7.0 World Scenario

Among the top ten producers of iron ores in the world, China, Australia, Brazil and CIS (former USSR) are important for their levels of production and Sweden is equally important for underground mining and its automation. In case of former four countries, 80 to 90 percent ores comes from opencast mines whereas in case of latter, actually entire production comes from underground mining. Mass production of iron ore in these countries has resulted in technological development especially in opencast mines, but every country has retained her technology culture in a particular form. In this Chapter, only the above mentioned countries are discussed to know mainly where India stands so far as technical advancement is concerned in the field of iron ore mining.

7.1 CHINA

Since the formation of People's Republic of China, iron ore mining has been developing from 0.6 Mt in 1948 to 225 Mt in the year 1995, 330-fold increase. Labour productivity of large-scale opencast mines with annual production of more than 5 Mt was 8,000 tonnes per man-year. Iron ore production from underground mines has only 10 percent share and labour productivity of these mines, being more than 1.5 Mt, was 750 tonnes per man-year. Further, considerable progress has been made in the field of mining technology and mining machinery. China is presently producing crude steel more than 90 Mt per year and may cross the mark of 100 Mt per year. This level of crude steel production will demand 300 Mt of iron ore annually and to cope up with this situation, the country has taken sound steps.

7.1.1 Present Status

Mining technology and major technical equipment for large opencast mines having production of 10 Mt and above have come up to the level of world developed countries in 1980, with labour productivity 25,000 - 30,000 tonnes per man-year, and other large opencast mines have come up to the level of foreign countries in the late 1970s by the way of technical transformation and equipment renewal. The recovery of iron ores from underground mines has come to about 80 percent, but dilution of ore with waste has come down to 15-20 percent, and for the under- ground mines, labour productivity has gone close to 2,000 tonnes per man-year.

7.1.2 Development of Heavy Duty and High Efficiency Mining Equipment

There are several iron ore mines having annual production over 5 Mt and up to 12 Mt where drilling rigs (rotary) of 310 mm dia bits, 7.6 - 12 m^3 shovels, 108-154- tonne electric wheel trucks and other supporting equipment are being used. But 250 mm dia rotary drills or 200 mm dia down-the-hole drills are common. Likewise 4-7.6m^3 shovels, 20 - 27-tonne trucks and 100-150-tonne electric locomotives are also commonly deployed in other opencast mines producting below 5 Mt per year. Since 1980, mechanization in iron ore mines has been started especially in opencast mines and at the same time foreign equipment imported from other countries are now being manufactured in that country and some 10 types of such equipment are now being manufactured by indigenous companies including a few joint ventures with foreign companies. Also, in a few cases, equipment are being manufactured in China but key components are being imported from other countries. With regards to quality and service life, these machines have come up to the world advanced level of similar products. Not only these equipment are marketed in China, but also have now made inroad in the international market.

As mentioned earlier, there are several underground iron ore mines, producing more than 1 Mt per year, of which Jingtieshan mine having annual capacity more than 3 Mt, has deployed two-boom hydraulic jumbos, 2-3.8 m^3 electric and diesel LHDs and 20-tonne electric locomotives; and in other mines, single boom pneumatic jumbos, 1-2 m^3 electric or diesel LHDs and 8-12 tonne electric locomotives are used. To enhance the degree of mechanization, more than 10 types of machines for underground mines, in recent years, are being designed and/or manufactured in China itself and in some cases in collaboration with other countries. Further, it is expected that such machines can be indigenously manufactured by AD 2000 for their deployment even in the large underground mines. Considerable improvement has been made in the transfer facilities for ore-waste transportation within the constraint of small floor area, especially in the area of railway-track haulage system. To improve the automation level of truck haulage, computerized despatch system has been introduced. Further, computer control rotary drills, excavators, crushers, and in-pit crushing conveying system are now in practice. Now being developed are the semi-mobile crusher-transfer units, high strength steel cord conveyor belts and overburden spreaders with 60 m long boom. Also, in underground mines, computer control system for hydraulic jumbos, remote-control LHD units and automatic hauling-hoisting system are being developed.

7.1.3 Development of High-Intensity and Low Loss Mining Technology

For the technology improvement, certain thrust areas have been identified, viz. increase in mining intensity, reduction of ore loss and mineral dilution including increase in extraction rate, especially from underground mines.

In China, earlier mining with gentle slope was in practice. Working slope was 8-15^o in general. Therefore, removal of waste was high in pre-production stage and construction period was also high. Thus, to have achieved full production, it used to take a long time. In 1980s, experiment on steep slope mining had been made successfully in certain mines and now slope angles of 20-30^o are achieved in working opencast iron ore mines. Stripping ratio during production period was decreased by 20 percent and also has the flexibility as to performing the exposure of final pit walls by 3-9 years. In Nanfen Iron Ore Mines, truck haulage has been introduced replacing the inflexible rail haulage which was predominant haulage system in China till the recent past. According to the feasibility report of this mine, which has been implemented now, stripping ratio during production has decreased from 3.4 to 4.8/t. Now, yearly development and stripping during the early period can be reduced by 15 Mt rock. Some 180 Mt rock stripping can be postponed during the full period. An investment of 120 million Yuan can be saved during the early period. So, the steep slope mining has brought in increased high wall and its steep angle of slope. There are a few mines having 13 to 15-m bench height which are now being increased to 15-17 m. Stability of these benches is being maintained by multiple row millisecond delay blasting technique. Such mining intensity and positive effects on economy of opencast iron ore mining have been experienced in China in recent years.

7.1.3.1 In-Pit /Crushing/Conveying System

Contrary to Indian practice, in China, both rail haulage and track transportation are employed and the former accounts for 53 percent of total iron ores handled. Some opencast mines have turned deep (more than 100 m) and more than ten such mines will be working by AD 2000. Under these circumstances, only rail haulage cannot handle such transportation of ores and this rail transportation necessitated increased traction force and raised climbable grade (4 percent). So, combined haulage system, such as truck-rail-road and truck-belt conveyor is now being deployed. This practice has given full advantage of both flexibility of truck haulage and large haulage capacity with steep grade negotiation of belt conveyors which relatively cost less. Till recently, truck-railway transport systems were used in open-pit with transfer facility set-up between railway and truck; and electric shovels were being used for reloading. But this mode was proved to be less effective and costly. For this purpose, a fixed transfer station having facility of appron feeder has now been used in some opencast mines and this practice is giving better results. As a whole, this combined system has brought in considerable cost reduction, improved labour productivity and decrease in truck haulage. Further, a rail-road and conveyor system for disposal of waste was built in Donganshan open-pit. This conveyor system is 3 km long with 1.2 m wide belt having disposal capacity of 6 Mt per year; and height of disposed waste is 90-130 m. Another medium size mine has 2.5 km long conveyor having disposal capacity of 5 Mt per year. In Daugshan open-pit, two conveyor belt systems for ore haulage and waste disposal, respectively, are installed in inclined shaft having total belt length of 2.8 km. Although a few problems exist in belt conveyor haulage system in China, advantages outweigh those problems. The conveyor belt systems in opencast iron ore mines are becoming popular especially in large open-pits of more than 100 m deep.

7.1.3.2 Blasting Technology

Since 1970, considerable progress has been made in blasting technique of metal mines in China. Along with the advent of big mining machinery, large area multiple row millisecond blasting technique has been developed. Site specific blasting practices like pre-splitting near the pit slope walls, buffer blasting and smooth blasting for underground are also developed. In big mines, 0.5 - 0.7 Mt of ore/waste are now being blasted in a single shot. Some 200-400 boreholes in 10 rows are now commonly blasted in a single fire involving 100-200 tonnes of explosives and good powder factors of 5-8 tonnes per kg have also been achieved. Boulder yield and formation of toe were also remarkably reduced. Shovel efficiency was increased by 30 percent due to better fragmentation of rock/ore.

To cope with the need of higher production of iron ore, blasting materials are also being developed/manufactured at the same pace. Nonel electric priming tube, detonators of non-priming charge, high precision millisecond relays and electric delay detonators, granulated ANFO, new TNT, powder rock explosives, emulsion explosives, heavy ANFO and high power liquid explosive have been developed and are being effectively used in iron ore mines. Detonators of non-priming charges and emulsion explosive have come up to the level of world class. As the quantum of rock/minerals blasted in a single shot has increased considerably, controlled blasting technique has also come to play an important role in the iron mining for which enough research work is being carried out, especially in the area of optimum blasting principal for reducing boulders and formation of toe, reduction of shock waves, flying rocks, noise, dust, etc., and for increasing the utilization factor of explosive energy.

7.1.3.3 Pit Slope Stability

There are several opencast iron ore mines which are being mined at deeper horizons (200 - 300 m vertical depth) and some opencast mines have proposals for working below 500 m depth. Therefore, slope stability studies have assumed greater significance both for technical and economic reasons. The pit slope angles of metal mines in China is 40° in general whereas in advanced countries, it is 45° which is being followed by this country now and for which continuous monitoring technique and pit slope maintenance and management are being practiced including effective drainage system.

To improve mining methods of underground mines and to reduce ore loss and mineral dilution, several steps have been taken. Though share of the iron ore production from underground mines is only 10 percent, due to convenient locational advantage and high grade ore compared to that of opencast mines, this segment of mines is also important.

In underground iron ore mines in China, predominantly non-pillar sub-level caving method is in practice and its share is about 70 percent of the total production from underground mines. This method results in high ore loss and mineral dilution. In large mines, percentage of dilution was as high as 20 percent but extraction rate was hardly 70 percent. Labour productivity was hardly 750 tonnes per man-year which is poor compared to that in advanced countries. Main reasons are complicated ore deposits and improper selection of mining methods. Due to these reasons, intensive researches are being carried out since 1986 as to how the method of mining can be improved, especially for existing mines having complicated, broken and soft ore. In the light of geological conditions of these mines, different mining methods have been tested, stope and blasting parameters have been improved, drive support reinforced, which finally resulted in reduction in mineral loss and its dilution but higher extraction. High-efficiency mining methods are further experimented mainly on decreasing amount of shaft sinking and driving of headings, lowering development ratio, speeding up deepening and reconstruction as well as employing deep-hole drilling and large capacity LHDs. All these concerted efforts are now going to give labour productivity close to 2,000 tonnes per man-year.

Further, in the field of ground control, significant achievements have been made including dust treatment, blasting safety, control of harmful gases and noise. All these research achievements are now in practice in underground iron ore mines in China.

7.2 THE CIS (FORMER USSR)

7.2.1 General Information

The former USSR (now CIS) is, as a whole, the top producer of iron ore in the world. The yearly production of raw ores in CIS, is now about 500 Mt (in early 1990s it was 550 Mt). Out of the total production of iron ores, about 87 (in the year 1990) percent comes from surface mining and rest from underground mines. The Independent States like Ukraine and Kazakstan are the main centres of iron ore production. Most of the iron ore deposits are inclined or steep-dipping ones. Some mines have reached the depth beyond 350 m. Of the total production of iron ores from opencast mines, about 60 percent is from mines having 250-300 m depth. Total waste rock removal for mining iron ores by opencast method is about 1,500 Mt per year.

The Commonwealth of Independent States (CIS) is technologically one of the world leaders, especially on the face of deterioration of mining and geological conditions like -

(a) increase of pit depth (maximum vertical depth at some large open-pits reaching up to 360 m.);

(b) decrease of ore content with pit depth;

(c) increase in stripping ratio (in absolute terms by 20-25 million cu m);

(d) increase in lift height and transportation distance including rehandling and retransportation volumes by 50-60 Mt.

Iron ore mines in the CIS are characterized by high concentration of production. The share of production from large mines of capacity over 10 Mt per year was 85 percent; and in 1990, 11 large mines produced 463 Mt and maximum annual output at Severnyj of Mining and Processing Integrated Works (MPIW) reached 48 Mt. In the last decade, average depth of opencast mines was 150-200 m, but in the current decade, it is about 300 m, and volume of hard rock mass removed has grown from 66 to 75 percent. The average rock hardness and its removal have also increased. But the raw iron ore mining decreased by 2 percent as the working condition of mining and transport equipment has been deteriorated along with increase in overburden removal and thus the mining cost. An increase in mining depth by 100 m (from 200 to 300 m) has led to increment of 25-30 percent cost per tonne. An analysis of the cost per tonne of raw ore shows that the main expenses correspond to both rock mass transportation (50-56 percent) and drilling and blasting operations (25-27 percent).

It is projected (up to the year 2005) that most of the above mentioned trends and characteristics of opencast mining evolution in the CIS will be maintained. However, due to recent political and economic reasons, production of raw ores and removal of rock mass have somewhat fallen, but it is stable.

Though most of mining operations are confined to deep seated deposits, productivity and cost effectiveness have increased. Also, detrimental mining impact on the environment has decreased. To achieve these goals, certain actual scientific and technical problems associated with mining are being faced and these are -

(a) development of progressive ecologically harmless waste-free and resource-saving mining methods for complicated mining conditions;
(b) securing open-pit wall stability up to 500 - 700 m depth.;
(c) development and deployment of new fleet of high performance mining and transport equipment of higher capacities;
(d) electrification of railway transport;
(e) development and use of new slurry explosives and other blasting agents;
(f) maintenance of normal hygiene and sanitary conditions, especially at deep opencast mines.

To exploit iron ore effectively and to enhance the production capacity in deep deposits, a process of dividing the working horizons in stages and increasing high wall slope angle in stripping areas, using temporary rock pillars are now in practice. Another step has been taken up by the way of increasing heights of working benches up to 20-30 m. This technology has been implemented in some important deep pits and is found to be effective. Another major trend in increasing mining intensification and efficiency is the changing over to cyclical-and-continuous method (CCW) in case of deep open-pits, i.e. from rigid railway transportation to track-railway and truck-conveyor systems. Due to introduction of these systems, some 15 mining complexes, with annual capacity from 10-22 Mt are now benefited and these mines are now handling upto 170-180 Mt of rock mass per year. Till now, over 1,200 Mt of rock mass and 900 Mt of iron ores were extracted by using this method. In-pit primary ore crushing and its transportation by off-highway tracks-conveyors are now very common in many mines. Jaco crushers and cone crushers are used in pits and conveyor system feeds ore at a secondary crushing and preparation plant for further treatment while rock is transferred into railway transport units with the purpose of delivering it to outside dump sites. All these methods together have resulted in cutting 20-30 percent operating costs for rock mass transportation from deep pits, decrease in truck number, increase in labour productivity by a factor of 1.2 - 1.5, reduction in ore mining cost by 10 - 15 percent and improved ecological conditions.

In the CIS, portable crushing and transferring plants with up to 2,000 tonnes per hour capacity as well as high angle belt conveyors are now available. The use of portable units have provided reduced construction activities and stone drivage. The share of this crushing and transferring points (CTP) in removal of ores from mines is 50-60 percent. This has further helped reduction in truck haulage. For implementation of this system, the erection of the expensive stationary in-pit CTPs has been eliminated in certain cases, resulting in more effective operation of CCW-based complexes at deep opencast mines.

The concept of in-pit overburden dumping is also being introduced in certain cases, it has provided not only a compensation of negative consequences of mining, but also it offers some improved efficiency which ultimately helps cut labour and material costs and reduces detrimental impact on the environment.

With the increase in depth of opencast mines, slope stability problems increase especially maintaining pit walls and bench stability in the final configuration when slope angle increases. In this direction, enough attention is being paid and for this purpose, more reliable data on geology and related engineering are being collected at the time of exploration and exploitation as well. In some mines, pit wall slope angles have been realized up to 2-4^0 and at one mine, final pit wall slope could be increased by 5^0, which resulted in decrease in the overburden removal by 96 million cubic metres.

7.2.2 Mining Machinery

To meet the requirement for huge production of iron ores and removal of waste rock in much higher quantity from deep opencast mines, a compatible fleet of equipment has been developed and now is being used. Roller cone drill rig of bit dia 320 mm has been developed and deployed for drilling at flexible angles of 45-75^0 for smooth blasting. On the basis of satisfactory results from rigs, higher capacity rig of bit dia 400 mm has been developed. Their productivity exceeds that of the existing rigs by a factor of 1.5 due to automatic control of drilling. Another module of roller cone drilling rig has been developed and preliminary trial results showed increased drilling rate by factor of 2.5 - 3 and reduction in power consumption by factor of 1.5 - 2.

The most vital activity in opencast mines is the extraction and loading operations which need, for iron ore mining, shovels. Different types of shovels manufactured in the CIS are in use including hydraulic shovels. These are the world class products so far as operating cost and service life are concerned. In the CIS, loading equipment, namely 'Uralmash', "Izhorsky Zarod" and "Krasmash" are specialized excavators for ferrous metal opencast mines. Bucket capacity of these shovels is 12 to 16 cu m and boom/arms can be extended for heavy and tough working condition.

As the transportation expenses at some mines is 60 percent of total mining cost, one of the thrust area of equipment development goes to this field. From the experience gained over the years, it is concluded that effective transport system is the judicious combination of railway transport, truck haulage and conveying.

In the CIS opencast mines, certain characterizations have been attained and these are large-scale production, favourable ecological condition and relatively low transportation cost. The main trends in the opencast mines are -

(a) improvement of facilities already available as well as development of new ones, such as locomotives and self-cleaning cars which will provide high technical levels and efficiency of mining operations;

(b) technical requirements of transport systems for deep opencast mines;

(c) using railway transport at deep levels of existing open-pits (up to 350-450 m depth) by introduction of heavy gradients and in-pit tunnels. Locomotives of 450 tonnes are required to be manufactured in that group of countries as their application in deep opencast mines will result in increasing the rolling stock productivity by 20-23 percent, improving a conveying capacity of transport inclines by 20-25 percent and decreasing power consumption by 5-7 percent. Further, in the CIS carriage, wagon factories are going to manufacture the reinforced self-closing cars with capacity in the range of 105-200 tonnes.

In Russia and Ukraine, where diesel locomotives were traditionally in use, now electric locomotives of higher traction force are replacing them. This substitution results in increase of the railway transport efficiency, expanded field of application, reduced fuel consumption, and improvement of ecological conditions at opencast mines. Construction of in-pit tunnels and inclines has augmented the application of electric locomotives further. Locomotives are being used in inclines having grade up to 50-60^0. A tunnel in a particular mine, allowed the railway transport up to 280 m depth to have reached to the pit bottom. Further, off-highway trucks of 75-110-tonne capacity are being commonly used in deep pits, but 120-180-tonne capacity trucks are also now deployed. In the CIS, now multi-drive conveyors are also developed and are in use. The main advantage of this system is that rock mass can be transported from deep levels to surface without rehandling. Further, high inclination conveyors up to 45° are developed, which can handle/transport up to 2,000 cu m/hr In two workshops of the CIS, high capacity crushers (up to 2000 cu m/hr) are being manufactured.

7.2.3 Environment

Environment problems associated with the ultra-large mines are stupendous as vast expanse of land is destroyed, occupied or disturbed by mining and related activities, especially lands are disturbed by overburden/tailings dam; and ambient air and groundwater are polluted. To mitigate these problems to some extent, about 3,000 ha disturbed land is being withdrawn from mining operation for rehabilitation purpose. It is heartening to note that more than the half of this land is being made suitable for agricultural use. Further, to reduce the negative consequences, some specialized research institutes have been carrying out studies for further improvement of environmental degradation caused by mining operations. Air normalization in deep opencast mines is the single most environmental hazard. Due to lack of natural ventilation, dust content at work place sometimes goes as high as 28 mg/cu m and carbonic oxide and nitric oxide go up to 14 mg/cu m and 5.8 mg/cu m, respectively. This unnatural ambient air at deep pits not only takes 10-15 percent of working time, but also leads to equipment breakdown. These problems are now being solved by taking following measures :

(a) effective suppression of dust at their source;
(b) use of air-conditioning system in cabins of mining equipments;
(c) introduction of rational means of artificial ventilation for 'stagnation zones'.

The practice of environment protection leads to capital investment which is expressed hereunder in relative terms:

Water resource protection	- 36.5 percent
Air basin protection	- 19.5 percent
Land reclamation	- 3.5 percent

In future, the CIS will be planning for returning alienable lands which will be rehabilated after mining operations to the permanent land users at the rate of 900-1,000 ha per year.

7.3 SWEDEN

In all the leading countries producing iron ore throughout the globe, opencast mines are the major sources of minerals (80-90 percent), but Sweden is the only exceptional country where practically the entire production comes from underground mines and that too from two mines only - Kiruna Mine of northern Sweden and Malamberget near Kiruna. Workings of these underground mines continuously for more than a century have brought in the highest degree of mechanization and automation with fine tune of perfection, efficacy and efficiency for producing about 18 Mt crude iron ore every year. In fact, there is no underground iron ore mine in the world, which even can be considered for the purpose of comparison with these mines.

7.3.1 The Kiruna Mine

The Kirunavaara (Swedish language) ore deposit has north-south strike and it dips to the east at 60°. The extent of the deposit along strike is 4 km and average thickness about 80 m. The orebody has been explored to the depth of 2 km.

The predominant method of mining is sublevel caving and about 25 percent of total ore has been extracted by this method. Of the total yearly production by sublevel, caving yields 12 Mt, sublevel stopping 4 Mt and the remaining comes from development work.

The sublevel interval of 27 m has been introduced in 1990 and in 1993 about 70 percent of the ore was produced by this method. Starter raise of 760 mm dia is normally drilled on the hang wall side for the purpose of stoping with the help of LKAB made large dia drill or an Alimak driven raise. The plane of the ring drill is maintained at an angle of 80° with the horizontal and the ring consists of 9-10 holes. Production drilling is carried out by five rigs capable of drilling 115 mm dia holes. Four of these have top hammer drills and fifth has an in-the-hole hammer. A fleet of 18 electric toro LHDs, each of 15 tonnes capacity has been deployed for loading ore which is discharged to

44 ore passes, leading to the current main haulage level at 775 m horizon (levels at Kiruna are counted downwards with reference to the top of the original mountain which had been mined out long back). The mine used to operate on two shifts, but seven days a week with blasting in the night shift. Recently, 3-shift working has been introduced. Now 100 percent blastholes in development tunnels are loaded with emulsion explosives. For the purpose of reinforcement of roofs, three bolting jumbos are deployed and some 55,000 rock bolts are being installed every year, but shotcreting is carried out by a subsidiary company of M/s. LKAB, the owner of the Kiruna Mine.

Ore is removed by remote-controlled trains to a discharge station on the main haulage level, where the bottom discharge rail cars are emptied and ores are delivered to a crushing station. The crushed ore passes to ore pockets from which skips in seven (out of eight) shafts carry the same to the surface. Selective mining is practiced and blending is done on the main haulage.

So far, 820 Mt ore has been mined and only 100-110 Mt of mineable reserves remains above the current haulage level (775 m). So, it has been planned (and partially executed) to develop the orebody between 775 m and 1045 m horizon, called "the KVJ 2000 Development" which will add some 330 Mt reserves for sustaining production for another 20-25 years at the present level of production.

The deposit plunges to the north and its northern part in depth has boundary under the lake Luorsajarvi. To exploit the deposit in a better way, a proposed dam may be constructed beside the lakeside train terminal for the purpose of draining part of the lake. This proposal could make available extra 25 Mt ore.

As mentioned above, 3-shift production system has been introduced with phased blasting which has been made possible by the introduction of new network of ventilation which divides the mines into eight sections. Some, 16 new ventilation raises of 3 m dia having total length of 16,000 m are being raisebored into the footwall, to ensure that they are not affected by rock movement as the caving practice has already gone to greater depths. These raises are arranged in eight pairs out of which four pairs are angled in such a fashion that all of them connect at surface with just four fan house buildings.

7.3.2 New Development

The new underground development project, KVJ 2000, will consist of a main haulage with new track on 1,045 m horizon, designed for five remote-controlled shuttle trains, each with a capacity of 500 tonnes, which in turn will give planned production capacity of 26 Mt per year. Crushers, skip-loading pockets, and four skip-hoisting sub-vertical shafts, to take the ore up to a reloading station on 775 m haulage level from where switching over to 1,045 m level will be accomplished without interruption to the existing production activities. On the contrary, production is envisaged to go a little up to meet the demand of market. To materialise this new level of production, some elements of change over period, such as renovation and reinstallation of hoists, have been planned to be executed over a period of about six years.

Due to the reorganisation of the mine, the 1,045 m haulage level will be served by 32 ore passes rather than existing 44. The project is expected to be completed by AD 2000 when only the haulage level at 1,045 m will be in use. The changeover will be complete by using the same haulage trains and the same crushers as are in use today. One by one, these will be taken out of service, overhauled and reinstalled on the new haulage level (1,045 m).

It has been possible to design the new haulage level for single-track operations over considerable lengths as improved computer control and smaller number of draw points will be utilised by the trains. The planning, as a whole, will result in saving capital development costs compared to the twin-track development existing on level 775 m.

Shafts including fittings and hoisting system will have most modern facilities and high degree of automation. This includes installation of constant retardation control during emergency braking, the pulley checked for cracks, an ultrasonic test for the main shaft, condition check of bearing a newly developed calibration system for load cell, and broken rope wire detector indicating wires which extend outside the perimeter of the ropes. Improvement in the electrical side includes new fully digital microprocessor controlled thyrister converters with fewer but more powerful thyristers and built in data logger for diagnostics with first-up indication and postmortem review (earlier ten parallel thyresters were used in each branch, now only one thyrister per branch is needed to carry the full current). The hoisting speed is limited to 10 m/second.

7.3.3 Sub-Level Caving in Future

To improve productivity, the sub-level interval for caving methods has continually increased over the years. At the earlier stage of operation, level interval was 12 m and a burden of 2 m used to be maintained between two successive fan rings of holes. The yield was 1,500 tonnes per ring blasted. The new interval between two successive levels is 28.5 m and in near future, it may be possible to use 30 m interval so as to produce 60,000 tonnes per day. Earlier, 40 rings were required to be blasted in 24 hours whereas in case of 30-m level interval with 3.5 m burden, only 4 ring blasts will be required to achieve the same production level.

The sub-level intervals of 30 m necessitate drilling longer holes of 55 m with correct direction. For this purpose, Atlas Copco has developed a special rig, "Simba W469". The drilling operation will be carried out by the water under high pressure in the hammer drills. The drill is already in use in another mine of LKAB (Malmberget mine) where four such jumbo rigs are reported to be drilling total 25,000 m with 115-mm dia holes every month. This drill uses between 180 and 280 litres water per minute, delivered at a pressure of 200 bars. Penetration rates are in the range of 0.6 to 1.0 m per minute.

7.3.4 Crushing

The crushed ore through the primary crusher installed underground is delivered at the surface into coarse ore bins and thereafter is fed to the fine crushing units wherein, to some extent, grinding takes place. A joint project team consisting of persons from the mine and Nordburg-Lokomo Oy of Finland had developed in 1990 a machine with mantles specially suited for crushing -10 mm ore and in the year 1991, two such cone crushers were installed, each with a daily capacity of 10,000 tonnes and one of which is always in operation round the clock while other remains as standby. These crushers have two major advantages over conventional grinding - increase in capacity and lower energy cost. Originally, target set for these two crushers was to reduce atleast 45 percent of 3.3 to 10-mm feed material to minus 3.3 mm at a capacity of 450 tonnes per hour, but practically the crushers make 60 percent material to size, minus 3.3 mm and this extra capacity has resulted in crushing/grinding additional 500,000 tonnes per year of the feed (iron ore) without any extra equipment. The uninterrupted good quality products are ensured by the electronic Lokoset automatic control system designed for G-Cone crushers. Further, this system automatically optimises the performance of the crusher.

7.4 AUSTRALIA

7.4.1 General Information

In Australia, there are three major iron ore producers -BHP Iron Ore Ltd, Hamersley Iron Pty and Robe River Iron Associates. All these companies are mining iron ores by opencast method.

In 1993-94, iron ore production was 123 Mt. Of the three iron ore mining companies in the Pilbara region of Western Australia (WA), the CRA was the biggest and in 1994 it shipped 51.7 Mt. Their operations include open-pit mining at Paraburdoo, Marandaroo, Channar, Brockman and Mount Tom Price. The CRA's ore reserves are estimated at 1,055 Mt grading 58-60 percent.

The second Pilbara iron ore miner is BHP which produced 48 Mt in 1994 mainly from that region. The new Marandaroo Mine was opended in 1994 and $A 290 million has been invested in upgrading its Nelson Point stockpiling area. BHP is also Australia's main steel producer, making 7.4 Mt in 1994 at its works at Newcastle Port Kumbla and Whyella.

The third iron ore producer in that region is the Robe River Iron Ore Associates and in 1993-94 Robe River produced 23 Mt ore. Total reserves are estimated at 1,000 Mt grading 60 percent Fe.

7.4.2 BHP Iron Ore Limited

Mount Whaleback is the BHP's primary iron ore mine which was made ore productive by widening the pit floor, thereby facilitating equipment movement. It was expected that production at the mine would reach 26 to 28 Mt per year in the near future. Railway and mine construction at BHP's Yandi deposit, 90 km west of Newman, have been completed. The Yandi (previously known as the Yandicoogina) started production since 1992 at 5 Mt per year. The mine design, however, was based on a yearly capacity of more than 7 Mt per year and could be expanded to 10 Mt per year with minimum capital costs, as most of the infrastructure would be already in place. In 1990, BHP, already part owner of Mount Goldworthy Mining Associates, purchased the balance. The Company began replacing Mine's 120-tonne truck fleet by 200-tonne trucks. Production of the mine at 7 Mt per year was expected to increase to 8.5 Mt per year, and the concentrator at Whaleback was capable of producing 3 Mt from stockpiled low grade ore. BHP shipped 54.811 Mt ore during 1991.

7.4.3 Hamersley Iron Pvt. Ltd.

This largest Australian iron ore producer, became the first company to produce and ship more than 50 Mt in one year. Production increased from 43.9 to 50.2 Mt in 1990 and shipment for the same period rose from 40.9 to 50.6 Mt. The commissioning of a new haul truck fleet at the Mount Tom Price Mine helped increased productivity to record level. At the Paraburdoo Mine, upgrading of the processing plant resulted in better throughput and record production. Production from the Channar Mine increased during the year while development work continued with the opening of new mining areas. The Marandaoo deposit, which was reported to contain 400 Mt of high grade ores, was slated to have come on stream in 1994. Located 40 km east of the Mount Tom Price Mine, the deposit is near the surface and varies in thickness from 27 to 40 m. The Mount Tom Price Mine was considered to be a jewel in the company's operation as it supplied high quality ore, of which 55 percent was lump and the remaining fines. However, reserves at Mount Tom Price were being depleted, and for maintaining a market product-mix, Hamersley produced 50 Mt per year. The Company mines all its deposits by opencast method.

To maintain its market share, the Company is spending a massive 1.2 billion Australian dollars over the next decade to expand production and to open new mines. Part of this investment is in the advanced earth-moving equipment. Individual mines/deposits are discussed here below:

7.4.3.1 Paraburdoo Mine

The bench height at this mine is maintained at 14 m. High grade ore is hauled to primary crusher installations located on the escarpment faces adjacent to the orebody limits. Low grade ore and waste are stockpiled separately. Stocks of drilled and blasted material equivalent to at least three months production are maintained in the mines for operational flexibility and quality control, which in turn determine the number and disposition of working benches and faces. Although the attitude of the footwall usually influences the width of the final berm, a minimum distance of 125 m is maintained between adjacent operating faces to ensure safe working clearance. Haulage roads of 30 m width with maximum grade of 10 percentage in good condition are maintained for efficient haulage and to maximise tyre life. The Paraburdoo fleet consists of 12 MT 2120 trucks and four MT 4000 trucks. One O & K RH 200 excavator was also purchased for this mine. The performance of this machine at 55° C in summer was excellent. It is an oil-tight excavator with the right design and good seals. Maintenance is the single biggest cost of the machine but the equipment has an enviable availability record of

85 percent. Further, the machine has a reserve capacity and is good match for the trucks of 240-tonne capacity each. It takes five passes to fill a 240-tonne truck. At Paraburdoo, the loading fleet now consists of five P & H rope shovels (1xP & H 2100 B4, 2 X P & H 2100 BLEs and 2xP & H 2300 X PAs). There are three Dresser 580 front-end loaders also. Blending is done with four shovels, simultaneously which are carrying out selective digging. This allows in-pit blending.

7.4.3.2 *Channar Mine*

The Channar project commenced in December, 1989 involves mining and recovery of iron from the Channar mining lease at an initial rate of 3 Mt per year which may go up to 10 Mt per year by 1998. The bench height of this opencast mines is maintained at 14 m. Two O & K RH 200 excavators are also deployed in Channar including two Dresser 580s front-end loaders. The ore is crushed to -50 mm and is then transported a distance of 20 km to the Paraburdoo plant via overland conveyor where it joins the Paraburdoo ore in the bins ahead of the vibrating screens. Other mining operations including blending practice are the same as in Paraburdoo.

7.4.3.3 *Mount Tom Price*

This mine has 15 m high benches. High grade ore is hauled to primary crusher located near the ore boundary. Waste rock is stockpiled separately and low grade ore is fed to the concentration plant. Here, in this mine also, three months production is maintained for the purpose of flexibility of operation. A minimum distance of 125 m is maintained between adjacent operating faces. Haul roads are also 30 m wide. In this mine, there is a fleet of 23 Mt 4000 electric wheel trucks and one RH 200 excavator. High grade ore is processed into lumps and fines by crushing and screening. Lump ore ranges in size from 30 mm to 6 mm while fine ore is minus 6 mm. Low grade ore is also mined and is further procured and upgraded into lumps and fines. The high grade ore is crushed in primary gyratory crusher to less than 200 mm. It is then converted to primary surge stockpiles ahead of the processing plant. Ore larger than 30 mm is again crushed in tertiary cone crushers and recyled to the screens. Lumps and fines are conveyed to stockpiles whereby they are separately stacked and blended prior to transportation to the port. Buckwheel reclaimers are used for reclaming the fines which are then loaded on to trains via train loaders.

7.4.3.4 *Brockman Mine*

The Brockman operation was brought on in June, 1992 at cost of $ 50 million. It produces about 4 Mt per year and has a life of five to seven years. It is supplementing Mount Tom Price's 29 Mt capacity, and Channar and Paraburdoo's 21 Mt.

7.4.3.5 *Marandoo Deposit*

When Mount Tom Price's high grade mine is depleted in 10 years, it will be replaced by Marandoo which had started production in 1994 at a cost of $ 500 million. It is a 400 Mt resource and is capable of supporting annual output of 10 to 15 Mt per year for more than 20 years.

7.4.3.6 *New Deposits*

The Company has the plan to develop Bakers and Yandi deposits for maintaining its production level in future.

7.4.4 Robe River Iron Associates

This Company was the world's fastest growing major iron ore producer in 1991. It has a long-term expansion programme under which the Company is making considerable improvements in the five following areas :

(a) Purchases of large capacity trucks for mining.

(b) Considerable exploration and development programme completed for mining sufficient ore reserves for more than 20 years.

(c) Expansion of ore processing plants.

(d) Upgrading the transportation facilities by purchasing new locomotives, and rehabilitating and extending the rail beds.

(e) Changes in the stockpiling system at the post of Cape Lambert resulted in increase in ship-loading rate and doubling the stockpiling capacity.

The expansion was expected to be completed in 1993 raising production capacity from 24 to 32 Mt. The Company's shipment of ore was 24.75 Mt in 1991.

7.5 BRAZIL

7.5.1 General Information

Brazilian iron ore production in 1994 was estimated at 165.6 Mt, an increase of 3.92 percent over the previous year's 159.4 Mt. Some 90 percent of this production is from six major mining companies, viz. CVRD, Mineracao Brasileiras Reunidas (MBR), Fertico, Samarco, Mineracao, Samitri and Companhia Sidirurgica Nacional (CSN).

Ore exported in 1994 was 125 Mt, with an increase of 11.6 percent over that in 1993. The commercial products sold are 70.3 percent of sinter-feed and pellet-feed, 21.4 percent of pellets and 8.3 percent of lump ore. CVRD sold 100.9 Mt in 1994. Large deposits of the minerals have lain untouched at CVRD's Timbopeba Mine in the State of Menas Gerais because of the low iron content.

The second producer Mineracao Brasileiras Reunidas (MBR) is also one of the largest iron ore exporters in the world. This Company increased its exports of iron ore to 21.2 Mt. The MBR's Pico Mine is under expansion, where annual capacity is being increased from 3.5 to 11 Mt. In Minas Geras State, MBR continues its long range plan including opening up of Tamandua Mines for achieving a production capacity of 35 Mt in the year 2000.

Samitri exported 8.4 Mt of iron ore in 1994, an increase of 37 percent above the previous year. The Company had an expansion programme concluded in 1993 to have production capacity of 13 Mt per year, but it actually produced 11.2 Mt in 1994.

7.5.2 Carajas Mine

Carajas, the largest opencast iron ore mine in the world, which has been producing iron ore since mid-eighties, lies in the Amazan Jungle of Brazil in the State of Para. After many years of high value production, the huge open-pit is now more than 200 m deep.

The iron ore resources at Carajas are remarkable both for their large size and high quality. Of the 18 billion tonnes resources outlined, 2.4 billion tonnes are measured and 2.5 billion tonnes are indicated at an average grade of over 66 percent Fe.

The CVRD planned to increase production at its Carajas iron mine to 50 Mt per year over a five-year period, depending on market acceptability. The mine, in Northern Brazil, produced 35 Mt ore in 1990. Because nearly all the ouput from Carajas is exported, CRVD ore shipments in 1991 amounted to 112.7 Mt.

The N4E orebody was chosen as the first to be developed due to the ease of railroad access and its proximity to two other deposits with 3 billion tonnes reserves. The mine is a typical opencast operation developed on 15 m benches but it deploys an exceptionally wide variety of equipment. Drilling is by Bucyrus Erie and Tamrock Driltech rotary units. But for loading, there are five BE 295 B 22 yd^3 rope shovels, two Demag H485 hydraulic excavators, two Le Tourneau L-1400 and two L-1100 electric wheel loaders and a caterpillar 9920 wheel loader. The loading fleet consists of 28 Haulpack (170 st and 240 st) and 10 caterpillar 190 st trucks. Truck movements are controlled by a Modular Mining Despatch system. In 1994, it produced about 46 Mt of raw ores and 27 Mt of waste.

Its operator Cia vale Do Rio Doce (CVRD) has been faced with hefty costs for pumping out water which accumulates in the enormous excavation. To contain this pumping costs in future, CVRD has decided to develop a dewatering tunnel which involves driving 2,000 m long 3.51 m wide x 3.27 m high excavation through an adjacent mountain and into the bottom of the pit. The tunnel is being excavated by conventional drill blast methods with support by rock bolts, wire mesh and layers of shotcrete. Some 10.3 m^3 of rock will be extracted for each metre of tunnel advanced and each square metre of tunnel will be supported by 0.56 m^3 shotcrete. For shotcreting, equipment consisting of AL- 262 wet and dry Duplo pump, an AL-305 spraying arm and an AL-403.1 automatic liquid accelerator dosing pump, have been brought from Widu, Switzerland. This set of equipment is mounted on a rail-bound working platform. Further 445-mm dia holes, lined to 335 mm dia are being drilled from the pit bottom to intercept the tunnel. Apart from these holes, some 20 holes are being dilled to lower the water table in the area. This project of excavation of tunnels and drilling holes had commenced in 1993 and was completed in 1995.

REFERENCES

CHINA

1. Technical Development in Shuichang Iron Mining of China Present and Future by Sun Bhong and Yu Yalun, 14th World Mining Congress.

2. The Development of Mining Subject in China by Peng. Shiji, 14th World Mining Congress.

THE CIS (FORMER USSR)

3. The Main Trends in Open Pit Iron Ore Mining in the USSR by Antonenko L. K. and Kotgashev A.A., 15th World Mining Congress.

4. State of the Art and Distinguishing Features of Iron Surface Mining in the Soviet Union by Antonenko L.K., Kolyashev A.A. and Trachev A.F., 14th World Mining Congress.

SWEDEN

5. Electrification and Automation of Mining Operation by Bengi Sinner, 14th World Mining Congress.

6. Mining Magazine, August, 1994, pp. 61-71

7. Mining Annual Review, 1994.

8. International Iron Ore 2000 and Jan Vestlund, the Swedish Iron Ore Industry towards the year 2000 Beyond, Bhubaneshwar Jan. 30- 31, 1993, pp. 254-258.

AUSTRALIA

9. Australian Mining, September, 1992 by Lou Caruana - pp. 24- 28.

10. Mining Annual Review, 1995 - pp. 101

11. Mineral Yearbook, Vol. I, USBM 1991.

BRAZIL

12. Mining Magazine, July 1994, p. 5

13. Mineral Yearbook, Vol. I, Metal and Minerals, United States Department of the Interior, Bureau of Mines, 1991, pp. 759-760

14. Engineering and Mining Journal, Nov., pp. 32-35