II. GEOLOGY OF THE KOLAR SCHIST BELT

Regional Setting.-

The granite-greenstone terrain in the South Indian craton covers most of Karnataka State, and hence could be referred to as Karnataka block. A generalized geological map of the block is shown in Fig. 2.1 (kept in the pouch). The geology and the regional tectonics of the South Indian craton and the Karnataka block are summarised by Drury et al. (1984) and Swaminath and Ramakrishnan (1981). The schist belts in the Karnataka block are surrounded by voluminous felsic rocks covering over 75% of the area (Radhakrishna, 1983). They are made up of mafic to acid volcanic rocks and of chemical sediments predominantly. In this regard they resemble many Archean greenstone belts found in Canada, South Africa and Western Australia. However, the ultramafic volcanism in the Karnataka block is relatively minor in scale and mostly restricted to small and narrow belts (Fig. 2.1). Also, the absence of nickel sulphide deposits, even in the mafic volcanic dominated greenstone belts, such as Kolar, is surprising (Rajamani, 1982, Rajamani et al. 1985). Thus, schist belts of Karnataka block seem to be different
in terms of their volcanic lithology and mineralization, from that of greenstone belts found elsewhere. This suggests that the formation and evolution of the greenstone-granite terrains need not be uniform.

Even within the Karnataka greenstone-granite terrain, the greenstone belts differ from each other in terms of size, shape, lithological association, mineralization and time of evolution. Just as the granitic gneisses, the greenstone belts of Karnataka block also seem to have evolved episodically (Balakrishnan and Rajamani 1986). Small bands or enclaves of supracrustals, migmatized at the margins, occur mostly in the southern part of the block and are known as Sargurs or Sargur Group. These are thought to have been intruded by all known phases of granitic gneisses called as the Peninsular Gneiss (Chadwick et al. 1981, Swaminath and Ramakrishnan 1981). A group of large schist belts, dominated by sedimentary rocks deposited in shallow environment, were laid over ensialic basement of Peninsular Gneisses older than 3.1 b.y. (Drury 1983, Drury et al. 1984, Ramakrishnan et al. 1984, Taylor et al. 1984, Chadwick et al. 1985a,b). Although the small, curvilinear, volcanic-dominated schist belts like Kolar, are well known for economic
mineralization, the cover-basement relationship between them and the surrounding Peninsular Gneiss is least understood (Ramakrishnan and Viswanatha 1981, Granath and Rajamani 1982, Radhakrishna 1983, Drury et al. 1984, Balakrishnan and Rajamani 1985). Such an understanding is important to construct the crustal evolution in the Karnataka block. To this end, each belt should be thoroughly investigated to evaluate the petrogenesis of various rock types and their relation to the surrounding gneisses.

**General Geology of the Kolar Schist Belt.**

The Kolar Schist Belt is located 90 km east of Bangalore. The belt is linear, N-S striking, 80 km long and attains a maximum width of 5 km in the central part. Systematic geological investigation of the belt was initiated only a few decades ago, although the belt is the chief producer of gold for the last several centuries in India. The belt is surrounded by polyphase Peninsular Gneiss and is thought to be intruded by diapiric granites at Patna and Bisanattam (Viswanatha and Ramakrishnan 1981). The contact relation between these gneisses and the schist belt is however not clear to indicate any such relationship (Balakrishnan and Rajamani 1986). Geology of the
Kolar Schist Belt is summarised recently by Viswanatha and Ramakrishnan (1981) and Shivkumar (1982).

The belt is essentially composed of mafic volcanic rocks, a felsic unit known as the Champion Gneiss consisting of felsic volcanic rocks, pyroclastics, arenaceous metasedimentary rocks and polymict conglomerates, and ferrigenous quartzites. A minor discontinuous horizon of graphitic schists occur along with ferrigenous quartzites. The Champion Gneiss and ferrigenous quartzite ridge occur on the eastern and western margins of the belt, respectively. A band of massive tholeiitic amphibolite occur at the center of the belt with a prominent topographic expression and with respect to this, the belt can be divided into eastern and western part. Ferrigenous quartzite also occurs at the south eastern part of the belt known as the Yerrakonda hill.

The belt and the surrounding rocks are metamorphosed to middle to upper amphibolite facies of metamorphism (Rajamani et al. 1981). The belt is intersected by two sets of dikes striking N-S and E-W. The distribution of the rock types and other important features of the belt are shown in Fig. 2.2.

The belt is cut by three major fault systems and several minor faults. Easterly younging pillow
GEOLOGICAL MAP OF KOLAR GREENSTONE BELT
KARNATAKA

INDEX

1. Laterite
2. Potassic granite (Porphyry Granite)
3. Granodiorite and tonalite including quartz-monzonite and pegmatite
4. Banded felsic-amphibolite, interbedded with amphibolite and phyllite
5. Chloritic and sericitic phyllite, interbedded with graphitic phyllite and chert
6. Massive meta-basalt, interbedded with meta-gabbro and sub-adaxial graphitic chert
7. Arkose and Detrital conglomerate
8. Interbedded with phyllite, meta-sediment and polymorphic/Chondritic Group
9. Chondritic meta-sediment interbedded with meta-gabbro and meta-pyroxene
10. Porphyritic Breccia: Meta-rock complex
11. Intrusive and volcanic rocks of Jurassic Group
12. Strike and dip of foliation and stratigraphy
13. Strike and dip of bedding
14. Plunge of minor antiformal
15. Plunge of minor synform
16. Faults
17. Gold mines

FIG. 22
After Viswanatha and Ramakrishnan (1981)
structures are seen on the eastern side of the belt. The belt is subjected to three or more phases of deformation and the structure is very complex. The belt is thought to be multiply refolded synform with a northerly plunge (Narayanaswami et al. 1960; Ziauddin and Ramachandra 1963).

Assuming the belt as a synform, Viswanatha and Ramakrishnan (1981) worked out the stratigraphy of the belt, which is given in table 2.1. Lensoidal mafic inclusions and highly schistose/sheared bocks that occur as enclaves in the granitic gneisses, near to the western margin of the belt are known as Sakarsanahalli Association. The above authors have suggested that they are equivalent to Sargur Group.

The basement for the Kolar Schist Belt is not known. Naqvi et al. (1978) suggested that the Kolar Schist Belt is older than the Peninsular Gneisses. On the other hand, Swaminath and Ramakrishnan (1981) correlated Kolar to Bababudan and thereby implied that Kolar belt was formed over ensialic basement. Unlike Bababudan, neither the belt is characterised by basal conglomerates nor the contact between the belt and the gneisses is clear to suggest unequivocally any cover-basement relationship. This controversy
**TABLE 2.1**

**STRATIGRAPHY OF THE KOLAR SCHIST BELT**
*(By Viswanatha and Ramakrishnan 1981)*

<table>
<thead>
<tr>
<th>Dharwar Supergroup (?)</th>
<th>Kolar Group</th>
<th>Sargur Group (?)</th>
<th>Sakarsanahalli Association</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Dykes</td>
<td>Dolerite, norite, diorite porphyry</td>
<td>Patna Granite</td>
<td>Gold Field Volcanics</td>
</tr>
<tr>
<td>Gold Lodes</td>
<td>Quartz veins</td>
<td>Bisanattam Granite</td>
<td>Dolerite, norite, diorite porphyry</td>
</tr>
<tr>
<td>Patna Granite</td>
<td>Porphrytic potassic granite</td>
<td>Champion Gneiss</td>
<td>Metabasalts, hypersthen basalt, basaltic andesite, pyroxenite and gabbro with ironstone and black shale</td>
</tr>
<tr>
<td>Bisanattam Granite</td>
<td>Diapiric tonalite to granodiorite</td>
<td>Yerrakonda formation</td>
<td>Wackes, felsic volcanics and pyroclastic rocks with iron stone and polymict conglomerate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kalahalli Amphibolite</td>
<td>Ironstones and graphitic schists with gabbro and pyroxenite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Peninsular Gneiss</td>
<td>Migmatic gneisses</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ultra-mafic rocks</td>
<td>Ironstone (locally manganiferous)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Veined calc silicate rock and veined amphibolite</td>
<td>Mangan Marble, Cordierite-anthophyllite rocks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mangan Marble, Cordierite-sillimanite-corrundum quartzite and mica schist, fuschite quartzite</td>
<td>Base not seen</td>
</tr>
</tbody>
</table>

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Note: The table lists various rock types and formations found in the Kolar Schist Belt.
can be resolved only by carrying out geochronological studies on various components of the Peninsular Gneiss around the belt and on the rocks of the belt itself using reliable methods. The age data reported so far on the Kolar rocks (Vinogradov et al. 1964, Crawford 1969, Venkatasubramanian et al. 1971, Bhalla et al. 1978) are at best preliminary or reconnaissance in nature.

In Kolar, the gold mineralization occurs as gold-quartz lodes and sulphide lodes on the eastern and western sides of the belt respectively. The structural aspects of the mineralization was studied by Narayanaswami et al. (1960) and Ziauddin and Ramachandra (1963). Recently, our group has undertaken extensive mineralogical and geochemical studies on the gold mineralization and preliminary results are reported in Siddaiah (1981), Rajamani and Siddaiah (1982), Siddaiah and Rajamani (1984, 1986).

Geochemical Studies.-

Early geochemical studies are limited in number and mostly on the amphibolites of the belt. The Champion Gneiss and the associated granitic pebbles/cobbles are reported to be granodioritic and tonalitic in nature (Working Group of AMD, GSI,
NGRI, 1977, Shivkumar 1982). Balakrishnan and Rajamani (1986) studied the volcanic component of the Champion Gneiss, along with the felsic gneisses surrounding the belt and found that these rocks have anomalously high Ni and Cr abundances for their SiO₂ and MgO contents. Further, based on the chemistry of these rocks, particularly compatible and rare earth elements, the above authors suggested that the melts representing these rocks could have been derived by melting komatiitic amphibolites, under hydrous conditions, at mantle depths.

For the first time, the ferrugenous quartzites are being studied, by our group and the preliminary studies indicate that they contain less than 15 wt% Fe and were deposited under turbid deep water conditions (Behera 1983, Behera and Rajamani 1985).

First detailed examination of the amphibolites of the Kolar Schist Belt was carried out by Ramachandra Rao (1937). He broadly grouped them into two varieties by comparing chemical analysis of Kolar amphibolites to that of Washington's (1917) chemical analysis of igneous rocks. They are:

1. Hornblendic variety, and
2. Pyroxenite-eucrite/hornblende gabbro - Olivine gabbro/picrite variety.
Viswanathan (1974) reexamined the chemical analysis of Kolar amphibolites reported by Ramachandra Rao (1937), and Dutta and Sen (1969), and interpreted that some of the amphibolites are of komatiitic affinity. Srinivasan and Srinivas (1974) suggested that the Kolar rocks are tholeiitic in nature and Divakara Rao (1974) considered them to be oceanic and continental tholeiites. However, the AMD, GSI, NGRI Working Group (1977) considered the amphibolites could be komatiitic. Anantha Iyer and Vasudev (1979) suggested that the Kolar amphibolites are more similar to marginal basin basalts. From the above discussion it is apparent that there is ambiguity even in finding chemical affinity of the Kolar amphibolites. Only a detailed geochemical study, in conjunction with field and petrographic studies can give some information on the nature and petrogenesis of this important and predominant rock type in the Kolar Schist Belt.

**Modern Petrogenetic Studies on the Amphibolites of Kolar.**

The Kolar Schist Belt is being studied intensively by Rajamani and his associates. Recent findings of their petrogenetic studies on the mafic rocks of the belt, using modern geochemical approach are reported in Rajamani et al. (1981, 1985) and Shivkumar (1982). The results of their
study are discussed here, because, they form the basis of the present work.

Based on the major element chemistry of the Kolar amphibolites, they are grouped into two types:

1. Low K-tholeiitic type, and
2. High MgO-amphibolites.

The high MgO-amphibolites have MgO contents more than 14 and up to 21.34 wt.%, whereas the tholeiitic type amphibolites have 5.5 to 10 wt.% MgO. Thus there appears to be a gap in the MgO content of the amphibolites between 10 to 14 wt.%. Based on the chemical classification scheme proposed by Arndt and Nisbet (1982), the Kolar amphibolites are classified into komatiites and komatiitic basalts (more than 14 wt.% MgO) and tholeiites (less than 10 wt.% MgO).

Trace elemental abundances, including the REE, of the Kolar amphibolites are found to be unusual. Particularly, the komatiitic variety has large variations in REE abundances and chondrite normalized REE patterns. The west central komatiitic amphibolites have essentially two types of REE patterns: LREE enriched, fractionated REE pattern with variable Ce depletion relative to Nd and LREE depleted REE pattern. This Ce depletion relative to Nd in the west central
komatiitic amphibolites could have been inherited from the mantle. The west central tholeiites have flat to slightly LREE depleted patterns. The eastern side amphibolites, both the tholeiitic and komatiitic varieties have sloping, LREE enriched, chondrite normalized REE patterns. It should be noted very rarely LREE enriched tholeiitic basalts are reported from Archean greenstone belts. The eastern side amphibolites also have higher concentrations of incompatible elements like K, Rb, Sr, Ba compared to that of west and central areas. The above features are also shown in Table 2.2. In general, the Kolar komatiitic rocks have higher TiO$_2$, Zr and Ni contents compared to the similar rocks reported from other greenstone-belts.

Geochemical data on the Kolar amphibolites is interpreted using major element modelling, involving FeO and MgO and CaO, Al$_2$O$_3$ and TiO$_2$ abundances and trace element modelling involving Ni, Zr, Cr and rare earth elements. The major element data indicate that the Kolar komatiitic rocks were derived at depths greater than 80 km at temperatures exceeding 1475°C. Modelling of major and trace element data indicate that the magmas representing these rocks had undergone small extents of fractional crystallization of olivine
TABLE 2.2
THE CHEMICAL CHARACTERISTICS OF THE KOLAR AMPHIBOLITES
(from Rajamani et al. 1985)

<table>
<thead>
<tr>
<th></th>
<th>West/Central</th>
<th>East</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tholeiitic &amp; Komatiitic</td>
<td>K, Rb, Sr, Ba depleted</td>
<td>enriched</td>
</tr>
<tr>
<td></td>
<td>Ce/Zr ≤ Chondritic</td>
<td>Ce/Zr &gt; Chondritic</td>
</tr>
<tr>
<td>Tholeiites</td>
<td>LREE slightly depleted</td>
<td></td>
</tr>
<tr>
<td>5.5 - 10% MgO</td>
<td>to flat chondrite</td>
<td>LREE enriched</td>
</tr>
<tr>
<td></td>
<td>normalised REE pattern</td>
<td></td>
</tr>
<tr>
<td>Komatiitic amphibolite</td>
<td>A: HREE fractionated</td>
<td>LREE enriched</td>
</tr>
<tr>
<td>14 to 21.3%</td>
<td>MREE enriched but</td>
<td>HREE fractionated</td>
</tr>
<tr>
<td></td>
<td>Ce depleted relative to Nd</td>
<td>Sloping REE patterns</td>
</tr>
<tr>
<td></td>
<td>B: HREE slightly fractionated</td>
<td>Ce - normal</td>
</tr>
<tr>
<td></td>
<td>LREE depleted</td>
<td></td>
</tr>
</tbody>
</table>
and in most cases, the olivine fractional crystallization is less than 20%.

The incompatible element abundances and the relative incompatibility of these elements in the komatiitic melts would indicate the nature of the residue with which they had equilibrated before melt separation. In the case of Kolar komatiites, the order of incompatibility is found to be Ce > Zr > Ti > Al. This order would correspond to low extents of melting of the mantle, leaving garnet in the residue. Even the rocks that represent highest percentages of melting (ca. 25%) have left garnet in the residue, which is indicated by the Al₂O₃ abundances in these rocks. This combined with the other trace elemental abundances suggest that the source region was not strongly depleted in the basaltic component and the mantle sources must have had higher Fe than 'Pyrolite'. If the mantle sources have undergone previous partial fusion to yield basaltic melt, then the melting would have occurred at lower temperature and therefore, the melt would be preferably enriched in FeO and incompatible elements, leaving the source depleted in these elements. However, what is inferred to be source character is contrary to this and thus
removal of basaltic melt, prior to the generation of komatiitic melt generation did not occur in Kolar area.

The depletion of LREE in the west central komatiites is thought to be as a result of preferential removal of these elements from the source region by fluids any time before melting. On the other hand, the eastern side komatiites would require mantle source enriched in LREE and other incompatible elements.

The west central tholeiites also seem to have come from LREE depleted sources and their parent magmas had undergone only small extents of fractional crystallization of ol + pyx ± plag (Rajamani et al. 1986). The eastern side tholeiites, just as the komatiites, are from LREE and incompatible element enriched sources, irrespective of their MgO content and P and T conditions of magma generation. In a given greenstone belt, the tholeiites are usually thought to represent low per cent melting and komatiites higher per cent melting of the same source (Arndt, 1977; Nisbet and Walker 1982, Sleep and Windley 1982). For Kolar the authors have suggested both the komatiites and the tholeiites represent similar extents of melting of the mantle sources, but at different pressure and temperature conditions or perhaps from different
sources. The komatiitic amphibolites represent deeper level of melting of mantle sources.

The above petrogenetic study has made first significant contribution towards understanding the evolution of Archean Kolar greenstone belt. This study has revealed unusual nature of the komatiitic rocks of the belt - in terms of major, trace and rare earth elemental abundances - found in these rocks. The melts representing the komatiitic rocks are suggested to have been generated by low per cent melting of mantle sources, that is enriched in Fe relative to Pyrolite. Thus the petrogenetic processes involved in generation of these rocks seem to be different from that of those suggested, so far, for komatiitic rocks throughout the world. These inferences have raised important questions pertaining to the evolution of the Kolar Schist Belt and they are:

1. How two completely different mantle sources - a LREE enriched and a LREE depleted, have produced melts that are now found in a single narrow, belt of maximum 5 km wide?

2. The Kolar komatiitic rocks have relatively higher Fe. How the melts with densities (>2.8 gm/cc) greater than normal crustal rocks
have come to the surface? It should be noted that the silicate melts are highly compressible, would be more denser at mantle depths.

3. The mantle sources for the west central komatiites are reported to have undergone LREE depletion prior to melting, caused by removal of a melt/fluid other than basaltic melt. Could this be a granitic melt? When this LREE depletion occurred? These questions can be addressed with the help of Sm-Nd systematics.

Besides these, there are several outstanding problems pertaining to the evolution of the belt and the origin of the Au mineralization. The temporal relationship between the rocks found in the schist belt and the surrounding gneisses is not known and is not possible to decipher using field criteria alone. Although some preliminary radiometric dating of the felsic rocks around the belt have been carried out by earlier workers (Vinogradov et al. 1964, Venkatasubramanian et al. 1971, Bhalla et al. 1978), the rocks within the belt were not dated. Detailed isotopic studies on the amphibolites of the belt and the surrounding gneisses would be necessary to
establish the temporal relationship between them and to understand the evolution of the crust in the Kolar area.

In Kolar, the most economic concentrations of gold form the Champion Lode, that occurs on the eastern side of the belt and is associated with the LREE enriched komatiitic amphibolites. Under mantle magmatic conditions Au is supposed to behave like an incompatible element (Rajamani, 1982). Considering that the komatiitic amphibolites are generated by low per cent melting of mantle, it would be important to see whether there is any relationship between their petrogenesis and ore genesis.

Thus, a detailed and indepth investigation of the komatiitic rocks can provide much more information than any other rock type in the belt to solve the problems mentioned above. A detailed geochemical study exclusively on the komatiitic amphibolites is undertaken to evaluate the petrogenesis of this rock type and its possible relation to other rock types found in the belt and the gold mineralization. The unusual nature of Kolar komatiitic rocks might be related to source characteristics of their magmas.
which may have a bearing on the origin of gold mineralization. Isotopic study, involving Sm-Nd systematics is aimed at understanding the source history, nature of the source and potentially to date these rocks. The present study forms part of our integrated effort to understand the relationship between petrogenesis and ore genesis in Archean terrains and to understand the evolution of the crust in this part of the Karnataka Craton.