ABSTRACT

The Precambrian earth, which covers nearly seven-eighth of the total geological history, stands as a big mystery. The petrogenic and the metallogenic evolution during this vast period are tools to unfold the Precambrian mystery. The sedimentary iron rich rocks belonging to this period, well known as the Precambrian banded iron-formation, appears to play a vital role in this direction. The Precambrian iron- formations are diversified rocks, and although extensively studied, their origin is yet highly controversial and poorly understood. Their formation could be a function of the Precambrian lithosphere, biosphere, hydrosphere and atmosphere, each interacting with the other. This interaction seems to be space and time dependent to give such a diversified rock, which, therefore, stands as a clue to understand the Precambrian earth.

The close association of the Archean iron-formations with greenstone belts and their hosting of gold mineralization is also another interesting aspect of their scientific potentiality. Although, the Indian subcontinent is well known for its Precambrian iron deposits, not much work has been done to realize the scientific potentiality of this interesting rock type. The Kolar Schist Belt of the Dharwar Craton, South India, was believed to be one of the oldest greenstone belts, well known for its gold mineralization and mining. A study of the banded iron-formation of this belt could be
very much useful to understand the evolution of this oldest greenstone belt and the possible relationship among greenstone belt volcanics, iron-formation and gold mineralization.'

The Precambrian banded iron-formations are presumed to be chemico-sedimentary rocks, which were formed in an aquatic environment either by chemical or by biochemical precipitation. These rock-formations are well banded, having alternative bands of chert and iron minerals, and are mostly confined to the Precambrian. They include such a wide range of rocks with diversified physical characteristics and chemical compositions that all of them never fit into any particular definition. They are also known differently in different parts of the world. The Precambrian iron-formations are widely distributed and occur in almost all continents of the world occupying a prominent place in the stratigraphy of the Precambrian Shield Areas.

The Precambrian banded iron-formations seem to have developed in episodic manner: their peak of formation falling into four age groups as: (i) the middle Archean (3500-3000 my), (ii) the late Archean (3000 - 2600 my), (iii) the early Proterozoic (2600-1900 my), and (iv) the late Proterozoic to early Phanerozoic (750-450 my), the most prominent of these groups being the early Proterozoic. Banding is the most distinct lithological feature of the Precambrian banded iron-formations, which are quite variable in their lateral continuity, thickness and mineralogical make up. They have been classified into two types
based on their lithology, stratigraphy and depositional environments. Iron-formations belonging to the Archean that are associated with volcanic rocks and were most probably deposited in intercratonic basins of eugeosynclinal type are known as the Algoma type. These are associated with greenstone belts and are very limited in their areal extent and thickness because of tectonic deformations and segmentations. On the other hand, the iron-formations of the early Proterozoic that are devoid of volcanic associations are known as the Superior type. These are quite extensive in their areal extent and were deposited in intracratonic continental shelf environments of miogeosynclinal types. Based on its mineralogy, iron-formations have been classified into four different facies such as: oxides (hematite & magnetite), carbonates (siderites), silicates (iron rich silicates) and sulphides (pyrites and pyrrhotites) depending upon the dominant iron mineral it contains. These facies patterns are very much gradational giving rise to mixed facies. Iron because of its variable oxidation state is very sensitive to environmental conditions, and therefore, can form different minerals in response to the available environmental conditions like Eh, pH and concentration of different active species like dissolved CO₂, S and SiO₂.

The Kolar Schist Belt is one of the Archean Schist Belts of the Dharwar Craton, South India. It is a small linear belt with a north-south trend, and extends nearly 80 km, from Srinivasapur in the north to Maharajagadhi in south, with a variable width of 3 to 4 km.
The Schist Belt has been divided into three main blocks as: (i) the Manigatta area in the north, (ii) the Kolar Gold Field at the centre, and (iii) the Mallappakonda area in the south. The belt consists of dominantly metavolcanics, from ultramafic to felsic, with relatively minor amount of sediments in the form of the banded iron-formation. The banded iron-formation occurs as a continuous ridge all along the western margin of the belt and as a prominent outcrop towards the south of the Kolar Gold Field, the Yerrakonda Hill.

The strike direction is almost north-south and dip in subvertical. The surface iron-formation of the Manigatta is essentially carbonaceous sulphidic chert. In the central KGF the iron formation is mostly cherty and thick chert bands dominate over thin weathered iron bands. This western ridge of the banded ferruginous quartzite in the central KGF is associated with a thin band of banded amphibole quartzite on its western and a thin band of graphitic/sulphidic schist on its eastern margins. The iron-formation towards the south of Mallappakonda gradually becomes magnetite rich i.e. banded magnetite quartzites. Similarly, three different types such as chert-rich, magnetite-rich and sulphide-rich are well identifiable in drill core samples.

All the different types of the iron-formation of the belt have the same mineralogy of quartz, iron amphiboles (grunerite-commingtonite), magnetite and sulphide (pyrrhotite). But they differ
in their mineralogical proportions and degree of crystallinity. Our mineralogical study includes X-ray diffraction study and petrographic study under both transmitted and reflected light using their thin and polished sections. Presence of carbonates in association with magnetites and iron amphiboles, with magnetite-pyrrhotite, with magnetite-pyrrhotite-chalcopyrite, and magnetite-pyrrhotite and arsenopyrite are interesting petrographic features. Our petrochemical study includes the chemical analysis of major oxides (SiO$_2$, Fe$_2$O$_3$, CaO, MgO, MnO, Na$_2$O, K$_2$O, Al$_2$O$_3$ & TiO$_2$) trace elements (Cr, Co, Ni, Cu, Zn, Cd, Pb, Rb, Cs, Sr, Ba, Zn, Hf, Sc and Th) and rare earth elements. Major oxides of Cr, Co, Ni, Cu, Zn, Cd & Pb have been analysed by wet-chemical methods using spectrophotometer and Atomic Absorption Spectrophotometer. Rare earth elements and rest of the trace elements have been analysed by Neutron Activation Analysis.

Samples of iron formation, both those of surface and drill core units, show a large variation in the proportions of various iron minerals and in the proportions of iron minerals and quartz. Therefore, their chemistry also varies considerably particularly in the relative abundances of silica and iron. For the iron formation in general, SiO$_2$ and Fe$_2$O$_3$(T) are the two major oxides, together making nearly 95 to 99% excepting in cases where samples are sulphidic. Other oxides are minor to trace in quantity. Only a few samples studied have chemical composition similar to a typical Precambrian banded iron formation.
Their chemical composition particularly is similar to Algoma type iron formation of Archean age. The overall chemical composition of the Mallappakonda iron formation appears to be higher in Fe$_2$O$_3$(T) and all other minor oxides, and in the central KGF the iron formation seems more cherty.

The Kolar iron formation, in general, has low abundances of many trace elements. This is true even for Cu and Zn in sulphide rich samples. Similarly, samples have low absolute concentration of the rare earth elements. Their REE patterns have strong positive Eu anomalies and show slight enrichment in both light and heavy REE. There seems to be some relation among abundances of iron minerals, the type of iron mineral and REE abundances. Samples rich in sulphide have the highest REE abundances. Cherty samples have very low REE abundances.

Our endeavour to find out a possible origin for the Kolar iron formation based on our geochemical study is constrained because of the uncertainties in the Precambrian geological and geochemical processes. Therefore our conclusions are not unequivocal. It is very difficult to establish the primary mineralogical facies pattern from the present petrography to understand the initial depositional condition because of uncertainties involved in the post depositional change. Most probably the Kolar iron formation could represent a transitional depositional environment fluctuating between sulphide
facies, carbonate facies and silicate facies. The precipitation of different iron minerals was a function of the Eh and pH conditions, and it is also a function of the active concentration of the reacting ions. The chemical kinetics also played a vital role to precipitate a mixed facies instead of a pure end member facies. Our chemical data indicate that the sulphide rich samples have the highest iron value followed by the magnetite ones and chert rich ones. So, we suggest that in high concentrations of iron and sulphide ions the stability field of sulphides was quite significant to start the precipitation of sulphides. But the rapid decrease of sulphide ion concentration with respect to iron, reduced the stability field area of sulphide to let the system to fall into the stability field area of carbonate without much change in the Eh and pH conditions. Perhaps, the precipitation of sulphides and carbonates decreased the concentrations of acidic ions and increased the Eh and pH values of the medium to drive the system to the stability field of magnetite and silicate for their precipitation.

Although it is difficult to say on the facies gradation in the Kolar Schist Belt, it appears that the Mallappakonda iron formation could be a dominantly sulphide and carbonate facies, and central KGF dominantly a carbonate and silicate facies. The geological setting, the mineralogical facies of deposition and the chemical composition of major and trace elements (particularly REE patterns) suggest that the source could
be submarine hot springs releasing hydrothermal solution loaded with components for precipitation which was more favourable during the waning phase of a submarine volcanism. Low absolute concentrations of the rare earth elements of the Kolar iron-formation with a positive Eu anomalies also strongly support a hydrothermal source.

Our field and chemical observations suggest a back arc basin type geological setting for the Kolar greenstone belt and associated ironformation. The low iron concentration in the Kolar iron-formation, the paucity of base metals even in samples as high as 60% sulphides, and gold only mineralization suggest that the hydrothermal system that operated in the Kolar basin could be a deep seated type. The percolating sea water went deep in to the oceanic lithosphere leading to a low water/rock ratio interaction which could bring less iron and base metals because of ineffective leaching and their precipitation during upward journey of the hydrothermal solution. The Kolar iron-formations appear to be a syn-discharge deposit because of a chemical gradation of Fe, most of the trace elements and rare earth elements from their high values in the sulphide rich samples to quite low value in chert rich samples through the magnetite richones. The hydrothermal solution that deposited the Kolar iron formation had high dissolved SiO₂ and low in other metallic ions. A sudden decrease of temperature and probably pH deposited iron as sulphide rich iron-formation. Most of the base metals, refractory elements and rare earth elements also went into this. Due to the decrease of sulphid
values due to the mixing of the ore solution with sea water. First carbonates and then hydroxides of iron precipitated. Further mixing of the ore solution with sea water diluted its concentration and increased its pH to precipitate rest of the iron as silicates. Banding in the Kolar iron-formation seems to be because of the continuous precipitation of SiO₂ and periodic precipitation of iron minerals. The hydrothermal solution of high temperature, high pH and low water/rock ratio responsible for an Archean iron-formation of the Kolar type also seems to be responsible for sulphide-gold mineralization.