Still gold is essential to the economy. It is the biggest Australia's manufactured export and can be a good investment portfolio apart from wives always want to wear gold.

During the course of researching this story, author finds the percentage of overseas control of Australian gold production. It has been called the Great Australian Gold Robbery. Overseas interests have robbed the king's share of Australia's gold production (30% Australian, 20% South African, 23% USA, 25% Canadian, 2% European/other). The foreign ownership has gone from 20% to 70% in five years. No one seemed to notice the increasing foreign control of $5 billion export industry. It is like having all our farms owned overseas. It has become an accepted corporate reality in an era of increasing globalisation. People look at each other on a regular basis to take over companies and plan for a coup.

The story on the history and industry of gold ends with the discussion about how all this money and effort being spent to produce gold - a generally non-essential product than other basic materials with greater practical utility such as nickel or aluminium. Why one would not ever get excited about other than this magical metal gold. The answers were 'gold is fabulous to look at and it has got this mystical power- it has got millenniums of history'.

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MAHABALESWARA TALANKRI

INDIAN PENINSULAR PRECAMBRIAN TERRAIN AND METAL POTENTIAL: A NEW APPROACH

Sediment hosted base metal deposits range in age from 900Ma to 2600Ma in tectonically active intracratonic settings within fault-controlled basins. Indian Precambrian metallic deposits present remarkable contrast in terms of their metal distribution and litho-tectonic association. The geological setting when compared to metallogenic and geological setting elsewhere on global scale provides scope for reassessment of the Proterozoic terrain with respect to its metal potential. Mineral deposits available at shallow depths have already been discovered by virtue of their signatures on surface in form of ancient workings and gossanisation etc. but, deepseated metal deposits which could be available in the existing conducive geological setting need to be studied and discovered. Future discoveries will depend on the input of modern exploration technology available based on integrated geological models.

Introduction

Mineral resources play an important role in the development of any society. They provide raw material for building, chemical, metal industries and fuel for industrial purposes and opportunity for earning livelihood. India depends to a great extent on the early and middle Precambrian for its need of metals as, the late - Precambrian and the post-Cambrian history of sedimentation is very limited in the Indian subcontinent since they are mostly platform or intracratonic in nature, without much of magmatic/volcanic activities in the basins, which are the major source of metal concentrations. A vast area of Western and Central India is covered by the Deccan Trap, which so far has not shown any major metalliferous concentration. The known Lead-Zinc occurrences/resource in various geological environment in India is shown in Fig.1.

There is a significant preferential distribution of lead-zinc occurrences/prospects in Aravalli/ Delhi basins as

![Fig.1. Distribution of Pb-Zn deposits by geological environments.](image-url)
compared to other Proterozoic basins. The reason for this variation needs to be understood by geological assessment.

Metallogenic Epochs

Sediment hosted stratiform basemetal deposits have formed over a broad time range from about 2600 Ma to 900 Ma. The significance of this time spread is related to broad evolutionary aspects of the earth’s crust. Meyer (1972) pointed out that prior to about 1800 Ma major base-metal deposits were mostly volcanogenic massive sulphide type, while until the onset of Phanerozoic, the deposits hosted in sedimentary rocks do not have close association with volcanic episodes. He related this to the transition from a mantle-tapping style of Archaean tectonics to the stable cratonic environment of Proterozoic. Most of the stratiform deposits of Lead-Zinc are reported from middle to late Proterozoic. The Indian Precambrian metasediments, which host the major metallic deposits, range in age from 1600 Ma to 3200 Ma. The periods of older metamorphic and basement complexes of 3200 to 3500 million years as found in Bihar, Orissa, South India, Eastern Ghats and Rajasthan and the late Precambrian of 500 to 1600 million years have not hosted any known major metallic deposits. The Erinpura granites and the Bengal gneiss with tungsten mineralization as observed in Sirohi and Bankura respectively hosting tungsten, gold, base metal and manganese mineralization are exceptions. Certain uneconomical Lead-Zinc deposits found in the Cuddapah also falls in the above category.

The important part of metallogeny in India relates to Delhi and Aravallis, Dhanjori (Singbhum), Dharwar (Upper), Eastern Ghats (Upper), Iron ore, Lower Dharwars and Lower Eastern Ghats. The placement of the groups by their probable age groups is given as under:

<table>
<thead>
<tr>
<th>Period</th>
<th>Group</th>
<th>Mineralization</th>
</tr>
</thead>
<tbody>
<tr>
<td>t00-2600</td>
<td>Delhi-Aravali</td>
<td>Cu-Pb-Zn-Ag</td>
</tr>
<tr>
<td>Super Group</td>
<td>Dhanjori</td>
<td>Cu with Ni, Au, Cu, Bi, Mo of Singhbhum shear zone</td>
</tr>
<tr>
<td>Upper Dharwar</td>
<td>Iron ore, low grade Cu, Pb, Zn</td>
<td></td>
</tr>
<tr>
<td>Upper Eastern Ghats</td>
<td>No significant mineralization</td>
<td></td>
</tr>
<tr>
<td>Biharwara</td>
<td>Zn, Pb, Cu</td>
<td></td>
</tr>
</tbody>
</table>

| 2600-2900   | Iron Ore Group | Iron Ore-Haematite, Au, W, Magnetite          |
|             | Lower Dharwar  | Mn-Khondalites and Magnetite-granulite and Chromite |
|            | Lower Eastern Ghats |                                      |
| 2900-3200   | Sargur         | Nuggihall schist belt hosting chalcopyrite and Aladahalli copper mineralization and Keminkute Gold |

It can be seen that the reported base metal prospects are restricted to the metallogenic period corresponding to 1100 - 2600 Ma, while iron, manganese and precious metals are reported from metallogenic period of 2600-2900 Ma

Orogenic Cycles

From a further study of these groups of rocks it is found that the metallogenic epochs are related mainly to six phases of orogenic cycles with two to three phases occurring simultaneously in different parts of India. Table 2 provides major orogenies of Peninsular India:

<table>
<thead>
<tr>
<th>Domains</th>
<th>Orogeny</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rajasthan-Gujarat</td>
<td>Delhi Orogenic cycle (1600-1800 Ma) - associated with Cu, Zn-Pb mineralization in the southern part of Delhi basin</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>Aravalh Orogenic cycle (2300-2600 Ma) - associated with Zn-Pb, Cu mineral/7ation</td>
</tr>
<tr>
<td>Bihar-Orissa</td>
<td>Dhanori Orogenic cycle (1600-3000 Ma) - associated with Cu &amp; Haematite</td>
</tr>
<tr>
<td></td>
<td>Satpura Orogeny</td>
</tr>
<tr>
<td></td>
<td>Sarsa Sakoli, Mahakoshal</td>
</tr>
<tr>
<td></td>
<td>Cudapah (900-1600 Ma) - associated with Au, Mn, and Cu</td>
</tr>
<tr>
<td>Karnataka</td>
<td>Dharwar Orogenic cycle (2500-2600 Ma) - associated with Au, Fe (magnetite) Pre-Dharwai (3200 - 3000) Ma</td>
</tr>
<tr>
<td>Andhra Pradesh-Orissa</td>
<td>Eastern Ghat Orogeny (2600-3000 Ma) - associated with Mn, Fe (magnetite)</td>
</tr>
</tbody>
</table>

Contrasts in Mineralisation Patterns

Throughout the world, including India, the metallogeny in the early Precambrian is related to the magmatism and sedimentation in the eugeosynclines, which started to form from 3400Ma and the miogeosynclines, which, started to form from 1800 Ma. The Indian tectonic domains/ eugeosynclinal basins are shown in Fig 2

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Fig. 2. Orogenic belts and Proterozoic Basins.

(Khetri), whereas the southern part is polymetallic (Ambamata belt). This may ultimately be found to be related to multiphase tectonism and volcanic/hydrothermal activities within the Delhi orogenic cycle. It is observed that the iron ores of Iron ore Group of Singhbhum is haematitic, whereas the iron ores of Eastern Ghats and Dharwar are both magnetite and haematite. Differences are also noticed in the nature of manganese mineralisation in the Dhawars, Eastern Ghats, Sausars and the Iron Ore Group. Scheelite mineralization of Sausar-Sakoli is associated with gold, whereas scheelite of Rajasthan and Uttar Pradesh are not associated with any significant amount of gold.

Spatial and temporal selectivity of ore deposits has been discussed by Mookherjee (1992) and Barley and Groves (1992). It has been explained partly by a progressive increase in $O_2$ concentrations in an evolving atmosphere-hydrosphere system and partly by a secular decrease in global heat flow. However, a large part of the temporal variation can be related to plate-tectonic cycles rather than the progressive change in tectonic processes, as earlier believed. Systematic temporal variation in the distribution of several important groups of metal deposits that form in continental basins associated with anorogenic magmatism were abundant in the middle Proterozoic (2.0 - 1.4 Ga), corresponding to the
assembly of the first large continent. It is important to note that peaks in the abundance of continental metal deposits also coincide with a postulated Late Proterozoic super continent (1.0 - 0.8Ga) and the near maximum extent of Pangea. In contrast, metal deposits that form in convergent margin orogenes were most abundant in the late Achaean (2.9 - 2.6 Ga) corresponding to a period of high global heat flow and rapid stabilisation of continental crust, and the past 200 m.y., which corresponds to the present tectonic cycle. The application of sequence stratigraphy to plan exploration strategy, as used in oil industry to recognise these cycles may help to identify more target areas for future exploration.

Problems

Ore deposits associated with eugeosynclinal sediments can be grouped as under:
1. Massive pyrite, Copper, Zinc-Lead, Silver and Gold
2. Massive pyrrhotitic nickel with copper
3. Gold
4. Magnetite iron formation
5. Chromite
6. Porphyry copper-gold

While the above five deposit types have been found in India, their potentiality had not been very encouraging. The porphyry copper/gold deposits in eugeosynclines of younger orogenic belts (such as Australian Triassic volcanics, Permian eugeosynclines and, South American Tertiaries) are totally absent in India. It is puzzling to note that the Indian eugeosynclinal sediments do not host any sizeable Cu-Zn deposit. It would be worthwhile to make a search for delineating the Cu-Zn mineralization of eugeosynclines of the Indian Precambrian Shield.

In the Archaean greenstone belts, massive Zn-Cu sulphide deposits are generally found associated with andesitic-felsic volcanics (Sangster and Scott, 1976) and such deposits like Matagami and Kidd Creek in Canada are more frequent in greenstone belts, which are not older than 2700 million years. The country rocks adjacent to the massive sulphide deposits are typically felsic pyroclastic rocks, most commonly agglomerates or breccias. In multicycle volcanic successions, economic mineralisation is generally confined to one cycle, Pyrite and pyrrhotite constitute half of the total sulphides whereas sphalerite and chalcopyrite constitute the rest along with minor amounts of tetrahedrite-tennantite, silver carrying galena and gold. One of the two origins, namely an epigenetic hydrothermal origin or a syngenetic volcanic exhalation origin is postulated for massive Zn-Cu sulphide deposits. The difference between these two models is primarily the timing of ore deposition.

For a concerted ore search, it is necessary to identify the andesitic-felsic metavolcanic rocks in the greenstone belts of India, which significantly are associated with such a type of mineralization.

Massive pyrrhotitic nickel deposits (e.g. Sudbury nickel) are confined to rocks older than 1800 Ma of age since the Ni-bearing ultramafics which are the host rocks have not been emplaced in eugeosynclines of post-1800 Ma age owing to further migration of nickel towards earth’s core as a result of thickening of mantle material. Though the Indian geosynclines are mostly older than 1800 million years, it is puzzling to observe that ultramafics with sizeable pyrrhotitic nickel deposits have not been found so far.

Archaean greenstone-hosted gold is known in India, Canada, Australia and South Africa. The Kolar, Hungund-Hagari-Kushtagi-Ramgiri-Penkacherla belt belonging to greenstone belts of Eastern Dharwars in India can be compared with that of South Africa. According to the classification of the greenstone belts proposed by Ramakrishnan (1994), gneisses with small enclaves of mafic-ultramafic rocks and BIF (Pre-Dharwar?) are of 3200-3000Ma ages. The Dharwar Group of rocks of the schist belt is of-2600 Ma age and Peninsular gneiss with Dharwar enclaves are of 2600 Ma age. The younger granites (Closepet type) are of 2500Ma. Considering the geochronological data it can be considered that western zone Dharwar belt and Eastern zone Dharwar belt are contemporaneous in respect of volcanic episodes (2600 Ma-2900 Ma) but no significant gold occurrence has been reported from Western Dharwar belts except BIF hosted gold mineralization in Chimmulgund and Ajjanahalli.

Ultramafic rocks of eugeosynclines (along volcanic arc) host chromite deposits. However, concentration varies significantly based on dynamothermal depositional characteristics. In India, major deposit of chromite ore is known only from Sukinda-Naushahi Chromite belt of Orissa. This unique occurrence needs to be studied in detail.

Carbonate hosted lead-zinc deposit with baryte - a characteristic of cratonic miogeosynclinal shelf has been reported from Cuddapah formation but the content is not encouraging. Looking to the occurrence of few rich copper deposits of Zambia in similar geological environment, Vindhyans and Cuddapah formations require a re-assessment.

Conclusions

It can be observed that in India there is still a vast scope to study the problems of the Precambrian, since large tracts of the Indian shield are occupied by them having a good frequency of outcrops. In India, a large number of the
basemetal, piecious and non ferrous metal deposits/ prospects are discovered on the basis of surface shows of mine exploitation and extensive old workings because of a long history of ancient mining. A stage has been reached where mineral discoveries based on surface indications have come to an end, since large areas have already been covered based on such evidence. To make a bi eakthrough in mineral finds, the problem has to be visualised in light of mineral genesis and then localisation in space and time. It is necessary to make systematic detailed analyses of the favourable host and tectonic settings and then relation to the geodynamical processes, which together are responsible for the emplacement and localization of different metallic phases. The analysis and approach to the problems of the Indian Piecambnan mineral deposits require an assessment not only though detailed geological geochemical studies of the known metal environments and basin studies laying stress on the nature of magmatic and hydrothermal activities in different types of basins along with their time connotations, but also through input of state-of-the-art exploration techniques in the Piecambnan like

1) An borne electromagnetics with advanced configuration systems both in frequency and time domains. The application of the system has led to considerable increase in the bandwidth of both helicopter-borne FDEM and fixed wing TDEM system

2) The technology for airborne spectral remote sensing based on spectral properties Spectral reflectance, emittance, and microwave remote sensing is in use for mineral exploration. The information received through spectral remote sensing technique is integrated with other available data such as geological, geophysical and geo-chemical and, inteipreted within the context of a geologic model within a geographic information (GIS) environment

3) Selective or Partial Geochemical Extraction (SPGE) technology enzyme leach, Mobile Metal-Ion (MMI), Nannoscale metals in earth gases (NAMEG) and mobile forms of metals in overburden (MOMEO) (Xueqiu Wang et al 1999) etc also will be of immense use to locate concealed ore deposits under different types of overburden

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