and the saturation of carbon dioxide in the atmosphere. When the equilibrium between these three is disturbed, carbon dioxide escapes and carbonates are precipitated in the form of limestones, as warm sea water is usually saturated with calcium carbonates. Inorganic limestones are formed this way.

In the organic process, action of algae, bacteria, corals and other micro-organisms are responsible for calcium carbonate precipitation. In the mechanical process, shell or coral matter gets deposited and cemented to form limestones[24]. Dolomite is a carbonate of calcium and magnesium and its origin is still an unsettled issue. However, most of the dolomites are thought to be of replacement origin.

In India, limestones and dolomites are reported from all geological formations in almost all states, and hence it is not possible to list even a few of them. Generally, limestone and dolomites of economic importance occur together. However, singular occurrences of dolomite in India are also known[78].

Limestone occurs as regular beds in sedimentary sequences. In metamorphosed terrain they tend to occur as thin narrow bands and show complex structures. Limeshell accumulations generally show highly irregular outlines. Depending on the size, shape and disposition of limestone deposits siitable for cement manufacture, the Cement Research Institute has recognised three types of limestone deposits[79]. They are : simple, complex and intricate deposits.

Table 8.21 : General guidelines for exploration work for limestone and dolomite (Generally valid for bedded gypsum)

Method	Simple type		Complicated type		Highly complicated type		Remarks
	Regional exploration stage	Intensive exploration stage	Regional exploration stage	Intensive exploration stage	Regional exploration stage	Intensive exploration stage	
1. Mapping	1:2000 to 1:5000	1:1000 to 1:2000	1:1000	1:1000	1:1000 to 1:2000	1:1600	
2. Drilling	400-600 m interval	200-300 m grid	300-400 m section interval, 1-2 boreholes in each section	150-200 m section interval	100-200 m section interval 1-2 boreholes in each section	50-100 m section interval	
3. Pitting	2-4 Nos. for every sq.km.	2-4 Nos. for every sq.km.	Not Recommended				
4. Trenching	--- Not Recommended ---------		150-200 m. section interval	75-100 m section interval	100-200 m section interval	50-100 m section interval	
5. Sampling	Core, blast and channel sample	Core blast and channel sample	——				

The distribution of important Indian gypsum deposits is shown in Table 8.22.

Table 8.22 : Geological distribution of gypsum deposits in India

State	District	Geological formation	Host rock
Rajasthan	Nagaur Pali	Nagaur series Vindhyans	Gypseous limestone, dolomite and clays
	Barmer	(1) Recent sands	Blown sand Lake bed
	Bikaner Ganganagar Bharatpur	Recent	Lake bed[80]
Tamil Nadu	Tiruchirapalli	Uttatur Cretaceous	Gypseous clays[80]
	Coimbatore	Recent alluvium	Soil
Jammu and Kashmir	Baramula	Sallchala schists	Schists[80]
	Doda	Precambrian or Nummulites (Eocene)	Limestone
Gujarat	Kutch	Jurassic Subnummulites (Eocene) Pliocene Pleistocene Recent	Shales, Clay, Sand, Marls.

The Indian gypsum deposits occur in a variety of geological formations although all of them appear to be of evaporite sedimentary origin. The thick-bedded deposits of gypsum are thought to have originated in isolated basins which are periodically invaded by sea-water which contains considerable gypsum in a dissolved state. The freshly evaporated layers sink into the basin and new layers form from subsequent invasions of sea-water, resulting in thick bedded deposits. The vein deposits are of uncertain origin. All the other deposits are secondary in origin, derived from primary sources.

Table 8.23 : Geological distribution of phosphorite deposits in India

State	District	Geological formation	Host rock
Rajasthan	Udaipur	Aravallis	Dolomitic marble
	Chittorgarh (Maton, Jhamarkotra)	Vindhyans	Phosphatic shale
Uttar Pradesh	Dehra Dun (Mal Deota)	Tal-Krol	Limestone, chert, cherty and calcareous limestone
Tamil Nadu	Tiruchirapalli	Uttatur (Cretaceous)	—

Phosphorite deposits originated in miogeosynclinal conditions as indicated by the deposits of Rajasthan which are associated with the Aravallis. Photosynthesis by marine organism is cited as the source of deposition in the case of Tiruchirapalli deposits. The configuration of the floor of the depositional basin is thought to have influenced the localisation of the phosphorite deposit of Mussoorie. Phosphorites are known in many varying geological conditions and in practically every geological formation.

The presence of pyrites and organic matter and association with black shales suggest that phosphorite was formed under conditions of negative Eh. It has been suggested that the basin floor was folded into synclinal and anticlinal forms by regional tectonic phenomena. The remains of planktons and noktons (micro-organisms) which thrive in the basin fall into the synclinal depressions. Decay of their soft parts generates soluble phosphates, ammonia and ammonium salts. Nitrogenous bacteria convert ammonia and ammonium salts into nitrates. The soluble phosphates and nitrates present in the water encourage the growth of phytoplanktons. As these life forms die out, the synclinal troughs get filled up with phosphates. The soluble phosphates react with the calcium carbonate to form calcium phosphates which being insoluble are precipitated. The accumulation of these precipitates gives rise to beds of phosphorite[82].

Phosphorite deposits occur as independent beds, lenses and in stratified forms in complete conformity with the sedimentary host rocks. The rock may be limestone, calcareous phyllite, black shales, calcareous cherts, orthoquartzite, etc.

Gypsum deposits of primary origin are usually regularly bedded and have regular size and shape. The vein concretionary and bouldery deposits are all highly irregular.

Prospecting and Exploration

Gypsum usually occurs along with limestone and clay beds. The initial target areas may be those which are known to contain limestone. Since gypsum resembles limestone to a great extent, chemical tests are essential to identify the two separately, for which chip sampling may be done.

Gypsum also occurs in drying lakebeds which receive a periodic supply of sea water. Areas where such lakes are known are good targets in the search for gypsum. Aerial photographs may be used for recognising such targets.

The nodular deposits tend to occur in the sub-soil and its presence is indicated by boulders of gypsum within the soil.

Vein-type deposits are difficult to locate. Areas having limestones and pyrites in close proximity generally contain vein-type gypsum deposits. Large-scale systematic mapping accompanied by chip sampling would appear to be the best method to locate such deposits.

Exploration guidelines for gypsum are summarised in Table 8.21 (for limestone).

Phosphorite

Geology

Phosphorite deposits are invariably chemico-sedimentary in nature and are found only in the sedimentary formations. Phosphorite occurs in seven forms. These are :

(1) granular phosphorite,

(2) pelletal phosphorite,

(3) banded phosphorite,

(4) phosphatic nodules,

(5) algal phosphorite,

(6) brecciated or fragmental phosphorite, and

(7) fossilliferous phosphorite[81].

All of them tend to occur in varying proportions and combinations. Some important Indian deposits are shown in Table 8.23.

Prospecting and Exploration

Areas of miogeosynclinal deposition are chosen as the first broad target area for prospecting. Economic deposits are associated with limestone, calcareous cherts, black shales, etc. and areas containing such rocks are separated out for detailed examination. Most phosphorite beds contain radio-active minerals. Therefore, a rapid survey by a Geiger-Muller counter or scintillation equipment would help in locating promising areas of mineralisation. This is followed by a millimetre by millimeter traverse of favourable outcrops in which different beds are recognised by acid test and scintillation counts. Phosphorite does not react to acid but activates the scintillation instrument. This is a positive criterion for the recognition of phosphorite in the field. Chip samples are collected from the suspected phosphorite bands and subjected to chemical analysis by Shapiro's method[83]. The method described above was used in a prospecting operation for phosphorite in Turkey which resulted in important discoveries[84].

Exploration guidelines for phosphorites are shown in Table 8.24.

8.3.5 Mineral deposits associated with metamorphic rocks

In this group, mineral deposits like kyanite, sillimanite, graphite, talc, etc., are the most important, since these deposits are undeniably metamorphic in origin. Iron and manganese ores are included in this group, although their origin cannot be attributed to metamorphism. Their host rocks are generally metasedimentary and hence these two are included in this group.

Iron Ore

Geology

Six types of iron ore deposits are recognised in India. These are[85]

(1) deposits associated with the banded ferruginous formations of Precambrian Age. These include both hematitic and magnetitic types,

(2) sedimentary iron ores of sideritic or limonitic composition,

(3) lateritic ores derived from the sub-aerial alteration of the iron ore bearing rocks, such as gneisses, schists, basic lavas, etc.,

(4) the apatite-magnetite rocks of Singhbhum copper belt,

Table 8.24 : General guidelines for exploration of phosphorite

Method	Flat or low dipping uniform bodies		Complicated deposits with variable thickness etc.	
	Regional exploration stage	Intensive exploration stage	Regional exploration stage	Intensive exploration stage
1. Mapping	1:2000 - 1:5000	1:1000	1:1000	1:1000
2. Drilling	200 - 300 m grid	100 - 200 m grid	200-300 m section interval, 1-2 bore-holes per line to intersect 50/100 m levels	100-150 m section interval inter-section at 2-4 levels.
3. Pitting	4-10 Nos. per sq.km.	4-6 Nos. per sq.km.	Not recommended	
4. Trenching	Not recommended		200 - 300 m section interval	100 - 150 m section lines
5. Exploratory mining	Not recommended			Two levels develop-ment by drives/ winzes, cross cuts at approximately 30 m. interval.
6. Sampling	Core and sludge, blast and channel samples, bulk samples for beneficiation			

Based on Manual of Mineral Exploration, Geol. Surv India Misc. Pub. No. 33 .

(5) the titaniferous and vanadiferous magnetites of south-east Singhbhum and Mayurbhanj, and

(6) fault and fissure fillings of hematite.

All the major Indian iron ore deposits belong to the first group and are associated with banded iron ore formations of Precambrian age. Hematite ore is under extensive exploration and mining. Magnetite ores have started receiving attention only recently. Some of the major iron ore deposits of India are listed in Table 8.25.

The other occurrences reported in various geological formations are not of any economic importance.

As mentioned earlier, all the iron ore deposits of India belong to the Iron Ore Series and their equivalents of the Dharwar group of meta-volcanics and metasediments. The immediate host rock is the banded ferruginous quartzite. These banded formations were probably formed as chemical precipitates in partially enclosed sedimentary basins of the back water type, in long periods of geological quiescence. It has not been possible to identify the original source of the iron and silica minerals which were precipitated in such basins[86].

The deposits are thought to have been derived from the enrichment of these Banded Iron Stone Formations by a process of progressive removal of silica. Controversies, however, remain about the development of massive ores and blue dust. One view is that the massive ores are the resultants of direct precipitation. Blue dust is thought to be a product of the action of circulating waters which leach away the silica from the massive ores[7].

The iron ore formations within the Dharwars have been folded repeatedly and are preserved in narrow elongated patches of schist belts, a few of them forming synclinoriums like the Sandur synclinorium in Bellary district. It has been observed that a very large number of deposits in Karnataka and Goa show typical structural features. The major deposits in these two areas appear to have been preserved in tightly folded regional synclinal structures. The individual iron ore deposits are preserved in local structures, predominently synclinal. However, cappings and narrow bands which show no obvious structures are also quite common.

Most hematitic ore bodies can be grouped into two categories on the basis of their shape and mode of occurrence as capping and reef types. The major difference between the two is the dip, which will be very steep in the case of reefs and rather shallow in the case of cappings; outcrop widths may be narrow in the case of reefs and broad in the case of cappings[87,88]. These differences may not be very sharp in many cases as both reef and capping types may have a common origin and tectonic background.

Table 8.25 : Geological distribution of important iron ore deposits in India

State	District	Geological formation	Host rock
Andhra Pradesh	Anantapur	Dharwars	Banded ferruginous quartzite
Bihar	Singhbhum	Iron Ore Series (Dharwar eq:)	Banded hematite quartzite
Madhya Pradesh	Baster (Bailadila)	Bailadila Iron Ore Series	Banded hematite quartzite
	Durg	(Dharwar eq:)	
Maharashtra	Ratnagiri	Dharwar	Not clear
	Chanda	Dharwar	Not known
Goa		Dharwar	Banded ferruginous quartzite
Orissa	Keonjhar (Malangtoli)	Iron Ore Series (Dharwar equivalent)	Banded hematite quartzite
	Sundargarh	--	--
	Mayurbhanj	--	--
Rajasthan	Jaipur	--	--
Karnataka	Bellary (Sandur)	--	--
	Bijapur, Chitradurga, North Kanara, Tumkur	Dharwar	Banded ferruginous quartzite
	Chikmagalur (Kudremukh), (Bababudan, etc.)	Dharwar	-do-
	Shimoga	Dharwar	-do-
Tamil Nadu	Salem (Kanjamalai, etc.)	Dharwar	Banded magnetite quartzite[19]

Prospecting and Exploration

Hematitic and magnetitic iron ore bodies are generally either confined to the surface or are very close to the surface. Their location is not likely to create any problem. Field guides which may help in the location of such orebodies are given in Table 8.1.

Iron ore bodies may be found either exposed directly or covered by laterite, soil or other detrital material. The directly exposed ore bodies can be recognised by the hard massive ore outcrops of iron ore. Those under soil, laterite, etc. can be recognised by the presence of float ore or recemented ore boulders embedded within laterite or soil.

When ore bodies are not exposed and there are no obvious floats or other indications, it may become necessary to rely on a combination of indirect criteria to locate favourable targets. These may consist of:(1) the presence of BHQ/BHJ, etc., (2) topographic prominences, (3) laterite with ore pieces, and (4) structural ridges. On concealed outcrops, scout pitting and trenching may be done to confirm the presence of ore.

Exploration for iron ore is summarised in Table 8.26.

Manganese Ore

Geology

Three types of manganese deposits are recognised in India. They are :

(1) deposits associated with Precambrian metamorphic rocks of Gondite type,

(2) deposits associated with Precambrian metamorphic rocks of Kodurite type, and

(3) lateritoid deposits in surficial concentrations with mineralisation extending into the underlying rocks.

All the three major deposits belong to the Dharwar group of rocks and their equivalents. The lateritoid deposits are almost invariably found in association with the Iron Ore Series of rocks and their equivalents and occur mostly in the stratigraphic horizon just below the Banded Iron Formation. A few small deposits are known in Cuddapah formations. They are exploited on a small scale locally[19]. The important manganese deposits of India are listed below in Table 8.27.

Table 8.26 : General guidelines for exploration work for iron ore (hematite) (Excluding purely leteritic deposits)

Method	Capping type deposits		Reef type with appreciable dip		Remarks
	Regional	Intensive	Regional	Intensive	
1. Mapping a) Underground mapping for adits	1:2000 to 1:5000	1:1000 to 1:2000 1:200	1:2000 to 1:5000	1:1000 to 1:2000 1:100 to 1:200	To map lithology and boundaries, soil-ore to waste contact ore types and their contact, structural features, etc. Sludge collection is important wherever core loss occurs. Dry drilling useful in soft zones.
2. Drilling	100-500 m section intervals 1-2 bore-holes in each section.	50-150 m section interval, 2-4 bore-holes in each section to outline bottom of the ore.	100-300 m section interval along two levels	100-150 m. section interval down to 90 m depth	
3. Pitting	2-4 nos.	Deep pits down to 15 m. depth, 2-4 nos. on each section line to determine lump : fine ratio etc.	Upto 3 deep pits	1-2 nos. in alternate for every third section.	
4. Aditing	Not recommended	Cross-cutting adit intersecting ore-body 2-3 nos. along representative sections with 30-50 m back.	Not recommended	2-6 adits at different levels and at 300-500 m. lateral interval.	
5. Sampling	Core and sludge, bulk sample from pit.	Cores, sludges, bulk from pits and adits for every 1-2 m. interval for grade and size classification.	Core and sludge, bulk sample for every 1-2 m. depth from pit for size and grade classification.	Core and sludge, bulk sample for every 2 m. depth from pits and adits for grade and size classification.	

Based on Manual of Mineral Exploration, Geol. Sur. India Misc. Pub. No. 33)

Table 8.27 : Geological distribution of manganese ore deposits in India

State	District	Geological formation	Host rock	Important minerals
Andhra Pradesh	Adilabad	Cuddapah	Limestone or shales with inter-banded chert	Psilomelane, pyrolusite and braunite
	Srikakulam, Vishakhapatnam	Dharwar	Garnet granulite rocks (Argillaceous facies) Garnetiferous quartzite, (Arenaceous facies[89])	-do-
Bihar	Singhbhum	Iron Ore Series	Laterites, phyllites shales and cherty quartzite[90].	Pyrolusite, psilomelane
Goa	—	Dharwar	Laterite, phyllite and quartzite	Pyrolusite and psilomelane
Karnataka	North Kanara, Chitradurga, Shimoga, Tumkur, Bellary	Dharwar	Laterite, phyllite and cherty quartzite and crystalline limestone	Pyrolusite, psilomelane[91], manganite
Madhya Pradesh	Balaghat, Chindwara, Jhabua	Sausar Series	High grade metamorphic products of argillaceous, carbonaceous and arenaceous sediments	Braunite, pyrolusite and psilomelane
Maharashtra	Bhandara, Nagpur			
	Ratnagiri	Dharwar	Phyllites and cherty quartzites	Pyrolusite, psilomelane
Orissa	Bolangir, Koraput, Keonjhar, Sundergarh	Dharwar; Iron Ore Series	Khondalites and kodurites, Laterites, pyllites, shales and cherty quartzites	Pyrolusite, psilomelane
Rajasthan	Banswara	Aravallis	Phyllites and quartzites[90]	Braunite, pyrolusite, psilomelane
Gujarat	Baroda	Aravallis	Phyllites and quartzites	Pyrolusite, psilomelane, braunite

Just as in the case of iron ore, the association of manganese with the Dharwar rocks and their equivalents is unmistakable. Besides, there would appear to be a definite, broad lithologic similarity between the host rocks, most deposits being confined to pure argillaceous and arenaceous rocks and their metamorphic products. Carbonaceous host rocks are seen in the Madhya Pradesh - Maharashtra belt and in some parts of the Tumkur-Chitradurga belts in Karnataka.

The economic manganese ore deposits appear to have close genetic association with various types of low grade manganiferous sediments. The deposits of Madhya Pradesh and Maharashtra are thought to have been derived from spessartite quartz rocks or gondites and similar other rocks. The ore bodies grade into gondites as they are traced along the strike. These spessartite quartz rocks are all thought to be metamorphic products of low grade manganiferous sediments. One of the products in this metamorphism was probably braunite bearing manganese ore bodies. Alteration of the braunite is thought to have produced psilomelane, pyrolusite, etc. The orebodies are bedded and occur in conformity with the host rock[7].

The deposits of Srikakulam area referred to as the Kodurite type are also unmistakably associated with two types of metasediments, viz. (1) a garnet granulite, and (2) a garnetiferous quartzite. Thus, deposits of Srikakulam of Andhra Pradesh, Koraput of Orissa and other deposits of Madhya Pradesh, Maharashtra are related to the process of metamorphism.

In the lateritic type, there are two types of deposits. One occurring within laterite cappings and the other occurring in the underlying phyllites, quartzites and shales. Of these, the deposits within the lateritic cappings are of lateritic origin but derived from the underlying rocks. The deposits within the quartzites, phyllites and shales may be of sedimentary origin as indicated by the conformity of the orebodies with the host rocks and the presence of continuous planar features within the deposits and the host rocks[91].

All manganese deposits including those associated with laterites have been influenced and controlled by structure. The major structural features recognised in the Madhya Pradesh - Maharashtra belt are isoclinal folds as shown by the Kandri Orebody[92]. Structural control is prominent in the Srikakulam deposits also where the ore shows preferential concentration along the noses of drag folds[89].

In the lateritoid deposits, the laterite cappings show deposits totally devoid of any structure. But the underlying phyllites and quartzites have preserved orebodies in regional scale isoclinal synclines and recumbent folds as at Sandur. Here, cross-folds have played a part in bringing the important ore bodies to the surface[91].

Table 8.28 : General guidelines for exploration work for manganese ore

	Method	Sample from stratabound deposits		Banded deposits with complicated structure		Lateritoid bodies		Remarks
		Regional exploration stage	Intensive exploration stage	Regional exploration stage	Intensive exploration stage	Regional exploration state	Intensive exploration stage	
1.	Mapping	1:2000 to 1:5000	1:1000 to 1:2000	1:1000 to 1:2000	1:1000 to 1:2000			
2.	Underground mapping	Not recommended	1:2000	Not recommended	1:100 to 1:200	The main method of exploring lateritoid manganese bodies is by pitting and trenching, if possible by shallow drilling in order to delineate individual bodies including blind ore bodies.		
3.	Pitting/ trenching	As necessary		50-100 m. Trenching section interval wherever feasible				
3.	Drilling	200-300 m. section interval at 2 levels with 60 m vertical interval	100-200 m section interval intersection at 3-4 levels	50-100 m section interval at 2-3 levels with 30-60 m vertical intervals.	25-50 m section interval at 3-4 m vertical interval			
4.	Exploratory mining	Not recommended	Two levels across entire strike length	Not recommended	2-3 levels 20-30 m vertical interval where necessary			
5.	Sampling	Core and sludge channel and blast pit/core sample for laboratory study	Core and sludge channel and blast for pilot plant beneficiation studied.	Core and sludge channel and cast blast etc. for laboratory scale beneficiation	Core and sludge channel and blast for pilot plant beneficiation test.			

Based on Manual of Mineral Exploration, Geol. Sur. India. Misc:Pub.No.63 .

Prospecting and Exploration

Manganese ore bodies occur in a variety of forms and in varying depths. Purely surficial deposits are confined to the lateritoid types, although here also some deposits are known to persist for some depth. The major surface indication of the presence of manganese ore is the presence of float ore. The prospecting history of many major deposits indicates that the first discovery was made on the basis of float ore. A comprehensive list of field guides for locating manganese deposits is given in Table 8.1.

Where outcrops are not directly visible but are inferred, geophysical methods may help in locating the ore bodies. Electrical methods are particularly useful in locating the ore bodies in deposits of the gondite type. These methods may, however, prove useless in the case of lateritic type of deposits where the country rock has a high iron content.

Pitting and trenching would be useful in locating outcrops. The presence of recemented ore pieces in narrow linear lateritic humps is considered very favourable in locating deposits underneath as in the Sandur Manganese field[91].

Exploration guidelines for manganese ore deposits are summarised in Table 8.28.

Kyanite and Sillimanite

Geology

Commercial deposits of kyanite occur in two forms, viz.along with metamorphic rocks, and as a product of residual concentration as float ore, etc.[7].

Both types of deposits are known in India.

The geology and distribution of some important Indian kyanite deposits are shown in Table 8.29.

Table 8.29 : Geological distribution of important kyanite deposits in India

State	District	Geological formation	Host rock
Bihar	Singhbhum (Lapsaburu)	Archaean	Soil-original host rock is a quartz kyanite rock
Maharashtra	Bhandara (Dahegaon)	Archaean	Kyanite-topaz-dumortiorite rock

Kyanite occurs as a product of dynamothermal metamorphism of aluminous sediments. The most important economic deposits are of residual origin and the ore occurs in the form of boulders in soil as seen in Lapsaburu, Singhbhum. Large deposits of low grade kyanite deposits have been located in Bihar, Karnataka and Andhra Pradesh in quartz-kyanite rock, and in talc-pyrophyllite deposits in Rajasthan.

Sillimanite

Sillimanite occurs very much like kyanite and has the same chemical composition, and often they occur together as seen in Dahegaon deposits of Bhandara district[93]. The important deposits are located in Meghalaya, Rewa, Madhya Pradesh, Bhandara, Maharashtra and in the beach sands of Kerala. Of these, the occurrence in Meghalaya is the most important and is associated with the Shillong series. The Kerala deposits are in beach placers and are of economic importance only because of their recovery as a by-product.

Prospecting and Exploration

In prospecting for kyanite and sillimanite, broad targets are selected from areas containing aluminous sediments which have undergone high grade metamorphism. Mineralisation can be easily established by tracing of float ore and systematic shallow pitting.

Exploration guidelines for kyanite and sillimanate are summarised in Table 8.30.

Table 8.30 : Guides to exploration of kyanite

Method	Details
1. Mapping	1:1000 to 1:5000
2. Pitting/trenching	30 m. interval, trench width varying from 1 to 2 m or more
3. Sampling	From pits and trenches for analysis and recovery tests.

Graphite

Geology

Graphite occurs in commercial quantities in high grade metamorphic rocks. The geology and distribution of the major graphite deposits of India are shown in Table 8.31.

Table 8.31 : Geological distribution of important graphite deposits in India

State	District	Geological formation	Host rocks
Orissa	Phulbani Sambalpur Kalahandi Bolangir	Archaeans	Felspathic khondalites and pegmatite[94]
Kerala	Ernakulam	Archaeans	Charnockites[95]
Bihar	Palamau	Archaeans	Pyritiferous phyllite[96]
Andhra Pradesh	Khammam Vishakapatnam	Archaean	Khondalites, and Carbonaceous schist
Rajasthan	Ajmer Banswara	Aravallis	Actinolite-graphite schist.

Graphite is a product of high grade metamorphism of argillaceous carbonaceous sediments. Deposits generally occur as veins, lenses and disseminations in the metamorphic rocks.

Structural controls have been recognised in the graphite mineralisation of Orissa. Here, mineralisation is noticed at the contact of khondalites and granites. Shear zones developed in the contact zones show migmatisation which has helped in localising the deposits. Deposits occurring in pegmatites are more pure in quality. The ore bodies show general concordance with the planar features of the host rock.

Prospecting and Exploration

Areas of high grade metamorphism particularly of argillaceous carbonaceous sediments are very good targets. Geophysical prospecting gives excellent anomalies in graphite. Electrical methods (SP) were successful in locating and delineating graphite ore bodies in Ernakulam district of Kerala. The anomalies were subsequently proved by core drilling[95].

Exploration guides for graphite are similar to those for talc, soapstone, etc. are given in Table 8.33.

Talc/Soapstone/Pyrophyllite/Diaspore

Geology

Talc and soapstone occur in practically every Indian state where Archaean metamorphic rocks are exposed. Some important deposits of soapstone are located in Madhya Pradesh and Rajasthan. Pyrophyllite is rather rare in occurrence. It is associated with post-Dharwar granites as in Madhya Pradesh. Some deposits have been reported from Jhansi district of Uttar Pradesh.

Table 8.32 : Geological distribution of important talc- pyrophyllite-soapstone deposits

State	District/area	Geological formation	Host rocks
Madhya Pradesh	Tikamgarh (Kari-Khora)	Post-Dharwars	Contact of granite and quartz pyro-phyllite rock.
Uttar Pradesh	Jhansi[97] (Bijri-Dhankura, etc.)	Archaean	Fine-grained granites
Rajasthan	Bhilwara Udaipur Dungarpur Banswara Jaipur	Archaean	Ultrabasics, quartzite and metamorphosed limestone and dolomites

Prospecting and Exploration

Metamorphic terrain which contains magnesium carbonate rocks forms the best target area for talc and soapstone. For pyrophyllite and diaspore, rapid reconnaissance, outcrop mapping, chip sampling, etc. help in locating individual deposits. The typical features which help in identifying talc and pyrophyllite are their softness, and powdery glossiness. Deposits tend to occur in large clusters of lenses.

Exploration guidelines for talc soapstone and pyrophyllites are summarised in Table 8.33 based on the experience of Indian Bureau of Mines[97,99].

Table 8.33 : Guides for exploration of graphite, talc-soapstone pyrophyllite-diaspore

	Method of exploration	Details
1.	Mapping/underground mapping	1:1000 to 1:4000, 1: 200 to 1:500.
2.	Pitting	May be given at suitable intervals
3.	Trenching	Cross trenching, 30-50 m apart may be given.
4.	Drilling	50 m interval with a staggered pattern depending upon the mineralisation.
5.	Sampling	Trench sampling,, core sampling and channel sampling.

8.3.6 Mineral deposits associated with residual formations

A large number of mineral deposits occur as residual enrichments. The most important ones are iron ore, manganese ore, nickel, bauxite and clay. Of these, however, most of the deposits were formed originally in other environments and residual action has only augmented them. Typical residual deposits are bauxite and clay.

Bauxite

Geology

Bauxite generally occurs in association with laterite and is of residual origin. Most Indian deposits are seen within cappings of laterite occurring on a variety of rock types. Some deposits are known to occur in soil and some in sediments, but all are clearly derived from original lateritic sources nearby. Some important deposits are listed in Table 8.34.

Table 8.34 : Geological distribution of important bauxite deposits in India

State	District	Geological formation	Host rock	Important minerals
Bihar	Ranchi	Tertiaries to Recent	Laterite	Gibbsite with minor boehmite
Madhya Pradesh	Bilaspur Mandla Shahdol Jabalpur Surguja	-do-	-do-	-do-
Maharashtra	Kolhapur Ratnagiri Kolaba	-do-	-do-	-do-
Goa	—	-do-	-do-	-do-
Tamil Nadu	Salem	-do-	-do-	-do-
Gujarat	Jamnagar Kutch	-do- -do-	-do- Laterite and sediments	-do- -do-
Andhra Pradesh	Visakhapatnam	-do-	Laterite	-do-
Orissa	Sambalpur Koraput	-do-	-do-	-do-
Karnataka	Belgaum North and South Kanara	-do-	Laterite and sediments	-do-
Kerala	Trivandrum Cannenore	-do-	Laterite	-do-

Indian bauxite deposits are products of sub-aerial weathering and lateritisation of a variety of rocks although the more important deposits of Madhya Pradesh, Maharashtra and Bihar have developed on Deccan Trap Lava flows. The process of bauxite formation is not very well understood. But it is recognised that any aluminous rock, subjected to long periods of weathering in stable geological conditions can give rise to bauxite. The original rocks are continuously attacked by water charged with acids and gradually silica, ferruginous matter, etc., are removed in solution leaving aluminous material behind. The residual aluminous matter eventually accumulates in economic sizes to form the bauxite deposits[100].

Within the laterite cappings, bauxite may occur as a continuous horizon or may be distributed as small lenses. The topmost horizon is usually laterite, soil, etc. It is followed by bauxite, then by clay, lithomarge, etc., till the host rock contact is reached.

Bauxite ore bodies may be of three types, viz., continuous regular deposits with consistent grades and thicknesses, lenticular but fairly extensive deposits with sharp grade fluctuations, and highly erratic and pockety deposits of inconsistent grades.

Prospecting and Exploration

Since bauxite is genetically associated with laterite, any lateritic terrain is a potential target for bauxite prospecting. Regional small-scale aerial photographs are ideally suited for locating potential bauxite-bearing laterites. Bauxite discourages the growth of luxuriant vegetation. In the aerial photographs, such areas stand out conspicuously and can be easily identified.

Scarp retreat is a common phenomenon of bauxite-bearing plateau country. In this, the edge of the plateau recedes towards the centre of the plateau by progressive weathering. Such areas show the outcrops of bauxite clearly. However, the absence of scarp retreat is not a negative indicator[100].

In India, most of the important bauxite deposits occur on plateaus which rise to 1000 m above the mean sea level. This criterion can be used for isolating the potential target areas.

Bauxite does not differ much from laterite in its physical appearance and it may be difficult to distinguish them without chemical analysis. Therefore, at the initial stages, rapid chip and channel sampling and chemical analysis of promising outcrop areas is very essential. Samples which show a loss on ignition of less than 20 percent are considered very poor. Deposits which show such poor values can be rejected on this basis alone.

Geophysical and geochemical methods have only limited value in bauxite prospecting.

Exploration procedures for bauxite are summarised in Table 8.35.

Clays

Various types of clays are known of which the most important are chinaclay and fireclay. The other clays are ballclay, bentonite, pottery clay, fuller's earth, diaspore-clay[101], etc. The exploration methods for chinaclay and fireclay, which are applicable to all other clays also, are described below :

Chinaclay

Geology

Chinaclay is a product of residual weathering of felspathic rocks in favourable climatic and geological conditions. The main clay mineral which is kaolin can form by the action of water of post-magmatic origin. Kaolinisation may also occur as a result of the action of post-magmatic emanations or by a process of hydrolysis[101].

Chinaclay occurs as pockets, lenses, and cappings, usually under a cover of thin soil or occassionally under a cover of laterite, as seen in the case of Akulam chinaclay deposits near Trivandrum in Kerala State[102]. Here, the parent rock is a granitic gneiss and the clay deposits of economic value occur just above the gneiss. The zone is about 3-8 m in thickness and consists of white, grey and red clay mixtures.

The important clay deposits of Singhbhum district of Bihar were formed from the weathering of granites and pegmatites. Some of the deposits here are quite thick, mining having reached a depth of about 18 m. The chinaclay deposits near Kundara in Quilon district of Kerala also occur above a weathered granitic gneiss. The clay layer is 9-10.5 m thick and is covered by Tertiary sandstones, laterite, etc. which attain a maximum thickness of 30 m. Clay may occur within the matrix sandstone as a result of weathering of felspathic sandstone of upper Gondwanas. Such a deposit is reported from Rajmahal area of Santhal Pargana, Bihar, where the clay is recovered from sandstone and the remaining silica is used as silica sand. Clay also occurs as bedded deposit in Cuddapah, Vindhyans, Gondwanas, etc.

Prospecting and Exploration

Being a product of residual weathering similar to bauxite, prospecting for clay is essentially similar to that of bauxite. However, there are many important differences. In selecting large areas for initial prospecting of chinaclay, it is better to confine attention to areas which have a known history of residual weathering, and contain acidic rocks like

Table 8.35: General guidelines for exploration work for bauxite (Generally valid for residual clays, nickel of lateritic origin and other purely leteritic deposits including manganese and iron ores.)

Method	Bedded extensive deposits with with uniform grade		Lenticular extensive deposits with variable grade		Complicated type with erratic distribution		Remarks
	Regional exploration stage	Intensive exploration stage	Regional exploration stage	Intensive exploration stage	Regional exploration stage	Intensive exploration stage	
1. Mapping	1:2000 to 1:5000	1:1000	1:2000 to 1:5000	1:1000	1:2000 to 1:5000	1:1000	To delineate contacts between bauxite and laterite, bauxite, clay and formation of host rock
2. Drilling	200 m interval, a few pilot holes to touch basement 50 m grid in test strip	100 m interval down to top of lithomarge	100 m intervals down to top of lithomarge, a few holes to touch basement, 25 m grid in test strip.	50 m centres down to top of lithomarge	2 to 4 nos. down to basement	Not recommended	
3. Pitting	4-10 nos. down to top of lithomarge for 1,000 m strike length and 100-300 m width	100 m. centres half way between boreholes	100 m. centres half way between boreholes down to top of lithomarge	50 m centres half way between boreholes down to top of lithomarge	50 m centres, a few pilot pits down to lithomarge, test strip study on 25 m centres.	25 m. centres	
4. Trenching	Not recommended*	Not recommended*	Not recommended*	Not recommended*	Not recommended*	Long trenches to establish the average recoverability of bauxite	
5. Sampling	Channel sample at 20 m interval along scarp exposure, channel and bulk samples from pits laboratory-scale beneficiation studies.	Core and sludge bulk and channel from pits, lump and fine to be analysed.	Core and sludge, channel sample at 10 m. intervals along scarp exposures. Bulk and channel from pits.	Core and sludge, channel and bulk sample from pits, blastwise analysis of lump and fine separately.	Bulk and channel samples from pits	Bulk and channel samples from pits	Scrap cutting is an important sampling practice.

*Trenches along long axis of the deposit was done by M.E.C. in their exploration of East Coast bauxite deposits and are said to be very useful in delineating the continuity of lenses.

(Based on Manual of Mineral Exploration, Geol.Surv.Ind.,Misc. Pub. No. 33) granite and pegmatites. In aerial photographs, clay and clayey soil give a very dark tone because of high moisture supported generally by good growth of vegetation. Swamps, marshy lands, water-filled depressions, etc. may also indicate the presence of chinaclay. Rapid reconnaisssance with random pits[103] and auger drilling will help locate specific targets for detailed search.

Chinaclay deposits usually occur near the surface and methods of exploration may consist of mapping, pitting, drilling, etc. as given in Table 8.35 which gives exploration guidelines, for bauxite.

However, the clay being soft, conventional wet core drilling may be of limited value, dry drilling, auger drilling or pitting being better suited. In the Akulam area, pitting was used very successfully in exploration. Pits were sunk at 30 m interval[102].

Fireclay

Fireclay is generally associated with coal seams and is of sedimentary origin. Some important clay deposits are listed in Table 8.36.

Fireclay contains Al_2O_3 above 31 per cent while good quality fireclay may contain about 38 per cent Al_2O_3. Fireclay occurs both above and below coal seams in this bedded sedimentary form, showing same dips of coal seams which are 10-20^o. Several seams of fireclay may occur in the same sequence as in the Amlo fireclay mine in Bihar[105]. It may also occur as small pockets within felspathic sandstones as seen in the Gondwana clay deposits of West Godavari district of Andhra Pradesh. The dip of the formations[103] here is between 4 and 8^o.

Although most of the fireclay deposits are associated with the coal-bearing formations, certain deposits are reported from other formations like Vindhyans[104], as in Jabalpur district of Madhya Pradesh where they occur in Kaimur sandstones. The clay bed which is 4 to 6 m thick here is covered by a lateritic cap and seems to have formed as a result of weathering of the sandstone.

Prospecting and Exploration

As most of the important clay deposits occur in association with the coal-bearing Gondwana formations like Barakar, Raniganj, and Karharbari formations, the initial target areas can be chosen from these formations. Since fireclay beds occur above or below the coal seams, all methods valid for locating the seams are valid for the fireclays too. Coal seams may be directly visible if they occur in the escarpment faces as in Chirimiri coalfields, Madhya Pradesh. However, in most cases, indirect evidences will have to be depended upon. In areas where coal seams outcrop, there will be usually linear

Table 8.36 : Geological distribution of important fireclay deposits in India

State	District	Geological formation	Host rock
Assam	Lakhimpur	Tertiary coal-bearing formation	Sandstone, shale, coal sequence
	Sibsagar	Tipam Series	
Bihar	Palamau	Gondwana formations coal-bearing Barakars	Coal, sandstone, shale sequence
	Dhanbad	-do-	-do-
	Hazaribagh	-do-	-do-
	Santhal Parganas	-do-	-do-
	Ranchi	-do-	-do-
	Giridih	Gondwana formation coal-bearing Karharbaris	-do-
Madhya Pradesh	Bilaspur	Gondwana formation coal-bearing Barakars	-do-
	Shahdol	-do-	-do-
	Jabalpur	Vindhyan formation	Kaimur Sandstone[104]
Maharashtra	Chandrapur	Gondwana formation (coal-bearing Barakar equivalents)	Coal, shale, sandstone sequence
Orissa	Cuttack Dhenkanal Sambalpur	Gondwana formations	-do-
West Bengal	Burdwan	Gondwana formation (coal-bearing Barakar and Raniganj formations)	-do-

depressions which retain high moisture. These depressions are used for paddy cultivation and are an excellent field guide for locating coal seams. The presence of fireclay can be confirmed by putting shallow pits towards edges of such depressions which coincide with the top or bottom of coal seams. In such sections, generally plastic fireclay may occur at the top followed by non-plastic clay. Black soil, carbonaceous particles, presence of coal matter, etc. are also good indications for the presence of coal seams.

However, the best areas for search would be opencast coal mines where fireclay beds, if present, can be seen outcropping below the coal seams. A search through the old dumps of abandoned opencast mines can also give a clue to the presence of fireclay. An examination of exposed seam sections also helps in locating the fireclay beds.

Since fireclay can be mined economically only when it occurs within a depth of say 30 m (maximum) or so, it would be futile to look for it in deep underground coal mines.

Fireclay beds also occur independent of coal seams within coal bearing sequence. However, the methods of prospecting already discussed are valid.

Exploration guides for fireclay are shown below in Table 8.37.

Table 8.37 : Exploration guides for fireclay

	Method	Details
1.	Mapping	1 : 2000 1 : 1000
2.	Pitting	50 m intervals along the strike 11-12 m along dip

8.3.7 Mineral deposits associated with placer formations

Important placer deposits known in India are monazite-bearing sands of Kerala, Tamil Nadu, Andhra Pradesh and alluvial tin deposits of Madhya Pradesh. Of these, the monazite-bearing sands contain, in addition to monazite, a number of other minerals like sillimanite, zircon, ilmenite, etc. These sands are essentially beach placers in which are concentrated the minerals from riverine sediments. All the other placers are of riverine alluvial origin.

Deposits of gypsum are known in certain sand dunes of Rajasthan which should be considered as an eolian placer. Prospecting and exploration for placer deposits have been dealt with in sections 8.3.1 and 8.3.3 dealing with diamond, tin, etc.

8.3.8 Miscellaneous mineral deposits

By virtue of their diverse origins and specific non-correlatability, the following minerals which are of economic importance have been grouped together. No prospecting guides or exploration guides can be offered for these minerals. However, whenever one of them resembles a major mineral described earlier, its exploration sequence may be comparable. In this group, various semi-precious stones, silica sand, felspars, vermiculite and quartz are described briefly. Please see Table 8.38.

Table 8.38 : Miscellaneous mineral deposits

Mineral	State	District/ Area	Host rock	Comparable group for which exploration methods are given	Remarks
PRECIOUS STONES					
Beryl (Emerald)	Rajasthan	Ajmer, Udaipur	Pegmatite	Mica	Beryl occurs in pegmatites and is usually recovered during mica mining. Float deposits of beryl are common.
Corundum (Spinel)	Andhra Pradesh	Khammam	Granites and pegmatites	--	Corundum, agate, spinel, etc. have varied occurrences and hence nothing specific can be suggested for their exploration by way of guides.
OTHERS					
Felspar, Quartz	Felspar, quartz occur fairly widespread in the country		Pegmatite, quartz veins	Mica	---
Silica sand	As residual product, occurs in many States		--	Clay	---
Vermiculite	Andhra Pradesh	Nellore		Mica	---
	Karnataka	Mysore			
	Rajasthan	Ajmer			
	Tamil Nadu	North Arcot			
	West Bengal	Bankura			

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Chapter 9

9.0 Exploration in producing mines

The earlier chapters have dealt with the location of prospects, prospecting and exploration of mineral deposits to arrive at a decision for opening a mine. This chapter deals with the exploration needs of producing mines. At the stage of opening a mine, all the basic data regarding the deposit should be available. However, it is often necessary to translate these data into a specific mining need. Each mine is designed to produce a quantum of ore every day. The quantum so produced should have specific average grade and size which are fixed according to the utilisation of the ore. The basic problem is to find the ore of specific quality from the benches or underground mining faces. Since mining, once started, is a continuing process over a period of time, the problem of finding the necessary tonnage and grade is a continuous one. There is generally a production schedule which has to take care of such needs on a day to day, week to week, month to month, and year to year basis. Data collected during the earlier exploration stages give only a general picture of the deposit and are not sufficient to give information on localised basis to enable taking up mine planning with production schedules on a reliable basis. Mine exploration is aimed at bridging this data gap.

The twin objectives of mine exploration (i) to verify and correct the earlier exploration data, and (ii) control of the mining procedure in grade control, and mine economics.

9.1 Verification and correction of earlier exploration data

At the mine exploration stage, more precise data are required which will enable the exploitation of the ore according to specific grade and tonnage needs. For this, it is necessary to verify and correct the earlier exploration data. The data needs of underground and opencast mines tend to be different and hence each case is dealt with separately.

9.1.1 Underground mines

In the case of underground mines, at the development stage, the data available would be of the following types :

(1) surface geological plans and sections showing the geology, mineralisation, location of mine and exploratory openings, boreholes, etc.,

(2) subsurface composite plans of various levels,

(3) composite plans showing level details, stope crosscut, winze, raise and drive positions, borehole intersection points, etc.; and

(4) levelwise geological and assay plans, and

(5) longitudinal or vertical projections of the underground developments.

Where the ore distribution is spotty and in the form of stringers, the data available above may need continuous verification and modification for day to day control of ore grade and tonnage. Even in the case of massive ores, some of these modifications may become necessary. Verifications may be continuously necessary at the mining stage also.

The factors which generally contribute to grade dilution and tonnage difference in underground mines are : imprecise definition of footwall and hangingwall contacts of the ore body, presence of non-mineralised portions within blocks of ore, and the necessity of leaving roof support pillars, etc. within the stopes.

These problems can be largely overcome by operations, like geological mapping, sampling, drilling, crosscutting, raising, winzing and driving, and re-interpretation of the consolidated data for small blocks of ore.

Geological mapping : The various underground openings available for detailed examination and mapping are drives, crosscuts, raises, winzes and stope faces. The details to be recorded are footwall and hangingwall contacts, strike and dip of all planar features inside and outside the ore body, small-scale structures like folds, faults, shears, contacts between various ore types, barren zones, etc.

The mapping may be done on a 1:200 or 1:100 scale base plan prepared for small sections of the level. The procedure for underground mapping has been discussed earlier and may be followed.

Sampling : The main purpose of sampling here is to precisely define the assay boundaries between the hanging-wall and footwall contacts and to know the grade of the ore. The boundaries between the mineralised, lean and unmineralised zones are also precisely defined by sampling. A more precise grade estimation is also one of the objectives of the sampling. The sampling points and interval of sampling should be judiciously chosen based on thorough inspections and checks. More precise spacing can be done by the various statistical methods discussed earlier in connection with the intensity of exploration. For practical convenience, the sampling may be done by cutting channels of 10 cm width and 1-2 cm depth, across the strike of the orebody as is being done in the case of a lead and zinc mine in Rajasthan. Here samples are subdivided into 50 cm lengths to enable the data to be treated statistically[2]. In many base metal mines, systematic chip sampling on 15-25 cm grid is being practiced with satisfactory results.

Drilling : The main purpose of drilling at this stage may centre around the guidance of headings, drives, stope definition, stope development, etc., and may be coring or non-coring. Specific grade and tonnage control drilling will have to be undertaken in certain cases. If this is undertaken, spacing of drill holes can be done either based on the experience in such deposits or statistical methods described earlier.

If the procedure based on experience is followed, then the exploration and exploitation data have to be compared and correlated. When the data obtained from a particular grid of density of exploration show close agreement with the exploitation data in tonnage and grade, then that grid density can be accepted for other blocks. This assumes, of course, the existence of a fair uniformity in the mineral value distribution within the deposit as a whole.

Cross cutting, raising, winzing and driving : In a working mine such openings will be readily available for observations. However, when exploratory data are generally insufficient or there is some necessity for specific verification or collection of bulk samples, these openings can be made for such exploratory purposes.

Reinterpretation of data : The methods for interpretting the data, computation of grades, reserves, etc., have been discussed earlier. At the exploitation stage, the volume of data will be very large and for each block/level/stope, etc., separate gradewise, typewise, reserves will have to be computed and shown in large-scale plans so that daily/weekly/monthly/yearly production schedules can be drawn up. The information available at this stage is listed below :

(a) borehole intersections of the orebody, both from the surface and underground,

(b) sampling details,

(c) typewise ore distribution details,

(d) pattern of distribution, ore tonnage and grade in stopes in each level, and

(e) details about exploration done in adjacent areas.

This information is processed and stope plans, level plans, assay plans, etc., are completed and fresh gradewise reserve assessment is made. In most mines, production comes mainly from the stopes and partly from the development faces. For grade control purposes, it is necessary that a certain quantum of ore comes from the stope and the rest from developmental headings. The ratio is generally decided at this stage. The geologist who conducts the mine level exploration should have a broad strategy to prove it in advance so that the necessary number of finally proved blocks are always readily available for mining. The geologist should also be continuously studying the rate of depletion from various sections periodically. Studies should be systematically conducted to see the correlation between the exploration data and the results of exploitation. Besides, at each stage of mine exploration, the new data should be studied with data of earlier exploration to compare and reconcile. These studies will lead to the formulation of local, mine/sectionwise norms for exploration.

9.1.2 Opencast mines

Verification and updating are required in the case of opencast mines also. Such needs may arise during development or actual mining.

The problems and verification procedures of opencast mines are broadly comparable with those of underground mines.

At the development and mining stage, the available data in the case of opencast mines would consist of :

(a) surface geological plan and sections showing all details such as borehole, pit, trench position, mine openings, bench locations, etc., on scales of 1:1000, 1:2000, or 1:4000, and

(b) slice plans on larger scales like 1:500, etc.

Additional exploration would be aimed at supplementing these data so that the day to day grade and tonnage requirements can be anticipated and controlled.

In opencast mines, the grade and tonnage variations occur because of the following factors :

(a) development of waste bands, poor grade ores, etc., between sampling points, boreholes, pits, etc.

(b) unexpected lensing out of high grade ore portions,

(c) imprecise definitions of footwall/hangingwall contacts with the orebody, and

(d) imprecise definition of overburden, sideburden and interburden.

Verification and re-evaluation at this stage is done by geological mapping, bench sampling, pitting and trenching, drilling by blasthole drills, and reinterpretation of the consolidated data for small ore blocks.

Geological mapping : The methods described earlier are valid here also. However, the scale would be very large (between 1:500 and 1:200) and the plans will pertain to sections, benches, slices and the details would be different. Some of the details which would require to be mapped are listed below :

(a) Footwall/hangingwall contacts (observation at every 2-3 meters),

(b) typewise ore occurrence,

(c) small-scale features like local folds, faults, shears, etc.,

(d) planar features, like strike, dip foliation joints, and

(e) ore control factors like lithology, colour, and mineralogy.

During mapping, all the data from nearby boreholes, pits, trenches and other exploratory openings should be studied and attempts made to correlate these data with the exposed ore block. This way it is sometimes possible to establish correlation between ore types, ore colours, ore mineralogy and related features with ore grades. Such correlations can help in grade control.

Bench sampling : The usual sampling techniques described earlier are useful here also. However, the objectives may be different. Instead of collecting general samples here, type-wise, colour-wise, and mineralogy-wise samples may be preferred to identify and establish the correlation between these physical features and grades. As in mapping, the available exploratory data are studied continuously to establish possible correlation between what is observed in the exploratory openings and exposed ore.

Trenching and pitting : The methodology has been described earlier. During mine exploration, trenching and pitting would be undertaken on a highly selective basis and for specific purposes like bulk sampling, recovery testing, etc.

Drilling by blast hole drills : During development and exploitation, the ore slices and blocks are drilled at fairly close intervals for blasting purposes. The collection and study of the cuttings generated by this is becoming a useful grade control tool. It is seen that 17 m deep holes of 32 cm diameter generate 3-4 tonnes of cuttings[3].

The cuttings so generated are allowed to accumulate in a heap around the collar of the drill holes. A trench is dug through the cutting radially from the hole. Some 10% of the cuttings are sliced and removed from one of the trench faces. A sample is now collected just beneath the sliced face by a square nose shovel. See Fig.9.1 for details. The sample is then reduced in bulk and prepared for chemical analysis[3].

The physical characteristics of the ore cuttings can be studied in the trench cutting itself. The cuttings will show the various strata in reverse order as they are encountered in the drill hole. Each separate layer of cuttings can be measured, studied and correlated with the data available from nearby drill core or ore exposed in benches. By a combination of this study and chemical analysis, the average grade of the ore block can be established just prior to its being blasted. Blocks of blasted ore having specific grades can thus be segregated.

9.1.3 *Re-interpretation of data*

Methods of interpretation have already been discussed. At this stage, however, the data are voluminous and the desired precision of estimate of grade and tonnage is higher. The data available are :

(a) large-scale geological plan of the deposit and mine as a whole, with cross-sections,

(b) slice and bench plans,

(c) borehole/pit/trench data, and

(d) blasthole data.

From these data, grade-wise and block-wise reserves are marked out for day to day, week to week production planning. As in the case of underground mines, here also the exploration needs of adjacent blocks are kept constantly under review, and several blocks of ore are kept proved a little in advance of production.

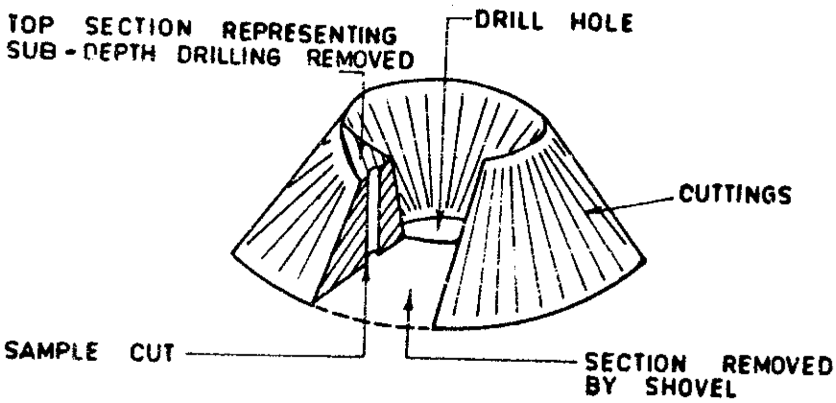

FIG: 9·1 SAMPLING BLAST — HOLE CUTTINGS

9.2 Control of mining operation

In the control of mining operations, there are two important factors to be considered. One is grade control (quality control) and the other is mine economics.

9.2.1 Grade control

Whatever may be the scale of mining operations, the mined ore should be of a specific usable grade. In order to achieve this constantly, grade control operations are necessary. Under Indian conditions, grade control has two objectives, viz. (i) to maintain constant ore quality and (ii) to maintain constant ore size. Before going into the grade control proper, certain operational mining principles like cut-off grade have to be understood.

Cut-off grade

Cut-off grade is rather broadly defined as the minimum grade of ore which meets the direct operational costs[4]. Cut-off grade is a highly variable quantity being dependent on too many external factors, such as market conditions, transportation facilities and ultimately the cost of operations[5].

Two types of cut-offs have to be recognised. These are planning cut-off and operational cut-off[6].

Planning cut-off : During exploration, ores have to be defined without taking into account the conditions of mining. In the projection of geological reserves and minable reserves (during a feasibility study) this cut-off is used. The aim is to predict the total tonnage available in a deposit[6].

Operational cut-off : When production starts, sectional reserves have to be defined. Such ores may be confined to a particular bench, section, stope, part of a stope, etc. This in short defines the available ore and the concept is centred more on the principle of the total profit of the mine[6].

Another concept which is basic to an understanding of grade control is the raw ore grade or the run-of-mine grade. The raw ore is that ore which has just been mined. This contains ores from the highest grades to the cut-off grade and also some very low grades which cannot be practically isolated; quite often, wall rock dilution could also be encountered. This ore also be contain ores of highly varying sizes, from large boulders to very small pieces, which may not be more than a few mm in size. Thus, the run-of-the mine ore is a very heterogeneous mixtures. In most mines, this does not go untreated to the point of utilisation.

The final product which comes out of the mine after some treatment is the marketable ore or concentrate which may have to conform to certain size and grade specifications.

A block of ore about to be mined normally consists of a variety of ore materials which can be recognised in the following categories :

(i) ores above cut-off grade,

(ii) ores below cut-off grade, and

(iii) waste rock.

The mining method may be mechanical or manual or a combination of both. In the manual and semimechanised mines, it is not very difficult to mine selectively only those ores which are above the cut-off grade. But, here also some low grades and wastes are bound to get into the mined ore to dilute it. In the case of mechanised mining, a higher amount of dilution is always anticipated because the machine cannot be as selective in mining as manual agencies. In certain types of veins mined underground, the width of valuable ore may be less than the minimum stoping width. Here also, a higher dilution is to be anticipated. These are the factors which have to be evaluated before any grade control can be attempted. These can not only be anticipated and understood but also computed and evaluated on the basis of detailed exploration data, which if absent, have to be collected.

A uniform grade and size of ore can be achieved by two methods:

(1) By selective mining, or by adopting grade controlled mining sequence, for obtaining the required grades.

(2) By blending of mined and sorted ore of different grades at the surface.

As mentioned before, selective mining is possible only in some cases. In many cases, blending may be a viable alternative. In order to carry out blending, various procedures are available. But only those which can be planned prior to mining are discussed here as they alone can be controlled by mine exploration. Some of these alternatives are discussed below :

(1) Reserving high grade blocks for blending only. In this, a proven ore block of high grade in a bench or section is exclusively kept to draw ores only for blending with the lower grades

of ores. The rate of production in this section will be such that it will last till the last of the low grade portions are mined out. From a practical stand point, this would be difficult.

(2) Having a large number of blocks from which any combination of choices can be made. This is more practicable, the only precaution that is necessary being the adjustment of the rate of production from a few selected stops or faces[7].

All these operations call for a very detailed knowledge of the deposit which can be obtained only by intensive exploration. Earlier, it was mentioned that plans made at this stage should contain exhaustive details like :

(1) distribution of ore types

(a) physical,

(b) mineralogical,

(c) colour-wise,

(d) hardness-wise,

(e) specific gravity-wise, etc.,

(2) distribution of poorly mineralised areas such as

(a) poor grade ore,

(b) ore which may crumble to minable types, etc.,

(3) distribution of mineralised areas, with lithological details and the quantum which might get mixed up with ore during mining,

(4) presence of surface/subsurface water, and the possibility of its accumulation in and around the mining areas.

There may be other details which would influence mining. These should be separately recognised.

It is often possible to recognise and correlate the grade of ore by one or more of the physical characteristics of the ore type. The presence or absence of a mineral or a group of minerals sometimes controls the ore grade.

The colour or weight of a type of ore may be correlated with a specific quality[7]. Therefore, such observations should be carefully made so that mining and blending could be planned in advance.

A typical blending scheme being worked out in an iron ore mine is discussed below. The planning of such an operation is done on the basis of mine exploration data. The ores in this case have 55-69% Fe and 1.5 - 10.0% Al_2O_3 with a heterogeneous mixture of hard, soft and friable ores. The blending schedule was worked out on the basis of the following data:

(i) data from plans and sections,

(ii) the quality of ore as determined from blast-hole samples,

(iii) the quality of the blasted material as determined from the samples,

(iv) recoveries of lumps and fines from different sections of the mines, and

(v) inspection of mine site for observing lithological variations.

Blending was done at different stages :

(i) sequencing of trucks from different mine faces (of different ore quality) to the primary crusher,

(ii) travelling of tripper conveyors on the primary surge piles and secondary surge pile at the ore processing plant, and

(iii) using three alternative feeders while loading wagons[8].

In the case of base metals, grade control is done on the basis of periodic grade and tonnage forecast for specific periods of time. In a copper mine in Bihar where grade control practices were studied, the forecast is generally confined to sections for periods of one month. Production is distributed between a few stopes and the nearby developmental drives. The progress is reviewed after every 10 days and if grade and tonnage deviate from those forecast, suitable adjustments are made by redistributing the production between the stopes and developmental drives. Most of the data for these operations come from closely spaced samples[2] and boreholes spaced at 60, 30, and 15 m.

9.2.2 *Waste generation*

The economics of any mine operation is dependent on many factors. Of these, the generation and handling of waste material incidental to mining is very important. The cost of production of the ore is closely influenced by the presence of these wastes. A precise estimate of the exact quantum of waste at each stage of mining is an important objective of mine exploration. The following types of mine wastes are usually recognised:

(i) Overburden

(ii) Sideburden

(iii) Interburden

(iv) Undergrade ore

(v) Undersize ore.

(i) Overburden

Overburden is defined as any non-ore material covering the ore body, which has to be removed to expose the ore. The constitution of the overburden may be anything from loose soil to hard rock. It may also be laterites, low grade ore materials, etc. In many cases, the overburden has to be stripped out completely before any mining can commence.

(ii) Sideburden

Sideburden is essentially overburden, but is recognised separately depending upon the attitude of the orebody. If the orebody is steeply inclined, then sideburden may occur on the hangingwall or footwall side or on both sides and is required to be removed before extracting the ore.

(iii) Interburden

Interburden is any waste rock which occurs within two mineable ore bodies or two or more mineable parts of an orebody.

(iv) Undergrade ore

Ore which has to be mined but cannot be sold because of its grade being below the cut-off grade is considered as undergrade or sub-marginal grade and is considered a mine waste unless otherwise used for beneficiating the same.

(v) Undersize ore

Just like undergrade ore there may be under size ore which cannot be utilised due to its small size. This also forms a mine waste unless it is used for beneficiation and/or agglomeration.

During the estimation of mineable reserves all these factors have to be taken into consideration. The market value of every tonne of ore should absorb alongwith other costs the cost of removing any or all these wastes. The ore to waste ratio is the most important aspect of mine economics in the case of opencast mines. In the case of underground mines, the major factor is the inevitable overbreakage and underbreakage along the footwall and hangingwalls which influence ore dilution, which in turn influences mine economics. When the cost of handling waste/undersize/undergrade material is not effectively absorbed by the market price of the ore, mining becomes uneconomic.

In opencast mines, this economic limit is forecast on the basis of exploration data by projecting the ultimate pit limit on cross section plans or slice plans. Consideration of the ultimate pit slope is also very important in these projections. The ultimate pit slope is determined by considerations of safety as well as the stability of the rocks involved.

In underground mines, the economic limit is guided among other things by the minimum stoping width. This is particularly applicable in the case of ore bodies which are very thin. The minimum stoping width defines the narrowest stope width in which miners can perform their work expeditiously[9]. If the orebody happens to be thinner than this width, the mining of the necessary extra width on both the sides will produce waste and poor grade ore which will dilute the ore grade and hence affect the mine's economics adversely. In mine exploration, such situations should be anticipated early by advance face exploration.

Most of the mine economic aspects discussed hitherto are basically mining problems. However, these problems can be tackled well only by systematic mine exploration. Mine exploration should be planned in such a way that answers to all these problems can be had whenever required, preferably in advance.

9.2.3 *Geotechnical investigation in open pit mining*

Geotechnical investigations are required for large scale open-cast mining. Although such investigations are essentially engineering studies, geological factors form important basic data required. Three types of geotechnical studies require geological data. They are stereographic projection (planar features, joints, minor fold axes, cleavage, etc.), physical scale models and finite element analysis[10].

(1) Stereographic projection

The planar feature studies may be of joints, cleavages, foliation, minor fold axes, etc. The edge of the friction of each joint is studied to select the most critical wedges. These data combined with the geological map provide information about the potential areas of failure.

(2) Physical models

These are made to select homogeneous units which are manageable as a unit in the context of slope stability. For this, the areas are studied and classified into homogeneous structural units.

(3) Finite element analysis

For this, the essential data are stress strain coefficients of each rock unit. Anisotropy of rocks can be studied this way. Tensile strength and shear strength values of each rock unit are also studied. Deformability characteristic of each surface of weakness is studied by the dilatancy characteristic of the joints in question[10].

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Appendix - 1.1

List of Selected References on Different Aspects of Mineral Exploration

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Appendix—2.1

Characteristics for identifying important rock forming minerals

MINERAL	CHEMICAL COMPOSITION OR FORMULA	PERCENTAGE OF THE CONSTITUENT/ RADICAL		CRYSTAL SYSTEM	HABIT	COLOUR	HARDNESS	SPECIFIC GRAVITY	CRITERIA FOR FIELD RECOGNITION
QUARTZ	SiO_2 FOR ALL VARIETIES	Si O	46.7 53.3	HEXAGONAL. TRIGONAL TRAPEZOHEDRAL FOR LOW TEMPERATURE QUARTZ AND HEXAGONAL TRAPEZOHEDRAL FOR HIGH TEMPERATURE QUARTZ.		USUALLY COLOURLESS WHEN PURE. TAKES ANY COLOUR ACCORDING TO IMPURITIES	7	2.65	GLASSY LUSTRE, CONCHOIDAL FRACTURE, CRYSTAL FORM, INSOLUBLE EXCEPT IN HYDROFLUORIC ACID. TRANSPARENT TO TRANSLUCENT COLOUR.
NOTE : A GREAT MANY VARIETIES OF QUARTZ ARE KNOWN WHICH CAN BE BROADLY DIVIDED INTO 2 CATEGORIES (A) COARSELY CRYSTALLINE VARIETIES, AND (B) CRYPTOCRYSTALLINE VARIETIES. AMONG THE FIRST CATEGORY ARE ROCK CRYSTAL (WITH DISTINCT CRYSTALS) AMETHYST (EXHIBITING VARIOUS SHADES OF VIOLET OFTEN WITH CRYSTALS), SMOKY QUARTZ, CITRINE (YELLOW LIKE TOPAZ), AND MILKY QUARTZ. SOMETIMES THESE MINERALS MAY INCLUDE SMALL CRYSTALS OF RUTILE, HEMATITE OR MICA OR LIQUID AND GASEOUS CARBONDIOXIDE. THE CRYPTOCRYSTALLINE VARIETY CAN FURTHER BE DIVIDED INTO TWO GROUPS,VIZ. FIBROUS AND GRANULAR. CHALCEDONY, CARNELIAN, CHRYSOPRASE. AGATE, AND HELIOTROPE OR BLOOD-STONE BELONG TO THE FIBROUS GROUP, WHEREAS FLINT, CHERT, JASPER AND PRASE FALL IN THE LATTER GROUP.									
TRIDYMITE	SiO_2			HEXAGONAL	CRYSTALS ARE SMALL AND COMMONLY TWINNED.	COLOURLESS TO WHITE	7	2.26	—
CRISTOBALITE	SiO_2			TETRAGONAL ISOMETRIC		COLOURLESS	6.5	2.32	CHARACTERISTIC BEHAVIOUR WHEN HEATED. ON HEATING TO 200°C IT TURNS WHITE. BUT ASSUMES ORIGINAL COLOURS AFTER COOLING.
OPAL	SiO_2nH_2O			AMORPHOUS, MASSIVE, BOTRYOIDAL		COLOURLESS, WHITE, PALE SHADES OF YELLOW, RED, BROWN, GREEN, GRAY AND BLUE.	5 - 6	2.0 - 2.35	LESSER HARDNESS AND SPECIFIC GRAVITY IN PRESENCE OF WATER. SOLUBLE IN STRONGLY ALKALINE SOLUTIONS. GIVES OFF WATER ON HEATING.
FELSPAR : ORTHOCLASE	$KAlSi_3O_8$	K_2O Al_2O_3 SiO_2	16.9 18.4 64.7	MONOCLINIC USUALLY SHORT PRISMATIC ELONGATED CRYSTALS	COMMONLY IN CRYSTALS OR IN CLEAVABLE TO GRANULAR MASSES	COLOURLESS, WHITE, GRAY, FLESH-RED	6	2.57	COLOUR, HARDNESS AND CLEAVAGE. INSOLUBLE IN ACIDS.
MICROCLINE	$KAlSi_3O_8$			TRICLINIC	CLEAVABLE MASSES	WHITE TO PALE YELLOW, RED OR GREEN	6	2.54 - 2.57	CHARACTERISTIC DEEP GREEN COLOUR.
NOTE : SODIUM OFTEN REPLACES POTASSIUM. IF SODIUM EXCEEDS POTASSIUM, THE MINERAL IS KNOWN AS ANORTHOCLASE.									
ALBITE-ANORTHITE	$NaAlSi_3O_8$ FOR ALBITE $CaAl_2Si_2O_8$ FOR ANORTHITE			TRICLINIC, DISTINCT CRYSTALS ARE RARE	TWINNED CRYSTALS SOMETIMES STRIATIONS ARE SEEN ON CRYSTAL FACE OR CLEAVAGE PLANE	COLOURLESS, WHITE, GRAY, GREENISH, YELLOWISH, FLESH-RED.	6	2.62	TWIN STRIATIONS. ALBITE IS INSOLUBLE. BUT ANORTHITE IS SOLUBLE IN HYDROCHLORIC ACID.
NOTE : THE ALBITE-ANORTHITE GROUP FORMS A SOLID SOLUTION SERIES COMPRISING ALBITE, OLIGOCLASE, ANDESINE, LABRADORITE, BYTOWNITE AND ANORTHITE.									
FELSPATHOIDS : LEUCITE	$K(AlSi_2O_6)$	K_2O Al_2O_3 SiO_2	21.5 23.5 55.0	ISOMETRIC USUALLY IN TRAPEZOHEDRAL CRYSTALS		WHITE TO GRAY.	5.5 - 6	2.47	TRAPEZOHEDRAL FORMS, INFUSIBILITY
NEPHELINE	(Na, K) $AlSiO_4$	Na_2O Al_2O_3 SiO_2	21.8 35.9 42.3	HEXAGONAL	RARELY IN SMALL PRISMATIC CRYSTALS WITH BASE	COLOURLESS, WHITE OR YELLOWISH	5.5 - 6	2.60-2.65	FUSIBLE TO A COLOURLESS GLASS, WITH A STRONG YELLOW FLAME. SOLUBLE IN HYDROCHLORIC ACID.

Characteristics for identifying important rock forming minerals Contd.)

MINERAL	CHEMICAL COMPOSITION OR FORMULA	PERCENTAGE OF THE CONSTITUENT/ RADICAL	CRYSTAL SYSTEM	HABIT	COLOUR	HARDNESS	SPECIFIC GRAVITY	CRITERIA FOR FIELD RECOGNITION
SODALITE	$3Na_2Al_2Si_2O_8$ $2NaCl$	Na_2O 25.6 Al_2O_3 31.6 SiO_2 37.2 Cl 7.3	ISOMETRIC	MASSIVE IN EMBEDDED GRAINS	USUALLY BLUE, WHITE, GRAY, GREEN.	5.5 - 6	2.15 - 2.3	SOLUBLE IN HYDROCHLORIC ACID. USUALLY DISTINGUISHED BY BLUE COLOUR.
PYROPHYLLITE	$Al_2(Si_4O_{10}/OH)_2$	Al_2O_3 28.3 SiO_2 66.7 H_2O 5.0	MONOCLINIC	RADIATING LAMELLAR CRYSTAL AGGREGATES GRANULAR TO COMPACT	WHITE, APPLE-GREEN, GRAY, BROWN.	1 - 2	2.8	MICACEOUS HABIT, CLEAVAGE AND GREASY FEEL. AT HIGH TEMPERATURE YIELDS WATER IN THE CLOSED TUBE. EXFOLIATES ON HEATING.
SERPENTINE	$3MgO.2SiO_2.2H_2O$	MgO 43.0 SiO_2 44.1 H_2O 12.9	MONOCLINIC	VARIEGATED IN LIGHTER AND DARKER SHADES OF GREEN		3 - 5	2.5 - 2.6	VARIEGATED GREEN COLOUR, GREASY LUSTRE OR FIBROUS NATURE
CHLORITE	$Mg_3(Si_4O_{10}/(OH)_2Mg_3$		MONOCLINIC	FOLIATED MASSIVE OR AGGREGATES OF MINUTE SCALES	GREEN OF VARIOUS SHADES, RARELY YELLOW, WHITE, ROSE, RED.	2 - 2.5	2.6 - 3.3	GREEN COLOUR, MICACEOUS HABIT AND CLEAVAGE INELASTIC FOLIA.
TALC	$Mg_3(Si_4O_{10}/OH)_2$	MgO 31.7 SiO_2 63.5 H_2O 4.8	MONOCLINIC	FOLIATED AND RADIATING FOLIATED GROUPS	APPLE-GREEN, GRAY, WHITE, SILVER WHITE	1	2.7 - 2.8	NOT AFFECTED BY ACIDS MICACEOUS HABIT. CLEAVAGE, SOFTNESS AND GREASY FEEL.
NOTE	WHEN COMPACT AND MASSIVE, IT IS ALSO KNOWN AS STEATITE OR SOAPSTONE.							
KAOLINITE	$2H_2O.Al_2O_3.2SiO_2$	Al_2O_3 39.5 SiO_2 46.5 H_2O 14.0	TRICLINIC	USUALLY IN CLAY LIKE MASSES, EITHER COMPACT OR FRIABLE	WHITE WHEN PURE	[illegible]	2.6	ASSUMES BLUE COLOUR WHEN MOISTENED WITH COBALT NITRATE AND IGNITED. USUALLY RECOGNISED BY CLAY LIKE CHARACTER.
PYROXENE : ENSTATITE HYPERSTHENE:	$MgO.SiO_2$ FOR ENSTATITE $(Mg,Fe)_2Si_2O_6$ FOR HYPERSTHENE		ORTHORHOMBIC	USUALLY MASSIVE, FIBROUS OR LAMELLAR	GRAYISH, YELLOWISH OR GREENISH WHITE, OLIVE GREEN AND BROWN.	5.5 - 6	3.2 - 3.6	COLOUR, CLEAVAGE, UNUSUAL LUSTRE.
DIOPSIDE-HEDENBERGITE-AUGITE	$CaMgSi_2O_6$ FOR DIOPSIDE $CaFeSi_2O_6$ FOR HEDENBERGITE $Ca(Mg,Fe,Al)(Si,Al)_2O_6$ FOR AUGITE		MONOCLINIC	GRANULAR MASSIVE, COLUMNAR AND LAMELLAR	WHITE TO LIGHT GREEN FOR DIOPSIDE. AUGITE IS BLACK.	5 - 6	3.2 - 3.3	CRYSTAL FORM AND IMPERFECT CLEAVAGE.

Characteristics for identifying important rock forming minerals (Concld.)

MINERAL	CHEMICAL COMPOSITION OR FORMULA	PERCENTAGE OF THE CONSTITUENT/ RADICAL		CRYSTAL SYSTEM	HABIT	COLOUR	HARDNESS	SPECIFIC GRAVITY	CRITERIA FOR FIELD RECOGNITION
SPODUMENE	$LiAl(Si_2O_6)$	Al_2O_3 SiO_2 Li_2O	27.4 64.6 8.0	MONOCLINIC	DEEPLY STRIATED VERTICALLY. OCCURS ALSO IN CLEAVABLE MASSES	WHITE, GRAY, PINK, YELLOW, GREEN.	6 - 5.7	3.15 - 3.20	GIVES CRIMSON FLAME ON HEATING. CHARACTERISED BY CLEAVAGE.
AMPHIBOLES ANTHO-PHYLLITE	$(MgFe)SiO_3$			ORTHORHOMBIC	COMMONLY LAMELLAR OR FIBROUS	GRAY TO VARIOUS SHADES OF GREEN AND BROWN	5.5 - 6	2.85 - 3.2	CLO..-BROWN COLOUR. YIELDS WATER IN CLOSED TUBE ON HEATING.
TREMOLITE-ACTINOLITE	$Ca_2(Mg,Fe)_5$ $(Si_8O_{22})(OH)_2$			MONOCLINIC	SILKY FIBRES, OFTEN BLADED, RADIATING COLUMNAR AGGREGATE	VARIES FROM WHITE TO GREEN.	5 - 6	3.0 - 3.3	SLENDER PRISMS AND PRISMATIC CLEAVAGE.
HORNBLENDE				MONOCLINIC	COLUMNAR OR FIBROUS	VARIOUS SHADES OF DARK GREEN TO BLACK	5 - 6	3.0 - 3.4	CRYSTAL FORM AND CLEAVAGE ANGLE. YIELDS WATER IN A CLOSED [illegible] TUBE ON HEATING.
CLINOZOISITE-EPIDOTE	$Ca_2Al_3O(SiO_4)$ $(Si_2O_7)(OH)$ $Ca_2(Al,Fe)_2Al_2O$ $(SiO_4)(Si_2O_7)(OH)$			MONOCLINIC	USUALLY COARSE TO FINE GRANULAR ALSO FIBROUS	PISTACHIOGREEN TO YELLOWISH. GREEN TO BLACK GREEN (EPIDOTE) PALE GREEN TO GRAY (CLINOZOISITE)	6 - 7	3.35 - 3.45	EPIDOTE IS CHARACTERISED BY PECULIAR GREEN COLOUR.
BERYL	$Be_3Al_2(Si_6O_{18})$	BeO Al_2O_3 SiO_2	14.0 19.0 67.0	HEXAGONAL		BLUISH GREEN OR LIGHT YELLOW, EMERALD GREEN	7.5 - 8	2.75 - 2.8	HEXAGONAL CRYSTAL FORM AND COLOUR.
TOURMALINE	$XY_3Al_6(SiO_3)_3$ $(Si_6O_{18})(OH)_4$ X IS USUALLY Na Y IS Fe, Mg, Li,Al			HEXAGONAL		VARIES. DEPENDS ON COMPOSITION	7 - 7.5	3.0 - 3.25	CHARACTERISTIC ROUNDED TRIANGULAR CROSS SECTION
ZIRCON	$Zr(SiO_4)$	ZrO_2 SiO_2	67.2 32.8	TETRAGONAL		COLOURLESS, BROWN GRAY, GREEN, RED.	7.5	4.68	CHARACTERISTIC CRYSTALS, COLOUR, LUSTRE, HARDNESS, HIGH SPECIFIC GRAVITY.
TOPAZ	$Al_2(SiO_4)(F,OH)_2$			ORTHORHOMBIC		COLOURLESS, PINK, YELLOW, WINE YELLOW, BLUISH.	6.0	3.4 - 3.6	CRYSTAL HABITS, BASAL CL[illegible], HARDNESS, SPECIFIC GRAVITY.
SILLIMANITE	$Al\ AlO(SiO_4)$			ORTHORHOMBIC	FREQUENTLY FIBROUS	BROWN, PALE GREEN, WHITE	6 - 7	3.23	SLENDER CRYSTALS WITH ONE DIRECTION OF CRYSTAL.
STAUROLITE	$Fe_2Al_9O_6(SiO_4)_4$ $(O,OH)_2$	FeO Al_2O_3 SiO_2 H_2O	16.7 53.3 27.9 2.0	MONOCLINIC	RARELY MASSIVE USUALLY IN CRYSTALS	RED BROWN TO BROWNISH BLACK	7 - 7.5	3.65 - 3.75	CHARACTERISTIC CRYSTALS AND TWINS.
OLIVINE	$(Mg,Fe)_2SiO_4$			ORTHORHOMBIC	EMBEDDED GRAINS OR IN GRANULAR MASSES	OLIVE TO GRAYISH GREEN, BROWN	6.5 - 7	3.27 - 4.37	GLASSY LUSTRE, CONCHOIDAL FRACTURE, GREEN COLOUR
SPHENE	Ca TiO (SiO_4)	CaO TiO_2 SiO_2	28.6 40.8 30.6	MONOCLINIC	MAY BE LAMELLAR OR MASSIVE	GRAY, BROWN, GREEN, YELLOW, BLACK	5 - 5.5	3.4 - 3.55	WEDGE SHAPED CRYSTAL AND LUSTRE.

Appendix - 2.2

Atomic Weights

(O= 16.0000)

Atomic No.	Element	Symbol	Atomic weight
13	Aluminium	Al	26.97
51	Antimony	Sb	121.76
18	Argon	A	39.944
33	Arsenic	As	74.91
56	Barium	Ba	137.36
4	Beryllium	Be	9.02
83	Bismuth	Bi	209.00
5	Boron	B	10.82
35	Bromine	Br	79.916
48	Cadmium	Cd	112.41
20	Calcium	Ca	40.08
6	Carbon	C	12.011
58	Cerium	Ce	140.13
55	Cesium	Cs	132.91
17	Chlorine	Cl	35.457
24	Chromium	Cr	52.01
27	Cobalt	Co	58.94
41	Columbium	Cb	92.91
29	Copper	Cu	63.54
66	Dysprosium	Dy	162.46
68	Erbium	Er	167.2
69	Europium	Eu	152.0
9	Fluorine	F	19.00
64	Gadolinium	Gd	156.9
31	Gallium	Ga	69.72
32	Germanium	Ge	72.60
79	Gold	Au	197.0
72	Hafnium	Hf	178.6
2	Helium	He	4.003
67	Holmium	Ho	164.94
1	Hydrogen	H	1.0080
49	Indium	In	114.76

(Contd.)

Atomic No.	Element	Symbol	Atomic weight
53	Iodine	I	126.92
77	Iridium	Ir	193.1
26	Iron	Fe	55.85
36	Krypton	Kr	83.7
57	Lanthanum	La	138.92
82	Lead	Pb	207.21
3	Lithium	Li	6.940
71	Lutecium	Lu	174.99
12	Magnesium	Mg	24.32
25	Manganese	Mn	54.93
80	Mercury	Hg	200.61
42	Molybdenum	Mo	95.95
60	Neodymium	Nd	144.27
10	Neon	Ne	20.183
28	Nickel	Ni	58.69
7	Nitrogen	N	14.008
76	Osmium	Os	190.2
8	Oxygen	O	16.0000
46	Palladium	Pd	106.7
15	Phosphorus	P	30.98
78	Platinum	Pt	195.23
19	Potassium	K	39.096
59	Praseodymium	Pr	140.92
91	Protactinium	Pa	231.0
88	Radium	Ra	226.05
86	Radon	Rn	222.0
75	Rhenium	Re	186.31
45	Rhodium	Rh	102.91
37	Rubidium	Rb	85.48
44	Ruthenium	Ru	101.7
62	Samarium	Sm	150.43
21	Scandium	Sc	45.10

(Contd.)

Atomic No.	Element	Symbol	Atomic weight
34	Selenium	Se	78.96
14	Silicon	Si	28.09
47	Silver	Ag	107.880
11	Sodium	Na	22.997
38	Strontium	Sr	87.63
16	Sulphur	S	32.066
73	Tantalum	Ta	180.88
52	Tellurium	Te	127.61
65	Terbium	Tb	159.2
81	Thallium	Tl	204.39
90	Thorium	Th	232.12
69	Thulium	Tm	169.4
50	Tin	Sn	118.70
22	Titanium	Ti	47.90
74	Tungsten	W	183.92
92	Uranium	U	238.07
23	Vanadium	V	50.95
54	Xenon	Xe	131.2
70	Ytterbium	Yb	173.04
39	Yittrium	Y	88.92
30	Zinc	Zn	65.38
40	Zirconium	Zr	91.2

Appendix - 3.1 A

Salient features of M. M. R. D. Act, M. C. R. and M. C. D. R.

All prospecting and mining activities for major minerals in the country are regulated by the Mines and Minerals (Regulation and Development) Act, 1957. Certain sections of this Act are of a common nature for both the activities, and a few sections apply specifically to prospecting activities.

Mineral Concessions Rules 1960 (MCR) have been framed in exercise of the powers conferred by Section 13 of M.M.R.D. Act, mentioned above, and Mineral Conservation and Development Rules, 1958 (MCDR) in exercise of the powers under 18 of the same Act. The salient features as observed in the M.M.R.D. Act, M.C.R. and M.C.D.R. are given below.

<u>Rules Common to P.L. and M.L.</u>

(i) Generally, P.L. or M.L. is granted to only Indian nationals, and all such activities should be carried out with the assistance of Indian nationals except with the prior approval of Central Government.

(ii) P.L. or M.L. is granted by a competent authority of the State Government who will obtain the concurrence of the Central Government in respect of the minerals under the first Schedule of M.M.R.D. Act, 1957.

(iii) The question of possessing a valid prospecting licence or mining lease arises only in case of major minerals. Any State Government may have its own rules in respect of minor minerals. Any work carried out without a valid P.L. or M.L. will make the person involved liable for punishment up to one year imprisonment and/or fine up to Rupees five thousand.

(iv) The holders of P.L. or M.L. will have to provide indemnity to the Government against third party claims.

(v) The State Government should maintain registers showing applications for and grant of prospecting licences and mining leases. These registers are open for inspection by any person on payment of the prescribed fee.

(vi) The Central Government with consultation with the State Government may decide that no prospecting licence or mining lease be granted in respect of any land to be specified by a notification to that effect.

(vii) The operations and records including that of accounts of P.L. or M.L. holder may be examined by the authorized agents of State Government or Central Government for collecting any information. Also, such agents should be allowed entry to the workings for surveying, sampling, etc.

(viii) Any contravention of the provisions of these Act and Rules will render the concerned P.L. or M.L. void and of no effect.

(ix) If any P.L. or M.L. holder is aggrieved by the decisions of directives made by the State Government or any other authority, he may apply for a revision of these decision/s or directive/s within a specified time and on paying the prescribed fee.

Rules Regarding Prospecting Licence

(i) The application for issue of prospecting licence should be accompanied by (a) Certificate of Approval in Form A. Application for obtaining the Certificate of Approval should be accompanied by a fee prescribed in MCR. (b) a fee calculated at the rates prevailing at that time. Currently, the rate of fee is as follows : Rs. 20/- for the first square kilometre and Rs. 4/- for the subsequent square kilometre or a part thereof, (c) an incometax clearance certificate (in Form C appended to MCR) from the Income Tax Officer concerned, and (d) a valid clearance certificate of the payment of all mining dues. In some cases, a sworn affidavit will suffice.

(ii) The financial obligations of a P.L. holder are towards (a) fee for Certificate of Approval, (b) application fee for the grant of P.L., (c) prospecting fee, currently ranging from 25 p. to Rs. 2.50 per hectare per annum, (d) security deposit, the present rate of which is Rs. 200/- per square kilometre, and (e) royalty at the existing rates for the material removed over and above the allowed limits in Schedule III of MCR.

(iii) A prospecting licencee may remove any material within certain limits from the prospecting area for testing purposes only.

(iv) Normally, prospecting licences may be issued to a person for a mineral or group of associated minerals to a cumulative total extent of 25 sq.km. only in any one State. However, the Central Government may decide depending on the merits of the case to grant more area for prospecting work.

(v) Prospecting licence is granted for one year for mica and two years for others. It may be renewed for an equal period as was originally covered by the P.L. provided that the State Government feels it necessary to renew the P.L.

Rules Regarding Mining Leases

(i) The application for the grant of a mining lease should be accompanied by (a) Certificate of Approval (if the certificate of approval has expired, a copy of the application made to the State Government for its renewal), (b) an application fee, presently Rs. 200/-, (c) income-tax clearance certificate, and (d) a valid clearance certificate issued by a competent authority of the payment of all mining dues, or a sworn affidavit wherever it suffices.

(ii) The financial obligations for a mining leasee are towards (a) fees for Certificate of Approval (if not a holder of P.L.), (b) application fee for grant of the M.L., (c) a deposit of Rs. 500/- or more for preliminary expenses, (d) surface rent not exceeding land revenue, (e) security deposit, at present Rs. 1,000/-, (f) dead-rent or royalty, no dead-rent need be paid during the first year.

(iii) Normally, mining leases are granted to a person for a mineral or minerals to a cumulative total of 10 sq.km. only in any one State. This can, however, be revised by the Central Government.

(iv) For iron ore and bauxite, the period of lease is for 30 years and in other cases it is 20 years. A renewal of lease can be made for an equal period as in the original grant, subject to satisfying other conditions.

(v) Persons holding a prospecting licence get preferential right over the area provided they have not violated any of the rules; otherwise, the claim for a particular area may be decided on a "first come first served" basis.

Appendix - 3.1 B

Rights and Obligations of Mining Lease Holders and Prospecting Licence Holders

There are certain rights and obligations which are of common nature to both the mining lessee and prospecting licencee. A few rights and obligations are specific. These are highlighted below.

Rights common to the P.L. and M.L. holder

(i) To enter upon the land and search for win, work, etc.

(ii) To sink, drive and make pits, shafts and inclines, etc.

(iii) To bring and to use machinery, equipment, etc.

(iv) To clear brushwood and to feel and utilise trees, etc. with the permission of the competent authorities.

(v) To transfer the licence or lease on approval from the competent authority.

Rights of a P.L. holder

(i) To work and carry away some material for testing purposes only up to a certain limit without paying royalty and upto certain limit on paying royalty as prescribed. He may also remove minerals like gold, silver, precious stones and mica (not exceeding 10 tonnes) also for commercial purposes on payment of royalty.

(ii) To obtain renewal of prospecting licence.

(iii) To get extension of the period of prospecting licence.

(iv) To get refund of a deposit under certain circumstances.

(v) To enforce preferential right for obtaining mining lease provided he has not violated other Rules.

Rights of a Mining Lessee

(i) To make roads and ways and to use the existing roads and ways.

(ii) To get building and road materials, etc.

(iii) To use water from streams without any obstruction of whatever nature.

(iv) To use land for stacking and heaping purposes.

(v) To use land for beneficiating and conveying away the material.

(vi) To work for other minerals after getting them included in the lease.

Obligations common to both P.L. and M.L. holders

(i) To pay royalty on minerals to the Government according to the rates prescribed from time to time.

(ii) To work and carry operations in a workman-like manner.

(iii) To maintain accounts of expenditure on prospecting and mining.

(iv) Not to carry out prospecting or mining operations within the vicinity (within 50 m) of a public utility structure like railways, canals, buildings, etc. unless otherwise permitted.

(v) Not to cut or remove timber in a reserved forest without permission.

(vi) Not to encroach on the property of others without consent of the concerned.

(vii) To give indemnity to the Government against all claims from a third party.

(viii) Not to be financially controlled by any trust, syndicate, corporation, firm, etc. without the approval of the Government.

(ix) To provide for weighing or measuring of material won.

(x) To arrange for the removal of machinery, building structure, etc. on the abandonment or closure of a mine.

(xi) Not to appoint foreign nationals without the approval of the Central Government.

(xii) To furnish all geophysical data to the D.G., G.S.I. and on atomic minerals to the Secretary, Department of Atomic Energy.

(xiii) To report accident taken place during the execution of work without delay.

Obligations exclusive to a prospecting licencee

(i) To annually pay the prospecting fee in advance.

(ii) To forefeit security deposit under certain exigencies.

(iii) Not to carry on prospecting work in any manner other than prescribed by these Rules.

(iv) To give a report of work done before claiming for the refund of security deposit.

(v) To make arrangements for plugging of boreholes, fencing and restoring the surface of land.

(vi) To send the notice of commencement of prospecting operations thirty days before the intended date to the C.I.B.M. in the prescribed form.

(vii) To intimate the C.I.B.M. in the prescribed form of the commencement of prospecting operations within seven days after the commencement.

(viii) To send a progress report within 30 days after the expiry of one year of P.L. or expiry of P.L. as the case may be.

Obligations exclusive to Mining Lessee only

(i) To pay dead rent or royalty whichever is greater.

(ii) To pay surface rent, water charges, taxes, etc.

(iii) To maintain and keep boundary marks in good order.

(iv) To commence operations within a year and work in a workman-like manner.

(v) To keep in good condition pits, shafts, etc.

(vi) To support and strengthen the mine workings to the necessary extent.

(vii) To report the discovery of other minerals.

(viii) To send notice of intention of opening a mine 30 days in advance.

(ix) To intimate the opening of mine within fourteen days of opening.

(x) To intimate the transfer or assignment within 30 days of change.

(xi) To send notice of the intended abandonment of mining operation before 30 days and under certain circumstances 15 days also.

(xii) To send notice of temporary discontinuance of mining operation within 15 days for abandonment, 75 days for discontinuance.

(xiii) To send notice of reopening of a mine thirty days in advance.

(xiv) To intimate the re-opening of a mine within fourteen days after doing so.

(xv) To send notice of commencement of stoping forty-five days in advance. Notice should be accompanied by plans and sections of scale not less than 1 cm = 10 m.

(xvi) To submit annual return in prescribed form in respect of major minerals.

(xvii) To submit monthly return in prescribed form for major minerals.

Apart from the periodical or ad hoc filling of these aforesaid returns, the P.L. or M.L. holders are required to fulfil many other requirements. The salient features of these Rules are given below :

(i) Copies of the annual returns and monthly returns should be sent to the respective State Governments.

(ii) Copies of plans and sections should be maintained. Their scale should not be less than 1 cm = 10 m. In case of abandonment or discontinuance of a mine, these plans and sections should be made over to the C.I.B.M.

(iii) Records of the mining activities like drilling and shaft sinking should be maintained properly.

(iv) The cores and specimens of different rock types and minerals obtained during shaft sinking or drilling operations should be preserved with proper identification at least for six months generally or up to a specific period as directed by the C.I.B.M.

(v) A qualified geologist or mining engineer should be appointed either full or part time depending on the size of the mine.

(vi) The mine or prospect should be open for inspection by any officer deputed by C.I.B.M.

(vii) Violation or contravention of the above Rules will make the concerned persons liable for prosecution with penalties ranging from a fine of Rs. 1,000/- to imprisonment up to six months, or both.

However, if any person is aggrieved by any order made or direction issued, he may apply to the Central Government within 30 days or more (with satisfactory reasons) for the revision of the orders or directions. The Central Government may confirm, modify or set aside the order or direction if necessary on hearing from an ad hoc Board set up for the purpose.

(Condensed from M.C.R., 1960 and M.C.D.R., 1958 revised and currently valid)

The First Schedule

(M.M.R.D. ACT 1957)

SPECIFIED MINERALS

1. Apatite and phosphatic ores.
2. Beryl.
3. Chrome ore.
4. Coal and lignite.
5. Columbite, samarskite and other minerals of the "rare earths" group.
6. Copper.
7. Gold.
8. Gypsum.
9. Iron ore.
10. Lead.
11. Manganese ore.
12. Molybdenum.
13. Nickel ores.
14. Platinum and other precious metals and their ores.
15. Pitchblende and other uranium ores.
16. Precious stones.
17. Rutile.
18. Silver.
19. Sulphur and its ores.
20. Tin.
21. Tungsten ores.
22. Uraniferous allanite, monazite and other thorium minerals.
23. Uranium bearing tailings left over from ores after extraction of copper and gold, ilmenite and other titanium ores.
24. Vanadium ores.
25. Zinc.
26. Zircon.

The Second Schedule

(M.M.R.D. ACT 1957)

RATES OF ROYALTY

1. The rate of royalty for coal has not been included for the purpose of this bulletin.

2.	MICA[1/]		
	(a)	Crude mica	Eight rupees per 100 kg.
	(b)	Trimmed mica of qualities other than heavy-stained, dense-stained or spotted second quality.	Sixteen rupees per 100 kg.
	(c)	Trimmed mica of heavy stained, dense-stained or spotted second quality.	Eight rupees and forty paise per 100 kg.
	(d)	Waste and scrap mica	Two rupees and eighty paise per 100 kg.
	(e)	Waste rounds	Three rupees and fifty paise per 100 kg.
3.	(a)	GOLD[1/]	One rupee and sixty paise per gram of gold per tonne of ore and on pro rata basis
	(b)	SILVER[1/]	Fifty rupees per kg. of metal.
4.	IRON[2/]		
	(i)	Ore Lumps -	
	(a)	With 65% Fe or more	Four rupees per tonne.
	(b)	With 62% Fe or more but less than 65% Fe	Three rupees per tonne.
	(c)	With 60% Fe or more but less than 62% Fe	Two rupees per tonne.
	(d)	With less than 60% Fe	One rupee and fifty paise per tonne.
	(ii)	Ore Fines -	
	(A)	Fines (including natural fines and fines produced incidental to mining and sizing of ore):	
	(a)	With 65% Fe or more	Two rupees and fifty paise per tonne

	(b) With 62% Fe or more but less than 65% Fe	One rupee and fifty paise per tonne.
	(c) With less than 62% Fe	One rupee per tonne.
	(B) Concentrates prepared by beneficiation and/or concentrates of low grade ore, containing 40% Fe, or less than 40% Fe	Fifty paise per tonne.
	(iii) Red oxide	Two rupees per tonne.
5.	(a)1/ All precious and semi-precious stones (except diamond and agate)	Twenty per cent of the sale price at the pit's mouth.
	(b) Diamond	Fifteen per cent of the sale price at the pit's mouth.
	(c)1/ Agate	Forty rupees per tonne
6.	MANGANESE ORE2/	
	(a) Manganese dioxide (containing 78 per cent or more of MnO_2 and 4 per cent or below Fe)	Thirty rupees per tonne.
	(b) 46% Mn and above.	Twelve rupees per tonne.
	(c) 35% Mn and above but below 46% Mn	Seven rupees and fifty paise per tonne.
	(d) Below 35% Mn but above 25% Mn	Five rupees per tonne.
	(e) 25% Mn or below	Two rupees per tonne.
7.	CHROMITE3/ (both lumpy non-friable ore and concentrates)	
	(a) Containing 48% Cr_2O_3 and above.	Twenty rupees per tonne.
	(b) Containing less than 48% Cr_2O_3 and more than 40% Cr_2O_3	Twelve rupees per tonne.
	(c) Containing less than 40% Cr_2O_3	Six rupees per tonne.
8.	LIMESTONE1/	Two rupees and fifty paise per tonne.
9.	DOLOMITE1/	Three rupees per tonne.

10.	GRAPHITE[1/]		
	(a)	With 80% or more carbon	Sixteen rupees per tonne.
	(b)	With 40% or more carbon but less than 80% carbon	Eleven rupees per tonne.
	(c)	With less than 40% carbon	Three rupees and fifty paise per tonne.
11.	CHINACLAY[1/] (including ballclay)		
	(a)	Crude	Two rupees per tonne.
	(b)	Washed	Eight rupees per tonne.
12.	KYANITE[1/]		
	(a)	60% Al_2O_3 and above	Thirty rupees per tonne
	(b)	Below 60% Al_2O_3 and above 50% Al_2O_3	Ten rupees per tonne.
	(c)	50% Al_2O_3 and below	Four rupees and fifty paise per tonne.
13.	GYPSUM[1/]		
	(a)	Fertilizer grade (gypsum supplied to fertilizer factories)	Two rupees per tonne.
	(b)	Other grades	Three rupees per tonne.
14.	LIMESHELL[1/] (including calcareous and sand chalk)		Three rupees per tonne.
15.	FIRECLAY[1/] [including plastic, pipe, lithographic and natural (pozzolanic) clay]		Two rupees per tonne.
16.	ILMENITE[1/]		Six rupees per tonne.
17.	COPPER ORE[2/]		Four rupees per unit per cent of copper metal per tonne of ore and on pro rata basis.

18.	LEAD ORE[1/]	One rupee and fifty paise per unit per cent of metal per tonne of ore and on pro rata basis.
19.	ZINC ORE[1/]	Three rupees per unit per cent of zinc metal contained per tonne of ore and on pro rata basis.
20.	GARNET (ABRASIVE)[1/]	Seven rupees per tonne.
21.	SILLIMANITE[1/]	
	(a) 58% Al_2O_3 or more	Thirty five rupees per tonne.
	(b) Below 58% Al_2O_3	Twenty rupees per tonne.
22.	BARYTES[1/]	
	(a) White (including snowhite)	Ten rupees per tonne.
	(b) Buff	Six rupees and fifty paise per tonne.
23.	(a) QUARTZ AND QUARTZITE[1/]	One rupee and twenty five paise per tonne.
	(b) SAND FOR STOWING	Twnety five paise per tonne.
24.	GLASS SAND AND MOULDING SAND[1/]	One rupee and fifty paise per tonne.
25.	CORUNDUM[1/]	Fifty rupees per tonne.
26.	BAUXITE[1/] (All grades)	Four rupees per tonne.
27.	OCHRE	Two rupees per tonne.
28.	STEATITE[1/] (Soapstone and talc)	
	(a) All grades except the inferior grade used in insecticide industry.	Four rupees and fifty paise per tonne.
	(b) Inferior grade used in insecticide industry.	Two rupees and twenty five paise per tonne.

29.	APATITE1/ (Rock phosphate)	
	(a) Ores with 25% or more P_2O_5	Five rupees per tonne
	(b) Ores with less than 25% P_2O_5	Four rupees per tonne.
30.	ASBESTOS	
	(a) Chrysotile of superior quality i.e. AS, A, B, and C.	Two hundred and fifty rupees per tonne.
	(b)1/ Chrysotile of inferior quality i.e. other than AS, A, B and C.	Sixty rupees per tonne.
	(c) Amphibole	Twelve rupees per tonne.
31.	CADMIUM	Eight rupees per unit per cent of Cadmium metal per tonne of ore and on pro rata basis.
32.	CALCITE1/	Three rupees per tonne.
33.	DIASPORE	Ten rupees per tonne.
34.	FELSPAR1/	Two rupees per tonne.
35.	FLUORSPAR1/	
	(a) Containing 85% CaF_2 or more	Forty five rupees per tonne.
	(b) Containing 70% CaF_2 but less than 85% CaF_2	Thirty rupees per tonne.
	(c) Containing more than 30% CaF_2 but less than 70% CaF_2.	Twenty rupees per tonne.
	(d) Containing 30% CaF_2 or less.	Ten rupees per tonne.
36.	MAGNESITE2/	Six rupees per tonne.
37.	NICKEL ORE1/	Two rupees per unit per cent of nickel metal per tonne and on pro rata basis.
38.	PYRITES1/	Four rupees per tonne of pyrites with forty per cent sulphur content and on pro rata basis.

39.	PYROPHYLLITE	
	(a) For all grades except the inferior grade used in insecticide industry.	Three rupees per tonne.
	(b) Inferior grade used in insecticide industry.	One rupee and fifty paise per tonne.
40.	RUTILE	Seventy rupees per tonne.
41.	VERMICULITE	Two rupees per tonne.
42.	WOLFRAM1/	Five rupees per tonne of ore with one per cent WO_3 and on pro rata basis.
43.	All other minerals not hereinbefore specified.	Ten per cent of sale price at the pit's mouth.

1/ G.S.R. No. 175(E) dated 31.3.1975, see Gazette of India, Exty. Pt. II, Sec. 3(i) dated 31.3.1975 (w.e.f. 1.4.1975).

2/ G.S.R.No. 2(E) dated 1.1.1979, Gazette of India, Exty. Pt. II, Sec. 3(i) dt. 1.1.1979.

3/ G.S.R. No. 584 (E) dated 13.12.1975, see Gazette of India, Exty. Pt. II, Sec. 3(i) dated 13.12.1975 (w.e.f. 15.12.1975).

The Third Schedule

(M.M.R.D. ACT 1957)

DEAD RENT

	Period of the mining lease	Rate of dead rent per hectare
1.	1st year	Nil.
2.	2nd year to 5th year	Rs. 12.50
3.	6th year to 10th year	Rs. 25.00
4.	11th year onwards	Rs. 37.50

Appendix - 3.2

List of offices of the Geological Survey of India

1. The Director General,
Geological Survey of India,
27, Chowringhee,
Calcutta - 700013.

2. The Dy.Director General,
Geological Survey of India,
Eastern Region,
12 A & B, Russell Street,
Calcutta - 700071.

3. The Director,
Geological Survey of India,
Bihar Circle (East),
5, Rajendra Nagar,
Patna-16.

4. The Director,
Geological Survey of India,
Bihar Circle (West),
Arati Building Boring,
Pataliputra Road, Patna-13.

5. The Director,
Geological Survey of India,
Orissa Circle,
69, Kalpana Chowk,
Bhubaneswar-6.

6. The Director,
Geological Survey of India,
West Bengal Circle,
4, Chowringhee Lane,
Calcutta-16.

7. The Director,
Geological Survey of India,
Bhutan Circle,
Samchi, P.O. Chamurchi,
Jalpaiguri.

8. The Dy.Director General,
Geological Survey of India,
Northern Region,
3-Gokhale Marg,
Lucknow.

9. The Director,
Geological Survey of India,
Punjab Haryana Circle,
S.C.O. 98-100 Sector-17 C,
Chandigarh.

10. The Director,
Geological Survey of India,
Jammu Circle,
67-68, 1/C Gandhi Nagar,
Jammu Tawi, Jammu.

11. The Director,
Geological Survey of India,
Uttar Pradesh Circle,
3, Gokhale Marg,
Lucknow.

12. The Director,
Geological Survey of India,
Kashmir Circle,
Niloger Rajbagh,
Srinagar (Kashmir)

13. The Director,
Geological Survey of India,
Himachal Pradesh Circle,
S.C.O., 98-100 Sector-17 C,
Chandigarh.

14. The Dy.Director General,
Geological Survey of India,
Central Region,
New Secretariat Building,
Nagpur.

15. The Director,
Geological Survey of India,
Madhya Pradesh Circle,
Super Market,
Jabalpur (M.P.).

16. The Director,
Geological Survey of India,
Maharashtra Circle (W),
Deccan College Road, Yerwada,
Poona.

17. The Dy.Director General,
Geological Survey of India,
North-Eastern Region,
Laithumkharah, Asha Kuttir,
Shillong-3.

18. The Director,
Geological Survey of India,
Arunachal Pradesh Circle,
Old Police Lane, P.O.Tezpur,
Distt. Darang, Assam.

19. The Director,
Geological Survey of India
Assam-Meghalaya Circle,
Nongrim Hill,
Shillong-3.

20. The Director,
Geological Survey of India,
Tirpura Mizoram Circle,
2, Ramanagore Road,
Agartala, Tripura.

21. The Director,
Geological Survey of India,
Manipur Nagaland Circle,
Imphal (Manipur).

22. The Director,
Geological Survey of India,
Madhya Pradesh Circle,
Shaila Hills,
Bhopal-2.

23. The Director,
Geological Survey of India,
Maharashtra Circle (E),
243, Canal Road,
Dharampeth,
Nagpur.

24. The Dy. Director General,
Geological Survey of India,
Western Region,
Himanshu Bhawan,
A/3, Sawai Jai Singh Road,
Banipark, Jaipur.

25. The Director,
Geological Survey of India,
Rajasthan Circle-I,
D-87, Meera Marg, Banipark,
Jaipur-6.

26. The Director,
Geological Survey of India,
Rajasthan Circle-II,
A/3, Sawai Jai Singh Road,
Banipark, Jaipur-6.

27. The Director,
Geological Survey of India,
Rajasthan Circle-III,
C-6, Sardar Patel Marg,
Jaipur.

28. The Director,
Geological Survey of India,
Rajasthan Circle-IV,
R-8,
Jaipur - 302005.

29. The Director,
Geological Survey of India,
Gujarat Circle,
Union Co-operative Insurance
Building, Ashram Road,
Ahmedabad-14.

30. The Dy.Director General,
Geological Survey of India,
Southern Region,
5-5-449, Mukharamzahi Road,
Hyderabad-29.

31. The Director,
Geological Survey of India,
Kerala Circle,
Palayam,
Trivandrum-1.

32. The Director,
Geological Survey of India,
Tamil Nadu Circle,
Shastri Bhawan, Block No.I & IV,
35, Hadows Road, Madras-6.

33. The Director,
Andhra Pradesh Circle (North),
Geological Survey of India,
3-6-22, Bashir Bagh,
Hyderabad-29.

34. The Director,
Andhra Pradesh Circle(South),
Geological Survey of India,
3-6-22, Bashir Bagh,
Hyderabad-29.

35. The Director,
Geological Survey of India,
Mysore Circle (North),
78, Diagonal Road, III Block,
"Jayanagar",
Bangalore-11.

36. The Director,
Geological Survey of India,
Mysore Circle (South),
78, Diagonal Road, III Block,
"Jayanagar",
Bangalore-11.

Appendix. 3.3

Addresses of Survey of India Regional offices in India

1. Surveyor General Office,
Hathibarkala Estate,
Post Box No. 37,
Dehradun-248001 (U.P.).

2. Surveyor General Office,
No. 17, E.C. Road,
Post Box 25,
Dehradun - 248001 (U.P.).

3. Survey Training Institute,
Uppal Post Box No. 1207,
Hyderabad-500974.(A.P.).

4. Pilot Map Production plant,
Uppal Post Box No. 1207,
Hyderabad-500974 (A.P.).

5. Research and Development,
Post Box No. 1207,
Hyderabad-500974 (A.P.).

6. (I) Geodetic and Research
Branch, No.17 E.C.Road,
Post Box No. 77,
Dehradun-248001 (U.P.)

(II) 14 Party,
No.37-A Curzon Road,
Dehradun.

(III) 19 Party,
No.17, E.C.Road,
Dehradun-248001 (U.P.).

(IV) 71, Party,
No.68, Rajpur Road,
Dehradun-248001 (U.P.).

(V) 72, Party,
No.23-A, New Cannt Road,
Dehradun.

7. Map Publication,
Directorate Hathibarkala
Estate, Post Box No.28,
Dehradun .

8. (I) Directorate of Survey
(Air), West Block No.4,
Wing No.4. 2nd Floor,
R.K.Puram,
New Delhi - 110022.

(II) 64 (A.H.S.) Party,
West Block No. 4,
Wing No.1, 2nd Floor,
R.K.Puram, New Delhi-110022.

(III) 67 (F.S.P.) Party,
No. 16, 2-699,
Malakpet,
Hyderabad - 500036 (A.P.).

(IV) No.105 (DLI) Printing
Group, West Block No. 4,
Wing No. 4, Ground
Floor, R.K.Puram,
New Delhi - 110022.

9. Eastern Circle,
No. 13, Wood Street,
Calcutta-700016 (W.B.)

(II) 11 Party,
Post Office : Hinoo
Ranchi-834002 (Bihar).

10. Western Circle,
Geejgarh House, Civil Lines,
Post Box No.4,
Jaipur-302006 (Rajasthan).

(II) 4 Party,
No.805-29, Mayo College,
Link Road,
Ajmer-305001 (Raj.).

11. Southern Circle,
No.81, Richmond Road,
Post Box No. 2544,
Bangalore-560025 (Karnataka).

(II) 17 Party,
No.9, Residency Road,
Bangalore-560027.

12. South Centre Circle,
No. 3-6-222
Himayatnagar,
Post Box No. 1004,
Hyderabad-500029 (A.P.).

13. Central Circle,
No. 314, Napier Town,
Post Box No. 93,
Jabalpur - 482001 (M.P.).

14. North-Western Circle,
House No. 12, Sector No. 4,
Chandigarh-160001.

(II) 9 Drawing Officer,
House No.52, Sector No. 2
Chandigarh.

15. North-Western Circle,
28 Party, Tatoo Ground,
Srinagar (J&K).

16. North-Eastern Circle,
Bonnie Brae Estate,
Post Box No. 89,
Shillong-193001 (Meghalaya).

17. South-Eastern Circle,
10 Drawing Office,
Plot No. 4C,
Shahidnagar,
Bhubaneswar-751007 (Orissa).

Appendix - 3.4

List of offices of the Indian Bureau of Mines

1. The Regional Controller of Mines, Indian Bureau of Mines, 7, Ganesh Chandra Avenue, Calcutta - 700 013.

2. The Regional Controller of Mines, Indian Bureau of Mines, Fatima Building, Bernado-Da-Costa Road, Margao - Goa - 403 601.

3. The Regional Controller of Mines, Indian Bureau of Mines, 17-Kumara Park East, Vimala Prabha, Bangalore - 560 001.

4. The Regional Controller of Mines, Indian Bureau of Mines, H.No. 3-6-170, Hyderguda, P.O. Himayat Nagar, Hyderabad - 500 029.

5. The Regional Controller of Mines, Indian Bureau of Mines, House No. A.M.C. 424/I, Purfiza Mahal, Anna Sagar, Link Road, Ajmer (Rajasthan).

6. The Regional Controller of Mines, Indian Bureau of Mines, House of Late Shri Nirmal Chandra Mitra, 'Imli Kothi', Barkagaon Road, Hazaribagh (Bihar).

The Regional Controller of Mines, Indian Bureau of Mines, 19/543, Janda Street, Nellore - 524 001 (A.P.).

8. The Deputy Controller of Mines, Indian Bureau of Mines, H.No. 17-D, Race Course, Dehra Dun (U.P.). PIN - 248 001.

9. The Deputy Controller of Mines, Indian Bureau of Mines, Town Improvement Trust Building, Block No. 2, Madan Mahal, Nagpur Road, Jabalpur (M.P.).

10. The Regional Controller of Mines, Indian Bureau of Mines, Sector No. 11, Plot No. 5, Hiran Magri, Udaipur (Rajasthan).

11. The Regional Controller of Mines, Indian Bureau of Mines, Plot No. 95, Bungalow No. 257, East High Court Road, New Ramdaspeth, Nagpur - 440 010.

Appendix—3.5

Addresses of State Departments of Geology, particulars of minerals with future potentiality, technical assistance for exploration, etc. in the different States and Union Territories of India.

STATE	ADDRESS OF THE OFFICE HQRS.	MINERALS WHICH NEED MORE ATTENTION	PUBLICATIONS, IF ANY, BROUGHT OUT BY THE STATE	TECHNICAL ASSISTANCE RENDERED TO PRIVATE PARTIES WITH DETAILS	INCENTIVE PLANS, IF ANY FOR PROMOTING MINERAL INDUSTRY	ACCESS TO TECHNICAL INFORMATION INCLUDING MAPS	LABORATORY FACILITIES, IF AVAILABLE, TO PRIVATE PARTIES.	ASSISTANCE IN MINERAL EXPLORATION BY MINERAL EXPLORATION DEPARTMENT, IF ANY.
ANDHRA PRADESH	DIRECTORATE OF MINES & GEOLOGY, 10-3-311, CASTLE HILL, MASAB TANK, HYDERABAD - 500 028, "DIRECTOR MINES"	APATITE, ASBESTOS, BARYTES, BAUXITE, COAL, COPPER, CLAYS, DIAMOND, GRAPHITE, GOLD, IRON ORE, KYANITE, LEAD, LIMESTONE, DOLOMITE, MANGANESE ORE, MICA, QUARTZ, STEATITE, VERMICULITE.	NOT RECENT.	NIL	NIL	MATERIAL OTHER THAN OF RESTRICTED NATURE ARE ALLOWED FOR EXAMINATION BY INTERESTED PARTIES	BOTH THE LABORATORIES AT HYDERABAD AND KURNOOL ARE NOT AVAILABLE TO PRIVATE PARTIES.	THE EXPLORATORY WING OF THE DEPARTMENT IS ONLY FOR THE DEPARTMENTAL WORK.
ASSAM	DIRECTOR OF GEOLOGY & MINING, GOVERNMENT OF ASSAM, ZOO ROAD, GAUHATI - 781 005. "GEOMINE" KAMRUP ASSAM.	COAL, LIMESTONE, FIRECLAY, KAOLIN, GLASS, IRON ORE ETC.	NIL	ASSISTANCE RENDERED AS AND WHEN THE REQUESTS ARE RECEIVED.	NIL	YES, EXCEPT THE SURVEY OF INDIA TOPOSHEETS.	THE LABORATORY IS NOT OPEN TO PRIVATE PARTIES.	NIL
BIHAR	DEPARTMENT OF MINES & GEOLOGY, NEW SECRETARIAT, PATNA - 800 015. "MINES"	BAUXITE, LIMESTONE, MICA, CHINACLAY, BENTONITE, CHROMITE, PHOSPHATIC ROCKS, GRAPHITE, IRON ORE, KYANITE.	NOTHING OTHER THAN A REPORT ON DEPARTMENTAL ACTIVITIES AND A FEW REPORTS ON MINERALS.	NIL	WHILE ACCORDING MINERAL CONCESSIONS, PREFERENCE IS GIVEN TO THOSE INTERESTED IN SETTING UP MINERAL BASED INDUSTRIES.	NIL	THE LABORATORIES OF THE DEPARTMENT SITUATED AT HAZARIBAGH, DEHRI-ON-SONE, AND DALTONGANJ ARE OPEN FOR PRIVATE PARTIES ON CHARGES.	ASSISTANCE CAN BE RENDERED ON REQUEST.
GUJARAT	DIRECTORATE OF GEOLOGY & MINING, 2/-, NEW MENTAL HOSPITAL BUILDING, ASARWA, AHMEDABAD - [illegible] 016 "GEOMINE" AHMEDABAD	LIGNITE, BAUXITE, BENTONITE, CHINACLAY, PLASTIC CLAY, FIRECLAY, PHOSPHATIC DEPOSITS, MARBLE, FLUORITE, WOLLASTONITE, AGATE, DIATOMACEOUS EARTH.	"MINERAL WEALTH" PUBLISHED HALF YEARLY. "MINERALS IN GUJARAT" A BOOKLET PUBLISHED BY THE DIRECTORATE.	ASSISTANCE RENDERED ON REQUEST	GUJARAT STATE FINANCIAL CORPORATION ADVANCES LOANS SO ALSO THE BANKS FOR ENTREPRENEURS.	YES, INFORMATION IS AVAILABLE TO PRIVATE PARTIES.	LABORATORY FACILITIES ARE AVAILABLE TO PRIVATE PARTIES ON CHARGES.	A SCHEME FOR RENDERING ASSISTANCE TO PRIVATE PARTIES ON CHARGES IS IN THE OFFING
HARYANA	DEPARTMENT OF INDUSTRIES, HARYANA SECTOR 17, CHANDIGARH - 160 017. "HARIND" CHANDIGARH.	GRAPHITE, SILICA SAND, QUARTZ, MARBLE, PHOSPHORITE, SLATE, LIMESTONE, ETC.	NIL	"UNDER QUARRY IMPROVEMENT SCHEME". TECHNICAL ASSISTANCE ALONG WITH SOME EQUIPMENT IS GIVEN.	NIL	NIL	LABORATORY NOT COMMERCIALISED.	NO PROVISION
HIMACHAL PRADESH	GEOLOGICAL WING, RAN BHAVAN, SANJOULI, SIMLA - 171 006. "GEOHIM".	LIMESTONE, DOLOMITE, GYPSUM, BARYTES, PYRITES, QUARTZITE, SILICA BOULDERS, ETC.	NIL	NIL	NIL	YES, IF AVAILABLE.	YES, ON CHARGES.	AVAILABLE
JAMMU AND KASHMIR	DEPARTMENT OF GEOLOGY & MINES, MINING, JAMMU & KASHMIR GOVERNMENT, 1) OLD SECRETARIAT BUILDING, JAMMU TAWI - 190 001 2) NEELAM CHOWK, SRINAGAR - 180 001, (SRINAGAR) "GEOMIN".	COPPER, LEAD, ZINC, IRON ORE, NICKEL, ABRASIVES, PRECIOUS AND SEMI-PRECIOUS STONES.	PUBLISHED PRICED REPORTS, UNPUBLISHED REPORTS, ETC.	NIL	PREFERENCE GIVEN TO UNEMPLOYED GRADUATES UNDER "SELF EMPLOYMENT SCHEME" WITH OTHER BENEFITS.	NIL	NOT COMMERCIALISED.	NO OTHER SERVICE OTHER THAN HELPING IN THE FORM OF INFORMATION NEEDED, ETC.
KARNATAKA	OFFICE OF THE DIRECTOR OF MINES AND GEOLOGY, RACE COURSE ROAD, P.BAG NO. 5355, BANGALORE - 560 001.	MAGNETITE, IRON ORE, TITANIFEROUS, VANADIUM BEARING IRON ORES, LIMESTONE, CLAYS, MOULDING AND SILICA SANDS, REFRACTORY BAUXITE, QUARTZITE.	REPORT OF MINERAL INVESTIGATIONS ENTITLED "GEOLOGICAL INVESTIGATIONS".	NIL	ONLY TECHNICAL ASSISTANCE GIVEN WHEN SOUGHT FOR	INFORMATION OF THE OPEN FILE TYPE IS AVAILABLE ON CHARGES.	AVAILABLE ON CHARGES	NIL
KERALA	DIRECTOR OF MINING AND GEOLOGY, VELLAYAMBALAM, TRIVANDRUM - 695 001.	BEACH PLACER SANDS, IRON ORE, CHINA CLAY, FIRECLAY, GRAPHITE, LIMESTONE, LIME-SHELL, SILICA SAND.	NIL	NIL	NIL	NIL	AVAILABLE ON CHARGES	ASSISTANCE RESTRICTED TO GOVERNMENT OWNED COMPANIES AND UNDERTAKINGS.
MADHYA PRADESH	DIRECTORATE OF GEOLOGY AND MINING, KAKKAR BHAWAN, KOTRA TALAB, RAIPUR - 492 001 (M.P.) "BHAUDIKI".	COAL, IRON ORE, LIMESTONE, DOLOMITE, BAUXITE, DIAMOND, FIRECLAY, OCHRE, PYROPHYLLITE, DIASPORE, MANGANESE ORE, TIN, QUARTZITE, KAOLIN, SILICA SAND, STEATITE, ROCK-PHOSPHATE, COPPER ORE, LEPIDOLITE, ATOMIC MINERALS, MARBLE, BUILDING STONE, ETC.	A) MINERAL RESOURCES OF M.P. DR. S.S.DAVE, (UNDER PUBLICATION) B) ANNUAL REPORTS OF THE DIRECTORATE OF GEOLOGY & MINING, M.P. C) MINERAL STATISTICS. D) DEPARTMENTAL FIELD REPORTS. E) HALF-YEARLY JOURNAL "MINERAL WEALTH OF M.P."	AT PRESENT, TECHNICAL ADVICE IS GIVEN AS AND WHEN NEEDED TO PRIVATE INDIVIDUALS, BUT FOR THE PRESENT NO ARRANGEMENT IS MADE TO PROVIDE THIS SERVICE ON COMMERCIAL BASIS	IT IS DONE BY THE STATE GOVERNMENT LOOKING TO THE SIZE AND UTILITY OF INDUSTRIAL UNIT.	AT PRESENT, THERE IS NO SUCH PRACTICE IN FORCE.	YES, ONLY IN SELECTED CASES THE SAMPLES OF PRIVATE PARTIES ARE ANALYSED.	YES, SERVICES ARE AT PRESENT ONLY OFFERED TO PUBLIC SECTOR UNDERTAKINGS. HOWEVER, IN SELECTED CASES SUCH SERVICES HAVE BEEN PROVIDED AS AND WHEN DIRECTED BY THE STATE GOVERNMENT TO THE PRIVATE PARTIES.

Addresses of State Departments of Geology, particulars of minerals with future potentiality, technical assistance for exploration, etc. in the different States and Union Territories of India. (Concld.)

STATE	ADDRESS OF THE OFFICE [illegible]	MINERALS WHICH NEED MORE ATTENTION	PUBLICATIONS, IF ANY, BROUGHT OUT BY THE STATE	TECHNICAL ASSISTANCE RENDERED TO PRIVATE PARTIES WITH DETAILS	INCENTIVE PLANS, IF ANY, FOR PROMOTING MINERAL INDUSTRY	ACCESS TO TECHNICAL INFORMATION INCLUDING MAPS	LABORATORY FACILITIES, IF AVAILABLE, TO PRIVATE PARTIES	ASSISTANCE IN MINERAL EXPLORATION BY MINERAL EXPLORATION DEPARTMENT, IF ANY.
MAHARASHTRA	DIRECTORATE OF GEOLOGY AND MINING, GOVERNMENT OF MAHARASHTRA, OLD SECRETARIAT, NAGPUR - 440 001. "DIRGEOMIN", NAGPUR.	IRON ORE, COAL, LIMESTONE, SILICA SAND, MANGANESE, SEMI-PRECIOUS STONES, KYANITE, SILLIMANITE, BARYTES, CHROMITE, ETC.	"MINERAL [illegible]" JOURNAL [illegible] PUBLISHED SINCE [illegible] 1968.	NOT IN A POSITION TO RENDER ANY TECHNICAL ASSISTANCE OWING TO ADMINISTRATIVE REASONS.	NOTHING OTHER THAN OFFERING TECHNICAL ADVICE.	NIL	NIL	NIL.
MANIPUR	DIRECTOR OF INDUSTRIES, GOVERNMENT OF MANIPUR, P.O. IMPHAL, MANIPUR.	NOT KNOWN.	NIL	NIL	NIL	NIL	NIL	NIL
MEGHALAYA	DIRECTOR OF MINERAL RESOURCES, NONGRIM HILLS, SHILLONG - 793 003. "MINSOURCE" KHASI HILLS DIST., MEGHALAYA.	COAL, LIMESTONE, SILLIMANITE, CLAY, GLASS SAND, KAOLIN.	NIL	TECHNICAL ASSISTANCE RENDERED ON REQUEST.	NIL SINCE MINERAL EXPLORATION IS NORMALLY DONE BY THE GOVERNMENT.	NIL	NOT COMMERCIALISED.	NIL.
NAGALAND	SPECIAL OFFICER, DIRECTORATE OF GEOLOGY AND MINING, DIMAPUR, NAGALAND.	NOT KNOWN.	NIL	NIL	NIL	NIL	NIL	NIL.
ORISSA	DIRECTORATE OF MINES, ORISSA, BHUBANESWAR, UNIT-V, CAPITAL HEAD POST, OFFICE, P.B.NO. 38, 751 001. "DIRMINES" BHUBANESWAR, PURI, ORISSA.	CHROMITE, BAUXITE, IRON ORE, CHINACLAY, COPPER, LEAD, PYRITES, NICKEL, COBALT, BERYL, COLUMBITE, TANTALLITE, MICA, GRAPHITE AND HEAVY MINERALS.	"EXPLORER", HALF-YEARLY PUBLICATION.	RENDERS GEOLOGICAL ASSISTANCE WHENEVER REQUESTED FOR.	NIL.	NIL	AVAILABLE ON PAYMENT OF CHARGES.	MINERAL EXPLORATION WING HELPS PRIVATE PARTIES ALSO.
PUNJAB	DEPARTMENT OF INDUSTRIES, (GEOLOGICAL WING) GOVERNMENT OF PUNJAB, 17, BAYS BUILDING, SECTOR-17, CHANDIGARH - 160 017. "DINDUSTRY"	WHITE QUARTZITE BOULDERS, CLAYS, KANKAR, SALTPETRE, ALKALINE EARTH, COAL, GOLD, FULLERS EARTH, TALC, TUFFA, BRICK EARTH, LIMESTONE, BUILDING MATERIALS, FOUNDARY STONE.	ONLY REPORTS OF INVESTIGATIONS.	ASSISTANCE RENDERED ON CHARGES.	CERTAIN FACILITIES LIKE INTEREST-FREE LOAN, EXEMPTION FROM ELECTRICITY DUTY, ETC.	YES, AVAILABLE.	YES.	YES.
RAJASTHAN	THE DIRECTORATE OF MINES & GEOLOGY, SHASTRI CIRCLE, UDAIPUR - 313 001.	ASBESTOS, FELSPAR, BAUXITE, MAGNESITE, LEAD, KYANITE, SLATESTONE, IRON ORE, WOLLASTONITE, GARNET, FIRECLAY, COPPER, ZINC, PYROPHYLLITE, QUARTZ, FLOURSPAR, ROCK PHOSPHATE, DOLOMITE, LIMESTONE, ETC.	ANNUAL REPORTS.	ASSISTANCE RENDERED	AWARDS FOR NEW DISCOVERIES, FINANCIAL ASSISTANCE, ETC.	INFORMATION OF ONLY CERTAIN TYPE IS AVAILABLE.	YES.	YES.
SIKKIM	------------------------------------ NO INFORMATION AVAILABLE ------------------------------------							
TAMIL NADU	GEOLOGY BRANCH, DEPARTMENT OF INDUSTRIES & COMMERCE, INDUSTRIAL ESTATE, GUINDY, MADRAS - 600 032.	GRAPHITE, CLAYS, QUARTZ & FELSPAR, SILICA SAND, IRON ORES, DOLERITE, (ORNAMENTAL)	NO PERIODICALS. A FEW REPORTS AND HANDOUTS ON MINERAL OCCURRENCES.	INFORMATION IS SUPPLIED TO PRIVATE PARTIES WHENEVER SUCH REQUESTS ARISE.	NO DIRECT INCENTIVE. BUT APPLICATIONS FOR LEASES ON QUARTZ, FELSPAR, LIMESTONE AND GYPSUM ARE GIVEN SPECIAL CONSIDERATION.	YES, WITH GOVERNMENT'S PRIOR PERMISSION.	THERE IS A SEPARATE LABORATORY RUN BY THE GOVERNMENT FOR TAKING UP ANALYSIS OF SAMPLES FOR PRIVATE PARTIES.	NIL
TRIPURA	DEPARTMENT OF INDUSTRIES, COLONEL CHOWMUHANI, AGARTALA - 799 001, WEST TRIPURA. "TRIPIND" .	NOT KNOWN	NIL	NIL.	NIL	NIL.	NIL	NOT AT PRESENT
UTTAR PRADESH	DIRECTORATE OF GEOLOGY & MINING, MAHANAGAR LUCKNOW - 226 006 (U.P.) "GEOMINING"	LIMESTONE, DOLOMITE, MARBLE, ROCK PHOSPHATE, PYROPHYLLITE, DAISPORE, SILICA SAND, MAGNESITE, TALC, FIRECLAY, COAL, BASE METALS.	NIL	NIL	ONLY TECHNICAL ASSISTANCE IS GIVEN TO INTERESTED PARTIES.	NIL	YES	YES.
WEST BENGAL	DIRECTORATE OF MINES & MINERALS, 45, GANESH CHANDRA AVENUE, CALCUTTA - 700013.	MINERAL PIGMENTS, OCHRES, FELSPAR, QUARTZ AND CHINACLAY, SILICA SAND, GARNET, KYANITE, SILLIMANITE, FIRECLAY, GRAPHITE, MOULDING SAND.	NIL	NIL.	NIL	NIL	NIL	NOT AVAILABLE
UNION TERRITORIES								
GOA	DIRECTORATE OF INDUSTRIES & MINES (MINES WING), DIOGO-COUTO-ROAD, MUNICIPAL GARDEN, PANAJI, GOA - 403 001. "MINES" PANAJI.	BAUXITE, LIMESTONE, CHINACLAY, SILICA SAND, IRON ORE, MANGANESE ORE, ETC.	NIL	NIL.	NIL	NIL	NOT AVAILABLE PRESENTLY	NOT AVAILABLE PRESENTLY
MIZORAM	------------------------------------ NO INFORMATION AVAILABLE ------------------------------------							

Appendix - 3.6

List of I. S. I. Publications Relating to Minerals

Sl. No.	Subject	No.	Year
1*.	Copper (second revision)	IS 191	1967
2*.	Zinc (second revision)	IS 209	1966
3*.	Antimony (second revision)	IS 211	1966
4*.	Ordinary rapid hardening and to wheat Portland Cement (second revision)	IS 269	1967
5.	Limestone slabs	IS 1128	1957
6.	Marble (Blocks, slabs & tiles)	IS 1130	1969
7.	Ferromanganese (revised)	IS 1171	1964
8.	Definitions of mica terms	IS 1174	1957
9.	Methods for grading and classification of muscovite mica blocks	IS 1175	1957
10*	Methods of test for mineral gypsum	IS 1288	1958
11.	Methods for sampling of mineral gypsum	IS 1289	1960
12.	Certified samples for metallurgical analysis (Explains certified samples, preparation of samples, method of chemical analysis, packing and storage and removal of sample).	IS 1338	1959
13*.	Ferrovanadium (first revision)	IS 1466	1969
14*.	Ferrotungsten (first revision)	IS 1467	1970
15*.	Ferrotitanium (first revision)	IS 1468	1968
16*.	Ferromolybdenum (second revision)	IS 1469	1970
17*.	Silicomanganese (first revision)	IS 1470	1969
18*.	Ferrophosphoras	IS 1471	1960
19*.	Portland-Pozzolana Cement (first revision)	IS 1489	1967
20*.	Antimonial lead (first revision)	IS 1658	1966
21.	Barytes for rubber industry	IS 1683	1960
22.	Dead burned pea-magnesite	IS 1150	1961
23.	Fireclay, cupola refractions (first revision)	IS 1751	1968

(Contd.)

Sl. No.	Subject	No.	Year
24.	Red phosphorus	IS 2012	1961
25*.	Metallic manganese	IS 2021	1962
26*.	Metallic chromium	IS 2023	1962
27.	Sillimanite refractions for glass melting tank-furnaces	IS 2044	1963
28.	Natural sillimanite blocks for glass melting tank furnaces	IS 2045	1962
29.	Method for sampling quartzite	IS 2245	1962
30.	Recommendation for bibliographic reference	IS 2381	1963
31.	Chinaclay for ceramic industry	IS 2840	1965
32.	Barytes for chemical industry and oil well drilling	IS 2881	1964
33*.	Ferrozirconium	IS 3011	1965
34*.	Chromo-manganese	IS 3012	1965
35.	Ferro-boron	IS 3013	1965
36.	Bentonite for use in foundries	IS 3021	1965
37.	Methods for sampling of cryolite and aluminium-trifluororide	IS 3191	1968
38.	Limestone for chemical industries	IS 3204	1965
39.	Method of sampling and grading structural granite	IS 3316	1965
40.	Bauxite for chemical and petroleum industries	IS 3605	1966
41.	Magnesite for chemical industries	IS 3607	1966
42.	Methods for sampling of ilmenite and rutile	IS 4166	1967
43*.	Ferronickel	IS 4409	1967
44.	Chromite for chemical industries	IS 4737	1968
45.	Manganese ore for production of ferromanganese	IS 4763	1968
46.	Glossarry of mining terms (Geology)	IS 5940	1970

(Contd.)

Sl. No.	Subject	No.	Year
47.	Classification of bauxite for use in the production of aluminium	IS 5953	1971
48.	Bentonite	IS 6186	1971
49.	General requirements for supply of metallurgical materials	IS 1387	1967
50.	Methods of chemical analysis of bauxite	IS 2000	1962
51.	Methods of sampling bauxite	IS 1999	1962
	Natural Red oxide	IS 46	1950
	Ochres	IS 47	1950
52.	Methods for the direct determination of alumina in refractory materials	IS 1335	1959
53.	Methods of chemical analysis of manganese ores	IS 1473	1960
54.	Methods of chemical analysis of iron ores	IS 1493	1959
55.	Methods of chemical analysis of fireclay and silica refractory materials	IS 1527	1960
56.	Methods of chemical analysis of ferro-alloys	IS 1559	1961
57.	Methods of chemical analysis of quartzite and high silica sand	IS 1917	1962
58.	Methods of chemical analysis of metallic manganese	IS 2017	1967
59.	Methods of chemical analysis of calcium silicon	IS 2018	1964
60.	Metallic manganese (Prescribes requirements of size, etc. of known Mn grades which are commonly used in the ferrous and non-ferrous metals industry)	IS 2022	1962
61.	Method of chemical analysis of fluorspar	IS 2411	1963
62.	Method of test for determination of wet volume of asbestos fibre	IS 3632	1969
63.	Methods of chemical analysis of rutile	IS 4104	1967

(Contd.)

Sl. No.	Subject	No.	Year
64.	Methods of chemical analysis of magnesium aluminium brazing alloys	IS 4354	1967
65.	Methods of chemical analysis of silver-manganese brazing alloys	IS 5328	1969
66.	Method of test for determination of chemical composition of asbestos fibre	IS 5328	1969

Appendix - 3.7

List of Various Chemical Constituents Required to be Determined by Conventional Chemical Analysis

Sl. No.	Ore/Mineral	Constituents
1.	Rock phosphate/ phosphorite	P_2O_5; CaO; MgO; F; Al_2O_3; Fe_2O_3; SiO_2; Cl; Organic matter; Moisture; CO_2.
2.	Barytes	$BaSO_4$; Water soluble matter; Al_2O_3; Fe_2O_3; CaO; SiO_2; CO_2; Oil absorption characteristics and water-soluble matters are important in some cases.
3.	Bauxite	Al_2O_3; Fe_2O_3; SiO_2; TiO_2; CaO; L.O.I. V_2O_5 (in composite samples); Gibbsite%; Ga; Ge.
4.	Chromite	Cr_2O_3; FeO; Total Fe; SiO_2; MgO; Al_2O_3; S; P; Physical characters: Hard and compact/friable.
5.	Corundum	Al_2O_3; Fe_2O_3; SiO_2; TiO_2; CaO; MgO.
6.	Dolomite/Limestone	CaO; MgO; SiO_2; Fe_2O_3; Al_2O_3; S; P; L.O.I.; Physical characters, like grain size, and texture etc.
7.	Fluorite	CaF_2; SiO_2; $CaCO_3$; Al_2O_3; Fe; Pb (Ba); Zn; S.
8.	Graphite	Moisture; Volatile matter; Sulphur, Ash content; Fixed Carbon; Physical characteristics: Flake amorphous, etc.
9.	Gypsum	CaO; Na_2O; SO_3; SrO; Cl; H_2O; CO_2.
10.	Iron oOre	Fe; FeO; SiO_2; Al_2O_3; P; S; TiO_2 (some cases).
11.	Magnesite	MgO; CaO; Total Fe; SiO_2; Al_2O_3; S; L.O.I.
12.	Manganese Ore	Mn; Fe; SiO_2; Al_2O_3; CaO; P; S.
13.	Glass and Quartz/ Quartzite	SiO_2; Al_2O_3 : Fe_2O_3; P_2O_5.
14.	Base metal ores	Cu; Pb; Zn; Cd; Sb; Co; Ni; Mo; Ag (in Pb-Zn ores); Ga (in Pb-Zn ores); Fe; S; As; Hg; Au; Cu; Zn; Te; Se.
15.	Gold bearing ores	As; Sb; W; Carbonaceous matter.

Appendix -4.1

Ore forming and other Economic Minerals

NAME OF THE MINERAL	CHEMICAL COMPOSITION (CHEMICAL FORMULA)	PERCENTAGE OF THE CONSTITUENT RADICALS	CRYSTAL SYSTEM	HABIT	COLOUR	STREAK	HARDNESS	SPECIFIC GRAVITY	CRITERIA FOR FIELD RECOGNITION
I. METALLIC MINERALS									
1. PRECIOUS METALS/MINERALS									
GOLD NATIVE GOLD	GOLD, BUT USUALLY ALLOYED WITH SILVER IN VARYING AMOUNTS AND SOMETIMES CONTAINING ALSO COPPER OR IRON		ISOMETRIC	MASSIVE AND IN THIN LAMINAE, FILLIFORM, RETICULATED, DENDRITIC SHAPES	GOLDEN YELLOW	GOLDEN YELLOW	2.5 - 3	15.6-19.33 19.33 WHEN PURE	SCRATCHED BY PENKNIFE. DISTINGUISHED FROM PYRITES BY ITS HEAVINESS AND MALLEABILITY.
SILVER NATIVE	SILVER, WITH SOME GOLD (UP TO 10 PER CENT), COPPER, AND SOMETIMES PLATINUM, ANTIMONY, BISMUTH, MERCURY.		-DO-	ALSO MASSIVE	SILVER-WHITE, OFTEN GRAY TO BLACK BY TARNISH	SILVER-WHITE	2.5 - 3	10.1 - 11.1	FERNLIKE DESIGNS, NETWORK PATTERN AND CRYSTAL GROUPS - AND SILVER GRAY COLOUR.
ARGENTITE	Ag_2O_3	SULPHUR 12.9 SILVER 87.1	-DO-	MASSIVE, EMBEDDED, AS A COATING	BLACKISH LEAD-GRAY	BLACKISH LEAD-GRAY SHINING	2 - 2.5	7.20 - 7.36	AN IMPORTANT ORE OF SILVER, ALTERS TO NATIVE
2. NON-FERROUS MINERALS									
ANTIMONY STIBNITE	ANTIMONY TRISULPHIDE, Sb_2S_3 SOMETIMES AURIFEROUS ALSO ARGENTIFEROUS	SULPHUR 28.3 ANTIMONY 71.7	ORTHORHOMBIC	RADIATING GROUPS OF ACICULAR CRYSTALS FINE COLUMNAR, COMMONLY BLADED.	LEAD TO STEEL-GRAY	LEAD-GRAY	2	4.52 - 4.62	STIBNITE IS FUSIBLE ENOUGH TO BE MELTED IN A MATCH FLAME. STIBNITE LOSES ITS BRIGHTNESS WHEN EXPOSED TO LIGHT.
BAUXITE BOEHMITE	Al_2O_3, H_2O								
DIASPORE	Al_2O_3, H_2O or $AlO(OH)$	ALUMINA 85.0 WATER 15.0	ORTHORHOMBIC	FOLIATED MASSIVE AND IN THIN SCALES SOMETIMES STALACTITIC	WHITISH, GRAYISH, WHITE, GREENISH, GRAY, HAIR BROWN, YELLOWISH TO COLOURLESS		6.5 - 7	3.3 - 3.5	
GIBBSITE	ALUMINIUM HYDROXIDE $Al(OH)_3$ OR $Al_2O_3 . 3H_2O$	ALUMINA 65.4 WATER 34.6	MONOCLINIC	OCCASSIONALLY IN SPHEROIDAL CONCRETIONS. ALSO STALACTITIC OR SMALL MAMMILLARY.	WHITE GRAYISH, OR REDDISH WHITE	—	2.5 - 3.5	2.3 - 3.4	
COPPER AZURITE	BASIC CUPRIC CARBONATE $2CuCO_3$, $Cu(OH)_2$	CARBON-DIOXIDE 25.6 CUPRIC-OXIDE 69.2 WATER 5.2	-DO-	MASSIVE, PRESENTING IMITATIVE SHAPES, HAVING A COLUMNAR COMPOSITION	AZURE-BLUE PASSING INTO BERLIN BLUE	BLUE	3.5 - 4	3.77 - 3.89	DISTINCT BLUE COLOUR.
BORNITE	A SULPHIDE OF COPPER AND IRON Cu_5FeS_4	COPPER 63.3 IRON 11.1 SULPHUR 25.6	ISOMETRIC	USUALLY MASSIVE STRUCTURE GRANULAR OR COMPACT	COPPER-RED, PITCH-BLACK BROWN ON FRESH FRACTURE SPEEDILY IRRIDESCENT FROM TARNISH	PALE GRAYISH BLACK	3	4.9 - 5.4	OFTEN DISGUISED BY THE PURPLISH TARNISH (BY WHICH IT HAS BEEN NAMED PEACOCK ORE) ON BREAKING OPEN THIS TARNISH GIVES WAY TO A BRONZE HUE.
CHALCOCITE	CUPROUS SULPHIDE, Cu_2S	SULPHUR 20.2 COPPER 79.8	ORTHORHOMBIC	MASSIVE, GRANULAR TO COMPACT AND IMPALPABLE.	BLACKISH LEAD-GRAY OFTEN TARNISHED BLUE OR GREEN	BLACKISH LEAD-GRAY	2.5 - 3	5.5 - 5.8	
CHALCOPYRITE	A SULPHIDE OF COPPER AND IRON $CuFeS_2$	SULPHUR 35.0 COPPER 34.5 IRON 30.5	TETRAGONAL	OFTEN MASSIVE, COMPACT, SOMETIMES BOTRYOIDAL OR RENIFORM	BRASS-YELLOW	GREENISH-BLACK	3.5 - 4	4.1 - 4.3	THE MOST IMPORTANT ORE OF COPPER. BRITTLE AND SCRATCHED BY PENKNIFE.
COVELLITE	CUPRIC SULPHIDE CuS	SULPHUR 33.6 COPPER 66.4	HEXAGONAL	MASSIVE	INDIGO-BLUE OR DARKER	LEAD-GRAY TO BLACK	1.5 - 2	4.6	COVELLITE CAN MARK PAPER.
CUBANITE	$Cu_2S\ Fe_2S_3$		ORTHORHOMBIC	ELONGATED, VERTICALLY STRIATED	BRASS TO BRONZE-YELLOW		3.5	4.7	

Ore forming and other Economic Minerals (Contd.)

NAME OF THE MINERAL	CHEMICAL COMPOSITION (CHEMICAL FORMULA)	PERCENTAGE OF THE CONSTITUENT RADICALS	CRYSTAL SYSTEM	HABIT	COLOUR	STREAK	HARDNESS	SPECIFIC GRAVITY	CRITERIA FOR FIELD RECOGNITION
CUPRITE	CUPROUS OXIDE Cu_2O	OXYGEN 11.2 COPPER 88.8	ISOMETRIC	CAPILLARY CRYSTALS, MASSIVE, GRANULAR, SOMETIMES EARTHY	RED TO VARIOUS SHADES	SEVERAL SHADES OF BROWNISH RED	3.5 - 4	5.85 - 6.15	NATIVE COPPER IS ALMOST ALWAYS PRESENT. TINY SECONDARY CRYSTALS OF CUPRITE GROW AROUND ANCIENT BRONZE AND COPPER OBJECTS.
MALACHITE	BASIC CUPRIC CARBONATE $CuCO_3$, $Cu(OH)_2$	CARBON-DIOXIDE 19.9 CUPRIC OXIDE 71.9 WATER 8.2	MONOCLINIC	OFTEN DELICATELY COATING, COMPACT, FIBROUS, GRANULAR, EARTHY.	BRIGHT-GREEN	PALE GREEN	3.5 - 4	3.9 - 4.03	FIZZLES WHEN TOUCHED BY ACID.
NATIVE COPPER	PURE COPPER, SOMETIMES CONTAINING SMALL AMOUNTS OF IRON, SILVER, BISMUTH, TIN, LEAD OR ANTIMONY.		ISOMETRIC	FREQUENTLY IRREGULARLY DISTORTED TWISTED AND WIRELIKE FORMS, MASSIVE, AS SAND.	COPPER RED	METALLIC SHINING	2.5 - 3	8.8 - 8.9	AT TIMES AS PSEUDOMORPHS AFTER CUPRITE, AZURITE, CHALCOPYRITE, CALCITE, ARAGONITE, ETC.
LEAD GALENA	LEAD SULPHIDE PbS OFTEN CONTAINS SILVER AND OCCASIONALLY SELENIUM, ZINC, CADMIUM, ANTIMONY, BISMUTH, COPPER AS SULPHIDES, BESIDES, SOMETIMES NATIVE SILVER AND GOLD.	SULPHUR 13.4 LEAD 86.6	ISOMETRIC	MASSIVE, CLEAVABLE, COARSE OR FINE GRANULAR, OCCASIONALLY FIBROUS OR PLUMOSE	LEAD-GRAY	LEAD-GRAY	2.5 - 2.75	7.4 - 7.6	THE MOST IMPORTANT ORE OF LEAD AND FREQUENTLY A VALUABLE ORE OF SILVER. IT CAN ALSO MARK THE PAPER.
TIN CASSITERITE	TIN DIOXIDE SnO_2. A LITTLE Ti_2O_5 IS SOMETIMES PRESENT. ALSO Fe_2O_3	OXYGEN 21.4 TIN 78.6	TETRAGONAL	RENIFORM SHAPES, MASSIVE GRANULAR IMPALPABLE.	BROWN OR BLACK SOMETIMES RED, GRAY WHITE OR YELLOW	WHITE, GRAYISH, BROWNISH	6 - 7	6.8 - 7.1	
ZINC SPHALERITE	ZINC SULPHIDE. ZnS OFTEN CONTAINING IRON AND MANGANESE, AND SOMETIMES CADMIUM, MERCURY AND RARELY LEAD AND TIN. ALSO SOMETIMES CONTAINS TRACES OF INDIUM, GALLIUM AND THALLIUM, MAY BE ARGENTIFEROUS AND AURIFEROUS.	SULPHUR 33.0 ZINC 67.0	ISOMETRIC	CRYPTOCRYSTALLINE TO AMORPHOUS, MASSIVE, CLEAVABLE COMPACT. FIBROUS AND RADIATED.	YELLOW, BROWN-BLACK, RED, GREEN TO WHITE.	BROWNISH TO LIGHT YELLOW AND WHITE	3.5 - 4	3.9 - 4.1	
3. FERROUS MINERALS									
CADMIUM GREENOCKITE	CADMIUM SULPHIDE CdS	SULPHUR 22.3 CADMIUM 77.7	HEXAGONAL		HONEYCITRONS OR ORANGE-YELLOW	ORANGE-YELLOW TO BRICK-RED	3 - 3.5	4.9 - 5.0	
CHROMIUM CHROMITE	$FeCr_2O_4$ or $FeOCr_2O_3$	CHROMIUM SESQUIOXIDE 68.0 PROTOXIDE 32.0	ISOMETRIC	COMMONLY MASSIVE FINE GRANULAR TO COMPACT	IRON BLACK AND BROWNISH BLACK, ALSO YELLOWISH, RED IN THIN SECTIONS.	BROWN	5.5	4.1 - 4.9	FEEBLY MAGNETIC. PITCHY LUSTRE, AND A BROWNISH COAT TO THE COLOUR ARE FREQUENT.
COBALT COBALTITE	SULPHARSENIDE OF COBALT $CoAs_5$ or CoS_2-$CoAS_2$	SULPHUR 19.3 ARSENIC 45.2 COBALT 35.5	ISOMETRIC	GRANULAR, MASSIVE TO COMPACT	SILVER WHITE INCLINED TO RED. ALSO STEEL-GRAY	GRAYISH BLACK	5.5	6 - 6.3?	
IRON GOETHITE	$FeO(OH)$ or $Fe_2O_3H_2O$	OXYGEN 27.0 IRON 62.9 WATER 10.1 IRON OR SESQUI-OXIDE 89.9 WATER 10.1?	ORTHORHOMBIC	ALSO FIBROUS, FOLIATED OR IN SCALES MASSIVE, RENIFORM AND STALACTITIC WITH CONCENTRIC AND RADIATED STRUCTURE.	YELLOWISH, REDDISH AND BLACKISH BROWN	BROWNISH YELLOW TO OCHRE-YELLOW	5 - 5.5?	4.28	CONCENTRIC RINGS OF VARIOUS SHADES, WITH TYPICAL ORANGE TINGE.

Ore forming and other Economic Minerals (Contd.)

NAME OF THE MINERAL	CHEMICAL COMPOSITION (CHEMICAL FORMULA)	PERCENTAGE OF THE CONSTITUENT RADICALS	CRYSTAL SYSTEM	HABIT	COLOUR	STREAK	HARDNESS	SPECIFIC GRAVITY	CRITERIA FOR FIELD RECOGNITION
HEMATITE	IRON SESQUIOXIDE Fe_2O_3. SOMETIMES CONTAINS TITANIUM AND MAGNESIUM	OXYGEN 30.0 IRON 70.0	RHOMBOHEDRAL	COLUMNAR, GRANULAR, BOTRYOIDAL AND STALACTITIC SHAPES, FRIABLE, EARTHY, COMPACT.	DARK STEEL-GRAY OR IRON BLACK.	CHERRY RED OR REDDISH BROWN	5.5 - 6.5	4.9 - 5.3	THE MOST IMPORTANT IRON ORE. USED ALSO IN PAINTS.
LIMONITE	$2Fe_2O_3 - 3H_2O$	OXYGEN 25.7 IRON 59.8 WATER 14.5	NOT CRYSTALLIZED	A MINERAL COLLOID, USUALLY IN STALACTITIC AND BOTRYOIDAL OR MAMMILLARY, MASSIVE.	VARIOUS SHADES OF BROWN COMMONLY DARK, NOT BRIGHT	YELLOWISH BROWN	5 - 5.5	4.28	CONCENTRIC RINGS OF VARIOUS SHADES, WITH TYPICAL ORANGE TINGE.
MAGNETITE	$FeO - Fe_2O_3$ THE FERROUS IRON SOMETIMES, REPLACED BY MAGNESIUM AND RARELY NICKEL, ALSO SOMETIMES PROTOXIDE CONTAINS TITANIUM (UP TO 6% TiO_2)	OXYGEN 27.6 IRON 72.4 IRON-SESQUIOXIDE 69.0 PROTOXIDE 31.0	ISOMETRIC	MASSIVE WITH LAMINATED STRUCTURE, COARSE OR FINE, IMPALPABLE.	IRON BLACK	BLACK	5.5 - 6.5	5.17 - 5.18	CHARACTERIZED BY STRONG MAGNETIC PROPERTIES.
SIDERITE	IRON PROTOCARBONATE $FeCO_3$. MANGANESE MAY BE PRESENT.	CARBON-OXIDE 37.9 IRON-PROTOXIDE 62.1	RHOMBOHEDRAL	BOTRYOIDAL AND GLOBULAR FORMS, SUB-FIBROUS, SILKY, COMPACT AND EARTHY.	ASH, YELLOWISH, GREENISH-GRAY BROWN AND BROWNISH RED, RARELY GREEN.	WHITE	3.75 - 4	3.8 - 3.9	READILY ALTERS ON EXPOSURE TO LIMONITE
MANGANESE BRAUNITE	$3Mn.MnO_3 - Mn.SiO_3$	SILICA 10.0 MANGANESE-PROTOXIDE 11.7 MANGANESE-SESQUIOXIDE 78.3	TETRAGONAL	ALSO MASSIVE	DARK BROWNISH BLACK TO STEEL GRAY.		6.6 - 5	4.75 - 4.82	
MANGANITE	$MnO(OH)$ OR $Mn_2O_3.H_2O$	OXYGEN 27.3 MANGANESE 62.4 WATER 10.3 OR MANGANESE-SESQUIOXIDE 89.7 WATER 10.3	ORTHORHOMBIC	COLUMNAR AND STALACTITIC	DARK STEEL GRAY TO IRON BLACK	REDDISH BROWN-NEARLY BLACK	4	4.2 - 4.4	SHINING LUSTROUS APPEARANCE.
PSILOMELANE	A MANGANESE OXIDE CONTAINING VARYING AMOUNTS OF BARIUM, POTASSIUM AND SODIUM OXIDES, AND WATER. TO BE REGARDED AS MnO_2 WITH VARIOUS ABSORBED IMPURITIES.			MASSIVE AND BOTRYOIDAL, RENIFORM, STALACTITIC.	BROWN BLACK TO DARK STEEL GRAY.	BROWNISH BLACK SHINING	5.7	3.3 - 4.7	DOES NOT STAIN HAND.
PYROLUSITE	MANGANESE DIOXIDE MnO_2 COMMONLY CONTAINS A LITTLE WATER		ORTHORHOMBIC	COLUMNAR, OFTEN DIVERGENT, GRANULAR, MASSIVE AND IN RENIFORM COATS.	IRON BLACK, DARK STEEL GRAY, SOMETIMES BLUISH.	BLACK OR BLUISH BLACK	2 - 2.5	4.73 - 4.86	SOILS HANDS WITH A DIRTY BLACK COLOUR.
RHODOCHROCITE	MANGANESE PROTOCARBONATE $MnCO_3$	CARBON-DIOXIDE 38.3 MANGANESE-PROTOXIDE 61.7	RHOMBOHEDRAL	CLEAVABLE, GLOBULAR AND BOTRYOIDAL, SOMETIMES INDISTINCT, ENCRUSTING.	SHADES OF ROSE RED, YELLOWISH GRAY, FAWN-COLOURED, DARK RED OR BROWN.	WHITE	3.5 - 4.5	3.45 - 3.60	CHARACTERISED BY ITS PINK COLOUR AND EFFERVESENCE IN ACIDS.
RHODONITE	MANGANESE META SILICATE $MnSiO_3$ or $MnO\ SiO_2$	SILICA 45.9 MANGANESE-PROTOXIDE 54.1	TRICLINIC	CLEAVABLE TO COMPACT, ALSO IN EMBEDDED GRAINS	LIGHT BROWNISH RED, FLESH-RED, ROSE PINK GREENISH	WHITE	5.5 - 6.5	3.4 - 3.7	CHARACTERISED BY ITS PINK COLOUR, DISTINCT CLEAVAGES, AND HARDNESS.
WAD	IN AMORPHOUS AND RENIFORM MASSES, EITHER EARTHY OR COMPACT, ALSO ENCRUSTING OR AS STAINS. USUALLY VERY SOFT SOILING THE FINGERS.				DULL BLACK, BLUISH OR BROWNISH BLACK.			3.0 - 4.26	
MOLYBDENUM MOLYBDENITE	MOLYBDENUM DISULPHIDE MoS_2	SULPHUR 40.0 MOLYBDENUM 60.0	HEXAGONAL	FOLIATED, MASSIVE OR IN SCALES, ALSO FINE GRANULAR.	PURE LEAD-GRAY	GREENISH GRAY	1 - 1.5	4.7 - 4.8	LEAVES A BLUISH GRAY TRACE ON PAPER. DISTINGUISHED BY BLUISH COLOUR AND GREENISH STREAK, HEAVINESS, ASSOCIATION WITH GRANITE AND QUARTZ.

Ore forming and other Economic Minerals (Contd.)

NAME OF THE MINERAL	CHEMICAL COMPOSITION (CHEMICAL FORMULA)	PERCENTAGE OF THE CONSTITUENT RADICALS	CRYSTAL SYSTEM	HABIT	COLOUR	STREAK	HARDNESS	SPECIFIC GRAVITY	CRITERIA FOR FIELD RECOGNITION
NICKEL GARNIERITE	$H_2(Ni, Mg)SiO_4$ + WATER VERY VARIABLE IN COMPOSITION		AMORPHOUS	SOFT AND FRIABLE	BRIGHT APPLE-GREEN, PALE GREEN, WHITE.		2.5 - 4	2.3 - 2.8	
MILLERITE	NICKEL SULPHIDE NiS	SULPHUR 35.3 NICKEL 64.7	RHOMBOHEDRAL	USUALLY IN VERY SLENDER TO CAPILLARY CRYSTALS, OFTEN IN DELICATE RADIATING GROUPS, INTER-WOVEN LIKE WAD OF HAIR.	BRASS, BRONZE YELLOW	GREENISH BLACK	3 - 3.5	5.3 - 5.65	SLENDER BRASSY CRYSTALS OFTEN MATTED TOGETHER LIKE A WAD OF HAIR.
PENTLANDITE	A SULPHIDE OF IRON AND NICKEL (Fe, Ni) S. IN PART 2 FeS, NiS.	SULPHUR 36.0 IRON 42.0 NICKEL 22.0	ISOMETRIC		LIGHT BRONZE YELLOW	LIGHT BRONZE BROWN	3 - 5.4	5.0	NOT MAGNETIC
TITANIUM ILMENITE	$FeTiO_3$ OR $FeO \cdot TiO_2$	OXYGEN 31.6 TITANIUM 31.6 IRON 36.5	TRI-RHOMBOHEDRAL	MASSIVE, COMPACT, EMBEDDED GRAINS, ALSO LOOSE AS SAND	IRON BLACK	BLACK TO BROWNISH RED	5 - 6	4.5 - 5	NOT MAGNETIC LIKE MAGNETITE.
RUTILE	TITANIUM DIOXIDE TiO_2	OXYGEN 40.0 TITANIUM 60.0	TETRAGONAL	OCCASIONALLY COMPACT, MASSIVE.	REDDISH BROWN TO RED, YELLOWISH, BLUISH, VIOLET, BLACK	PALE BROWN	6 - 6.5	4.10 - 4.25	
TUNGSTEN SCHEELITE	CALCIUM TUNGSTATE $CaWO_4$ (MOLYBDENUM IS USUALLY PRESENT)	TUNGSTEN-TRIOXIDE 80.6 LIME 19.4	TETRAGONAL	RENIFORM WITH COLUMNAR STRUCTURE, MASSIVE GRANULAR.	WHITE YELLOWISH, WHITE PALE YELLOW, GREENISH, REDDISH.	WHITE	4.5 - 6	5.9 - 6.1	FLOURESCENCE IN ULTRAVIOLET LIGHT WITH BRIGHT BLUISH WHITE COLOUR.
WOLFRAMITE	TUNGSTATE OF IRON AND MANGANESE (Fe, Mn) WO_4		MONOCLINIC	OFTEN BLADED, LAMELLAR COARSE, DIVERGENT, COLUMNAR.	DARK GRAYISH OR BROWNISH BLACK	NEARLY BLACK	5 - 5.5	7 - 7.5	

II. NON-METALLIC MINERALS

NAME OF THE MINERAL	CHEMICAL COMPOSITION (CHEMICAL FORMULA)	PERCENTAGE OF THE CONSTITUENT RADICALS	CRYSTAL SYSTEM	HABIT	COLOUR	STREAK	HARDNESS	SPECIFIC GRAVITY	CRITERIA FOR FIELD RECOGNITION
APATITE	FORMULA FOR FLUOR-APATITE IS $(CaF)Ca_4(PO_4)_3$ OR $3Ca_3P_2O_8 \cdot CaF_2$ FORMULA FOR CHLOR-APATITE IS $(CaCl)Ca_4(PO_4)_3$ OR $3Ca_3P_2O_8 \cdot CaCl_2$	P_2O_5 42.3 CaO 55.5 F 3.8 OR $Ca_3P_2O_8$ 92.25 CaF_2 7.75 P_2O_5 41.0 CaO 53.8 Cl 6.8 OR $Ca_3P_2O_8$ 89.4 $CaCl_2$ 10.6	HEXAGONAL	FIBROUS OR IMPERFECTLY COLUMNAR, GLOBULAR AND RENIFORM, MASSIVE GRANULAR TO COMPACT	SEA-GREEN, BLUISH GREEN OFTEN VIOLET BLUE. OCCASIONALLY YELLOW GRAY, RED, FLESH-RED AND BROWN	WHITE	4.5 - 5	3.17 - 3.23	
ASBESTOS ANTHOPHYLLITE	(Mg, Fe) SiO_3 ALUMINIUM IS SOMETIMES PRESENT IN CONSIDERABLE AMOUNT.	[illegible] 3 : 1 SILICA 55.6 IRON-PROTOXIDE 16.6 MAGNESIA 27.8	ORTHORHOMBIC	LAMELLAR OR FIBROUS MASSIVE	BROWNISH GRAY, YELLOWISH BROWN, BROWNISH GREEN, CLOVE BROWN, EMERALD GREEN.	UNCOLOURED OR GRAYISH	5.5 - 6	2.85 - 3.2	
AMOSITE	IT IS A VARIETY OF ANTHOPHYLLITE RICH IN IRON	—	—	—	—	—	—	—	LONG FIBERS, ASH GRAY TO GREENISH COLOUR.
CHRYSOTILE	CORRESPONDS TO THE COMPOSITION $H_4Mg_3Si_2O_9$ OR $3MgO \cdot 2SiO_2 \cdot 2H_2O$	SILICA 44.1 MAGNESIA 43.0 WATER 12.9	MONOCLINIC	MASSIVE FIBROUS	SUB-RESINOUS TO GREASY, PEARLY, EARTHY, RESIN LIKE LUSTROUS WITH LEAF BLACKISH-GREEN COLOUR.	WHITE SLIGHTLY, SHINING.	2.5 - 4	2.50 - 2.65	

Ore forming and other Economic Minerals (Contd.)

NAME OF THE MINERAL	CHEMICAL COMPOSITION (CHEMICAL FORMULA)	PERCENTAGE OF THE COMPONENT RADICALS		CRYSTAL SYSTEM	HABIT	COLOUR	STREAK	HARDNESS	SPECIFIC GRAVITY	CRITERIA FOR FIELD RECOGNITION
CALCITE	CALCIUM CARBONATE $CaCO_3$	CARBON-DIOXIDE LIME	44.0 56.0	RHOMBOHEDRAL	FIBROUS, BOTH COARSE AND FINE LAMELLAR, GRANULAR STALACTITIC, TUBEROSE, NODULAR AND OTHER IMITATIVE FORMS.	WHITE OR COLOURLESS, VARIOUS SHADES OF GRAY, RED, GREEN, BLUE, VIOLET, YELLOW.	WHITE OR GRAYISH	3	2.71	ALWAYS BREAKS WITH A RHOMBOHEDRAL CLEAVAGE.
CORUNDUM	ALUMINA Al_2O_3	OXYGEN ALUMINIUM	47.1 52.9	-DO-	MASSIVE WITH PSEUDO-CLEAVAGE GRANULAR, COARSE FINE.	BLUE, RED, YELLOW, BROWN, GRAY AND NEARLY WHITE.	UNCOLOURED	9	3.95 - 4.10	HARDNESS
DIAMOND	PURE CARBON C			ISOMETRIC	SPHERICAL FORMS, MASSIVE	WHITE OR COLOURLESS ALSO VARIOUS PALE SHADES		10	3.516 - 3.525	EXTREME HARDNESS AND CRYSTAL STRUCTURE
DOLOMITE	CARBONATE OF CALCIUM AND MAGNESIUM $CaMg(CO_3)_2$ or OR $CaCO_3 - MgCO$	CARBON-DIOXIDE LIME MAGNESIA	47.9 30.4 21.7	TRIRHOMBOHEDRAL		WHITE, REDDISH OR GREENISH WHITE ROSE-RED, GREEN, BROWN, GRAY AND BLACK		3.5 - 4	2.8 - 2.9	REACTS TO HYDROCHLORIC ACID.
FLUORITE FLUORITE OR FLUORSPAR	CALCIUM FLUORIDE CaF_2	FLUORINE CALCIUM	48.9 51.1	ISOMETRIC	MASSIVE GRANULAR, COARSE OR FINE, RARELY COLUMNAR, COMPACT.	WHITE, YELLOW, GREEN, ROSE CRIMSON RED, AND VIOLET BLUE.	WHITE	4	3.01 - 3.25	IT MELTS AT LOW TEMPERATURE.
GARNET ALMANDITE	IRON ALUMINIUM GARNET $3FeO.Al_2O_3.3SiO_2$	SILICA ALUMINA IRON-PROTOXIDE	36.2 20.5 43.3	ISOMETRIC	OFTEN IRREGULAR EMBEDDED GRAINS, MASSIVE GRANULAR COARSE OR FINE, FRIABLE, LAMELLAR.	DEEP RED TRANSPARENT, BROWNISH RED.	COLOURLESS	AROUND 6.5 - 7.5	4.25	ISOMETRIC CRYSTALLINITY OFTEN WITH WELLFORMED CRYSTAL FACES.
ANDRADITE	CALCIUM-IRON GARNET $3CaO.Fe_2O_3.3SiO_2$	SILICA IRON SESQUIOXIDE LIME	35.5 31.5 33.0	-DO-	-DO-	WINE TOPAZ AND GREENISH YELLOW, APPLE TO EMERALD GREEN, BROWNISH RED, YELLOW, GRAYISH GREEN, GREEN-BROWN, GRAYISH BLACK.	-DO-	-DO-	3.75	-DO-
PYROPE	MAGNESIUM ALUMINIUM GARNET $3MgO.Al_2O_3.3SiO_2$	SILICA ALUMINA MAGNESIA	44.8 25.4 29.8	-DO-	-DO-	DEEP RED TO NEARLY BLACK.	-DO-	-DO-	3.51	-DO-
SPESSARTITE	MANGANESE ALUMINIUM GARNET $3MnO.Al_2O_3.3SiO_2$	SILICA ALUMINA MANGANESE PROTOXIDE	36.4 20.6 43.0	-DO-	-DO-	DARK HYACINTH RED, WITH A TINGE OF VIOLET TO BROWNISH RED.	-DO-	-DO-		-DO-
UVAROVITE	CALCIUM-CHROMIUM GARNET $3CaO.Cr_2O_3.3SiO_2$	SILICA CHROMIUM-SESQUIOXIDE LIME	35.9 30.6 33.5	-DO-			COLOURLESS	-DO-	3.41 - 3.52	-do-
GROSSULARITE	CALCIUM ALUMINIUM GARNET [illegible]	SILICA ALUMINA LIME	40.0 22.7 37.3	-DO-		A) COLOURLESS TO WHITE B) PALE-GREEN C) AMBER, AND HONEY-YELLOW, D) WINE-YELLOW, BROWNISH-YELLOW, CINNAMON-BROWN E) ROSE-RED, EMERALD-GREEN	COLOURLESS	-DO-	3.53	
GRAPHITE	PURE CARBON			RHOMBOHEDRAL	MASSIVE WITH PSEUDOCLEAVAGE, GRANULAR, COARSE OR FINE.	IRON BLACK TO DARK STEEL GRAY	BLACK	1 - 2	2.09 - 2.23	MARKS THE PAPER. A GOOD CONDUCTOR OF ELECTRICITY. CHARACTERISED BY GREASY FEEL.
GYPSUM	HYDROUS CALCIUM SULPHATE, $CaSO_4.2H_2O$	SULPHUR-TRIOXIDE LIME WATER	46.6 32.5 20.9	MONOCLINIC	ALSO FOLIATED MASSIVE LAMELLAR-STELLATE, GRANULAR, MASSIVE	WHITE, GRAY, FLESH-RED HONEY-YELLOW, OCHRE-YELLOW, BLUE, BLACK, BROWN RED.	WHITE	1.5 - 2	2.31 - 2.33	SOFTNESS. EASY TO MARK WITH FINGER NAIL.

Ore forming and other Economic Minerals (Concld.)

NAME OF THE MINERAL	CHEMICAL COMPOSITION (CHEMICAL FORMULA)	PERCENTAGE OF THE CONSTITUENT RADICALS	CRYSTAL SYSTEM	HABIT	COLOUR	STREAK	HARDNESS	SPECIFIC GRAVITY	CRITERIA FOR FIELD RECOGNITION
TREMOLITE	CALCIUM-MAGNESIUM SILICATE $Ca_2Mg_5(OH)_2(Si_4O_{11})_2$		MONOCLINIC	FIBROUS, LONG THIN COLUMNAR.	WHITE TO DARK GRAY	TRANSPARENT COLOURLESS	5 - 6	2.9 - 3.2	FIBROUS AGGREGATES IN SEAM LIKE VEINS.
BARITE (BARYTES)	BARIUM SULPHATE $BaSO_4$	SULPHUR-TRIOXIDE 34.3 BARYTE 65.7	ORTHORHOMBIC	GLOBULAR FORMS FIBROUS, LAMELLAR CROSSED.	WHITE, INCLINING TO YELLOW GRAY, BLUE, RED OR BROWN.	WHITE	2.5 - 3.5	4.3 - 4.6	MARKED BY ITS HEAVINESS.
KYANITE	Al_2SiO_5 OR $Al_2O_3.SiO_2$		TRICLINIC	COARSELY BLADED, COLUMNAR TO SUB-FIBROUS	BLUE, WHITE, GRAY, GREEN, BLACK.	UNCOLOURED	5 - 7.5	3.56 - 3.67	CHARACTERISED BY ITS VARIABLE HARDNESS.
SILLIMANITE	Al_2SiO_5 = AlO $AlSiO_4$	SILICA 36.8 ALUMINA 63.2	ORTHORHOMBIC	FIBROUS AND COLUMNAR MASSIVE FORMS, RADIATING.	HAIR BROWN, GRAYISH BROWN, GRAYISH WHITE, GRAYISH GREEN, PALE OLIVE GREEN.	UNCOLOURED	6 - 7	3.23 - 3.24	FIBROUS WITH FLESHY COLOUR.
MAGNESITE	MAGNESIUM CARBONATE $MgCO_3$	CARBON-DIOXIDE 52.4 MAGNESIA 47.6	RHOMBOHEDRAL	GRANULAR, CLEAVABLE TO VERY COMPACT, EARTHY.	WHITE, YELLOWISH OR GRAYISH-WHITE, BROWN	WHITE	3.5 - 4.5	3.0 - 3.12	AMORPHOUS CLAY WHITE COLOUR BUT HARD WITH CONCHOIDAL FRACTURE.
MICA BIOTITE	ESSENTIALLY $H_2K(Mg, Fe)_3Al(SiO_4)_3$		MONOCLINIC	OFTEN IN DISSEMINATED SCALES, SOMETIMES IN MASSIVE AGGREGATIONS OF CLEAVABLE SCALES.	GREEN TO BLACK, DEEP BLACK, BLOOD RED OR BROWN.	UNCOLOURED	2.5 - 3	2.7 - 3.1	GREEN COLOUR.
FUCHSITE	SAME AS MUSCOVITE WITH CHROMIUM								
LEPIDOLITE	CHIEFLY (OH,F) 2KLiAl$_2$			SHORT PRISMS, OFTEN WITH ROUNDED TERMINAL FACES. MASSIVE, SCALY-GRANULAR.	ROSE-RED, VIOLET GRAY OR LILAC, YELLOWISH GRAYISH WHITE.	-DO-	2.5 - 4	2.8 - 3.3	
MUSCOVITE	AN ORTHOSILICATE OF ALUMINIUM AND POTASSIUM $H_2KAl_3(SiO_4)_3$ - $2H_2O.K_2O\ Al_2O_3.6SiO_2$	SILICA 45.2 ALUMINA 38.5 POTASH 11.8 WATER 4.5	MONOCLINIC	FOLIATED, FOLIA OFTEN VERY SMALL AGGREGATED IN STALLATE, PLUMOSE OR GLOBULAR FORMS.	COLOURLESS, GRAY BROWN, HAIR BROWN. PALE-GREEN AND VIOLET, YELLOW, DARK OLIVE GREEN, ROSE-RED.	-DO-	2 - 2.5	2.76 - 3	THINLY FOLIATED APPEARANCE WITH EASY CLEAVABILITY.
PHLOGOPITE	A MAGNESIUM MICA $H_2KMg_3Al(SiO_4)_3$		-DO-	YELLOWISH BROWN TO BROWNISH RED, PALE BROWNISH, YELLOW, GREEN, WHITE, COLOURLESS.	YELLOWISH BROWN TO BROWNISH RED, PALE BROWNISH, YELLOW, GREEN, WHITE, COLOURLESS.	-DO-	2.5 - 3	2.7 - 3.1	GREEN COLOUR.
VERMICULITE	INCLUDES NUMBER OF MICACEOUS MINERALS ALTERED FROM BIOTITE, PHLOGOPITE, ETC.		-DO-	FOLIATED LIKE MICA	WHITE, YELLOW AND BROWN	-DO-	— LIKE MICA	—	EXFOLIATES WHEN HEATED.
PYRITE (IRON PYRITES)	IRON DISULPHIDE FeS_2	SULPHUR 53.4 IRON 46.6	ISOMETRIC	SUB-FIBROUS, RADIATED, RENIFORM, GLOBULAR, STALACTITIC.	PALE BRASS-YELLOW.	GREENISH BLACK OR BROWNISH BLACK	6 - 6.5	4.95 - 5.10	GIVES OFF SPARKS WHEN STRUCK WITH HAMMER.
SULPHUR NATIVE SULPHUR	PURE SULPHUR OFTEN CONTAMINATED WITH CLAY, BITUMEN, AND OTHER IMPURITIES.		ORTHORHOMBIC	MASSIVE RENIFORM, INCRUSTING, STALAGTITIC AND STALAGMITIC IN POWDER.	SULPHUR-YELLOW, STRAW YELLOWISH BROWN, GREENISH REDDISH TO YELLOWISH, GRAY.	WHITE	1.5 - 2.5	2.05 - 2.09	SULPHUR CRYSTALS CRACKLE EVEN DUE TO THE WARMTH OF HAND. ORPIMENT IS DISTINGUISHED FROM SULPHUR BY ITS PRONOUNCED CLEAVAGE. SULPHUR BURNS EASILY WITH A BLUE FLAME EMANATING PUNGENT ODOUR OF SULPHUR DIOXIDE.
WOLLASTONITE	$CaSiO_3$	SILICA 51.7 LIME 48.3	MONOCLINIC	TABULAR, PRISMATIC FIBROUS.	WHITE, GRAY, YELLOW.		4.5 - 5	2.8 - 2.9	FIBROUS NATURE.