SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

For facility of reference, the conclusions arrived at and the recommendations made under each chapter are reproduced below:

Chapter I. Demand and supply of ferrous and non-ferrous metals and ferroalloys in India.

(A) (1) Steel production capacity of the order of 29 million tonnes in the year 1984 has been worked out in this thesis. To sustain his level of production, iron ore requirements may be of the tune of 50 million tonnes per annum. The calculation is based on the assumption that approximately 1.8 tonnes of iron ore is required to produce one tonne of steel ingot. The figure of 1.8 tonnes has been arrived at by averaging the present consumption rates of iron ore in the furnaces of Tata Iron and Steel Company, Indian Iron and Steel Company, Mysore Iron and Steel Works and Hindustan Steel Ltd. It has also been assumed that proportion of steel scrap as a furnace charge will not materially differ from the current levels.

(2) Pig iron production for sale is anticipated to be about 10 million tonnes in the year 1984. An additional quantity of the order of 20 million tonnes of iron ore may be required for this purpose.

(3) Any prediction about the exports of iron ores in the world markets is difficult. The international market has become very competitive due to the emergence of a number of new sources of
supplies and preference of "tailored" ores by the buyers. The Planning Commission have fixed export target at 30 million tonnes in the year 1974 as against the exports of 19 million tonnes in 1968. In view of the new situations developing in the world trade especially keen interest being shown by Japan in Australian, African, South American and also Canadian deposits, the export target appears to be over-ambitious. It would be a good performance if India could export 30 million tonnes per annum even by 1984.

(4) Thus an annual production of the order of 100 million tonnes of iron ore may be anticipated by the year 1984. To sustain this rate of production for next 20 years, mineable measured reserves requirements may be of the order of 2,000 million tonnes.

(B) (1) The requirements of standard grade high carbon ferro-manganese both for internal consumption and exports are estimated at 4,27,000 tonnes in the year 1984. As 2.5 tonnes of manganese ore analysing 45% manganese are required to produce one tonne of ferro-manganese, about a million tonne of high grade ore will be required for the production of the quantity assessed above.

(2) At present the steel mills in the country are using substantial quantity of low grade manganese ore analysing 30% manganese as direct feed for blast furnaces. There is considerable variation in the consumption rate of low grade ore in various steel plants, the maximum being in Rourkela steel plant and the minimum in Jamshedpur. The average quantity of manganese ore used in blast furnace per tonne of pig iron works out to 47 kilogrammes. On this basis the requirements of low grade ores may rise to about 1.7 million tonnes in the year 1984. Future technological changes, if any, might bring down the above consumption rate.
(3) As the international market of manganese ore is highly competitive, any sizeable increase in exports from the current levels of one million tonne is not visualised.

(4) A total production of 3.7 million tonnes of manganese ore may be anticipated in the year 1984, out of which 1.7 million tonnes may be of high grade ore and the rest of low grade ores. To sustain this level of production for the next 20 years period, measured, mineable reserves of the order of 40 million tonnes of high grade ore and about the same quantity of low grade ore will be required.

(C) About 40,000 tonnes of low carbon and 5,000 tonnes of high carbon ferrochrome are likely to be produced internally by the period 1984. This level of production would require about 50,000 tonnes of chrome ore in lump form and 80,000 tonnes in fines. In addition, about 100,000 tonnes of lump chromite may be required by the refractory industry and about the same quantity by the chemical industry. Exports of the level of 100,000 tonnes may be continued. Thus the total annual requirements of chrome ore in the year 1984 may be of the order of about 0.4 million tonnes. To sustain this rate of production for the next 20 years period a measured, mineable reserve of the order of eight million tonnes will be required.

(D) (1) The requirements of primary copper metal have been estimated at 2,80,000 tonnes in the year 1983-84.

(2) In the United States of America, on an average, to produce a ton of copper, 130 tons of ore are required. Applying this norm, an annual production of about 36 million tonnes of ore will have to be planned, if the entire requirements are to be met by domestic production.
(3) To sustain the above rate of production for the next years period, a measured, mineable reserve of the order of about 700 million tonnes will have to be established.

(E) (1) The demand of primary aluminium is estimated at 500,000 tonnes in the year 1984.

(2) To sustain the above rate of production, about 2.5 million tonnes of metallurgical grade bauxite will have to be produced per year.

(3) To maintain the above production rate for another 20 years period, a measured, mineable reserves of the order of 45 million tonnes will be required.

(F) (1) The requirements of primary zinc is placed at 300,000 tonnes in the year 1984.

(2) In the United States of America, on an average, to produce a ton of zinc, 30 tons of ore are required. Applying this norm, an annual production of 9 million tonnes of ore will have to be planned, if the entire requirements are to be met by domestic production.

(3) To sustain the above rate of production for the next 20 years period, a measured, mineable reserve of the order of 180 million tonnes will have to be established.

(G) (1) The requirements of primary lead is estimated at 2,50,000 tonnes in the year 1984.
(2) To produce a ton of lead, about 40 tons of ore are required in U.S.A. Applying this norm an annual production of about 10 million tonnes of ore will have to be planned if the entire requirements are to be met by domestic production.

(3) To sustain the above rate of production for the next 20 years period, a measured, mineable reserve of the order of 200 million tonnes will have to be established.

(4) Lead and zinc ores generally occur together in varying proportion. It may not be necessary to block out reserves separately for both the metals, if the ratio in which they occur together is appropriate.

Chapter II. An inventory of Mineral Resources.

If the requirements of various ores as worked out in Chapter I is set against its availability discussed in this Chapter, it should normally be possible to draw up a balance sheet showing self-sufficiency, surpluses and deficiencies, as the case may be. But, it would be seen from the discussions contained in this Chapter that mineral resource position is rather vaguely known. The factors considered in reserve calculations have not been properly defined. The result is that most of the reserve figures are unfit to be used for a study of supplies against demands.

A review on each mineral follows in the following paragraphs:-
(i) **Iron Ore:**

It has been worked out in Chapter I that 'measured reserves' of the order of 2,000 million tonnes will be required to sustain an annual level of production of 100 million tonnes of iron ore by the year 1984. Proved reserves of iron ores as calculated by the Geological Survey of India in various areas is placed at 9,728 million tonnes. The classification 'proved reserves' is generally taken equivalent to 'measured reserves' as defined in this thesis. But the Geological Survey of India has not given the details of reserve calculations. Moreover, the figure is not entirely based on bore-hole and other exploration data.

Some of the iron ore deposits have only recently been subjected to intense exploration by Government agencies and private companies. The Bihar-Orissa belt has been extensively explored. Considerable work has been done in Madhya Pradesh and Mysore regions also. Based on these data, the Planning Group on Minerals have placed the measured reserve figure at 5,623 million tonnes. The reserve is likely to increase considerably on the basis of further work in other regions and utilisation of low grade ores and "fines".

It may be concluded from the foregoing that iron ore reserves in ground are sufficiently large to meet the entire demand, both for internal consumption and for exports. The deposits, however, will have to be explored by closely spaced bore-holes, pitting, trenching and tunnelling, before any new mine is opened up, as is being done at present. This procedure is standard one and can not be avoided because mining, geological, metallurgical and other engineering data will have to be collected before any large investment is made in opening a new mine.
(ii) Manganese Ore:

It has been worked out in Chapter I that a measured mineable reserve of the order of 40 million tonnes of high grade ore and about the same quantity of low grade ore will be required to sustain an annual production of 1.7 million tonnes of high grade ore and 2 million tonnes of low grade ore. The resources position of manganese as discussed in Chapter II is rather hazy. Estimates of reserves are available, but it is not possible to make out in which specific category do they fall, i.e. measured, indicated or inferred except that for Madhya Pradesh - Maharashtra region where measured and indicated reserves are placed at 20 million tonnes by the Geological Survey of India. Recently the Indian Bureau of Mines, on the basis of data regarding thirteen working mines in this region, have estimated a measured reserve of the order of 3.8 million tonnes and indicated reserve of the tune of 12.9 million tonnes, analysing 48 per cent manganese, down to a depth of 650 feet.

It is evident from what has been stated above that very little work has been done in manganese fields to block out reserves. Much needs to be done by way of large scale mapping followed by drilling. Geophysical and geochemical methods of prospecting should be pressed into service, where possible.

Although the above type of work is imperative for deciphering the dimensions of ore-bodies, there is no denying the fact that general resources position of manganese in the country is quite encouraging. The manganiferrous sediments are widespread, and, the history of past production of manganese ore in many areas has been quite impressive. As a matter of fact general resources position of manganese given by the Geological Survey of India is placed at 180 million tonnes, out of which 75 million tonnes are of high grade ores. These figures may not be of practical use, but it is a definite
pointer that our resources of manganese are large.

It is also important to mention that Indian manganese ores suffer from serious drawbacks of containing high phosphorous and low Mn:Fe ratio. It is necessary to conduct field studies to demarcate, if possible, low phosphorous and also high Mn:Fe ratio areas, in addition to conducting researches in the reduction of phosphorous and iron.

(iii) Chromite:

A measured mineable reserve of chromite of the order of 8 million tonnes will be required to sustain the level of production anticipated in the year 1984. Known resources are inadequate to meet this demand. Considerable prospecting operations will have to be taken up to decipher possible resources both in new areas and those held under lease by private parties. Bulk of the present production of chromite comes from Orissa State, although minor quantities are accounted for by Mysore and Maharashtra States. In Orissa promising areas are held under lease by the Tata Iron and Steel Company and the Orissa Mining Corporation. An important point to mention is that bulk of chromite reserves are in the form of 'fines' but the industries need them mostly in lumps. While prospecting for chrome ore, due regard will have to be given to this aspect of the problem.

(iv) Copper:

It has been worked out in Chapter I that a measured reserve of the order of 700 million tonnes of copper ore will be required to develop mines which would sustain the level of production anticipated in the year 1984. As against this, the resources position as discussed in Chapter II is definitely dismal.
Considerable efforts will have to be made to locate new reserves.

(v) **Lead-Zinc:**

It has been assessed in Chapter I that measured, mineable reserves of 200 million tonnes of lead ore and 180 million tonnes of zinc ore will have to be proved for attainment of the levels of production of these two metals, in the year 1984. The available resources fall far short of requirements.

(vi) **Aluminium:**

Resources of bauxite are large enough to meet the requirements as worked out in Chapter I. As against the requirements of 45 million tonnes of metal grade bauxite, the available resources as indicated by the Geological Survey of India are of the order of 130 million tonnes. Moreover, it must be borne in mind that recent trend is to use bauxite having low alumina content, 48% $\text{Al}_2\text{O}_3$ and less, provided it has high proportion of easily recoverable monohydrate variety and reactive silica is absent. Detail exploration, however, will have to be done before opening up new mines of bauxite.

(vii) **Scarce Metals:**

The search for scarce metals like nickel, tungsten, tin, molybdenum, vanadium, cobalt and antimony will have to be augmented taking into account the latest knowledge about their mode of occurrence and habitat, etc. At the same time, their recovery as by-products will have to be examined, especially in the wake of new smelters being set up for non-ferrous metals.
Chapter III. Geological opportunities for Mineral Exploration.

1. The demands for metals are rising rapidly. Knowledge of mineral resources in the country with special reference to their measured reserves is rather hazy. All concerted efforts will have to be put in deciphering the known deposits and locating new reserves.

2. While drawing up prospecting and exploration programmes, the new concept of geological opportunity must be kept in view. Advancements made in mining, beneficiation and metallurgical research have made it possible to convert minerals of almost any grade into a usable substance.

3. The rock types of the Archaean system are predominantly the one which play host to metallic formations. It is significant to note that these formations are widespread in India. The formations occurring in the plains are important both from the point of view of reserves and mineability.

4. In the case of iron ores, the surface deposits are widespread. These deposits, however, will have to be explored in detail, before exploitation begins. The engineering, mining and geological data have to be collected for evaluation to design a mine. Such work is already being conducted by Government and private agencies. Even low grade deposits nearer to coasts are under investigation with a view to exporting them after beneficiation and pelletisation.

5. Manganiferous sediments are extensive in India, and the history of production of manganese ore has all along been very impressive. But the resources position has not yet been ascertained with certainty. The important deposits both from the point of view of quality and dimension are those of Madhya Pradesh.
and Maharashtra, which are associated with the Gondite series of rocks. There is considerable scope for prospecting this belt in greater detail. Large scale mapping followed by drilling might reveal interesting results. Attempts may also be made to estimate reserves on the data available in the working mines of the region. The estimation of reserves of low grade ores available in mine dumps should also be taken up with a view to upgrading them or selling them direct to steel mills.

There is urgent need to understand the chemistry of the distribution of phosphorous both laterally and at depth in Madhya Pradesh-Maharashtra belt with a view to locating low phosphorous zones, and also to collect data for the reduction of phosphorous in these ores.

Zig-zag mining is most prevalent in Orissa and Mysore States where the ores occur in pockets and lenses. Large scale mapping should be taken up in these areas to locate large concentrations of ores. Test drilling may be done, where necessary. The Government agencies should assist the mine-owners in this work and drilling machines may be provided to them on hire basis.

Time and finance should not be spent on Andhra Pradesh and Gujarat ores unless reduction of phosphorous in these ores is made possible. Rajasthan ores are unimportant at present due to their remote location from the ports as well as domestic steel and ferro-manganese plants.

6. The chromite deposits of India are not of 'stratiform' type like the South African 'Bush-veld' igneous complex. They are, on the other hand, of 'podiform' type resembling the deposits of Turkey and Pakistan. Due to this reason, prospecting of chromite in India becomes a difficult task. The tools available to prospectors, geophysical and geochemical, are of little avail.
Evaluation of geological data elsewhere in the world shows that prior attention should be paid to the known promising deposits and producing districts for the purpose of proving their potentialities. The less important occurrences as well as examination of ultrabasic rocks of other areas should find second place in priority of prospecting and exploration work.

Orissa contributes about ninety per cent of all India production of chromite. According to the present knowledge Orissa also contains the largest resources of this mineral. In view of this position it seems desirable that the Geological Survey of India or other agencies should devote more time in this belt and the investigation that may be taken up should end with conclusive results.

The ultrabasis rocks are widespread in the Singhbhum district of Bihar. The chromite occurrences near Jojohatu are famous. Occurrences of relatively less importance are also reported from Ranchi and Bhagalpur districts. Krishnan recommends that these and other occurrences in ultrabasic rocks in Eastern Singhbhum should be examined in detail for finding out where workable deposits exist.

Efforts should be directed to establish reserves in Hasan and Mysore districts, Mysore State by large scale mapping, petrographic studies and drilling.

7. Prospecting and exploration of non-ferrous metallic ores except bauxite is a serious problem. The Geological setting is difficult to decipher and the expenditure on prospecting and exploration tends to be quite high. However, the redeeming feature in India is that most of the country has been geologically mapped. The old workings are extensive. The persistence of ore
in some of these areas has been established to a depth of 2,500 feet, although the old workings extend to a depth of 300 feet only. The data available in the old workings can be taken maximum advantage of in drawing up exploration programmes. These old workings are, as it were, 'foot-prints on the sands of time' which point the way to where ore is likely to be found.

(a) Copper:- In respect of copper, the prospects situated on the plains deserve prior attention compared to those in the Himalayan terrain. The deposits in Bihar, Rajasthan and Andhra Pradesh should receive immediate attention. The occurrences of the Himalayan region, i.e. those of Sikkim, Jammu and Kashmir and Kulu valley should be considered from long range point of view and their exploration should be planned in such a way that these deposits are ready for exploitation as soon as deposits in the plains get depleted.

(b) Lead-Zinc:- As is known lead and zinc occur together. In the majority of cases, they have limited lateral and depth persistence. It appears reasonable to recommend that concerted efforts should be put to explore the Zawar belt, Rajasthan, in the first instance. Other areas such as Agnigundala, Andhra Pradesh, Dariba-Rajpura, Rajasthan where the Geological Survey of India is already doing some work, will come next to Zawar. Regarding the Himalayan region the same comments hold good as those for copper.

(c) Aluminium:- The bauxite deposits generally form cappings on trap rock types which are widespread in the country. It will be necessary, however, to prove the reserves by shallow drilling, pitting and trenching on various deposits in relation to a particular project keeping various economic factors in view.
(d) **Scarce metals:** The occurrences of nickel, cobalt, tungsten, tin, molybdenum, vanadium and antimony have been discussed in Chapter II in some detail. It appears difficult to expect that any sizeable deposits which can be worked alone for any of the above metals can be found. Most of them such as nickel, cobalt and molybdenum may be produced as by-products during the smelting of sulphide ores. The envisaged production of nickel sulphate and selenium by the Indian Copper Corporation is a case in point. However, it may be worthwhile to examine in detail the reported nickel in the laterites of Assam and Orissa. The known deposits of tungsten in Rajasthan and West Bengal have been examined in detail by the Government agencies and private parties and the results obtained indicate sporadic mineralisation with limited reserves. The tin occurrences so far known have been of uneconomic dimensions. The vanadium bearing titaniferrous magnetites of Bihar and Orissa are large enough and could be a source of vanadium. Antimony deposits are located in rather inaccessible regions.

It may be worthwhile for the Geological Survey of India to have a special team of geologists and geochemists and embark on a long drawn programme to study the habit of mineralisation of these and other scarce metals. Potential rock as well as ordinary rock types should be studied in detail. A so-called 'geo-chemical census' of rock types should be taken up.
Chapter IV. Present procedures of Mineral Prospecting and Exploration in India.

1. The beginnings of mineral prospecting and exploration in India are lost in the limbo of antiquity. Numerous old workings, slag heaps, which are found scattered in different parts of the country, however, bear convincing testimony to the existence of flourishing mining industry in ancient times. These workings, are so to say 'foot prints on the sands of time' and form useful guides for locating metallic deposits. Maximum use is being made of these indicators in various investigations for copper, lead and zinc metals.

2. The existence of an old Geological Survey in the country, set up as far back as 1851, has been a boon in evaluating the Geology and Mineral resources of the country, although, in the initial stages, most of the work of the survey was concentrated on coal geology.

3. Most of the country, barring a few inaccessible regions, has been geologically mapped on a scale of 1"=8 miles. The present expanded Geological Survey is engaged in many other fields, in addition to basic studies in the science of ore finding which should be its prime function. From 1965, the work of detailed exploration of promising deposits have also been given to this organisation, which is a step in retrograde as the crowding of functions might result in neglecting the basic research. The work of detailed exploration should appropriately be given back to the Indian Bureau of Mines.

4. A crash programme of exploration is in progress in various fields for iron ores and non-ferrous metals, etc. The information available on known deposits is evaluated in the first instance and promising deposits are examined by a group of
geologists for preliminary appraisals. If the indications are favourable, exploration by way of large scale mapping, drilling and exploratory mining is carried out. The procedures followed have been detailed in the thesis.

One important comment that might be made in this connection is that the time taken on various projects has been unduly long, without conclusive results except for certain bright exceptions. Work has been in progress on certain deposits for more than 10 years e.g. the Sikkim multi-metal deposits. Normally a deposit (non-ferrous) should be evaluated in detail in a maximum period of 3-4 years. The work of the survey should be organised accordingly.

5. An airborne geophysical survey with the assistance of U.S.A.I.D. has been launched recently and the work, according to schedule, is likely to be completed within 30 months time. The results of this survey should be watched with interest and expectations. The application of photogeology and geophysics has now been extended from oil exploration to mineral investigations with good results in other countries. It is a worthwhile attempt to apply new techniques for location of hidden deposits.

6. In India there is a tendency to set up new organisations to deal with almost the same type of work. For example, almost all the State Governments have also organised their geological surveys, drilling units, etc. and are engaged in mapping, drilling etc. for various minerals in their own States in addition to mineral disposition and royalty collection work. The efforts are good but undue expansion should be checked and rigorous co-ordination should be maintained to avoid overlapping and duplication.
7. The achievements of various organisation in the field of mineral discovery have not so far been of any great consequence. The monumental work done by the Geological Survey of India in the past still remains its only trump card. During the last 20 years considerable money has been spent but not even a single new mine of copper, lead, zinc, etc. has been opened up. Similarly, other organisations both at Central and State levels are tending to expand every year unmindful of the negligible contribution that they make to the national economy. Such tendencies must be curbed.

Chapter V. Modern Philosophy of Minerals Exploration.

1. Sophisticated methods of exploration such as photogeology, geophysics and geochemistry will have to be pressed into service in the exploration of blind deposits.

2. Exploration will increasingly become a capital intense economic activity. Patience will be required to test a large number of indicators, and narrow down the search for the target by a well laid down out "skimming" process. In Indian conditions direct Government's participation is inevitable. Apart from paucity of capital, lack of requisite technical expertise will be a limiting factor. Technical skill will be very much needed to be developed. In the meantime inter-governmental assistance will hasten the search. The results of recently launched 'operation hard rock' in India with U.S. assistance should be watched with interest.

3. The primary importance of appraising the expectations of finding ore, and maximising the returns from prospecting, needs hardly and emphasis. To achieve these ends a better
understanding of the origin and kinds of metallic deposits is needed. Extensive research in environments of deposition and nature of metals is the most important problem. Statistical analysis regarding expectations of discovery based on the distribution of ore bodies and their value, etc. will lead to significant conclusions and improve the art of prospecting blind.

4. According to the Industrial Policy of the Government of India, development of almost all the minerals is largely the responsibility of the state. The division of responsibility is not water tight and a fair amount of flexibility is provided, but the policy, as it stands today, puts severe limitations on exploration activities of the private sector. The State's role in this field, for this reason, has got to be more active and pronounced.