CHAPTER-V

DISCUSSION

In this chapter, the author has made attempts to discuss some significant aspects of ultramafics based on detailed petrological and geochemical investigations with reference to mineralisation during the present study. Petrological and geochemical data, their appraisal and interpretation in the light of relevant parameters available in literature comprise the thesis. The main rock types of the present study area are ultramafic complex and they indicate critical differences in lithology, lithologic association and geochemical affinity. Two distinct units of the complex are classified as

(a) Cumulate ultramafics and
(b) Tectonised peridotites.

Cumulate ultramafics are formed by accumulation of precipitated crystals called prime crystals in magma. The crystals in the cumulate rocks are non-interlocking but in contact as they do not crystallise in situ and accumulate generally through settling from magma body. These rocks are coarse grained, dark green to black in colour, comprise various proportions of olivine, clino-pyroxene, ortho-pyroxene and opaques. The cumulate ultramafic rocks are classified as dunite, harzburgite, lherzolite and wehrlite in the study area. Spinel group of minerals, mostly chromite, magnetite and platinum group elements are observed in these rocks.
The tectonised peridotites are characterized by partial to complete serpentinisation and also by penetrative schistosity. Coleman (1977) suggested that serpentinisation is due to the addition of water and removal of magnesium oxide. Complete serpentinisation results in a mesh-texture. Hess (1962) considers the serpentinisation to have taken place where mantle material is connected and crosses the 500°C isotherm. The tectonised peridotites of the study area are composed largely or entirely of serpentine minerals and are formed by alteration of ferromagnesian minerals such as olivine and pyroxenes. From the field observations, relict and partially altered grains of olivine, residual chromites, texture and field relationship among the peridotites show that tectonised peridotite bodies were formed by hydrothermal metasomatism of peridotites of alpine type. The internally brecciated and slickensided nature of the rocks in the mobile belts point, at least in some cases, to serpentinisation prior to final emplacement to their present sites of steep and rocky mountains.

Tectonised peridotites form the maximum assemblage of rock in Nunghar area. They are formed by alteration of ferromagnesian minerals such as olivine and pyroxenes. In tectonised peridotites, polished and slickensided or slip surfaces are visible (Plate-3). The degree of development of slicken slides and foliation or schistosity is the measure of syn- and serpentinisational movement. Serpentine appears as a complete or partial pseudomorph after olivine or pyroxenes. The alteration from olivine being most common and is also earlier than pyroxenes in the rock samples of the study area. It shows that olivines are easily altered to serpentine than pyroxenes. Three types of serpentine are recognised on the basis of structure:

(a) antigorite, (b) chrysotile and (c) lizardite.
The presence of the above minerals are confirmed by XRD at d-values at 7.31 Å (antigorite), 4.61 Å (lizardite) and 4.61 Å (chrysotile). The other minerals present are olivine, chlorite, enstatite, nickel, talc and opaque minerals. Their d-values are given in table-3.10. Mineral assemblages, alteration products and textures in tectonised peridotites are given in table -3.1. Harzburgite is the most dominant peridotite occurring in the ultramafics of the study area. Normally, the rock shows shades of superficial serpentinisation, schillerization and bronzy lustre. Slickensides and striations are observed in some rocks. Owing to weathering the resistant minerals like bronzite protrude out on the surface and a characteristic structure known as Hob–nail structure is formed (Plate -5). In some samples olivine grains are surrounded by OPX minerals, and the OPX in turn are found altered to greenish chlorite and talc. The d-value of chlorite and talc are given in table-3.10. Serpentes altered from olivines are associated with chromite and magnetite. OPX minerals are represented by enstatite, hypersthene and bronzite. The intergranular boundaries are more or less sharp indicating the cumulate nature of the rock (Plate-9). CPX is represented by diopside and augite. Bronzite is the main constituent mineral of the rock. Inclusions are common in bronzite and produce what is known as schiller structure (Plate -10).

The modal composition of harzburgite for olivine, OPX, CPX and opaque are shown in table -3.2. The mean modal values of the above minerals are 70.00, 23.00, 2.00, 5.00 respectively. The opaque minerals are separated into chromite and magnetite through ore microscopic studies and confirmed by XRD at 2.44 Å for chromite and 2.97Å for magnetite.
Lherzolite is the next dominant member of peridotite in the ultramafics of the study area. The rock is found to be composed of olivine, OPX with appreciable amount of CPX and a few opaque minerals. The rock shows hypidiomorphic granular texture. Tabular grains of OPX showing corroded margins are sometimes found enclosed within larger grains of clino-pyroxene. This suggests that the sequence of crystallisation was olivine – orthopyroxene – clinopyroxene.

Sometimes lamellae of CPX are present within OPX and cut across the prismatic cleavage of OPX (Plate-8D). This indicates probable crystallisation temperature for the particular composition of pyroxene (Philpotts, 1989). OPX (enstatite) shows pressure shadow and bent lamellae as reflection of post – deformation phases. CPX is represented by diopside and augite. Fine grained CPX develops bordering olivine grains and along the intergranular spaces which are thought to have resulted due to reaction between olivine and interstitial liquid and indicates second order of generation. The modal composition of lherzolite is shown in table -3.4.

Wehrlite is a rare variety of peridotite in the study area. Olivine and CPX are abundantly present. CPX is represented diopside and augite. Most of the CPX grains are fractured which may be indication of high degree of shearing (Plate-7B). CPX is altered to chlorite and alteration is of lesser degree as shown by chlorite colour. Two generations of CPX are found, one being the phenocryst type and other fine-grained matrix type (Plate-7A). OPX is represented by few grains of enstatite and bronzite which exhibit strain effect by presence of bent lamellae. Modal composition of wehrlite is shown in table -3.6.
Dunite is one of the important members of the ultramafic rocks. The rock occurs abundantly along the Siroi range in the form of lensoid body (Plate-4). It contains relict of olivines, but otherwise it passes into peridotite. Deformation lamellae are often observed in many of the grains with corroded margins in different shape and size within the altered olivine. Bent lamellae caused by deformation are well developed in the olivine grains (Plate-12A). Granules of magnetite and chromite are found to arrange in linear fashion along the border and fracture networks of olivine grains indicating alteration of olivine to serpentine and released of opaque phases (Plate-12B&12D). The minerals present are confirmed by XRD peak values as shown in table -3.10. The ultramafics are classified according to their mineral composition based on Streckeisen (1973) as dunite and peridotites (harzburgite, lherzolite and wehrlite). The classification of ultramafics are shown in table -3.11.

On the basis of observation made by major, trace and Platinum Group Element (PGE) geochemistry of the rock types, the following points are discussed.

In the present geochemical studies, the value of Fe/Mg ratios of tectonised peridotites and cumulate ultramafics fall in a wide range. In tectonised peridotites, Fe/Mg value ranges from 0.26- 0.38 and for cumulate ultramafics, the value ranges from 0.29-0.57. This wide ranges indicate the igneous origin of the studied rocks. The narrow ranges of Fe/Mg ratio is meant for metamorphic origin (Ranjit,2002). Though, the tectonised peridotites of the study area are of igneous origin, the rocks experienced metamorphic environment as shown by texture, structure and alteration of minerals to serpentines.
The low SiO₂ content ranging from 36.16 to 37.56 (wt %) which mark tectonised peridotite. The SiO₂/MgO ratios in these rocks are nearly one and are good agreement with the tectonised peridotites occurring in the neighbouring Nagaland Ophiolite belt.

The high value of LOI (16.43 – 19.28)wt.% indicates high degree of serpentinisation. The main oxides SiO₂, MgO and FeO⁴⁺ constitute more than 80% of the average composition of the rock after deducting H₂O (LOI) restricted in all samples of tectonised peridotites. Compared to cumulate ultramafics, tectonised peridotites contain low SiO₂, Al₂O₃, CaO and high MgO.

The refractory mineralogy is also reflected by the high magnesia content in bulk composition of the rock i.e. MgO/MgO+FeO ratio varies from 0.77 to 0.83. Compared to tectonised peridotite, the cumulate ultramafics have wider SiO₂/MgO ratios (1.12 to 1.48) for harzburgite, (1.24 – 1.35) for dunite, (1.46 – 1.49) for lherzolite and (1.61 – 1.74) for wehlrite.

In wehlrite, SiO₂/MgO ratio is higher than other ultramafics of the area. The CaO/MgO ratio of wehlrite is also higher than other ultramafics of the same area. This is due to the presence of Ca-bearing minerals in the rocks which is supported by petrographic data. In the ternary plot of AFM (Fig.- 4.13), (A=Na₂O+K₂O, F= FeO⁴⁺ and M= MgO), all the points fall in the field of early differentiates and accumulate (Thayer,1969). The feature indicates that the cumulate ultramafic rocks of the study area were derived from an alkali-deficient and highly magnesian magma (Laurent et al., 1979). In the ternary plot of MgO-CaO-Al₂O₃, all the analysed ultramafic samples fall in the field of cumulate ultramafics (Venkataramana, et al., 1986). Again, all the samples of the studied rocks are concentrated in MgO corner and these reflect parental magma chiefly
of picrite. A comparison of the MgO/MgO+FeO ratios for tectonised peridotites and cumulate ultramafics have been made after deducting water (table-4.5). The ratio MgO/MgO+FeO has been calculated that all Fe₂O₃ is converted to FeO. The above ratio shows a range (0.77-0.83) with a mean value of 0.80 . The ratio is rather low (0.77) in the case of cumulate ultramafics. The above variation in the ratio reflects mainly the change in the composition of coexisting olivine and pyroxene. This phenomenon can be illustrated by the binary plots of 100 X MgO/ MgO+FeOᵣ with CaO, FeO, MgO and Al₂O₃ (Figs.4.15-4.16).

The Plots of MgO vs 100X MgO/MgO+FeOᵣ (Fig.4.15) shows that the MgO values of peridotites- harzburgite, lherzolite and wehrlite increase with the increasing 100X MgO/MgO+FeOᵣ value. Dunites are not showing any peculiar distribution pattern. Tectonised peridotites are also showing the same pattern/trend with peridotites of the study area (Figs.4.15-4.18) This shows that serpentinisation is an isochemical process except for the introduction of water. In (Fig.4.16), the value of 100X MgO/MgO+FeOᵣ of lherzolite, wehrlite and harzburgite decreases with the increasing CaO. The same pattern can be seen in tectonised peridotites also. It shows that the element (Mg⁺²) double charge is already substituted for (Ca⁺) with structural and textural changes. The amount of substitution is less in wehrlite and lherzolite. However this relation cannot be seen in dunites of the present area.

In (Fig.4.15), the value of 100X MgO/MgO+FeOᵣ decreases with increasing FeO. It shows that iron plays an important role in the formation of ultramafics of the study area. In (Fig. 4.17), Al₂O₃ increases with decreasing 100X MgO/MgO+FeOᵣ in case of tectonised peridotites. It is due to the presence of chlorite as altered product and partial alteration of augite. The same trend is also followed by lherzolite.
Fig. 4.13: A (Na₂O₃ + K₂O) - F (FeO⁰⁻) - M (MgO) PLOTS FOR ULTRAMAFIC CUMULATES AND TECTONISED PERIDOTITES OF THE STUDY AREA. (after Chattopadhyay et al., 1986)
FIG. 4.14: CUMULATE ULTRAMAFICS : PLOTED ON MgO- CaO-Al₂O₃.
( after Venkataramana et al, 1986 ).
FIG. 4.15: PLOTS OF 100 x MgO/ MgO + FeO Vs FeO & MgO OF CUMULATE ULTRAMAFICS, STUDY AREA.
FIG. 4.16: PLOTS OF 100x MgO / MgO + FeO Vs Al₂O₃ & CaO OF CUMULATE ULTRAMAFICS, STUDY AREA.
FIG. 4.17: PLOTS OF 100 x MgO/ MgO + FeO Vs FeO & Al₂O₃ OF TECTONISED PERIDOTTITES, STUDY AREA.
FIG. 4.18: PLOTS OF 100 x MgO/ MgO + FeO VS MgO & CaO OF TECTONISED PERIDOTITES, STUDY AREA.
FIG. 4.19: PLOTS OF $100 \times \text{MgO}/(\text{MgO} + \text{FeO})$ Vs $\text{TiO}_2$ & $\text{MnO}$ OF TECTONISED PERIDOTITES, STUDY AREA.
FIG. 4.20: PLOTS OF 100 x MgO/ MgO + CaO Vs Na₂O & K₂O OF TECTONISED PERIDOTITES, STUDY AREA.
FIG. 4.21: PLOTS OF SI Vs MgO & FeO OF CUMULATE ULTRAMAFICS, STUDY AREA.
FIG. 4.22: PLOTS OF SI Vs CaO & Al₂O₃ OF CUMULATE ULTRAMAFICS, STUDY AREA.
FIG. 4.23: PLOTS OF SI VS MgO & FeO OF TECTONISED PERIDOTITE, STUDY AREA.
FIG. 4.24: PLOTS OF SI Vs CaO & Al₂O₃ OF TECTONISED PERIDOTITE, STUDY AREA.
FIG. 4.25: PLOTS OF 100 X MgO/MgO + FeO Vs TiO₂ OF CUMULATE ULTRAMAFICS, STUDY AREA.
In wehlrite, Al$_2$O$_3$ increases with increasing value of 100XMgO/MgO+FeO$^{(0)}$. This is due to the presence of augite mineral in wehlrite as clinopyroxene. In the binary plots of Al$_2$O$_3$ and 100x MgO/MgO+FeO, dunite and harzburgite do not show any peculiar distribution pattern. It shows that the rocks are not influence by aluminium bearing minerals. The plots variation of various oxides with the solidification index (SI=100X(MgO/MgO+FeO$^{(0)}$ +Na$_2$O +K$_2$O) (Figs.4.21-4.24.) of cumulate ultramasics and tectonised peridotite indicates that they are a comagmatic sequences. The plots of TiO$_2$ vs 100X(MgO +FeO of tectonised peridotites and cumulate ultramasics (Fig.-4.21&4.22) show the same trends which indicate comagmatic sequence as Ti is an immovable element. The other plots 100X(MgO/MgO+FeO vs FeO, MgO and CaO of both tectonised peridotites and cumulate ultramasics show the same trends except Al$_2$O$_3$ (Figs. 4.15,4.16&4.18). The ratios of MgO: FeO of alpine type of ultramafic compositions drop in range from 9:1 to 3:1 in peridotites (Thayer, 1960). Majority of MgO/FeO ratios of the present ultramafic samples fall within the alpine composites.

The Cr, Cu, Ni, Rb and Sr are the trace elements analysed from the ultramafic samples of the study area to decipher petrographic parameters. The Ni-content of a serpentinite is directly related to that of the parent rock from which it was derived (Edel'shtein, 1963). The Ni concentration in the studied samples ranges from 2450 to 2766 ppm with an average value of 2589 ppm. The Ni values can be correlated with the suite of serpentinite (Hess and Otalora, 1964), dunite of Shangshak - Shingcha (Ranjit, 2002) and alpine type rock (Wedepohl, 1963). The Ni increases with the increasing MgO but there is no well defined relationship between FeO and Ni. Iron does not play any role in the Ni concentrations. The Ni values of the present samples are within the values of ultramasics.
(1000 to 4000 ppm) given by Hess and Otalora, (1964). On the basis of Ni concentration of the ultramafic rocks, the rocks of the study area can be correlated with those of alpine type rocks. The chromium content in the ultramafic rocks is high in comparison with those of other ultramafics except some ultramafics of Karnataka given by Hussain and Raju, (2005) and world ophiolite (Coleman, 1977). In the present samples, the chromium shows sympathetic relations with MgO but antipathetic relation with iron (Fig.4.8). The high content of chromium could be related with the occurrence of chromite in the ultramafics of the area.

Rb along with Sr is of great interest because of potentialities of the Rb-Sr, decay system for investigating the relationship between the crust and mantle. The Rb data of the studied rock samples is two times more than those of meta ultramafics and ultramafic intrusion given by Chattopadhyay (1983), Stueber and Murthy, (1965) respectively. The ratio of the Rb/Sr values are given in table-4.30. Majority of the ratios of samples can be correlated with the ratios of the alpine type intrusion (0.08) given by Roe et al.,(1965) and (0.07) of ultramafic inclusions given by Stueber and Murthy (1965). In recent years, a great deal of attention is being paid in studying ophiolite in order to better understand the core-mantle intrusion, chemical evolution of the upper mantle and to explore their noble metal potential. This is because, Platinum Group Elements were effectively and quantitatively fractionated into the core and mantle, leaving the crust strongly depleted, during the formation of the earth. In the rocks of the study area, the amount of IPGE content is less than PPGE content. The high IPGE content are normally derived/ fractionated as primary magmatic alloys from mafic magma whereas the enrichment of PPGE content are due to partial melting and crystal fractionation of basaltic magma.
Fig. 4.26: Plots of chrome-spinel on Cr/(Cr + Al) Vs Mg/(Mg + Fe) discrimination diagram of alpine type peridotite and abyssal peridotite of the study area (after Dick & Bullen, 1984)
In contrast to it, the PGE content in the ultramafic of southern Tibet (Hussain and Raju, 2005) show the enrichment in Os, Ir and Ru relative to Rh, Pt and Pd are believed to have formed from a boninitic magma produced by a second stage of melting. The extensive fractionation of the magma would have led to a large increase in Pd and Pt content but a decrease in Ir, Os and Ru (Keays, 1995). On the basis of PGE data – that is the relative enrichment of PPGE over IPGE, the ultramafic rocks of the study area are formed by partial melting and crystal fractionation of basaltic magma which is supported by ternary plot of MgO-CaO-Al₂O₃ (Fig.4.14). In the plot all the analysed samples of the study area are found to concentrate in MgO corner and this reflects parental magma chiefly of picrite. The mineral chemistry data, particularly very high Mg/(Mg+Fe) ratio of the olivine are comparable with that of alpine oceanic peridotite and are considered as residual part of the partial melting of the upper mantle rocks (Dick and Fisher, 1983). The chrome-spinel numbers show limited range from 0.2910 to 0.3236, suggesting a partial melting for some of the peridotites. The chrome-spinel associated with the ultramafic rocks of the area are in conformity with the accepted origin of alpine type peridotite formed due to partial melting and consequent magma generation in the mantle (Dick, 1977b). The compositional feature of the chrome-spinel from the present rocks reflect the various tectonics settings. It can be seen from the plots of Cr/(Cr+Al) vs Mg/(Mg+Fe) that the compositional features reflect the oceanic environment i.e., the field of alpine peridotite and abyssal peridotite of Dick and Bullen (1984). It is worth to mention that the whole rock chemistry of neighbouring Nagaland Ophiolite indicates the possible tectonic setting to be oceanic island chain or nonspreading aseismic ridge, comparable to those of Indian ocean (Venkataramana et al, 1986).