CHAPTER-VI
SUMMARY AND CONCLUSION

The thesis embodies the data accruing from a detailed and diversified investigations carried out by the author in one of the most representative ultramafic assemblages of the ophiolitic belt of the Manipur –Nagaland Orogenic belt (MNOB). It encompasses the area between latitudes $25^\circ05'\text{N}$ and $25^\circ16'\text{N}$ and longitudes $94^\circ20'\text{E}$ and $94^\circ34'\text{E}$ bounded by Siroi and Nunghar of the Ukhrul district in the state of Manipur, India (Fig.-1). Ultramafic rocks are important members of the ophiolitic complex. The term "Ophiolite" is derived from the Greek term "ophi" that means snake or serpent. Because of the resemblance of certain species of snakes with the greenish, mottled and shiny appearance of serpentinite, these rocks came to be known as "Ophiolite" a synonym for serpentine used by European geologists. However, different workers used this term not with the same meaning during the late 19th and 20th century.

The term "ophiolite" was first used by Brongniart as early as 1827 to describe serpentinites and found use only in European and Russian literature. Steinmann used the term for the serpentine-diabase-spillite-radiolarian chert. At present "ophiolites" refer to a distinctive assemblage of mafic to ultramafic rocks often capped by layers of sediments
interlayered with volcanics. In completely developed sequence, the rock types from the bottom upward occur as (1) Ultramafic complex, usually with a metamorphic tectonite fabric, more or less serpentinitised, (2) Gabbroic complex, ordinary with cumulus peridotites and pyroxenites, grading upwards into layered gabbros, often containing plagio-granite differentiates at the top, (3) Sheeted dyke and dyke breccias, (4) Pillow lavas/basalt.

The Manipur-Ophiolite Belt runs discontinuously for a length of about 110 kms. with width varying up to 10 kms. as an extension of Manipur-Nagaland ophiolite Belt from Jessami in Ukhrul district to Moreh in Chandel district of Manipur (Fig.2). The belt continues up to Andaman-Nicobar island and has an accurate shape trending NNW-SSE to NE-SW direction. The ophiolites in Manipur-Nagaland Ophiolite Belt constitutes ultramafic, mafic and associated sediments. The principal theme of the work is to identify all the signatures decipherable in the ultramafics which could help in understanding the ultramafic geology of the area in keeping with the progress made in the field world over and astounding changes in geodynamic concept which are often applied to explain the MNOB evolution.

The endeavor as per the theme of this work has been to obtain the possible data by encompassing geological, petrological and geochemical methods of investigation in order to use these basic data for an authentic and modern appraisal without hypothesizing the formulations arrived at. The author has, therefore, reviewed all the published literature and attempts have been made to discuss the present data in relation to most of the observations given by various researchers in respect of ultramafics of Manipur state and some of the thoroughly investigated ultramafics of the
world. Besides, the routine methods of investigations, X-Ray Fluorescence (XRF) spectrophotometry, Fire Assay and Electroprobe Analyser (EPMA) have been used to obtain major oxides, trace element, PGE, etc.

The geological and stratigraphic data obtained by the author in relation to those published by various workers have been presented in the second chapter of the thesis. After a reconnoitring survey, the author has geologically mapped the study area on the scale 1:50,000.

A very detailed petrographic account of ultramafic rocks in the study area has been discussed in Chapter-III. The petrographic investigation aims at the determination of textural, structural and mineralogical characteristics in the rocks. One of the main objectives of the petrographic study is to classify the ultramafic rocks. The serpenitinisation of the olivine rich rocks makes it difficult for megascopic identification of the original lithological units. Microscopically, the original mineralogy and rock type can be distinguished and primary rock names are used in the petrographic classification. The petrographic classification of the ultramafics proposed by Streckeisen,(1973), have been followed. On the basis of modal composition of Streckeisen (1973), the following rocks are noticed in the study area.

1. Dunite (ol = 92.40, OPX = 4.60, CPX = 1.40 and opaque = 1.60)
2. Harzburgite (ol = 70.00, OPX = 23.00, CPX = 2.00 and opaque = 5.00)
3. Wehrlite (ol = 69.00, OPX = 3.33, CPX = 24.66 and opaque = 3.00)
4. Lherzolite (ol = 62.43, OPX = 20.14, CPX = 13.71 and opaque = 3.71)
Not only the above ultramafic rocks, some altered ultramafics (tectonised peridotite) are also encountered in the field and studied. The mineral assemblages and altered products/minerals of tectonised peridotites are given in table -3.1. The classification of ultramafic rocks are given in table -3.11. Harzburgite and dunite are the dominant rock types in the study area. The minerals are identified through binocular microscope and confirmed by X-Ray Diffractogram (XRD) studies. The d-values along with the minerals are given in table-3.10. Well controlled samples of ultramafic rocks of the study area were chemically analysed for their major, trace and PGE content. The data have been discussed with the help of some variation diagrams to ascertain their chemical composition, the abundance of elements and to decipher the tectonic setting of the ultramafics.

The analysed data of different rocks are presented separately for detailed studies. The major oxides (wt %) cation (%), ratios of oxides and cations of tectonised peridotites are presented in tables- 4.1, 4.2, 4.5 and 4.6 respectively. Correlation of cations are also represented in table- 4.2. The SiO₂/MgO ratios of the tectonised peridotites ranges from 1.08 to 1.15 with an average value of 1.10 that is nearly one and are in good agreement with the tectonised peridotites occurring in the ophiolite belt of Nagaland. The high value of LOI (16.43-19.28) indicates high degree of serpentinisation. Compared to cumulate ultramafics, tectonised peridotite contains low SiO₂, Al₂O₃, CaO and high MgO. The MgO/MgO+FeO⁰ of tectonised peridotite shows a range (0.77 to 0.83) with a mean value of 0.80 and cumulate ultramafics shows an average value of 0.77. The ratios of CaO/MgO (table-4.5) of tectonised peridotites are almost nil. This is due to low content of CaO (wt%) and high MgO (wt%) of the rocks and also due to the alteration of Ca-bearing minerals mostly diopside and
augite. During transformation, Ca\(^+\) is replaced by Mg\(^+\). The higher concentration of MgO in all the samples suggest that the parental magma to be chiefly of a picrite. In (Fig.4.17), Al\(_2\)O\(_3\) increases with decreasing 100XMgO/MgO+FeO\(^0\). It is due to presence of chlorite as altered product and partial alteration of augite.

Only 5 (five) samples of dunite were selected for chemical analysis and the oxides data are presented in table-4.14, cation in table-4.15 and ratios in table-4.18. The SiO\(_2\) of the dunites of the study area is higher than the dunites of other area. This is due to the partial conversion of olivine to serpentine, presence of silicate minerals and chlorite in the rock. The high value of Al\(_2\)O\(_3\) and CaO is the characteristic of cumulate nature of the rocks (Ranjit, 2002). The MgO of dunites of the study area are somewhat less than other dunites. MgO has antipathetic relation with CaO. With the increase of CaO the value of MgO decreases (Fig. 4.2). The LOI of dunites ranges from 9.45 to 13.57 (wt\%) with an average value of 11.33 (wt\%) which is lower than other peridotites of the same area. The value shows that less serpentinisation occurs in dunite than peridotites. The ratio of MgO/FeO ranges from 3.05 to 3.42 with an average value of 3.20. The values of MgO /FeO ratio of dunite fall within the alpine composites (Thayer, 1960). In the ternary plots (Fig.4.14) of MgO-CaO-Al\(_2\)O\(_3\), all the analysed samples of dunite fall in the field of cumulate ultramafics (Venkataramana et al., 1986). All the samples are concentrated in MgO corner and these reflect parental magma chiefly of picrite.

Ten representative harzburgite samples were selected for chemical analyses. The major oxides (wt\%) is given in table-4.7, and the cation in table-4.8.
The SiO₂ of harzburgite ranges from 39.18-41.13 (wt%) with an average value 40.50 (wt%). The MgO ranges from 27.06-29.21 (wt%). The SiO₂/MgO ratios of harzburgite ranges from 1.21 to 1.48. The values are higher than tectonised peridotites of the same area. The ratio values of SiO₂/MgO of ultramafics fall within the values of cumulate ultramafics (Venkataramana et al, 1986). The MgO/FeO ranges from 3.05-4.36 with an average value 3.37. The values fall within the alpine composite (Thayer,1960). From the (Fig.4.14) of MgO-CaO-Al₂O₃, it can be seen that all the samples of harzburgite are concentrated in MgO corner and these indicate parental magma chiefly of picrite. In the ternary plot of AFM (Fig.4.13), all the analysed samples fall in the field of early differentiate and accumulate. It shows that the cumulate ultramafic rocks of the study area were derived from an alkali-deficient and highly magnesia rich magma. The (Fig.4.15) shows that the MgO values of harzburgite increases with the increasing 100 X MgO /MgO + FeO. The value of CaO decreases with the increasing 100 X MgO/ MgO+ FeO⁰⁻¹ (Fig.4.16 ). The ratio of MgO/ MgO + FeO of harzburgite ranges from 0.74 to 0.81 with an average value of 0.77 which is lower than tectonised peridotite but similar with dunites and lherzolite of the study area. In harzburgite CaO/MgO value ranges from (0.01 to 0.07) which is higher than those of tectonised peridotites.

In lherzolite and wehrlite, SiO₂ (wt%) ranges from 40.99 to 41.28 and 39.65 to 41.26 respectively. CaO (wt%) ranges from 4.33 to 4.81 in lherzolite and 10.06 to 11.86 (wt%) in wehrlite. The high content of CaO in the rock is related with the presence of pyroxene minerals like diopside and augite (CPX). The CaO shows antipathetic relationship with MgO in both the cases. MgO increases with the decreasing CaO. The values of
LOI of the two rock types are somewhat less than those harzburgites and tectonised peridotites but more than those of dunites. It shows that partial alteration took place in these two rock types. SiO$_2$/MgO values of lherzolite ranges from 1.46 to 1.56 and 1.90 to 1.97 for wehrlite. The values of SiO$_2$/MgO of both lherzolite and wehrlite show the characteristic of cumulate ultramafics. The CaO/MgO ratio of lherzolite ranges from 0.15 to 0.22 which is higher than those of dunite and harzburgite but less than that of wehrlite. Wehrlite has got highest CaO/MgO value, which ranges from 0.46 to 0.59. The highest ratio value in wehrlite is due to the presence of Ca-bearing minerals like diopside and augite in the rock which are supported by petrographic investigation. The value of MgO/FeO ratios are less due to the decrease of MgO.

The trace element data accruing from the analysis of the studied rocks are presented in table -4.30. The chromium concentrations in the ultramafic rocks of the study area ranges from 2230 to 3370 ppm with an average value of 2636.38ppm. In the studied rocks, the chromium has sympathetic relation with MgO and also shows slight antipathetic relationship with Fe$^{0}$ (Figs. 4.8 & 4.9). The present Cr data can be correlated with Cr content in ultramafic rocks given by Wedepohl (1963) and in dunites of Shangshak-Shingcha, Ukhrul given by Ranjit (2002) and ultramafic given by Stueber and Goles (1967). The nickel concentration in the ultramafics of the study area ranges from 2450 ppm to 2766 ppm with an average value of 2589 ppm. In the binary plots (Figs. 4.11& 4.12) between Ni vs FeO and MgO, the Ni increases with increasing MgO but there is no well defined relationship between FeO and Ni. It shows that iron does not play any role in the nickel concentration within the rocks. The ultramafic rocks in general should be between 1000 and 4000 ppm Ni (Hess and Otalora,1964). The Ni values
of the studied rocks are within the values given by the above authors. The Ni data can be compatible with the Ni content in the dunite of Shangchak-Shingcha, Ukhrul (Ranjit, 2002), Suite of Serpentinite (Hess and Otalora, 1964) and alpine type rock (Wedepohl, 1963). The high content of Cr and Ni are the result of their substitution for Mg and Fe (Watson, 1967). Rubidium concentration in the rocks of the study area ranges from 5 ppm to 8 ppm with an average value of 5.42 ppm. The Rb data of the studied rocks is more than those of ultramafics given by Hussain and Raju (2005), Chattopadhyay (1983) and Alpine type inclusion and intrusion given by Stueber and Murthy (1965). The high content of Rb in the ultramafic rocks of the study area could be related with the K content (from 500 ppm to 700 ppm) The strontium (Sr) content in the rocks of the study area ranges from 10 ppm to 106 ppm with an average value of 36.60 ppm. This element, along with Rb is of great interest because of the potentialities of the Rb-Sr, decay system for investigating the history of the relationship between the crust and mantle. The ratios of Rb/Sr values are given in table-4.30. Majority of the ratio values of the rock samples can be correlated with the ratios of the alpine type intrusion (0.08) given by Roe et al (1965).

Only 5 (five) representative samples were selected for PGE analyses at NGRI, Hyderabad by using Fire Assay technique. The PGE data are presented in table-4.36. Nowadays, a great deal of attention is being paid in studying ophiolites in order to better understand the core-mantle interaction and chemical evolution of the upper mantle. The PGE content in dunite, harzburgite, wehrlite, lherzolite and tectonised peridotite (excluding Au and Ag) are 490 ppb, 445.4 ppb, 547 ppb, 511.2 ppb and 577.2 ppb respectively.
In the studied samples of the area, the amount of IPGE content is less than PPGE content. It shows that the ultramafic rocks of the study area are formed by partial melting and crystal fractionation of basaltic magma. The PGE content in the ultramafic of southern Tibet show the enrichment of 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 (Hussain and Raju, 2005). 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).

The olivine, ortho-pyroxene, clino-pyroxene and Cr-spinel are the four minerals analysed by Electron Prope Micro analyser. The Mg-number or Mg/(Mg+Fe) of olivine are similar with alpine type and abyssal peridotite of Saluvesi ophiolite (Monnier et al., 1995). The data of Cr-spinel chemistry are comparable with those of alpine-oceanic peridotites and can be considered as residual part of the partial melting of the upper mantle rocks. Some of the residual fragments experienced metamorphic environment and represent the tectonised peridotites in the present area. From the (Fig.4.26) i.e. the plots of 100Cr/(Cr+Al) vs 100Mg/(Mg+Fe), it can be concluded that the ultramafic rocks of the present study area belong to abyssal peridotite and alpine type.