The purpose of the present investigation has been to investigate the nature of mineralization of copper sulphide ore deposits in the southeastern and central sectors of the Singhbhum shear zone, Bihar State, with particular reference to the geochemistry of the ores and the host rocks as well as of some adjacent lithic units. Considerable attention has also been given to study the petro-mineralogy of the host rocks and the mineragraphy of the sulphide ores. A summary of this investigation and the conclusions drawn, are presented as follows:

1. The Singhbhum shear zone is generally considered synonymous with the Singhbhum copper belt, Singhbhum thrust belt and Copper belt thrust in the Precambrian geology of India.

Stratigraphically, the Precambrian rocks of the belt are divisible into two stages, viz., Chaibasa Stage (Lower) and Iron Ore Stage (Upper). The copper bearing host rocks (predominantly metasedimentary/older volcanics), belong to the Iron Ore Series or Iron Ore Group (3000-3200 M.Y.). Another important rock type, known as Dhanjori volcanics, which was
encountered close to the shear zone rocks, is devoid of any copper mineralization. These volcanics are much younger than the host rocks since their age was determined to be 1600 M.Y. This shear zone evolved from a pre-existing zone of deep seated fracture and volcanism that separated an Archaean granitic platform to the south from a Proterozoic belt on the north. The tectonic history of the area suggests that before the rocks attained their present status, four distinct deformational stages (2000, 1500, 1100 and 850 M.Y.) having distinctive features of their own affected the shear zone rocks to a great extent.

2. The structural pattern of the rocks are coaxial with the tectonic evolution of the area, mainly during the four successive deformational stages resulting in the formation of various types of planer and linear structures. The general strike trend of the rocks of the area, being from NNW to SSE, follows closely the trend of the shear zone.

The sulphide ores are usually localized in the closely spaced planer structures, mainly the schistosity ($S_2$) and slip planes ($S_3$) and sometimes they are sporadically distributed in the host rocks in the form of small specks and blebs. The present disposition of the ore bodies has largely been guided by the major structural trend of the shear zone and the ore localizations are intimately controlled by the various minor
structural elements of the host rocks.

3. The various rocks that compose the Singhbhum shear zone and fall within the study areas have been distinguished on the basis of their mineral assemblages, modal distribution, mineralogic population, textural characteristics and classified as follows:

- Feldspathic rock
- Chlorite-quartz schist
- Biotite schist
- Chlorite-biotite schist
- Biotite-quartz schist
- Quartz-kyanite schist
- Massive quartzite
- Quartz schist
- Dhanjori volcanics
- Muscovite schist (occasionally garnetiferous)

The rocks which appear as schist, gneiss or granite at the outcrop level compose the host rocks in the southeastern sector. They are introduced here as feldspathic rock because they are essentially composed of plagioclase, quartz, chlorite, biotite and muscovite. Modal plots and Colour Index (C.I.) of feldspathic rock lie outside of the granite field. Complex twinning, replacement texture and sieve structure shown by plagioclases in the feldspathic rock indicate that the rock has been affected by soda-metasomatism.
In the central sector, the chlorite-quartz schist, which appears as host rock, is composed of chlorite, biotite, quartz and muscovite. The texture of the rock is characteristically granoblastic.

In both the feldspathic rock and chlorite-quartz schist, second generations of chlorite, magnetite and quartz have been identified. The second generations of chlorite and magnetite were derived from biotite in course of retrogressive metamorphism whereas quartz belonging to the second generation is related to silicification.

The chlorite-biotite and biotite schists which are found in contact with the Dhanjori volcanics in the central and south-eastern sectors have almost identical mineralogical assemblages. Their identity is however, based on the dominance of either chlorite or biotite.

The mylonitic rock (biotite schist) of the central sector is predominantly composed of finely granulated quartz, biotite, muscovite and chlorite with epidote and tourmaline as accessories. The schist exhibits typical mylonitic texture with preferred orientation of the sheet minerals.

The Dhanjori volcanics, which occur as non-foliated (massive) or foliated (meta-volcanic) rocks, are composed of actinolite, hornblende, plagioclase, chlorite, biotite, augite, epidote, clinodiasite, quartz and some accessories. The non-
foliated type exhibits blasto-sub-ophitic texture and the foliated type, lapidoblastic texture.

The muscovite schist, found commonly in the two sectors, is composed of muscovite, biotite, chlorite, quartz with occasional presence of elongated porphyroblasts of garnet. The texture of the rock is typically porphyroblastic.

Besides soda metasomatism, the host rocks were subjected to alteration, the sequence of which has been determined to be as follows:

Silicification $\rightarrow$ biotitization $\rightarrow$ chloritization $\rightarrow$ sericitization.

The study of the mineral assemblages, textures and other petrographic character of most of the rocks, mentioned above, indicates that they have undergone progressive metamorphism varying from the green schist to lower amphibolite facies.

4. Morphologically, three types of sulphide ores have been identified as i) massive, ii) braided, and iii) disseminated. Mineralographic study of the ores led to the identification of a number of major, minor and exsolved ore minerals. They are as follows:

**Major:** Chalcopyrite, pyrite and pyrrhotite.

**Minor:** Sphalerite, magnetite (ilmenite), chalcocite, covellite, bornite, molybdenite, millerite, galena, tellurbismuth and tetradyrite.
Exsolved: Cubanite, valeriite, marcasite, pentlandite and violarite.

The metamorphism of the ores is pervasive and it is evidently manifested through certain characteristic textural features such as replacement, annealing, exsolution and deformation. Replacement and annealing textures are supposed to be the characteristics of dynamothermal and dynamic metamorphism whereas the exsolution texture is indicative of falling temperature at retrogressive stage.

The primary mineral assemblages and the presence of some exsolved ore minerals suggest that the temperature at which they were formed ranged between 200°C and 450°C.

The paragenetic sequence of the ore minerals (primary and secondary) has also been determined on the basis of their mutual textural relations.

5. The geochronical abundance and variation ranges of the major oxides as well as some of the important trace elements in the host rocks of copper and also of the Dhanjori volcanics are critically studied with a view to trace the original nature of the rocks. The major and minor constituents of the host rocks have also been compared with those of some well-known acidic, basic and pelitic rocks of the world.

A close examination of the major oxides, viz., SiO₂, Al₂O₃, TiO₂, FeO, Na₂O, K₂O, MgO and CaO in the feldspathic rock,
collected from varying distances from the lode zone to the barren host rocks, indicates that the constituents have different trends of concentration with respect to the lode zone. Total iron particularly, FeO, MgO and Na₂O show a decreasing trend in their abundance away from the lode. On the other hand, SiO₂ and CaO decrease in their abundance towards the lode. K₂O has a slightly increasing tendency and TiO₂, a decreasing one towards the lode. Only a marginal reduction in the abundance of Al₂O₃ towards the lode has been recorded.

The major oxides of biotite schist are also compared and contrasted with those of Dhanjori volcanics and some other well-known basalts of the world as well as average pelitic rocks. The biotite schist and the Dhanjori volcanics have more or less similar concentration trends with respect to their total iron, magnesium and alkalies contents. The higher concentration of silica in biotite schist as compared to Dhanjori volcanics may be due to the effect of moderate silicification of the former. On the basis of similarity in abundance of the above oxides, a close genetic relation between the two rocks has been suggested.

The concentrations of SiO₂, TiO₂, Al₂O₃, Fe₂O₃, FeO, MgO, CaO, Na₂O, K₂O, P₂O₅ and MnO in the chlorite-quartz schist show orderly variation and follow certain spatial trends with respect to the position of the ore zone. Total iron, TiO₂, MgO and CaO increase towards the lode. On the other hand, SiO₂ and
Al₂O₃ decrease in their abundances as the lode is approached. MnO, P₂O₅ and Na₂O increase slightly towards the lode whereas K₂O has a decreasing tendency towards the lode. The variation trends of the above oxides are more or less similar in the host rocks of southeastern and central sectors. Generally, the abundances of major oxides in the chlorite-quartz schist are quite different from those found in the well-known pelitic or basaltic rocks. The total iron in the chlorite-quartz schist is higher than in the average basaltic or pelitic rocks. MgO content in the rock is lower than in the average basaltic rocks but higher than the average pelitic rocks.

Among the major oxides, total iron, magnesia, alkalies (mainly Na₂O), P₂O₅, MnO and K₂O in the chlorite-biotite schist and biotite-quartz schist are almost as abundant as in average basalts or the Dhanjori volcanics. The chlorite-biotite schist and the Dhanjori volcanics appear to be geochemically related because their average MgO, FeO, CaO, Na₂O and K₂O contents have more or less similar values. The higher values of SiO₂ in the schist than in Dhanjori volcanics may be attributed to silicification of the former. According to the above observation, it is suggested that the chlorite-biotite schist might be related geochemically with the Dhanjori volcanics. The chemical composition of the Dhanjori volcanics resemble closely the tholeiitic basalt as indicated by various discriminatory diagrams. Its oceanic tholeiite nature was supported by TiO₂-K₂O-P₂O₅ diagram.
6. Commonly the host rocks and their sub-lithounits indicate alteration as a result of chloritization, biotitization, sericitization, and silicification. The host rock of the southeastern sector was also subjected to soda metasomatism but to a very limited extent.

However, the alteration zones found in the country rocks of the study area are not developed as prominently as they are usually found in hydrothermally altered rocks.

Appreciable increase of Fe and Mg relative to Ca and Na and simultaneous decrease of Ca and Na relative to Al in both the host rocks indicate that their alteration trends are similar (Fig. 9A-H).

It is evident from the ACF diagram (Figs. 10 and 11) that there is practically no difference between the two host rocks, viz., feldspathic rock and chlorite-quartz schist, as far as their mineralogical assemblages and chemical constituents are concerned. It is rather difficult to identify the original chemical nature of the host rocks due to metasomatism and the combined effect of various other alteration processes on them.

7. The trace elements such as Cu, Pb, Zn, Co, Ni, Cr, Rb and Sr in feldspathic rock, chlorite-quartz schist, biotite schist, chlorite-biotite schist and biotite-quartz schist are quantitatively determined with a view to study their distribution trends in the above rocks, and to compare the rocks of the study
area with the average metasedimentary and metavolcanic rocks of Dharwar schist belt, India; some of the average pelitic, acidic and basaltic rocks of other parts of the world on the basis of their trace element contents.

Copper has not only higher average values but also a wider variation range in the feldspathic rock and chlorite-quartz schist than in chlorite-biotite schist, biotite schist and biotite-quartz schist. Generally, copper shows a tendency to increase in abundance in the host rocks as the ore bodies are approached. The average concentration of zinc in the feldspathic rock is slightly higher than in chlorite-quartz schist. But both biotite schist in the southeastern sector and biotite-quartz schist in the central sector, which have almost identical averages of zinc, recorded higher averages of zinc than either in feldspathic rock or chlorite-quartz schist. Like copper, this trace element in the host rocks increases in abundance as the ore bodies are approached.

Nickel shows a tendency to increase in its abundance towards the ore zone in chlorite-quartz schist but the element does not show any such trend in the feldspathic rock.

Traces of cobalt have almost similar average values in chlorite-biotite schist, biotite schist and biotite-quartz schist. In the host rocks, however, the element increases in abundance towards the ore zone.
Generally, the concentration of chromium is slightly more in chlorite-quartz schist and other subunits than in the two host rocks.

Rubidium in the feldspathic rock or chlorite-quartz schist or in chlorite-biotite schist do not vary much in its concentration. Strontium in the feldspathic rock is significantly higher than in chlorite-quartz schist, although there are little differences in their average values in the chlorite-biotite schist, biotite schist and biotite-quartz schist.

From the nature of the distribution trend of the trace elements as stated above, it is obvious that no definite opinion regarding the geochemical relations among the rocks under study could be expressed. The average Cu, Co, and Ni contents in the host rocks are appreciably higher than those in some well-known acidic, granitic, metasedimentary or pelitic rocks.

The average copper content in the Dhanjori volcanics is lower than that of quartz-normative tholeiites, tholeiites and basalts. On the other hand, Ni and Co contents of the volcanics appear to be significantly higher than those of basaltic suites including the oceanic ones.

A comparative study of some trace elements of the Dhanjori volcanics with those of well known basaltic rocks reveals that the concentration of Cu and Sr is lower, and that of Zn, Co and Ni is higher in the volcanics than in the average basaltic rock.
Only the average contents of Cr and Rb in the two rocks are comparable.

8. About 27 ore samples, collected from both the southeastern and central sectors were analysed for the quantitative determination of their Cu, Fe, Ni, Co, Zn, Pb, Rb, Sr, Mn and Ti contents. Generally, the ores from Mosaboni have higher concentration of Cu, Fe, Ni, Co and Zn than in those of Tamapahar. The amount of Pb is, however, higher in the ores of Tamapahar than in those of Mosaboni.

In most of the ore samples of the study area, Ni, is invariably dominant over Co and the concentrations of Co, Ni and Cr are higher than in the vein type of prophyry copper deposits.

So far as the trace elements are concerned the only common feature in the ores and the host rocks is the presence of Co, Ni, Zn and Pb in their decreasing order of abundance away from the lode zone, though individually their average concentrations in the former are higher than in the latter.

9. Co, Ni, Zn and Ti in the three dominant mineral fractions of the sulphide ores, viz., chalcopyrite, pyrite and pyrrhotite of Mosaboni and Tamapahar have been studied in an attempt to trace their distribution trends in the ore deposits. Generally, the concentration of Co in chalcopyrite of Mosaboni is higher than
that of Tamapahar whereas that of Ni in the chalcopyrites of two sectors, have nearly been equal concentration. There is no depth-wise variation in the abundance of Ni and Co in chalcopyrite at the Mosaboni and no lateral variation of Ni in the chalcopyrite of the two sectors. Mn and Ti in chalcopyrite show narrow variation ranges both vertically and laterally in the two sectors.

Pyrites from Mosaboni and Tamapahar have also similar concentration of Ni and Co and this is also found in the case of Mn and Ti. The four trace elements in pyrrhotite do not show any significant lateral or vertical variation in their abundance in the two sectors.

On the basis of average Co:Ni ratios in chalcopyrite, pyrrhotite and pyrite, the sulphide ores of the study area are compared with those of known genetic type particularly hydrothermal deposits. The average Co:Ni ratios in chalcopyrite and pyrrhotite associated with the ores of Mosaboni and Tamapahar are lower than those found in the same ore minerals of hydrothermal origin. On the other hand, the average Co:Ni ratios in pyrite of the study area are appreciably higher than those recorded from pyrites of hydrothermal or sedimentary origin. Accordingly, it is obvious that sulphide ores having chalcopyrite, pyrrhotite and pyrite of the study area could not either be regarded as hydrothermal or sedimentary, as suggested by some of the earlier workers. However, the pyrites in the ores of the study area with a range of their average (3.20-5.82) Co:Ni ratios are considered to be mobilised.