Chapter - VI

GEOCHEMISTRY OF THE ROCKS AND ORES

A. Geochemistry of the rocks

The major oxides and their distribution in the shear zone rocks

The distribution, variation ranges and frequency trends of the different oxides composing the rock types encountered in the study area (Table 11, Figs. 5A, B) are described as follows:

Silica (SiO₂) - Silica is fairly variable and shows a unimodal frequency trend in the feldspathic rock and chlorite-quartz schist. It may be further noted that the silica content is usually higher in the feldspathic rock as well as chlorite-quartz schist than in biotite-quartz schist and chlorite-quartz schist.

Titania (TiO₂) - In all the rock types titania shows a wide range of variation with bimodal frequency characteristics in the feldspathic rock and chlorite-quartz schist.

Alumina (Al₂O₃) - Alumina being moderately concentrated in the feldspathic rock as well as in the chlorite-quartz schist
Figure 5a: Frequency distribution of major oxides in the host rock of copper in Tamapahar sector, Rakhia Mines.

Figure 5b: Frequency distribution of major oxides in the host rock of copper in Khonson - Badia Mines.
indicates unimodal frequency trends. Its variation range in chlorite-biotite schist and biotite-quartz schist is, however, moderate.

Alkalies (Na_2O and K_2O) - Soda in feldspathic rock shows a wider variation with unimodal characters. Also in chlorite-quartz schist (0.35-4.45) it varies widely with bimodal characters. In other rock types, viz., biotite schist, biotite-quartz schist and chlorite-biotite schist its variation ranges are narrow.

Potash shows a wider range of variation than soda with bimodal characteristics in feldspathic rock but unimodal in chlorite-quartz schist. On the other hand in biotite schist and biotite-quartz schist it has a relatively narrow range while in chlorite-biotite schist its variation range is again wider.

Calcium oxide (CaO) - Calcium oxide content in feldspathic rock or in chlorite-quartz schist shows a wide variation with bimodal characteristics whereas in biotite schist, biotite-quartz schist and in chlorite-biotite schist the range is relatively narrow.

Magnesia (MgO) - The variation range of magnesia in most of the rock types is narrow except in chlorite-quartz schist, in which it is moderate with unimodal characters.

Ferrous oxide (Fe_2O_3) and Ferric oxide (FeO) - Fe_2O_3 in feldspathic rock shows a moderate variation with bimodal characters whereas FeO has a wider variation range with unimodal characters. Fe_2O_3 and FeO in chlorite-quartz schist show unimodal characters with narrow and moderate variation respectively. On the other hand, both the oxides in biotite schist and chlorite-biotite schist show
narrow variation. In biotite-quartz schist $\text{Fe}_2\text{O}_3$ indicates narrow while FeO shows wider variations.

**Manganese oxide** ($\text{MnO}$) - The range of $\text{MnO}$ in feldspathic rock and chlorite-quartz schist is wide and characteristically bimodal and unimodal in the above rocks respectively. In biotite schist, biotite-quartz schist and chlorite-quartz schist its variation ranges are also wider.

**Phosphorous pentoxide** ($\text{P}_2\text{O}_5$) - Generally, $\text{P}_2\text{O}_5$ is poorly represented in most of the rock types. It shows a wide variation range and bimodal characteristics in feldspathic rock and chlorite-quartz schist whereas in biotite schist, its variation is narrow (0.13-0.19). The constituent shows wide variation range in biotite-quartz schist and also in chlorite-biotite schist.

**Loss of ignition** - The LOI in all rock types is usually low and varies within narrow ranges. It has unimodal characteristics.

**Major oxides in the rocks of southeastern sector**

It is evident that the host rock of the southeastern sector shows appreciable variation in their major oxides constituents. The major oxides are being dealt individually with a view to present and discuss their mutual geochemical relationship in terms of abundance and variation. The analytical data of the major oxides of feldspathic rock is presented in table 14. The chemical compositions of some well-known acidic, pelitic as well as basic rocks of other parts of the world have been quoted for the sake of comparison and a better understanding
of the geochemical nature of the rock types under study (Table 13). None of the chemical data of the rocks of the study area compares well with the known data of granitic, basic or pelitic rocks. However, the abundance of some constituents in the present rocks follows closely some basic rocks so far as their ferromagnesium constituents are concerned. The sample locations of the feldspathic rock has been referred to the text with respect to their spacings from the lode such as, away from, nearer to, and nearest to the lode, as shown in table 15 and figure 7.

Feldspathic rock

Silica - An attempt has been made to determine the mutual geochemical relation of silica with other oxides. SiO$_2$ shows strong negative relation with Na$_2$O, Fe$_2$O$_3$ and FeO and weak or insignificant negative relation with Al$_2$O$_3$, MgO, CaO, TiO$_2$ and P$_2$O$_5$ (Fig. 6A).

From the above observation, it is imperative that SiO$_2$ replaces partially the above oxides except MnO. The SiO$_2$/Al$_2$O$_3$ ratio of the individual rock samples decreases towards the lode. Na$_2$O shows increasing values with decreasing concentration of SiO$_2$ and this is generally the tendency in the rock samples up to the vicinity of lode (e.g., at the 26th level). However, the gneissose variety of the rock having low concentration of
FIG. 6 PLOTS SHOWING VARIATIONS OF SiO₂ WITH RESPECT TO OTHER MAJOR OXIDES IN THE FELDSPATIC ROCK (A) AND CHLORITE-QUARTZ SCHIST (B)
Na₂O, does not show any such variability with respect to SiO₂ content. Both the oxides of iron also indicate an increasing tendency with the increase of SiO₂. Though the coefficient correlation of SiO₂ and MgO does not show much significant relation, yet with the increase of SiO₂, the regression trend is linear. The relation between SiO₂ and MnO is positive and fairly prominent. The general characteristic feature of silica is its gradual depletion in the rocks including coarse feldspathic schist occurring towards the lode. Further evidences of silicification of the host rock is provided by the unimodal characteristic of silica in term of frequency distribution (Fig. 5A).

Alumina - The average value of Al₂O₃ in the rock is slightly lower than its average in granitic rocks of Nockolds, S.R. (1954) and the average pelitic rocks (Table 13) of Shaw, D.M. (1956). The low Al₂O₃ content in feldspathic rock indicates that its concentration remained almost unchanged after the rock had undergone soda-metasomatism. Its coefficient correlation with other oxides (Table 14) does not indicate any significant relation. However, alumina shows only minor variation particularly, in the rock samples close to the lode although alumina is considered to be chemically stable during any metasomatic process (see Mehnert, K.R., 1968).
Titania - The average TiO₂ in the rock is fairly close to that of oxide in granite rock (0.37 per cent, Nockolds, 1954), but less than its average in high calcium granite (Turekian, K.K. and Wedepohl, K.H., 1961), and appreciably higher than in low calcium granite (op. cit.). However, in comparison to average basaltic rocks of Nockolds (1954) and average pelitic rocks of Shaw (1956), the rock, under study, shows much depletion of TiO₂ (Table 13). The antipathic relation (Table 14) of TiO₂ (Ti ionic radius 0.69Å°) with Fe₂O₃ (Fe³⁺, ionic radius 0.67Å°) may be due to replacement of the latter by the former. This is rather an unusual feature as the weak correlation coefficient does not indicate any such replacement relation. Moreover, it is known that TiO₂ remains mostly immobile during the processes of alteration and metasomatism. Its strong positive relation with P₂O₅ is a unique feature showing characteristic coherence between the two constituents (Table 14). Vogt, J.J.L. (1931) suggested that phosphorous followed very closely the course of titanium during the magmatic differentiation. It may, therefore, be possible that these two constituents had similar coherence in the parent rock provided TiO₂ remained immobile at any stage of metasomatism.

Ferrous and ferric oxides - Both the oxides have appreciably high values in the rock nearest to the ore zone (Table 15). The FeO content, however, has much higher concentration in granitic
and other igneous or pelitic rocks (Table 13), though the level of concentration is less than that of the basaltic rocks (average 5.70) of Nockolds (1954). The coefficient correlation between Fe$_2$O$_3$ and FeO shows a strong positive relation (Table 14) which is an indication of higher state of oxidation. Although the Fe$_2$O$_3$/FeO ratio is insignificant yet the rock samples nearer to the lode give an indication of higher state of oxidation (Table 15). This may have probably aided the conversion of biotite and chlorite to their green and brown varieties and vice versa (see Deer et al., 1963).

Alkalies (Na$_2$O and K$_2$O) - A fairly higher concentration of Na$_2$O is certainly an unusual character of this rock. From the table 13 it is evident that the concentration of Na$_2$O in the rock is higher than in the average granitic rocks or the basaltic rocks but significantly higher than the average pelitic rocks. About 75 per cent of the samples show 3 to 5 weight per cent of Na$_2$O. Therefore, the introduction of additional Na$_2$O is obvious in many of the samples, specially in those that were previously impoverished in this constituent (see Mehnert, 1963). It has been observed that Na$_2$O content increased nearly by 4 to 5 weight per cent mainly with the increase of sodic plagioclase up to 45-60 by volume per cent (see modal analyses, Table 9). Therefore, high soda content justifies the nomenclature of the rock as 'feldspathic rock' instead of 'soda
granite', an opinion which was also suggested earlier by Talapatra (1969) on the basis of higher content of soda. In some rock samples belonging to the granitic variety, $\text{Na}_2\text{O}$ is 3 to 4 times higher than $\text{K}_2\text{O}$ only with the exception of its gneissose variety having a much lower concentration of $\text{Na}_2\text{O}$. $\text{Na}_2\text{O}$ in the feldspathic rock samples collected away from the lode have lower concentration than in the granitic and gneissic rock samples. It is, therefore, evident that the variation of the alkalies in the schist, gneiss or granite does not have any significance as far as the abundance of the constituent is concerned.

The average $\text{K}_2\text{O}$ value of 0.72 weight per cent in the host rock does not show any significant difference with those of other acidic, basic or pelitic rocks (Table 13). The weak coefficient correlation between $\text{Na}_2\text{O}$ and $\text{K}_2\text{O}$ (Table 14) also suggests that their relation is insignificant. Such a feature possibly indicates that during soda metasomatism much of potash ($\text{K}_2\text{O}$) remained almost unaffected. $\text{Na}:\text{K}$ ratio (4.75) in the feldspathic rock is much higher than that of normal granite (see Daly, R.A., 1933). The limited field of $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratios in the rock shows that it has practically nothing in common with the differentiated granite in which the range from a low soda/high potash to high potash/low soda ratios is wider (Mehnert, 1968). The average ratio of $\text{Na}_2\text{O}/\text{K}_2\text{O}$ (9.17) of some
samples nearest to the lode is lower than that of rock away from the lode (Table 15). There is a gradual increase in the abundance and dominance of soda over potash with the spatial distance of the rock samples from the lode. The increasing preponderance of sodic minerals in the rocks closer to the lode is indicative of soda metasomatism.

Magnesia - MgO in the foldspathic rock is appreciably higher than in some other acidic rocks of the world (Table 13). About 69 per cent of the foldspathic rock samples have 3 to 6 weight per cent of MgO content. However, in comparison to the average basaltic rocks of Nockolds (1954), the host rock has lower concentration of MgO. Only the host rock nearest to the lode is comparable with the known basaltic rocks (op. cit.) on the basis of their MgO concentration.

The average ratio of MgO/Na$_2$O + K$_2$O (Table 15) in the rock away from the lode is 0.86 and the rock nearest to the lode has also almost identical average ratio of the constituents. MgO dominates only in the rocks which are nearer to the lode (Table 15). Evidently, the alkalies dominate over magnesia in the rock or in other words sodic plagioclase appears to be on the higher side in the rock.

The FeO/MgO ratio in the different samples of the host rock, taken from different localities away from the lode, does not show any significant variation trend. The rest of the
constituents, viz., $P_2O_5$, CaO and MnO which occur in minute quantities do not also show any significant variation with change of location with respect to the lode.

The variation trends of the oxides in the host rocks sampled from different locations from the lode towards the host rock (Table 15, Fig. 7), as discussed above, are summarized below:

1. There is a gradual depletion of $SiO_2$ towards the lode.
2. There is a marginal reduction of $Al_2O_3$ near the lode.
3. A slightly increasing tendency is indicated by $K_2O$ and decreasing tendency by $TiO_2$ towards the lode.
4. MnO indicates a slightly increasing trend away from the lode.
5. The concentration of total iron decreases away from the lode and this is particularly true for FeO.
6. MgO decreases in its concentration away from the lode and likewise $Na_2O$ has a decreasing trend.
7. CaO shows a decreasing tendency towards the lode though the difference in average value is marginal.
8. $P_2O_5$ does not indicate any particular variation trend.

**Biotite Schist** - On the southeastern sector of the study area, there is a narrow and thin band of biotite schist which lies in gradational contact with the Dhanjori volcanics on one side and to some extent sharp contact with the feldspathic rock on the other. This rock unit shows some mineralogical and chemical differences with the feldspathic rock.
FIG. 7 VARIATION DIAGRAMS OF THE MAJOR OXIDES IN SCHISTOSE ROCKS, SOUTH-EASTERN SECTOR
The distribution of major oxides, their average values and variation trends in different samples of the rock have been indicated in table 16.

An attempt has been made to compare and contrast the major oxides of biotite schist with those determined or known from Dhanjori basalt and also with some other basaltic rocks of the world (Table 17). The biotite schist has appreciably higher concentration of silica than that of Dhanjori volcanics or other basalts (Nockolds, 1954; Turekian and Wedepohl, 1961) and lower than that of average pelitic rocks (average 61.5%) of Shaw (1956).

The average Al$_2$O$_3$ content in biotite schist is significantly lower than the average pelitic rocks of Shaw (1956). Its average value is unusually lower in the basalts (Nockolds, 1954) than in biotite schist but there is a little difference of Al$_2$O$_3$ between the rock and the average basalts (Turekian and Wedepohl, 1961).

The average TiO$_2$ content in the rock is not similar to that of either Dhanjori basalt or other basaltic rocks (Table 17) but it is closer to that of feldspathic rock.

A comparison of the total iron (Fe$_2$O$_3$ + FeO) contents between biotite schist and Dhanjori basalt shows that the former has lower concentration of iron than the latter. In the biotite schist the total iron is almost similar to the
average recalculated total iron in basalts (Turekian and Wedepohl, 1961) though it is lower than those of basalts of Jockolds (1954) as well as pelitic rocks (average 6.44 weight per cent) of Shaw (1956).

The average MgO content of the rock matches well with other basaltic rocks of the world (Table 17) though it is on the higher side as compared to average MgO content in Dhanjori basalt which indicates a tendency towards higher values of MgO. Moreover, the average value of MgO is definitely higher in biotite schist than in feldspathic rock and also it is significantly higher than (average 2.52) in pelitic rocks (Shaw, 1956).

Almost similar variation trend of Na₂O as of MgO in the biotite schist as well as in other basaltic rocks, as stated above, makes them comparable. However, this is not true in the case of feldspathic rock in which the soda content is higher than in biotite schist. The average K₂O value (1.76 weight per cent) in biotite schist is appreciably higher than its averages reported from basaltic rocks and also from the Dhanjori volcanics (Table 17) but lower than the average in pelitic rocks (3.45) of Shaw (1956). Appreciably higher potash content in biotite schist is obviously due to the presence of more potassic minerals than in other rocks, which is also substantiated by petrographical studies.
As far as the CaO contents in biotite schist and basic rocks including Dhanjori volcanics are concerned, they are not comparable since the latter have much greater abundance of CaO than the former. Apparently, lime deficiency in biotite schist may be due to higher proportion of biotite than hornblende in the rock.

Interestingly, the average MnO and P$_2$O$_5$ values are more or less consistent in the biotite schist as well as in all other rocks under study and comparison.

Discussion

In sum, it may be stated that the geochemical abundance of some major constituents in biotite schist like thal iron, magnesium and the alkalies have more or less the same average values as in normal basaltic rocks. The above major constituents are found to be similar with those of Dhanjori volcanics as far as their average concentrations are concerned. However, the constituents do not have any such conformable relation with those of politic rocks. The higher amount of silica in biotite schist may be explained as due to the effect of moderate silicification, the evidences for which may be seen otherwise in the mineralogical composition of all other associated rock types of the study area. The high concentration of oxides of iron and magnesium in biotite schist than in feldspathic rock is obviously due to higher amount of mafic
minerals in biotite schist. However, the similarity in abundance of some of the oxide constituents of biotite schist with those of Dhanjori volcanics probably suggests a close genetic relation between the two rocks. Possibly there was some elemental readjustment and redistribution initiated by later metasomatic process which partially transformed the part of Dhanjori volcanics lying close to the shear zone rocks to biotite schist to a certain extent. Earlier, Sarkar (1967) has also expressed a similar view regarding alteration of Dhanjori volcanics to biotite schist in the shear zone of Mosaboni due to metasomatism.

The major oxides in the rocks of central sector

General Statement:

The chlorite-quartz schist, being the host rock of sulphide ore in the central sector, has two lithological variants, viz., chlorite-biotite schist and mylonitized biotite-quartz schist, which have not been mineralized. The rock unit and its lithic subunits are analysed separately for the determination of their major oxides for determining their geochemical characteristics.

There are several impersistent bands of conglomerate on the southern side of the area, which are demarcated by the chlorite-biotite schist composing the top of the formation.
The chlorite-biotite schist which is in gradational contact with the Dhanjori volcanics on its southern limits, grades imperceptibly into chlorite-quartz schist occurring on the northern side. The narrow band of mylonitized biotite schist, a variant of the host rock, occurs on the northern side of chlorite-quartz schist.

The sampling of the host rock has been made as far as possible systematically along and across its strike at regular intervals and depending upon the availability of good rock exposures.

The analytical data of the major oxides of chlorite-quartz schist is presented in table 18. The plots of frequency percent histograms of the major oxides in chlorite-quartz schist have been shown in figure 5B.

The variation trend of the different oxides in the samples of each rock unit and its subunits are represented individually by variation curves (Fig. 8). The geochemical characteristics of the chlorite-quartz schist are discussed separately whereas those of chlorite-biotite and biotite-quartz schists are dealt together. The analytical data of the major oxides of chlorite-biotite schist and biotite-quartz schist are presented separately. The frequency range and distribution trends of the oxides constituents of chlorite-quartz schist are shown in table 11.
Chlorite-quartz schist

The sample locations of the rock are categorised broadly into three groups depending on their distances from the lode in order to present their chemical characteristics and variation, if any.

The underground samples of the rock are collected carefully as far as away from the visible sulphide mineralisation in order to avoid any sort of contamination of ores with the rock samples.

The major oxides which have relevance to the present study with particular reference to their chemical characteristics, have been discussed and compared with the same oxides known from other rocks having similar chemical nature.

So far as the average value of $\text{Al}_2\text{O}_3$ is concerned, the host rock is comparable with the basaltic and pelitic rocks. $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios in the host rock vary from 3.85 to 18.41 (Table 15), and the average being 6.21. It is clearly evident from the table 15 and figure 3 that $\text{Al}_2\text{O}_3$ diminishes as the ore zone is approached. It may be therefore, generalized that in the host rock as well as in the feldspathic rock of the southeastern sector, $\text{Al}_2\text{O}_3$ has a tendency to decrease in abundance towards the ore zone.

The schist has higher concentration of total iron ($\text{Fe}_2\text{O}_3 \cdot \text{FeO}$) than in average basalt and still higher than in average pelitic rocks (Table 19).
Generally, Fe\textsubscript{2}O\textsubscript{3}/FeO ratios with a narrow variation between 0.35 and 0.74 and an average of 0.48 (Table 18) indicate a higher state of oxidation (see Deer et al., 1963).

The decrease in the Fe\textsubscript{2}O\textsubscript{3}/FeO ratios is chlorite-quartz schist encountered vertically from the surface to underground sections closer to the lode is an indication of diminishing state of oxidation of rocks downwards. The average value of TiO\textsubscript{2} (0.26 weight percent) is quite different from the average of TiO\textsubscript{2} either in basaltic rocks or pelitic rocks (Table 19). MgO with a variation range from 4 to 8 weight percent, and with an average value of 4.23 weight percent, is lower than that of the average basalts and considerably higher than that of average pelitic rocks (Table 19). Strikingly, the average MgO content in chlorite-quartz schist is very similar to the feldspathic rock. The average ratio of FeO/MgO, which varies in the rock from 0.83 to 4.28, is 1.83. The ratios decrease with the increasing distance of the rock from the lode.

Generally the rock has little of CaO and this lime deficiency may be attributed to selective replacement of lime in lime bearing minerals (e.g., hornblende, augite, clinohumite, etc.) in course of silicification followed by limited alteration.

Coefficient correlation table 20 indicates that K\textsubscript{2}O has negative relation with MgO and positive with FeO whereas
MgO has positive relation with Fe$_2$O$_3$. Alteration of ferromagnesium minerals (biotite, chlorite) was probably facilitated due to such relations among the above constituents.

An attempt has been made to define the geochemical relation of SiO$_2$ with other oxides (Fig. 6B). SiO$_2$ does not show any comparable quantitative relation with most of the other oxides in the chlorite-quartz schist. The fairly strong antipathic relation of SiO$_2$ with Al$_2$O$_3$, total iron (Fe$_2$O$_3$ + FeO) and CaO may be explained as due to significant silicification of the rock and accompanying replacement of the above constituents by silica. In comparison to the known basaltic and pelitic rocks, the concentration of K$_2$O in the rock is appreciably higher and that of Na$_2$O is considerably lower. The K$_2$O/Na$_2$O ratios which vary from 0.03 to 1.56 have a tendency to diminish gradually towards the lode. In the chlorite-quartz schist adjacent to the lode, Na$_2$O dominates over K$_2$O though the rock is generally deficient in alkalies as compared to the feldspathic rock.

The variation trends of the various oxides in the host rock collected from the different locations with respect to lode are presented in table 15, figure 8 and summarized as -

1. SiO$_2$ decreases towards the lode.
2. TiO$_2$ content increases towards the lode.
3. Al$_2$O$_3$ increases away from the lode.
FIG 8  VARIATION DIAGRAMS OF THE MAJOR OXIDES IN SCHISTOSE ROCKS.
CENTRAL SECTOR
4. Total iron has increasing tendency towards the lode.
5. There is a gradual increase of MgO and CaO towards the lode.
6. Na₂O increases marginally towards the lode whereas K₂O has a reverse tendency.
7. P₂O₅ and MnO show slightly higher concentration in the samples located away from the lode.

The variation trends of the above oxides in chlorite-quartz schist have much in common with those of the feldspathic rock of southeastern sector.

**Chlorite-biotite schist and biotite-quartz schist (Mylonite)**

The two variants of the host rock, viz., chlorite-biotite and biotite-quartz schists (Tables 21 and 22, Fig. 8) show some mineralogical departures from the main host rock (chlorite-quartz schist) as far as their chlorite and biotite constituents are concerned.

An attempt has been made to define the chemical characteristics of the two litho-units on the basis of their petrochemical studies. The chemical constituents of these two rocks (Table 19) are compared and contrasted with those of known basaltic rocks (Nockolds, 1954; Turekian and Wedepohl, 1961), the average pelitic rocks (Shaw, 1956) and also chlorite-biotite schist with the adjacent Dhanjori volcanics (Table 17).
It is evident that total iron and MgO in chlorite-biotite schist and biotite-quartz schist being higher than in chlorite-quartz schist, are more comparable with those of average basalts rather than with the chlorite-quartz schist. They are also significantly higher than in the average pelitic rocks. The average $\text{Al}_2\text{O}_3$ of biotite-quartz schist is nearly similar to that of basalts of Turekian and Wedepohl (1961) but in the chlorite-biotite schist it is in excess of 3 per cent and significantly lower than in the pelitic rocks (Table 19). The average CaO content in biotite-quartz schist is more than double of that of chlorite-biotite schist and both of them are significantly lower than the average CaO values in the basalts including Dhanjori volcanics (Table 17), but higher than the average in chlorite-quartz schist and pelitic rocks. There is no significant difference in the average values of $\text{Fe}_2\text{O}_3$, $\text{MnO}$ and $\text{K}_2\text{O}$ among these rocks and the basalts of Rockolds (1954) and Turekian and Wedepohl (1961) or Dhanjori volcanics (Table 17) but strikingly they are lower than in the pelitic rocks (Table 19).

**Discussion**

The marked difference in the abundance of certain oxide constituents which are common in either chlorite-biotite schist or biotite-quartz schist and the average pelitic rocks indicates that they are not geochemically similar. However,
the schistose rocks appear to be comparable with the known basaltic rocks so far as their total iron, magnesium and alkalies are concerned though the constituents are usually higher than those of chlorite-quartz schist. A close similarity in the abundance trends of total iron, magnesium and alkalies in the chlorite-biotite schist and Dhanjori volcanics may perhaps be due to their genetic relation. Earlier, Banorji (1974) regarded the rock unit as the metamorphosed equivalent of Dhanjori volcanics.

**Alteration trend of the host rocks**

The term 'wall rock alteration' is mainly used in connection with epigenetic hydrothermal ore deposits but in the case of the volcanogenic type of sulphide deposit, which is syngenetic in most cases, it is rather difficult to define the alteration as found in classical hydrothermal ore deposits (Meyer, C. and Namely, J.J., 1967). In the present case, the effect of alteration in the host rocks is largely guided by the remobilization leading to redistribution of the various chemical elements involved. However, the alteration zones adjacent to massive sulphide deposits in metamorphic rocks are commonly difficult to distinguish from regionally metamorphosed country rocks, particularly, belonging to the green schist facies.
The chloritization is more pronounced in the host rocks around sulphide lodes than elsewhere in them. The chemical composition of the rocks of the southeastern and central sectors indicate that the relative proportions of SiO₂, Al₂O₃, total iron (Fe₂O₃ and FeO), MgO, CaO, K₂O and Na₂O are such that they cannot be compared favourably with any regionally metamorphosed pelitic schists.

Considering the associations of the aforesaid components with different mineral constituents like chlorite, sericite, biotite and feldspar in the host rocks, an attempt has been made to represent them in a four-component system in a manner suggested by Riverson, G. and Hodgson, C.J. (1980) and examine their chemical trend with regard to alteration, if any. For a better presentation, the tetrahedron of the four component systems have been unfolded in the form of four triangles and the major oxide components were plotted separately for the two sectors (Figs. 9A-D, E-H). All the elements have been determined after recalculating their oxides in order to examine their mutual chemical trends and significance in terms of alteration of the feldspathic, ferromagnesium and micaceous minerals. It is evident that most of the plots (Fig. 9A) fall nearer to Fe + Mg corner indicating dominance of ferromagnesium minerals like chlorite over sodic feldspars.
Fig. 9 Triangular diagrams showing the variation of major constituents in the rocks of South-Eastern (A-D) and Central (E-H) sectors.
In figure 9B the plots lying slightly away from the Ca + Na - Fe + Mg tie line suggest the presence of plagioclase and chlorite along with a minor amount of biotite. The trend also suggests the dominance of ferromagnesian minerals over Ca + Na minerals. The plots of biotite schist follow a trend almost similar to that of feldspathic rock (Figs. 9A, B). There is a gradual decrease of Ca + Na towards the Al-corner and a slight shift of Ca + Na and Al trends towards the K-corner (Fig. 9C). This indicates that plagioclase and muscovite have suffered practically no chemical alteration except that plagioclase might have undergone slight sericitization.

The trend of plots of biotite schist is similar to that of feldspathic rock but without much indication of sericitization (Fig. 9C).

Most of the plots of the host rock and biotite schist (Fig. 9D) do not show any positive trend except that they are concentrated in the midway between and adjacent to Al - Fe + Mg tie line.

On the other hand, it is evident that the plots of host rock (Fig. 9E) in the central sector are concentrated towards the Fe + Mg corner with none towards the Ca + Na and Fe + Mg tie lines. This situation possibly suggests the dominance of chloritization and limited replacement of chlorite by biotite. The plots of chlorite-biotite schist are almost similar to
those of chlorite-quartz schist except that they have a
greater shift towards the K-corner which is obvious due to
the presence of biotite in the rock. In the case of biotite-
quartz schist, there is, however, very little shift from
the Ca + Na and Fe + Mg tie lines, which suggests that there
has been no alteration of the rock into sericite. It may,
therefore, be generally stated that all the three subunits of
the host rocks have nearly similar linear trends with increasing
Fe + Mg and decreasing Ca + Na.

The plots of the host rock and chlorite-biotite schist
(Fig. 9F) do not have any specific trend. However, the majority
of them falling adjacent to Al – Fe + Mg tie line only indicates
the existence of biotite and perhaps with a little of plagioclase. From the general trend of the plots (Fig. 9G) it is
evident that the concentration is more towards the Al-corner
than the Ca + Na-corner. It is imperative that the micaceous
minerals represented by Al have dominance over feldspar
represented by Ca + Na. The apparent shift of the plots of
biotite-quartz schist (Fig. 9H) towards Fe + Mg may be taken
as an indication of increase of biotite and chlorite in the
rock and gradual decrease of sericite. Though there is a
little shift in the plots of the host rock towards the K-corner
at the tail end of the triangle, they die out with a shift of
the plots towards Fe + Mg-corner.
Discussion

From the general trends of the major chemical constituents as indicated by their plots in most of the diagrams referred to above, it is somewhat obvious that the host rocks of both the sectors have more or less similar alteration trends. Though chloritization in the rocks, under study, provides an evidence of marked alteration as a result of increase in Fe and Mg constituents, yet sericitization and biotitization of the rocks have taken place though not to that extent as chloritization. MacGheon, P.J. (1978) also observed similar type of alteration trends in the host rocks adjacent to massive sulphide deposits of Matagami, Quebec, Canada. Wall rock alteration phenomenon associated with the hydrothermal sulphide ores was found to be most useful in interpreting the physical environment of ore deposition and zoning of minerals in terms of the movement of ore fluids and formation of some specific zones of alteration characterized by a particular set of mineral assemblages (Lowell, J.D. and Gilbert, J.M., 1970; Rose, A.W., 1970; Meyer and Hamely, 1967).

As far as the present case is concerned, the alteration of the host rocks has practically nothing in common with hydrothermal alteration as indicated above.
Analysis of geochemical data in relation to mineralogy of the host rocks

An attempt has been made to use the geochemical data particularly, of the oxides of major elements for verifying the mineralogical composition of the host rocks with the help of ACF diagrams as proposed by Winkler, H.G.F. (1967). In the ACF diagram (Figs. 10 and 11), the apices of the three components are $A = \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 - (\text{Na}_2\text{O} + \text{K}_2\text{O}); \quad C = \text{CaO} - 3.3 (\text{P}_2\text{O}_5); \quad F = \text{FeO} + \text{MgO} + \text{MnO}$, in which the demarcation lines have been adopted after Hutchinson, C.S. (1974). The feldspathic rock and the biotite schist of the southeastern sector are plotted on the diagram (Fig. 10). It is evident that most of the plots are located very close to AF join of chlorite-muscovite tie line, and the plots fall between F-32 and F-70.

From the distribution of plots (Fig. 10), it is apparent that they do not fall in the biotite/chlorite field. Most of the clusters are in and around the chloritoid field along the AF join and fall largely within the magnesian field.

In the diagram (Fig. 10) the plots of the subunit, biotite schist, have resemblance with those of feldspathic rock though slightly placed lower in the magnesian field.

In the same manner, the chemical constituents of host rock of the central sector (chlorite-quartz schist) along with those of its two other lithic units (viz., chlorite-biotite...
FIG. 10 ACFC DIAGRAM SHOWING THE COMPOSITIONAL REGIMES OF THE ROCKS IN MOSABONI AREA

FIG. 11 ACFC DIAGRAM SHOWING THE COMPOSITIONAL REGIMES OF THE ROCKS IN TAMAPAHAR AREA
schist and molyonitic biotite-quartz schist have been plotted on the ACF diagram (Fig. 11). It is evident that majority of the plots of chlorite-quartz schist are placed very close to the AF join as also those of other two units. The plots of biotite-quartz schist lie exactly within the biotite field but slightly deviate from the chlorite-muscovite tie line. The majority of the sample plots of the host rocks and their subunits of the southeastern and central sectors fall within the magnesian field. The conspicuous shift of the plots of the host rocks and chlorite-biotite schist towards and nearer the chloritoid field may be attributed to oxidation (see Turner, 1968). The position occupied by the plots in the diagram also indicates some deficiency of alkalies in the rocks of the central sector. From the foregoing observation, it is evident that the two sectors fall nearly in the same fields in the diagram but with minor shifting from the normal position. The depletion of alkali in the host rocks as well as its partial alteration and soda metasomatism is corroborated by the mineralogical assemblage and the distribution pattern of their oxide constituents.

Discussion

The petrochemical nature of a suite of host rocks associated with an ore body can usually be determined from unaltered or slightly altered rocks adjacent to or some
distance away from the lode. But the absence of unaltered rocks from the study area makes it virtually impossible to follow the restricted rule of geochemistry for investigating the original composition of the rocks. Nevertheless, a possible identification of the original nature of the host rocks has been attempted based mainly on their chemical composition and behaviour and comparing them with those of similar other known rocks elsewhere. The relation of chemical constituents with the mineralogical assemblages in the host rocks indicates (Figs. 10 and 11) that there is no visible discrepancy between them. It is evident that chlorite-quartz schist and the subunits do not generally show any resemblance either with the known acidic or pelitic rocks so far as their major oxides are concerned. However, the host rocks with abnormally higher ferromagnesium constituents show a tendency towards basic rocks and this is particularly more pronounced in the central sector. Chloritization and biotitization with limited metasomatism of the rocks coupled with pronounced silicification are the alteration processes which probably obliterated the original chemical nature of the parent rocks. There is ample evidence to conclude that the host rocks have suffered considerable alteration as a result of chloritization, biotitization and soda-metasomatism.

The distribution of some of the major chemical constituents of the host rocks supports the above statement. Though
the diagrams show that the host rocks have suffered considerable alteration due to chloritization, biotitization and soda-metasomatism yet it is difficult to identify precisely the original nature of the host rocks.

**The major oxides in Dhanjori Volcanics and their geochemistry**

**General Statement:**

The Dhanjori volcanics occurring close to the host rocks of copper have been encountered in both the sectors of the study area. They provide certain chemical as well as mineralogical evidences that indicate their alteration but to a limited extent by the post-igneous activities. Till todate no detailed account on the geochemistry of the Dhanjori volcanics are available except those of Ghosh and Banerji (1970) and Sarkar and Deb (1971), who tried to throw some light on the petrochemistry of the rocks based on a limited number of chemical determinations but without any observation on their relation with the sulphide mineralization.

**General chemical characteristics**

The analytical results of the rock samples collected from the two sectors do not show much differences in their chemical compositions. In the study of the altered lavas, the major problem arises as to what was their composition prior
to alteration and up to what extent the original composition was affected by post-igneous processes. Such processes tend to modify the original petro-chemistry resulting in redistribution of various petrogenetically important elements. Sometimes the chemistry of altered rocks may be confused with those of primary rocks from another environment. Therefore, the degree of such chemical changes should be known before reaching to any meaningful conclusion. The distribution of the various oxides and their frequency range have been presented in table 11. The chemical constituents of Dhanjori volcanics along with their ranges of abundance and average oxide ratios and C.I.P.W. norm have been shown in table 23 and the coefficient correlation in table 24. In terms of frequency diagram, the variation of major oxides in Dhanjori volcanics is presented in figure 12.

The average chemical and normative compositions of Dhanjori volcanics are compared with some other basaltic provinces of the world (Nockolds, 1954; Engels, A.E.J. et al., 1965; Melson, W.G. et al., 1968; Cann, J.R., 1971; Hart, S.R. et al., 1972) and shown in table 25. It is evident that the overall composition of Dhanjori volcanics is very similar to that of oceanic tholeiite with few exceptions where their $\text{Al}_2\text{O}_3$ content appears lower and FeO content higher than oceanic tholeiite. The chemical composition of Dhanjori volcanics shows that the rocks have more affinity towards the
FIG. 12 FREQUENCY DISTRIBUTION OF MAJOR OXIDES IN DHANJORI VOLCANICS
oceanic tholeiite than other basaltic rocks as indicated above.

**Effect of alteration**

In general, the higher contents of Fe$_2$O$_3$ and H$_2$O in basaltic rocks and their systematic relationship are considered to be the indices of secondary alterations (Miyashiro, A. et al., 1969). H$_2$O and Fe$_2$O$_3$/FeO contents of Dhanjori volcanics are plotted in a manner suggested by Miyashiro et al. (1971) and Cann (1969) and found that their relationship does not indicate any significant alteration of the volcanics (Fig. 13). On plotting various constituents of the Dhanjori volcanics in the ACN diagram (A = Al$_2$O$_3$-K$_2$O; C = CaO; N = Na$_2$O) as suggested by Jolly, W.T. and Smith, R.L. (1972), it was observed (Fig. 14) that the concentration of most of the plots fall in the field (I, unaltered basalt) and only three other points are slightly away from the field (I) but not fall within the fields (II) or (III). Therefore, the diagram also provides no evidence of alteration of the basalt.

**Geochemical classification of magma type**

The nature and origin of source material and the processes involved in the magma generation were investigated by various workers, who have suggested certain models on the basis of experimental and field studies (Yoder, H.S. and Tilley, C.E.,
The most commonly used method to distinguish the magma type of basaltic rock has been the alkali-sillia diagram (Kuno, 1959; McDonald, G.A., 1968) which matches well where there is little or no alkali redistribution. In the diagram (Fig. 15) which was constructed according to the alkali-sillia diagram of Kuno (1959) and McDonald (1968), all the plots except two fall in the tholeiitic field. The two plots which fall in calc-alkaline field may perhaps be due to the higher proportion of plagioclase in the volcanics. The quartz-normative nature of the rock has also been evident from the plots of Dhenjori volcanics on the normative diagram (Fig. 16).

Further, in the AFM diagram (A = Na_2O + K_2O; Σ = total iron as FeO; M = MgO, all represented in weight percent), the concentration of majority of plots above the dividing line in the tholeiitic field (Fig. 17) is an indication of tholeiitic nature of the basalt. The nature of the rock is further corroborated by the comparison of their average Fe_2O_3/FeO ratio with the tholeiitic rocks of other areas (Kuno et al., 1957). In order to distinguish between the composition of tholeiitic and alkaline basalts, their FeO*/MgO ratios (FeO* = FeO + Fe_2O_3 x 0.9) have been plotted against SiO_2 and FeO* according to the method adopted by Miyashiro, A.
FIG 13. H₂O VS Fe₂O₃ plots for Dhajori volcanics data for generalized submarine weathering trend and spilitization trend from Miyashiro et al. (1971) and Cann (1969) respectively.

FIG 14. ACN diagram (one face of ACFN of Jolly and Smith, 1972) of Dhajori volcanics showing the field of unaltered basalt.

FIG 15. Na₂O + K₂O vs SiO₂ plots of Dhajori volcanics showing their tholeiitic affinity.

and Shido, F. (1975). The curves in the diagrams (Figs. 18a,b) show that majority of the plots also lie within the tholeiitic field. The volcanics further indicate their oceanic environment as the TiO\(_2\)–K\(_2\)O–P\(_2\)O\(_5\) (Fig. 19) plots in the ternary diagram of Pearce, T.H. et al. (1975) fall in the field of oceanic basalt.

**Distribution trend and salient characteristic features of the trace elements of the host rocks and their subunits**

**General Statement**

Goldschmidt, V.M. (1937) made certain useful observations on trace element distribution in rocks and minerals and proposed a geochemical classification based on their chemical affinity and also stated that the distribution of chemical elements in the different phases depended on the electronic configuration of the atoms. Subsequently, Mason, B. (1958), Tauson, L.V. (1965), Burns, R.G. and Fyfe, A.C. (1966, 1967), Nockolds (1966), etc., added further valuable information on the trace elements.

No serious effort has been made by the earlier workers to study the trace elements of the host rocks of the study area, except perhaps by Ghosh (1972), who made a preliminary study of the trace elements of the rocks belonging to the central sector. In the present case, some of the trace elements
FIG 17  AFM (A-Na$_2$O + K$_2$O, F-TOTAL IRON AS FeO, M-MgO) DIAGRAM INDICATING THOLEIITIC FIELD OF DHANJORI VOLCANICS

FIG 18  (a) PLOTS OF SiO$_2$ VS FeO$^\text{Mg}$/MgO RATIO INDICATING THE THOLEIITIC FIELD (b) PLOTS OF FeO$^\text{Mg}$/MgO VS FeO$^\text{Mg}$/MgO RATIO INDICATING THE THOLEIITIC FIELD

FIG 19  K$_2$O - TiO$_2$-P$_2$O$_5$ - TERNARY DIAGRAM DEMONSTRATING OCEANIC BASALT AFFINITY OF DHANJORI VOLCANICS (After Pearce et al 1975)
such as Cu, Pb, Zn, Co, Ni, Cr, Rb and Sr in the host rocks were determined in an attempt to examine their relative geochemical abundance. The trace element abundance in the host rocks (Tables 26 and 27, Figs. 20 and 21) and their subunits are presented separately in tables 28, 29 and 30. A few trace elements which show anomalous values have been excluded though they are used in the calculation of the coefficient correlation (Tables 14 and 20). An attempt has also been made to compare the host rocks with the average metasedimentary and metavolcanic rocks of the Dharwar schist belt, South India, besides some of the average acidic and basaltic rocks of the world on the basis of their common trace elements. The variation trends of some of the trace elements in the rock samples, collected according to their spatial positions with respect to the ore zone or lode (i.e., nearest to, nearer to and away from the ore body) have been determined (Table 31, Figs. 22 and 23). The samples of feldspathic rock and chlorite-quartz schist were collected from the hanging wall side of the lode whether they are on the surface or in the underground sections. The samples of the subunits, viz., biotite schist and chlorite-biotite schist are collected from the footwall side whereas the samples of biotite-quartz schist are taken from the hanging wall side. All the samples of the above subunits are, however, collected only from their outcrops because they were not encountered in the underground mine sections.
FIG 20 HISTOGRAMS SHOWING RELATIVE ABUNDANCE (PPM) OF CERTAIN TRACE ELEMENTS IN THE HOST ROCK OF COPPER IN MOSABONI-BADIA MINES
FIG. 21 HISTOGRAMS SHOWING THE RELATIVE ABUNDANCE (PPM) OF CERTAIN TRACE ELEMENTS IN THE HOST ROCK OF COPPER IN TAMAPAHAR SECTOR, RAKHA MINES
Distribution trend

The salient characteristic features of the trace elements are presented as below:

**Copper** - Generally, copper varies appreciably in the feldspatic rocks in the southeastern sector, where it varies from 42 ppm to 510 ppm and the average being 81 ppm. Similarly, the element has a wider variation range (208 ppm to 1225 ppm) with a much higher average of 515 ppm in the chlorite-quartz schist. Contrastingly, chlorite-biotite schist and biotite schist on the footwall side are poorer in copper, their averages being 60 ppm and 45 ppm respectively. Likewise, biotite-quartz schist occurring on the hanging wall side is poor in copper with an average of 45 ppm. It may, therefore, be stated that copper in the host rocks occurring on the hanging wall side, has not only a wider variation but also higher average value than in the chlorite-biotite schist, biotite schist and biotite-quartz schist. Further, it may be stated that the abundance of the element increases in the host rocks across their strike and also towards the ore body.

**Zinc** - Zinc in the chlorite-quartz schist is slightly lower than in the feldspatic rock with an average of 34 ppm. On the other hand, the average values of the element in the biotite schist on the footwall side in the southeastern sector
FIG. 22 VARIATION DIAGRAMS OF THE TRACE ELEMENTS IN SCHISTOSE ROCKS, SOUTH-EASTERN SECTOR
FIG. 23 VARIATION DIAGRAMS OF THE TRACE ELEMENTS IN SCHISTOSE ROCKS, CENTRAL SECTOR.
and biotite-quartz schist on the hanging wall side in the central sector are almost identical. Both the rocks recorded slightly higher average values of zinc than in the feldspathic rock or chlorite-quartz schist. Zinc, like copper, has a tendency to increase in abundance in the host rocks across the strike and towards the ore body.

**Nickel** - The average nickel content in feldspathic rock is 90 ppm. The footwall rocks, viz., chlorite-biotite schist and biotite schist from both the sectors have a higher concentration of the element than in the hanging wall rock, biotite-quartz schist. Nickel in chlorite-quartz schist generally increases in abundance towards the ore zone. No such trend of Ni was, however, detected in the feldspathic rock.

**Cobalt** - The average concentration of cobalt in feldspathic rock is slightly lower than in chlorite-quartz schist. Its average values in chlorite-biotite schist, biotite schist and biotite-quartz schist are almost similar. Like nickel, cobalt also has a tendency to increase in abundance towards the ore zone in the host rocks.

**Chromium** - Chromium is concentrated slightly more in the chlorite-quartz schist than in the feldspathic rock as indicated by its average values in the two rocks. The concentration of the element is also higher in other subunits than in the host rocks.
Lead - The element has apparently no geochemical significance due to its presence in negligible amounts in both the feldspathic rock and chlorite-quartz schist.

Rubidium - There is not much difference between the average values of rubidium in feldspathic rock and chlorite-quartz schist. The highest average value of the element was recorded in biotite schist (106 ppm) on the footwall and the lowest one in the biotite-quartz schist (38 ppm) on the hanging wall sides. There is practically no difference in the concentration of Rb in the chlorite-biotite schist and the feldspathic rock.

Strontium - The concentration of strontium in the feldspathic rock is significantly higher than in chlorite-quartz schist. The average values of the element in the chlorite-biotite schist, biotite schist and biotite-quartz schist, however, do not vary much.

Evaluation

From the abundance of the trace elements and their trends of distribution, as found in the host rocks as well as the associated schistose sub-units, it is apparent that their trends in some rocks are similar and in others dissimilar. Accordingly, no definite opinion can be formed regarding the behaviour of the trace elements in the host rocks except that
the concentration of certain elements like Cu, Co and Ni increases towards the ore body. Such a trend may perhaps be suitably attributed partly to the mineralization activity and its metasomatic effect in the host rocks adjacent to the lodes. It is, however, a difficult task to throw any light on the original nature of the host rocks on the basis of these trace elements which do not show any definite similarity with those of some well-known igneous, acidic, metavolcanics, metasedimentary, basic or even the pelitic rocks of other parts of the world (Table 32). Moreover, among the trace elements determined in the host rocks, only Cu, Co, Ni were found to be occurring in much greater proportion than in those of known acidic (Wager, L.R. and Mitchell, R.L., 1951), granitic (Turekian and Wedepohl, 1961), metasedimentary (Naqvi, S.I. and Hussain, S.I., 1972) and pelitic rocks (Shaw, 1954). The only rock which is more or less comparable with the host rocks on the basis of the abundance of these trace elements is either the metabasalt of Dharwar schist belt (Naqvi and Hussain, 1973b) or the average basaltic rock (Turekian and Wedepohl, 1961). The average Ni:Co ratio in the host rocks are also appreciably higher than in those found in some well-known acidic, pelitic or basaltic rocks. The distribution trends of Cu, Co, Ni and Cr also do not provide any reliable support for their comparison with some of the known average rocks.
Trace elements and their characteristics in Dhanjori volcanics

Since some trace elements are sometimes known to provide useful evidences for the fractionation trend of the magma (Taylor, S.R., 1965; Gast, P.W., 1968; Haskin, L.A., et al., 1970; Wioll, D.F., et al., 1974), a preliminary study of some trace elements of the Dhanjori volcanics has been made for determining their trends in the rocks. The trace element data accompanying the element ratios are presented in table 33 and coefficient correlation in table 24. The study includes comparison of trace elements of the rocks with those of basaltic rocks of some other regions of the world (Table 34). The Dhanjori volcanics with the average of 70 ppm of copper appears to be deficient in Cu in comparison to the oceanic tholeiites (average 87 ppm) of Cann (1971); Hart et al. (1972) and Melson et al. (1968), average quartz-normative tholeiites, (141 ppm) average tholeiites (127 ppm) and average basalts (123 ppm) of Prinz, M. (1967) in table 34. On the other hand, the rocks appear to be significantly enriched in Ni in comparison to other basalts including the oceanic ones (Table 34). Like nickel, cobalt also shows a higher concentration trend in the rocks than in other basaltic suites including quartz-normative tholeiites (Cann, 1971; Hart et al., 1972; Melson et al., 1968 and Prinz, 1967). Chromium with a wider variation trend fall within the known values of oceanic tholeiites but in
comparison to other basalts it is higher (Table 34). The positive correlation among Co, Ni, Cr is fairly strong (Table 24). A wider variation of Cr: Ni ratio in the Dhanjori volcanics (1.39 to 2.49), which is comparable with the variation range found by Ghosh, N.C. and Trofimov, N.N. (1970) for the Precambrian basalt, may be also taken as an indication of its derivation from the upper mantle (see Turekian, K.K., 1963).

B. Geochemistry of ores

I. Ore samples

General statement

About 27 ore samples representing the four underground mine levels (Fig. 24; 23rd, 24th, 25th and 26th) in the north Badia section of Hosaboni mines and the 3rd level (Fig. 25) of Tamapahar (a section of Rakha mine) were selected and analysed for the determination of some of their important major, minor and trace elements. According to their level of abundance, Cu and Fe are categorised as major, Ti, Ni, and Co as minor and Cr, Zn, Nb, Sr, Pb and Mn as trace elements in the ore samples. The lateral interval of the sample locations at each level ranges between 15 and 80 metres.

The analytical data are presented in table 35 and 36, their levels of detection, precision, accuracy, etc., are given in table 3. The elemental abundances are also presented in histograms (Figs. 26 and 27). The lateral variation curves are given separately in figures 28 and 29. The mutual correlation
FIG 24 LEVEL MAP OF THE NORTH-BADIA SECTION (MOSABONI MINES) SHOWING LOCATION OF THE SAMPLES
coefficients of the eleven elements are calculated separately along with the significant level of the correlation data at 5 per cent for a better understanding of their correlation (see Dixon, K.J. and Massey F.J. Jr., 1951). They are shown in the tables 37 and 38.

Distribution trends of Cu, Fe, Ni, Co, Zn, Pb, Rb, Sr, Mn and Ti

Cu, Fe, Ni, Co and Zn in the ore samples of Mosaboni are relatively more abundant than in those of Tamapahar area. Only Pb is comparatively higher in the ore samples of Mosaboni than in those of Rakha mines. It is apparent from the chemical data that by and large the above five elements in the samples of the two sectors remain the same though quantitatively, they are slightly more in the Mosaboni mines than in Tamapahar (Fig. 33). A few samples in which the values of Zn, Mn, Rb, and Cr are anomalous have not been taken into consideration.

Discussion

The Cu and Fe ratios are higher than one in more than 50 per cent samples of the southeastern sector and 37 per cent of the samples in the central sector. Nickel is invariably dominant over cobalt and they have strong sympathetic relation (Tables 37 and 38) possibly due to the coexisting minerals of pyrite and pyrrhotite and such a relation was also observed by Galvlin, S. and Gabrielson, O. (1947); Richard, D.T. and
FIG. 26. HISTOGRAMS SHOWING THE CONCENTRATION OF THE METALLIC ELEMENTS IN THE ORE SAMPLES OF NORTH BADIA SECTION OF MOSABONI MINES.
FIG. 27 HISTOGRAMS SHOWING THE CONCENTRATION OF THE METALLIC ELEMENTS IN THE ORE SAMPLES OF RAKHA-TAMAPAHAR SECTOR, RAKHA MINES
FIG. 28 CURVES SHOWING THE VARIATION TREND OF THE METALLIC CONSTITUENTS IN THE SULPHIDE ORES OF NORTH BADIA SECTION OF MOSABONI MINES
Fig. 29 Curves showing the variation trend of the metallic constituents in the sulphide ores of Rakha-Tamapahar sector, Rakha Mines area.
Zweifel, H. (1975) in the sulphide ore of Skellfte, Sweden. The concentration of all the three minor elements, viz., Co, Ni, Cr is considerably higher in the ore samples of the study area than those of the vein type of porphyry copper deposits (Nash, T.J., 1975) in which Cu and Fe are much lower than those of the samples of the study area.

An attempt has also been made to establish the correlation of Fe and Cu with other elements as determined in the samples (Figs. 30A, B). In the southeastern sector (Fig. 30A) Fe does not show any significant relation with the other minor and trace elements except its fairly strong negative relation with Ti. On the other hand, Cu indicates positive relation only with zinc and almost insignificant with the others. This situation may probably suggest coexistent of the two elements at the time of ore formation. In the ores of central sector (Fig. 30B) Fe does not show any significant relation with other elements. The strong positive relation of Cu with Pb indicates the coexistence of Cu and Pb since their mineralization. There is a strong negative relation between Pb and Zn, Zn and Mn, Co and Sr in the ores of central sector and also between Ni and Mn, Co and Mn in the southeastern sector. The poor concentration of Cr may be attributed to its low solubility in sulphide phase. Similarly, Pb in very minor traces may be due to near absence of galena or potash feldspar. A comparison between the abundances of Co, Ni, Zn and Pb in the sulphide
FIG. 3o ABUNDANCE OF CERTAIN METALLIC ELEMENTS IN RELATION TO COPPER (A) AND IRON (B) IN THE ORES OF NORTH-BADIA SECTION OF MOSABONI MINES AND RAKHA-TAMAPAHAR SECTION
ores and their host rocks indicates that the elements have more or less similar trends of concentration though their proportions are relatively higher in the former.

II. Sulphide ore mineral fractions

Three predominant metallic minerals, viz., chalcopyrite, pyrite and pyrrhotite of the sulphide ores of Mosaboni and Tamapahar mines were separated and some of their trace element constituents were determined. The abundance and distribution trends of some trace elements in sulphide ore minerals often provide valuable information regarding the genetic type of the ore-deposit.

The trace element data in the ore minerals of southeastern sector (Mosaboni mines) and central sector (Rakha-Tamapahar section of Rakha mines) are presented in tables 39 and 40 and illustrated in the form of histograms (Figs. 31 and 32). It may be noted here that in the Rakha mines including the Rakha-Tamapahar section, mining has not been extended to more than a few levels while in the Mosaboni mines it has been done up to deeper levels. Accordingly, the levels from which the ores are collected from Tamapahar and Mosaboni areas are different.
FIG 31 HISTOGRAMS OF MINOR ELEMENTS IN THE ORE MINERALS OF NORTH BADIA SECTION (MOSABONI MINES)

FIG 32 HISTOGRAMS OF MINOR ELEMENTS IN THE ORE MINERALS OF RAKHA-TAMAPAHAR SECTOR (RAKHA MINES)

FIG 33 HISTOGRAMS SHOWING RELATIVE ABUNDANCE OF CERTAIN METALS IN THE COPPER ORE DEPOSITS OF SOUTH-EASTERN AND CENTRAL SECTORS
Distribution trend of the elements

Chalcopyrite - The average concentration of Co in chalcopyrite from Mosaboni and Tamapahar mines are 410 ppm and 320 ppm respectively. In most of the chalcopyrite samples of Mosaboni, Co is generally higher than those of Tamapahar area. The variation of Co in the chalcopyrite with depth in the Mosaboni mine does not show any definite trend though at the 24th level a little increasing tendency is indicated. There is practically no significant lateral variation of Co in the chalcopyrite of Tamapahar. The average concentrations of Ni in the chalcopyrites of two sectors (638 in Mosaboni and 646 in Tamapahar) is practically alike. Like cobalt, there is no significant variation in Ni with depth and that it also shows a slightly increasing tendency at the 24th level. The variation ranges of Mn and Ti in chalcopyrite are very narrow and almost insignificant both vertically as well as laterally in both the sectors.

Pyrite - The average concentration of Co in the pyrites of Mosaboni and Tamapahar mines, being 1242 and 1283 ppm respectively, indicates almost similar values. At the 25th level of Mosaboni mines it shows comparatively a decreasing tendency. Generally, Co and Ni do not show any depth-wise variation. The Mn and Ti in pyrites of both the sectors have almost similar trends.

Pyrrhotite - The lateral or vertical variations of Co, Ni, Mn and Ti in the pyrrhotites of the two areas are practically insignificant.
Evaluation

Among Co, Ni, Mn and Ti, the latter two elements do not show any relevance to the genetic types of the ores. Only the concentration of Co and Ni in significant proportions in the three different ore minerals may perhaps be used for determining the genetic type of the sulphide ore deposits. An attempt has been made to compare the average ratios of cobalt and nickel, with those of some well-known genetic types of sulphide deposits of the world like those of magmatic-hydrothermal and sedimentary.

The average Co: Ni ratios of chalcopyrites in the ores of Noseboni and Tamapahar area, being 0.61 and 0.47 respectively, are appreciably lower than those reported from the known hydrothermal ore deposits in which the average ratios are greater than one as reported by Haxel, J.E. and Nichol, I. (1961).

Similarly, the average Co: Ni ratios in pyrrhotites of the study area are less than one whereas their average ratios in the pyrrhotite of hydrothermal origin are greater than one (Thole, R.H., 1976). The unusually high amount of Ni in the pyrrhotites of the study area is probably due to the presence of exsolved nickel bearing mineral, pentlandite in pyrrhotite (cf. Loftus-Hills, G. and Solomon, M., 1967).

Usually, the average Co: Ni ratio in pyrites of sedimentary origin is limited to 0.63 (Price, B.G.in Bralia, A., et al.,
and in those of hydrothermal origin it ranges from 0.1 to 1.0 (Jørg, C. and Friedensburg, G., 1944). The Co:Ni ratios in pyrite of Mosaboni and Tamapahar area are 3.20 to 4.28 and 3.93 to 5.82 respectively. It is therefore, evident that the pyrites with much higher Co:Ni ratios could neither be of hydrothermal nor of sedimentary origin. On the other hand, the pyrites of Mosaboni and Tamapahar with limited variation range (3.20-5.82) may be regarded as mobilized pyrite deposits (see Bralia et al., 1979).