CHAPTER 2

GEOLOGICAL REGIME OF FORMATION, MODE OF OCCURRENCE, GENESIS AND CLASSIFICATION OF BAUXITE DEPOSITS

2.1 DEFINITION AND HISTORY

The term "bauxite" refers to a rock consisting chiefly of hydrated aluminium oxides viz. gibbsite, boehmite and diaspore. The bauxite rock has been variously described and defined by various authorities. The 'Dictionary on Mining, Minerals and Related Terms' of the U.S. Bureau of Mines, defines bauxite as a rock composed of aluminous hydroxide, essentially Al_2O_3; $2H_2O$, besides impurities occuring in form of silica, clay, silt, and iron hydroxide and appears to have been formed in tropical and sub-tropical latitudes under good drainage conditions[1].

The Chamber's Mineralogical Dictionary defines bauxite as "a residual clay consisting essentially of aluminious hydroxide formed in tropical regions by chemical weathering of basic igneous rocks. It is the most important ore of aluminium"[2]. W. Schettmann (1982,1983) in co-operation with IGCP project 129 (Lateritization Process) have defined laterite and bauxite separately. According to him "the laterites are product of intense sub aerial rock weathering. They consist pre-dominantly of mineral assemblages of goethite, haemetite, aluminious hydroxide, Kaolinite and quartz. The SiO_2: (Al_2O_3+ Fe_2O_3) ratio of the laterite must be lower than that of the kaolinized parent rock in which all the alumina of the parent rock is present in the form of kaolinite, all the iron in the form of iron oxide and which contains no more silica than fixed in the kaolinite plus the primary quartz". This definition includes all highly weathered materials strongly depleted in silica and enriched in iron and alumina regardless of their morphological and physical properties (fabric, colour, consistency etc.)[3]

Bauxite is also defined as a member of the family of lateritic rocks, which is characterised by a particular enrichment of free aluminium hydroxide minerals such as gibbsite, boehmite and diaspore[3].

The bauxite deposit is a basic geological unit which is continuous in space and is composed essentially of bauxite and genetically closely related rock such as siliceous bauxite, ferruginous bauxite, Bauxitic laterite etc. A bauxite deposit may contain one or several ore bodies, consisting of commercial grade bauxite usable as a alumina ore. The bauxite district is a larger area comprising several individual bauxite deposits, or group of deposits but having similar geological characteristics while the bauxite province/belt is the largest geotectonic unit incorporating closely relating bauxite districts[3].

In 1821 French Professor P. Berthier discovered, analysed and described a clayey rock from "Les Beaux (now (Les Baux) area of France and gave it the following composition Al_2O_3 52%, Fe_2O_3 27% and combined water 20.4%. The name bauxite was given to this aluminous rock by Dufrenoy in 1837 after the French city of Les Baux. Rocks of comparable chemical composition as above appear to have been referred to as bauxite since then[3,4] Laterite the rock usually associated with bauxite, was first named by F. Buchanan (1807) for a typical rock occuring in Malabar (coastal Kerala), South Kanara and parts of Karnataka in South India. This rock was found to be soft when wet and became hard like brick on drying and hence named after "later" meaning brick in Latin[3]. It now refers to all weathering products formed under wet, tropical conditions.

It has been proposed that some bauxite and laterites have a close genetic association. Considerable overlaping in the use of the term bauxite, laterite and aluminious laterite have occured perhaps because of the above factors. Bauxite and laterite show a tendency to occur together and it is not easy to identify them separately by their chemical composition alone. This is owing to the fact that the ferric and aluminous hydroxide in both these genetically associated rock are found in form of colloides. A laterite with high alumina and low silica content from which alumina can be economically extracted can be termed as bauxite.

2.2 GEOLOGICAL REGIME OF FORMATION AND MODE OF OCCURENCE.

2.2.1 The typical laterite bauxite profile

Most of the bauxite deposits of the world are found in association with laterites. They have highly variable thickness, both absolute and relative, with variable chemical and mineralogical composition. A complete lateritic bauxite profile usually comprises four horizons and rests on the parent rock which provides the source material for bauxitisation.

I. Residual soil horizon :[3]

It is the upper most horizon of the profile and comprises mechanical and chemical weathering products of the underlying horizon mixed with plant remains and humic matter. The colour of this horizon may depend upon the underlying horizon.

II. Duricrust horizon :

This is the upper part of the main accumulation zone of the profile. This is normally formed due to recrystallized iron minerals and is therefore the hardest part of profile. The duricrust horizon has the strongest colour varying from brick red, red brown to blue black. It is hard to very hard, often ranging from vasicular colloform, nodular,concretionary to more rarely aphanitic in texture.

III. Bauxite horizon

This horizon represents the lower sequence of the lateritic part of total profile and is mainly differentiated from the upper duricrust by its higher accumulation of alumina minerals and hence is normally less hard. The horizon can be homogeneous throughout or composed of different zones having varying structures, texture, composition or colour. The colour of the bauxite horizon is highly variable ranging from almost white, pinkish, yellowish, orange, reddish brown to brown. It is extremely variable in lithology and this can be divided into zones of different textures and structures.

IV. Saprolite horizon

It is composed of weathering products of the aluminium sheet silicates present in the parent rock, mainly kaolinite and minerals such as quartz, rutile, zircon etc., that are highly resistant to weathering. Minerals like illite, montmorillonite etc. may occur in the lower part of the horizon but gradually disappear upwards over short vertical distances. Locally the saprolite horizon may consist of two zones, one upper thin zone without any relict texture and strucutre, and the lower thicker zone with relict textures and structure of the parent rock. The saprolite has lighter colour than the overlapping laterite or bauxite with whitish, pinkish, orange and reddish, variegated and mottled colours. It is often mottled, soft, earthy and porous.

V. Parent rock

This horizon is so named as weathering profile is derived from this rock and its composition strongly influences the nature of the weathering profile. In case of parent rocks their composition is difficult to be identified in the field as often they are completely weathered and altered to bauxite.

The above horizons show a transition from top to next lower horizon. This may vary from a sharp contact to a gradational transition over a vertical distances of several meters. Between the bauxite and saprolite the transition can be marked by a decreasing incidences, size and number of gibbsite concentration and the corresponding increase in kaolinite content of the matrix.

Laterite and bauxite surface deposits are liable to be greatly affected by erosion agencies. Thus mechanical surface weathering may produce brecciation in the duricrust. The primary or insitu laterite may be transported to a short distance and re-deposited as secondary reworked bauxite deposit at suitable loci.

2.2.2 Parent Rocks for formation of bauxite (3)

The rock that is found just below the bauxitic weathering profile is generally supposed to be the parent rock for bauxite deposits. In many cases the parent rock is completely altered to bauxite or saprolite and so in such cases the rock found below the deposits are in fact not the parent rocks. The weatherability of a rock depends mainly on its mineralogy, crystallinity, size, related mineralized surface area, and its porosity and permeability.

On making a comparision of the parent rocks of the lateritic bauxites of the world, it is revealed that they are formed from almost every type of rock that contains alumina. There is more than one parent rock in several bauxite deposits. In some large bauxite deposits, even 3 to 4 different parent rocks may contribute to the formation of bauxite.

(I) Sedimentary Parent rock

The largest proportion of world's bauxite deposits have been formed from sedimentary rocks. The most frequent rock types noticed in this group of parent rock are arkosic sandstone and silt stones. Shales and slates of Palaeozoic to upper proterozoic age also constitute a significant proportion. Relatively little bauxite has been formed from kaolinitic sandstone and silt stone. Carbonate rocks - dolomites and limestone, are weathered, transported and deposited in local Karstic depressions where bauxitization generally continues. The geo-chemical environment of the weathering of these carbonate rocks is quite different and therefore such bauxite deposits forming out of carbonate rock are separately grouped under karst bauxites.

II. Igneous Parent Rock

The second most frequent parent rocks for bauxite are volcanic rocks. Lava flows, tuffs and volcanic agglomerates, have been weathered to bauxite mainly due to their higher permeability. The most frequent volcanic parent rock in these category is basalt, (ranging in age from Lower Proterozoic to Plio-Pleistocene), followed by andesite, andesitic tuff and agglomerate, phonolite, trachyte rhyolite etc.

More than 17% of the total lateritic bauxites are derived from hypabyssal rocks i.e. igneous rocks which solidified before reaching the earth's surface. Dolerites constitute the most important rock type of this genetic group.

Relatively quite a large quantity of bauxite has been derived from plutonic rocks mainly from granite. Gabbro is the second important plutonic rock which has given rise to large bauxite deposits in South East Asia. Nepheline syenite, foyaite, monzonite, anorthosite, syenite, dunite and peridotite are other plutonic rocks which are known to have given rise to bauxite deposits.

III. metamorphic parent rocks.

The proportion of metamorphic rock is the smallest among main genetic parent rock groups. The most important metamorphic parent rocks belong to granulite facies - khondalite, charnockite and leptynite. The East coast bauxite deposit of Orissa and A.P. (India) and those of Tamil Nadu state have originated from these parent rocks. Rock deposits of green stone facies, sericite and chloritic schists, basic metavolcanics, amphibolites, hornfels and gneiss are other important metamorphic parent rock of bauxite.

In conclusion it is apparent that about 42 rock types covering sedimentary (34%), igneous (53%) and metamorphic (13%) type can give rise to lateritic, Tikhvin and Karst bauxite deposits. The most important of these according to tonnage in order of significance are basalt followed by dolorite, arkosic sandstone, kaolinitic sandy/clayey shale, slate, granite, and rocks of granulite facies. Other rock types share a much smaller proportion in the formation of bauxite deposits.

2.2.3 Extent & Geometry of deposit

The extent of an individual bauxite deposit or a province can vary differently. The largest deposit may extend over several thousand sq.km, for example deposits of

Australia,(Darling range and Weipa deposits,) South Vietnam and Guinea. The extent of bauxite deposit is genetically related to several factors, most important of which include geo-morphology, parent rock composition and climatic changes which have brought about bauxitisation. Geo-morphology largely determine the outline of a bauxite belt. Often the bauxite deposit gradually pass into laterite with decreasing altitude of plateaux. Parent rock composition has determined the extent of many bauxite deposits. For example in Brazil the occurrence of bauxite is limited to an area unoccupied by circular intrusion of alkaline magmatic rocks. The distribution of a bauxite province or a belt is also highly variable. In some areas the deposit may be evenly distributed, in others distinct cluster of deposits can be identified. Mainly erosion, shapes the sizes and outline of many bauxite deposits.

The geometry of the laterite/bauxite deposit is generally simple and comprises flat lying blanket with highly irregular lateral outline. While the geometry of karst bauxite is much more complicated because these deposits are found in depressions and are affected by frequent tectonic deformation that takes place after their burial.

The size and shape of individual deposits is determined mainly by erosional process. In case of plateau type deposit, the entire plateau can be covered by bauxite. Where the plateau is very large, continuous laterite covers it and bauxite occur only in some parts. The more dissected and eroded the area, the more irregular the outline of bauxite plateau. Deep embayment and long tongues covering the main plateau area through narrow necks are common features of many bauxite plateaux. This irregular out line is one of the most conspicuous feature of the geometry of bauxite deposits.

The surface area of individual deposit range from a few hectares to some tens of Sq. km. The largest continuous deposits are known in Australia,(Weipa and Gove deposits) Guinea and India (East Coast, . .) The largest surface area of bauxite does not necessarily correspond with the largest tonnage in a bauxite belt.

The lower boundary of bauxite zone is relatively flat or gently undulating in many cases. It is very irregular in deposits situated high above the ground water level (either at present or presumably during the period of their formation). In such geological condition the largest thickness of bauxite which has been observed is 54 m in East Coast deposits, India. The upper boundary of depositsare determined by the present day topography in all surface deposits. There are gently undulating bauxite surfaces in deposits of Saurashtra and Kutch (Gujarat) because these deposits were subsequently covered by marine transgression.

2.2.4 Vertical thickness and constitution

The horizons of a typical bauxite profile essentially show difference in chemical and mineralogical composition. This makes the saprolite horizon as kaolinitic in composition, the overlying bauxite horizon as alumina and iron rich and desilicated rock, the duricrust mainly ferrugineous in composition and soil horizon characterised by high content of humus and organic matter. The four horizon which develop in most bauxite deposits, have the following range of thickness.

S.no.	Horizons	Range
1.	Soil horizon	0 - 2 m
2.	Duricrust	0 - 4 m
3.	Bauxite horizon	1 - 54 m
4.	Saprolite horizon	0 - 100 m

The largest average bauxite thickness have been observed in the deposits presently situated at high altitudes(e.g. east coast deposit of India) and where the duration of the bauxite formation could have been the longest. On the contrary bauxite zones are thin at places where they are situated just above the water table or in high areas where period of formation was comparatively short.

Two main types of bauxite horizons can be distinguished with respect to vertical constitution. The first type is characterised by a homogeneous bauxite horizon with only gradual chemical and mineralogical changes within it. The second type consists of two or more zones of different lithology and chemical compositio

2.2.5 Stratigraphic position and burial

A majority of the bauxite deposits identified in the world are surface deposits, which were rarely covered by younger sediments. The position of these deposits in the stratigraphic column can at the best be indirectly established on basis of geomorphology, absolute age determination and paleoclimate.

The geomorphological evidences establish that most bauxite deposits are genetically related to certain large scale erosional surface that have formed during well known geological periods. The bauxitisation process is still going on in several tropical belts, though the begining of the process could not be precisely dated. However, a bauxite deposit cannot be older than the age of its parent rock. The geomorphological studies by various authors have established that the oldest preserved and unburied large scale erosional surface over the continents was late Jurasic. The bauxite deposits developed on these surfaces can obviously be expected to be younger. In certain enigmatic bauxite deposits related with oldest erosional surface (representing period of denudation) found to be situated over Gondwana and post Gondwana surfaces; the bauxitisation probably started during the early and middle Cretaceous.

The stratigraphic position of buried bauxite deposits can be determined more accurately through the dating of overlying sedimentary sections particularly through its fossil records. Burial protect the deposits from later erosion. The pressure of over burden produces compaction and changes in the lithology, geo-chemistry and mineralogy of the bauxites. Owing to this fact it is important to know the total thickness of over burden and nature of underlying rocks. Majority of buried deposits have a shallow cover (less than 50m thickness). In India buried bauxite deposits are found in Gujarat and Kerala. The burial occured due to widespread subsidence under quiet non erosional condition, so as to preserve the deposit. The karstic and Tikhvin type deposits of bauxite have been buried to a large extent than the lateritic ones. In fact nearly all Tikhvin type deposits are buried deposits.

2.2.6 Tectonic position

The earth's crust can be geotectonically divided into (1) continental platform, (2) Orogenic belts, (3) Oceanic basin. Bardossy (1979, 1982) established that 91.7% of the total lateritic bauxite tonnage occurs on continental platform, 8% on orogenic belts and less than 0.3% on islands of the great oceanic basins. The above distribution of bauxite deposit explains the need for stable conditions for formation of bauxite. In the highly mobile orogenic belts, repeated sedimentation prevents bauxitisation in most of the low lying localities. On the contrary in higher mountains strong erosion destroys the newly formed lateritic beds.

2.2.7 Geomorphology

The lateritic bauxite deposits as they are found today are confined to the following types of land forms listed by Bordossy and Aleva (1990) in order of diminishing frequency :-

i) Plateaux - Flat or uneven topped
ii) Dome shaped hills
iii) Elongated Cuestas
iv) Slopes of mountain ranges
v) Flat coastal peneplains and sedimentary flats.
vi) Shallow depressions on flat peneplains.

i) Plateaux

The plateaux are by far the most frequent bauxitic land form. They stand elevated compared to surrounding country and are marked by abrupt descent on atleast one side. Their top is more or less flat and peneplained. The highest lying bauxite bearing plateaux in the world occur in Nilgiri and Palni hill of South India where the bauxitisation has developed between 1980 to 2400m height (Subramanian 1981). The biggest bauxite belts having reserves of over 1000 million tonnes occur in narrow altitudinal interval, ranging between present day sea level to 1450m . Of these the East coast deposit of India and those of Cameroon are situated at the highest altitude. It is conspicuous that most of the largest bauxite bearing belts of the world occur between altitudinal interval of 0 - 400 m. This altitude interval characterises for the highest number of deposits having largest reserves. In Tamil Nadu the bauxite bearing plateaux of the Palani, Nilgiri, Shevroy and Kollimalai hills are at present seperated by 100 - 200 km. But Subramanian (1978) presumed that these plateaux are remnant of a single large scale ancient erosional surface which extended over the entire South India and dipped, 1 - 2^{o} east wards This explains the reason why most of the western plateaux range between 2000 - 2400 m, while those of the eastern end range between 1200 to 1300 m above MSL.

II. Dome shaped hills

The dome shaped hill constitutes much less frequent bauxite bearing land forms. Typical examples of few such bauxite deposits are found in Brazil, Kalimanthan, (Indonesia) and Guinea.

III. Elongated Cuestas

Elongated cuestas are known only in the bauxite deposits of Venezuela. They correspond to outcrops of inclined dolerite sills rising 150 to 200 m about the flat surface, the top portion of which is occupied by the bauxites.

IV. Slopes or mountain ranges

The slopes of mountain ranges where bauxite has developed, can be examplified from Brazil.

V. Flat coastal peneplains and sedimentary flats.

The flat coastal peneplains are characterised in the middle Timan mountain (USSR) and Queensland (Australia)..

VI. Shallow depressions on flat peneplains

The bauxite deposits associated with the shallow depression on flat peneplains have been described from South Eastern Australia and Tasmania.

The genetic significance of the Geomorphology can be summarised as below :-

1. Positive land forms assure good drainage conditions that are essential for the bauxitisation process.

2. The elevated plateau and other bauxite bearing land form protects the weathering profile from the accumulation of transported sediment during the bauxitisation period.

3. The low relief of the elongated surfaces assure low erosion rates over them.

2.2.8 Hydrogeological Condition

Water acts as the main agent in chemical weathering and the hydrogeological conditions, play an important role in the formation of bauxite deposits. To achieve efficient leaching and solute removal, good drainage is essential, which can be ensured through high permeability of the parent rocks. The chemical weathering may itself create additional pore spaces and permeability in the parent rocks Other factors influencing the permeability of parent rocks, are its structure (bedding or foliation). The steeply dipping or foliation fecilitates bauxitisation as in case of East coast deposits of India. The surface morphology influences the proportion of infilteration and run off of rain water. In proper geomorphological setting a continous flow of ground water through the weathering profile takes place which leaches out mobile chemical components.

In conclusion bauxitisation can take place only above the ground water table particularly under good drainage condition and the action of infiltrating rain water.

2.2.9 Climatic condition

It is known that intensity of chemical weathering increases with the temperature and amount of rain fall. Weathering is, therefore, most intense in wet tropical zones where it is characterised by the widespread occurence of actively developing laterite profiles. Bauxite being an extreme case of lateritisation, drainage and leaching conditions play a governing role.

A number of authors have studied the climatic conditions necessary for bauxitisation. Making a summary of their observations, the climatic conditions essential for formation of bauxite which correspond to tropical monsoon climate, are as follows -

1. Mean annual temperature of the region should be more than 22°C.

2. Annual rain fall of the region should be more than 1200 mm distributed over 9 - 11 rainy and 1 - 3 relatively dry months.

It can be stressed that a very uneven concentrated rain fall distribution is less favourable for bauxitisation because most of the water runs off on the surface.

The local climatic conditions working within small areas called microclimate can also determine bauxitisation process. Similarly the humidity of air, both on surface and within the pores of the weathering profile play an important role in bauxitisation.

2.2.10 An overview of mode of occurrence of Indian Bauxite deposit(5)

A. Geographical distribution

Practically the entire Indian bauxite resources are confined to peninsular shield, barring the sole occurrence in Jammu in the extra peninsular region. In the peninsular region 88% of the total resources are confined to high level formations occurring in proximity to eastern & western coast lines. Out of which again majority of about 77% is confined to the Bengal coast and rest to the Arabian Sea coast. Only 12% total resources occur amidst inland pleateaux and plains.

B Physiographic disposition

The Indian bauxite occur right from near the sea level in Gujarat to over 2000 m above MSL in Tamil Nadu. Traditionally the Indian Bauxite has been described under high & low level deposits. However their altitudinal limits remain to be quantified. Thus there remains an ambiguity in classifying some deposits specially those occurring between 200-600 m above M.S.L.

The bauxite deposits of the eastern ghats and western ghats and inland plateaux can be regarded as high level and essentially consisting of insitu primary deposits While the coastal inland hillock and plains may be clubbed under low level deposits consisting of both insitu and detrital primary & secondary/reworked types of bauxite.

C. **Localization of Indian Bauxite deposit from climatic view point**

The bauxite deposit of eastern ghats and western ghats can be considered to be located under zones of high rainfall (more than 120 cm p.a.). While the bauxite deposit on inland plateaux and coastal plains and inland plains occur amidst isohyetal zone having less than 100 cm annual rain fall.

D. **Lithostratigraphic base**

The Indian Bauxite occurs in diverse geological and geomorphic environment. It overlies Archaean metamorphics, proterozoic, Gondwana, Tertiary sediments and Cretaceous-Eocene volcanics. Laterite, bauxite and clay or a partially weathered bed rock are the main litho units that constitute a residual profile, irrespective of compositional variation and stratigraphic position of the associated rocks. The intensity of development of the different litho unit show a broad correlation with the constitution of parent rock. Bauxite is not only a subordinate member but is also highly pockety in nature, whereas the other members i.e. laterite and clay occur as blankets and in larger proportion in the residual profile overlying Deccan trap. In case of residium derived from the khondalite rocks of east coast, the entire thickness is essentially aluminous (gibbsitic) and the sub grade ore is subordinate and obscure. Clay is not a compelling associate in the east coast profile.

On making a lithostratigraphic evaluation the following conclusions may be drawn -

1. Nearly 77% of the total resources occur overlying and derived from the Archaean khondalites constituting the Eastern ghats physiographic province. This also includes the negligible proportion

of bauxite derived from the charnockites rocks.

2. The underlying/sources rock next in abundance to give rise to workable bauxite deposits are the Deccan traps of cretaceous-Eocene (Oligocene) age. Nearly 21% of the resources stem from the area underlain by Deccan basalts both in high and low level deposit

3. Bauxite derived from Proterozoic, Gondwana, Tertiary sediments, granitic gneiss, phyllitic schist and other litho types account for the balance 2% of the total resources. Incidence of detrital bauxite is rather negligible.

All the bauxite deposit of India are of lateritic type, the only exception being the diasporic bauxite of Jammu which may perhaps the classified under the Tikhvin type of Bardossy (1981).

E. Mineralogical and Geo-chemical attributes of Indian Bauxite

i) The bauxite deposits of Eastern Ghats are essentially blanket type and/cappings with aerial spread up to 15 sq. km and thickness upto 54 m. Mineralogically these are gibbsite dominant with scarce boehmite. Other minerals are haematite, goethite, kaolinite and anatase and relict grains of sillimanite, garnet, corundum sphene etc. These are characterised by moderate alumina, high iron and low silica content.

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ii) The bauxite deposits of Western Ghats are essentially pockety, lensoid & tabular bodies of limited lensoid dimensions where the thickness seldom crosses 5 m. These have subhorizontal to gentle sloping landforms. Boehmite is relatively more in proportion than the eastern ghats deposits. Gibbsite is the major mineral. The bauxite derived from basalts is characterized by oolitic and pisolitic texture. Titania is relatively more in trap derived residium while iron and silica are high in the charnockite derived bauxite. Thick clay bed marks the transition between the residium and unaltered rock below.

iii) The bauxite deposit of inland plateau, have aerial extent and thickness more or less similar to those of western ghats. The other features are also comparable to deposit of western ghats.

iv) The coastal and inland plains have no specific Geomorphic expression. They have erratic chemistry, mineralogy and mode of occurrence. They have more association of clay which include montmorillonite and illite besides kaolinite.

2.3 GENESIS OF BAUXITE

2.3.1 Historical perspective

The genesis of bauxite and the process of bauxitisation have always been enigmatic problems which have generated considerable discussions and controversies. Considerable research has been carried out over the years with the aim to satisfactorily explaining the process of bauxitisation. Fox (1927) was perhaps the first to furnish a comprehensive and comparative account of distribution of bauxite deposit of India and abroad. He tried to explain the genetic relationship between bauxite, laterite and terra-rossa and developed his theory on the formation of lateritic bauxite. Later the foundation of international committee on the study of bauxite alumina d aluminium (ICSOBA) in 1963, de Weisse (1964), Valeton

(1972) and Bushinsky (1975) made significant contributions on the genesis of bauxite. The bauxite symposium held in Los Angles in 1984 and finally the monumental works of Patterson (1986) made valuable contribution towards explaining the process of bauxite formation.

2.3.2 Favourable conditions and factors

C.S. Fox in his monumental work on the origin of bauxite postulated following conditions for the formation of lateritic bauxite;

1. A tropical climate with alternating dry and wet seasons.
2. A levelled or gentle sloping elevated land
3. Suitable source rock
4. Porous texture of source rock to allow entry of percolating water
5. Retention of infiltrating water for maximum period in the rocks to give maximum play to chemical erosion.
6. Acidic or alkaline medium of infiltrating water.
7. This annual process should be continuously in operation for atleast a geological epoch (atleast a million years)[5].

The theories given by various geologists to explain the origin of bauxite deposits can be summarised on the basis of the following contentions[6]

1) Precipitation of hot water rich in aluminous salt 2) Alteration of aluminious parent rock under the sea

water 3) Deposition of aluminious material in the lakes 4) Leaching of aluminious rocks by naturally evolved acids.

A consensus view of the origin of bauxite is that it is formed by the weathering of aluminious rocks under conditions favourable for the retention of alumina and the leaching of other constituents present in the parent rock[6,7].

A detailed account of various factors and conditions favouring the formation of bauxite, have already been given under section 2.2

2.3.3 Mechanism of bauxitization

The mechanism of formation of new mineral phases during bauxitisation has been a long debated problem. The three most important and popular theories given to explain the formation of minerals during bauxitisation are as follows :-

2.3.3.1 Direct Bauxitisation theory of Millot (1964)

This theory postulates a direct replacement of the original alumino-silicate minerals by gibbsite, for example felspar of the parent rock are directly replaced by gibbsite pseudomorphs. The direct bauxitisation needs highly favourable leaching conditions, much rainfall in the monsoon type climate and quick removal of dissolved silica and other constituent etc. This process presumably takes place by means of ionic solution and there is no saprolite horizon developing between the bauxite and the parent rock. This process of direct bauxitisation has been demonstrated by several authors from a large number of deposits notably among which are south America, India, South Africa, Australia, Guinea etc.

2.3.3.2 Indirect Bauxitisation

In this process the bauxitisation proceeds through a intermediate clay mineral stage and occurs when the release of the dissolved silica is not fast enough. In this process mainly kaolinite or halloysite is formed. In the 2nd stage gibbsite residue is formed through an incongruent dissolution. The first stage of this process is represented by saprolite horizon while the second stage is marked by bauxite horizon itself.- In case of indirect bauxitisation the texture and structure of the bauxite may show relict character which may later be reorganised to give rise to aphanitic and colloform textures. This process of indirect bauxitisation is so named by Millot in 1964 but Boulange (1984) used the term Alloteritic bauxitisation for the same.

The indirect bauxitisation is more common than the direct one. However, the two type of processes are not always separated from each other in space. Both direct and indirect bauxitisation can occur repeatedly if changes in the environment allow it.

2.3.3.3 Besides the above two processes, the process of selective bauxitisation has also been suggested by certain authors for some bauxite deposits of Guinea, Surinam, Belgorod and middle Timan mountain deposits of U.S.S.R. This process reflects differences in weathering of parent rocks.

2.3.3.4 Another group of geologists suggest a poly phase origin to bauxite deposits of Amazon basin which postulate 2 or 3 main bauxitation events and sedimentation[3].

2.3.3.5 Butty and chapallaz (1984) in the bauxite symposium at Los Angeles gave their theory on bauxite genesis which is as follows. According to them bauxite is derived by surficial weathering of alumino - silicate rock forming under warm and humid climatic conditions. Variations in climate combined with base level changes promote cyclical, evolutionary weathering and concentration, the residual product of which are closely controlled by biological activity. Rock decomposition result mainly from hydrolysis chelation and solution. The affect of these are (1) Removal of bases and silica in dilute solution (2) Depletion of iron in areas where low pH - Eh prevail (3) Concentration through direct precipitation of aluminium hydrate in variable associations with Iron hydrates and clay minerals.

The two authors regarded bauxite as aluminious soil which result from cyclic or polygenetic pedogenesis.

2.3.4 Secondary - post bauxitisation processes

The following secondary post bauxitisation processes take place in nature.

2.3.4.1 Physical disintegration and subsequent redeposition of Bauxite

Large blocks of bauxite break off from plateau scarps and are rolled down the slopes. This reduces the size of the blocks. At gentle slopes and terraces, the bauxite debris can accumulate as simple colluvium or be transported further by the downward flowing rain water. The detrital bauxite accumulation can be distinguished from the residual deposits by their clastic structure and locally by their bedding.

2.3.4.2 The secondary compaction and recrystallization of bauxite occur due to burial of deposits without essential changes in the chemical composition.

The bauxite deposits buried below heavy overburden are compacted due to load pressure of the over burden. Porosity diminishes from 50% to as low 5%. The burial alone does not produce major chemical changes in the bauxite except some loss of combined water.

2.3.4.3 Secondary changes in mineralogical and chemical composition

In buried bauxite deposits mineralogical and chemical changes like resilication(introduction of dissolved silica in bauxite horizon by the ground water to form mainly kaolinite), deferrification, carbonatisation, sideritization, pyritization and alunization etc. take place[3].

2.3.5 Origin of Indian Bauxite

Several geologists have considered the problem relating to the origin of Indian bauxite deposits, notable among these research workers are Fox, Mallet, Roy Choudhury, Rane, Deshmukh, Banerjee, Sahasrabhude, Swaminath, M.G. Rao and P.K. Raman. Nearly all these workers have recognised the clear association of Indian Bauxite with the lateritic profile, except the deposits of Jammu which are associated with karstic environment. They have also recognized that sub-aerial weathering is the main process which has given rise to bauxite and laterite in the country. However, for the segregation of bauxite within laterite various alternative processes have been suggested.

Perhaps the first scientific explanation for bauxite genesis was given by Holland (1903). He postulated that Indian Bauxites have resulted due to bacterial action. According to this view, low organism have power of separating alumina from silica. The silica thus seperated is soluble and so is removed in alkaline solution leaving concentrated Al_2O_3 bodies.

Fox (1923) was perhaps the first geologist to make an elaborate discussion and comparision of Indian Bauxite deposits. His view on the genesis of Indian Bauxite as later modified by Roychoudhury[4,6], are fairly well accepted Fox suggested that laterite and bauxite have resulted from the action of rain water charged with corrosive acids or salts on the parent rock over a prolonged geological period. The corrosive liquid has removed all soluble rock component leaving behind insoluble alumina and ferric hydroxide. All the preconditions essential for the formation of bauxite mentioned earlier were also recognised by Fox for Indian deposits. However, Fox's theory does not fully explain all the features of typical Indian bauxite. Notably there are thick ferrugineous laterite horizons below bauxite horizons. Also all laterite cappings do not contain bauxite. Roychoudhury tried to explain this by highlighting the role played by sub-aerial weathering in bauxitisation.

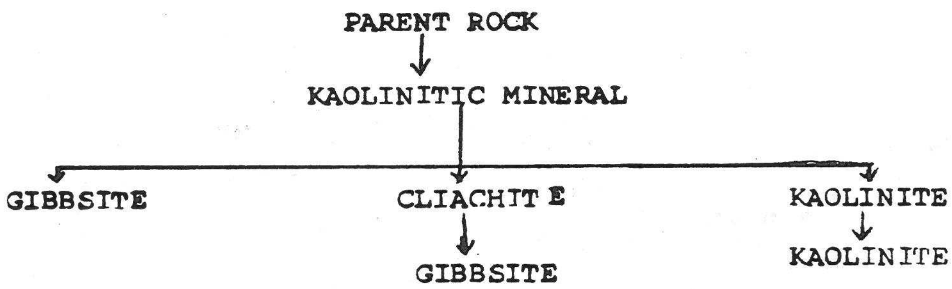
Whatever may have been the exact mode of formation of Indian bauxite, it is becoming increasingly clear that no single theory or idea can explain all the complex factors involved in the formation of different deposits. According to Fox (1923), later supported by Roychoudhuri (1958) the major bauxite deposit in the high plateau regions of M.P., Bihar and Maharashtra are confined to the laterite profile developed by the weathering of Deccan Basalts.

Roy and Bagchi believed that the bauxite deposits of Ranchi having clay beds at the base, show distinct sedimentary features and gradational relation with the overlying laterite and bauxite. Therefore they have assigned sedimentary origin for the bauxite deposits of Bagru and Maidanpat deposits of Ranchi district (Bihar). According to them this deposit has derived from the clays of upper Gondwana sediments suggesting the formation of lower laterite by lateritisation of underlying clay. The exact machanism of the mode of formation of bauxite and upper laterite have not been clearly stated.

The study of laterite cappings of Surguja and Bilaspur districts (M.P.) reveal that the bauxites rest directly on the Deccan traps and show clear evidence of a genetic relationship. However in bauxite deposits of M.P. some areas like Amarkantak deposit show characterstics of a secondary (or reworked) origin. The prominent features of this type of deposit are bouldery nature of bauxite occurrences and also the sharp contact between the bauxite and the underlying clay[10]. Agglomerates and ash of Deccan traps have been suggested as the probable parent rock of phutkapahar deposit (Bilaspur) M.P. Besides the high level bauxite, large areas of low level bauxites associated with the laterite have been traced in Katni-Jabalpur (M.P), Saurashtra and Kutch areas (Gujarat), Thana and Kolaba districts (Maharashtra), Coastal Karnataka and Goa. The deposits of Katni M.P. are found in association with sandstone of Vindhyan age and quartzite of Dharwar age and show evidences of transported origin[12].

The conspicious low level bauxite deposits of Saurashtra and Kutch district (Gujarat) have been studied by Sahasrabudhe (1978). According to him these bauxites have been formed by an insitu alteration of Deccan traps and associated pyroclastic facies of lava flows. He has cited field and laboratory evidences supporting the insitu alteration of bed rock leading to laterite and bauxites.

The writer suggested that the laterite has formed as a result of insitu alteration of pyroclastic material ejected during the Deccan trap volcanic episode. The typical and unusual tuffaceous appearance of the bauxite and the remnents of ashes in some of the laterite favour his hypothesis. The bauxites of Kutch, comprising gritty and conglomeratic types are regarded as reworked and transported facies of earlier formed bauxite. According to him the probable paragenesis of Gujarat bauxite may be as below[13] :-



The discovery of East coast bauxite belt, of late has drastically changed the resources position of bauxite in the country. The East coast deposits have been studied by M.G. Rao and P.K. Raman (1979). According to them the deposit occur in the Eastern ghat belts ranges at altitudes varying from 900 - 1450 m. Most of the deposits overlie the khondalite group of rocks while few are associated with charnockite. The bauxite outcrops thus overlying the khondalite, are characterized by relict foliation that conform to those of subjacent rock. However, there is an indisputable lithological gradation between residuum and the subjacent rocks. The gradation is more often marked by a partially altered rock (Khondalite/

charnockite). Partially lateritized rock occur as intercalations within the bauxite zone. The observed evidences and the supporting mineralogical and chemical data clearly indicates the insitu nature of the East coast bauxite deposit[14].

The bauxite deposits of Kerala are reported to have formed by insitu sub-aerial weathering and decomposition of underlying Archean rocks. At some places the original structures like lineation of the parent rock are still preserved in the bauxites. Besides insitu occurrences, bauxite transported and deposited in the sedimentary basin are also below the Warkalli formation[15].

2.4 CLASSIFICATION OF BAUXITE DEPOSITS[3]

A number of geologists have attempted to make a realistic classification of bauxite. Thus classifications based on geology, pedology and alumina technology are available. However, a universally acceptable classification of bauxite has not been evolved till date. This is owing to the fact that none of above classifications are directly comparable or use common parameters. A review of various bauxite classifications available today is made in the following paragraphs -

2.4.1 Classification based on chemical composition of bauxite

J. de Lapparent (1930) distinguished eight different types of bauxite on the basis of their chemical composition, alumina - silica ratio and the iron content, were taken as the criteria for classifications. The classification has since been abondoned but the alumina silica-ratio, called 'module' or 'modulus' is still in use in some countries to distinguish between high and low grade bauxites[3].

2.4.2 Classification based on mineralogical composition

2.4.2.1 Schneiderhohn (1944) classified bauxite on the basis of principal alumina minerals into the following :

1. Diasporites
2. Boehmitites
3. Gibbsitites

This classification was further developed and modified by Konta who distinguished 5 types, and Ida Valeton who distinguished 10 types of bauxites[3].

2.4.2.2 Classification of Fritz Von Kerner-Marilaun :

The mineralogical classification by above author, quoted by Roychudhoury is given below -

(i)	Diasporic Bauxite	:	Contain only monohydrates of a lumina
(ii)	Low bauxite or Mio bauxite	:	Contains more monohydrate than trihydrate minerals.
(iii)	Bauxite	:	Contains mono and trihydrates in matching proportions
(iv)	High bauxite	:	Contains more trihydrates than monohydrates
(v)	Gibbsitic bauxite	:	Contains only trihydrates[16].

The problem with the chemical and mineralogical classification lies with the fact that most bauxite deposits have a heterogenous chemical and mineralogical composition. This enables only bauxite types to be distinguished but not the entire deposit.

2.4.3. <u>Classification based on shapes of the deposit and the type of their geological occurrences</u> :

2.4.3.1 Grubb (1973), on the basis of differences in texture, structure, thickness and geometry of bauxite deposits situated at higher or lower altitudes (geomorpho logical consideration), classified bauxite deposits into –

1. High level or upland bauxites
2. Low level or peneplain type bauxites.

The difficulty with this classification was that it referred to the altitudes at which the deposits were formed and so it was nearly impossible to place the burried bauxite deposits whose initial altitude could not be confirmed.

2.4.3.2 Harder and Greig (1960) suggested the following classification of bauxite on the basis of their geological occurrences.

1. <u>Blanket deposits</u> - Extensive bauxite deposits occuring as a near uniform cover over ancient erosional surface.

2. <u>Inter layered deposits</u> - Discontinous beds and lenses inter-straified in sedimentary or volcanic rocks or along contacts between igneous or meta-morphic and younger rocks.

3. **Pocket deposits** formed as filling in the depressions of limestone or dolomite[3].

This classification has also been used by Patterson (1967 & 1986). A slightly modified and elaborate version of this classification is given below :

(1) Blanket deposits : All the blanket deposit are of residual type formed from alumino silicate rocks. They occur on plateau remnants in association with old erosional surfaces and peneplains. Some of the blanket deposits are of large aerial extent and are also covered by thick soil cover. Typical examples of this are found in Australia, Dhangarwadi and Bagru hill (India), Suriname Ghana and Guinea.

(2) Interstratified deposits : Such deposits occur as discontinous beds or lenses within or below sedimentary formations or along the contacts between igneous or metamorphic and younger sedimentary rocks. They generally mark a zone of unconformity whose base tends to be irregular and have residual clay beds. Typical examples of these are found in Arakansas (USA), Dalmatia (S. Europe), Guyana and USSR.

(3) Pockety deposits : These deposits are mainly connected with karst topography and found within solution openings in dolomites and limestones. Examples of this type are found in S. Europe.

(4) Transported or Detrital deposits

Deposits of this type are of minor significance and are always associated with a nearby source of primary deposit; They may be transported or bedded deposits. Typical examples of these are deposits of USA, Ghana, Katni (M.P.) and parts of Jamnagar (Gujarat).

2.4.4 Classification based on tectonic position of deposit

Peive (1947) recognised the following types on basis of tectonic position of bauxite deposits[3]

(i) Deposits in Geosynclinal zones -

Such deposits overlie carbonate rocks and are marine in origin.

(ii) Deposits in Platform areas :

Such deposits are residual or are deposited in lake and marshes.

2.4.5 Genetic classification of Bauxite

Such classification was proposed and developed by a number of workers notable among them are Vikulova (1946), Bushinky (1975) and Kirpal (1977). A more detailed genetic classification was suggested by Saposhnikov (1975) which distinguishes 15 types of bauxite deposits having different origin. A common disadvantage of genetic classification is that many of the criteria are of theoritical nature whose field application is not possible. Moreover origin of many deposits is still not clearly understood[3].

2.4.6 Classification based on parent rock peterography

2.4.6.1 Fox (1927) first classified bauxite into

1) Lateritic bauxites - derived from alumino silicate rocks

2) Terra - rossa bauxites - presumably derived from the weathering residue of limestone and dolomite. Vadasz (1951) renamed the second type as Karst bauxite deposit. This classification was further developed by Valeton.

2.4.6.2. Working classification

The modified bedrock classification as proposed by Bardossy (1982) is presently the best working classification available. The following main groups are distinguished :-

(1) Lateritic bauxite : There are residual deposits derived from underlying alumino silicate rocks. This type also includes bauxite redeposited within the lateritic boundary.

(2) Tikhvin type bauxite - There are deterital bauxite deposits overlying the eroded surface of alumino silicate rocks and are products of the erosion of lateritic bauxite deposits. The type locality for this is near the town of Tikhvin (USSR). These are located in the upper parts of ancient erosional valleys.

(3) Karst bauxite deposit - overlies karstified surface of carbonate rocks. Bardossy distinguishes six sub types in karst bauxite which are based on mode of karstification -

1. Mediterranean sub-type
2. Kazakhstanian sub-type
3. Ariege sub type
4. Timan sub-type
5. Salento sub-type
6. Tula sub-type

The main advantage of this classification is that it reflects fundamental differences in the mode of formation and occurrence of the deposit. Further it is simple and enables easy field identification. Approximately 88% of the world's bauxite resource belong to lateritic bauxite deposit, 11.5% to Karst bauxites and about 0.5% to the Tikvin type.[3]

2.4.7. Technoeconomic classification of Bauxite

2.4.7.1 Classification based on end use of bauxite

Based on use to which the bauxite can be put, it can be classified as -

1. Metallurgical grade
2. Refractory grade
3. Chemical grade
4. Abrasive grade
5. Other grades.

2.4.7.2 Russian technoeconomic classification[16]

The following classification is used in Russia for grading bauxite deposits.

Grade	Composition	
1. Prima	$Al_2O_3 > 50\%$	$SiO_2 < 10\%$
2. Ist grade	$Al_2O_3 > 50\%$,	ratio of $Al_2O_3 : SiO_2 > 3$
3. IInd grade	$Al_2O_3 > 40\%$,	" > 2
4. IIIrd "	$Al_2O_3 > 30\%$,	" > 1

2.4.8 Classification of Indian Bauxites[13]

2.4.8.1 Roychoudhury (1971) first classified Indian bauxites on basis of their mode of occurence into following classes -

I. High level bauxites - Occuring in association with laterites as blankets & cappings on high plateaux and hill ranges of Peninsular India, at the following places -

1. Plateau regions bordering Bihar & M.P.
2. Maikala range M.P.
3. Western Ghats
4. Eastern Ghats

II. Low level bauxites - Recorded from Katni area (M.P.), Saurashtra, Kutch, and Kheda (Gujarat), Kolaba and Ratnagiri (Maharashtra), North Canara (Karnataka), Cannanore, Aleppy and Quilon district (Kerala) and Goa.

The Indian Bauxite deposits occur at wide range of altitudes ranging from near MSL in Gujarat to over 2000 M, above sea level in Nilgiris, since Roychoudhury's classification does not qualify the altitudinal limits, it is ambiguous and hence fails to classify the deposits occuring between 200 - 600 M above MSL.[17]

2.4.8.2 Balsubramanian (1989) classified Indian Bauxites based on parent rocks[18]

Sl.No.	Parentage	Localities
I.	Volcanic & other rock types.	West coast, M.P.,Goa, Kerala, A.P., Bihar, East Coast, T.N. etc.

S.No.	Parentage	Localities
II	Sedimentary Rocks	
A.	Sandstone/Shale	U.P., M.P., Kutch (Gujarat)
B.	Karstic/Orogenic type	-
C.	Alumina Sediments/ Clay with tectonic Environment	J & K
D.	Sandstone/Shale in Marine environment	Kutch (Gujarat)
III.	Transported	Katni, (M.P.)

2.4.8.3 Physiographic classification of Swaminath (1982)

J. Swaminath Classified Indian bauxite deposits on basis of their physiographic disposition into following groups[5].

1. Eastern Ghats
2. Western Ghats
3. Inland Plateaux
4. Coastal and Inland plains

2.4.8.4 Technological classification by Nandi (1991)[17]

The classification proposed by Swaminath was further developed and enlarged by Nandi (1991) who respectively suggested division of inland plateau into inland high level plateaux and inland low lying hillocks. His technological classification is based primarily on the dominent alumina mineral which determines the processing parameters. The relative concentration of Al_2O_3, Iron titania & silica define further characterstics and sub-division. The detailed classification is given in tables 2.4.8.4 A & B.

Table 2.4.8.4 (A)

Classification of Indian Bauxite

Bauxite Category	Deposit/ Type	Characteristic Feature	Ore body	State	Main Deposits Mines
I. Gibbsitic Iron Rich					
Alumina as Monohydrates < 5% and Fe_2O_3 > 15%	(A) Panchpatmali (Eastern Ghats)	SiO_2 1.5-4% TiO_2 2-3% Low impurities	Thick continuous with occasional sub-grade patches	Orissa	Pottang, Ballada, Kodingamali, Baphlimali, Lanjigarh Maliparbat, Sijimali, Karlapat, Sasbahumali Pasangmali, Kutrumali, Gandhamardhan.
	(B) Shevroy	SiO_2 3.5% TiO_2 < 2%	Presence of organic matters	Andhra Pradesh	Galikonda, Chittamgondi Sapparla, Jerrela, Gudem, Gurtedu.
				T.N.	Nilgiri, Palni Hills Kollimalai Hills
II. Boehmitic - Titanium Rich					
Alumina as Boehmite 5-30%, TiO_2 4-12%	(A) Amarkantak	TiO_2 > 6%	Irregular lenticular Intermediate with laterites	Madhya Pradesh	Mainpat, Phutkapahar Paunkhera, Jamirapat, Katni
				Bihar	Bagru, Hisri, Bhusar, Pakhar, Serangdag, Uttar Pradesh Banda Manikpur, Mirzapur,

Table 2.4.8.4 (A)
Classification of Indian Bauxite Contd.

Bauxite Category	Deposit Type	Characteristic Feature	Ore body	State	Main deposits Mines
	(B) Dhangarwadi	$TiO_2 < 6\%$		Maharashtra	Udgiri, Kasarsada, Ngarataswadi, Iderganj, Radhanagari, Kolaba, Satara
III. Mixed Gibbsitic Boehmitic Alumina Rich (Alumina as Boehmite 1-10%, Al_2O_3 50-65%)	(A) Jamnagar	$Fe_2O_3 < 10\%$ Presence of $CaCO_3$	i) Massive Blanket type	Gujarat	Saurashtra, Kutch, Subarkantha, Kaira, Broach Surat
			ii) Nodular embedded in clayey matrix	Maharashtra.	Kolaba, Ratnagiri (Low level)
	(B) Belgaum	$Fe_2O_3 > 10\%$ presence of significant amount of quartz.		Karnataka	Mundalli, Bhatkal, Baindur Kangangi, Mahipaigad, Paduvare
				Goa	Pernem, Mopa, Betul
				Kerala	Aleppy, Quilon Nileshwar, Cannanore
IV. Diasporic High Alumina Bauxite (Alumina as Diaspore > 70%)	Chakar	$Al_2O_3 > 60\%$	Nodular surface occurance	Jammu & Kashmir	Poonch, Chhaparban Panhasa Salal

Table 2.4.8.4 (B)

Salient Characteristics of Major Bauxite Regions

	Eastern Ghats	Western Ghats	Inland High Level Plateaux	Inland Hillocks	Coastal Plains
Location	Andhra Pradesh Orissa Tamil Nadu	Maharashtra Karnataka	Madhya Pradesh Bihar	Madhya Pradesh Uttar Pradesh	Gujarat
Typical Deposits	Panchpatmali Distt. Koraput Orissa.	Dhangarwadi, Distt. Kolhapur, Maharashtra	Amarkantak, Distt. Shahdol M.P.	Katni M.P.	Kutch Deposits
Al_2O_3	42-50%	48-54%	46-52%	48-54%	52-60%
SiO_2	1.5-4%	2.5-4.5%	3-4.5%	2-4%	1.5-3%
Fe_2O_3	15-25%	9-16%	9-18%	4-16%	2-12%
TiO_2	2-3%	3-6%	7-9%	6-8%	3-6%
Contaminants	$(P_2O_3+MnO+V_2O_3+MgO+CaO+Ca_2O_3+Na_2O+K_2O)$ 1%	Low Level	Low Level	Low Level	CaO:0.5-2% & MgO).05-1%
Mineralogical type	Gibbsitic Bauxite (95% alumina in gibbsitic form)	Boehmitic Bauxite	Boehmitic Bauxite with significant diaspore in some	Boehmitic Bauxite	Mixed Gibbsitic Boehmitic Ore.

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