CHAPTER-5

MINERAL CHEMISTRY

5.1 Introduction

The mineral assemblage and the relationship of various minerals are essential criteria for establishing its metamorphic evolution. Aside from that, the chemical composition of these coexisting minerals is vital in understanding metamorphic evolution because it aids in describing mineralogy and estimating the *P–T* condition of metamorphic rocks. A complete description of minerals and their textural relationships with each other of different rock types of the BuC has been discussed in detail in petrography (chapter 4). This chapter represents the mineral chemistry of different minerals using the Electron Microscope Analysis (EPMA). The EPMA method is helpful because it displays chemical variation inside a mineral grain and chemical equilibrium regions. Most of the other analytical techniques yield only bulk rock composition. EPMA is also helpful in determining the composition of certain minerals which are not easily detectable under a microscope, such as cordierite, as it looks very similar to quartz and feldspar under a microscope. EPMA chemical data is also helpful for applying various models of geothermobarometry.

Electron Microprobe Analyses (EPMA) has been carried out to know the chemical composition of each mineral present in various rock types. Fresh rock samples were selected from the study area for the EPMA analysis of various silicate minerals. The EPMA has been carried out for fresh minerals (avoiding altered minerals). Each grain is analyzed from core to rim to report the chemical zonation in the minerals if any. During the analyses, care was taken to avoid the altered domains. The co-existing mineral pairs, viz., garnet-biotite, garnet-cordierite-biotite-plagioclase, garnet-orthopyroxene-biotite-plagioclase, amphibole-clinopyroxene-plagioclase, and garnet-amphibole-biotite-plagioclase, have been selected for EPMA analyses. This is to evaluate the cationexchange like Fe-Mg between garnet and biotite, garnet and orthopyroxene, garnet and clinopyroxene and Mg, Fe and Al between plagioclase and amphiboles and the Ti content in amphibole and biotite. The pressure and temperature conditions of regional metamorphism have been approximated using various contemporary thermodynamic models.

Before discussing mineralogy, the analytical method used to analyze the rocks and minerals is discussed below.

5.2 EPMA analytical technique

The analytical work was carried out on the EPMA (CAMECA SX Five) instrument at the DST–SERB National Facility, Department of Geology, Centre of Advanced Study, Institute of Science, Banaras Hindu University. A thin polished section was coated with a 20 nm thin layer of carbon by using the LEICA-EM ACE200 instrument. The CAMECA SX Five instrument was operated at a voltage of 15 kV and a current of 10 nA with an aLaB6 source in the electron gun for the electron beam generation. Natural silicate mineral andradite as an internal standard was used to verify the positions of crystals (SP1-TAP, SP2-LiF, SP3-LPET, SP4-TAP and SP5-PC1) concerning the corresponding wavelength dispersive (WD) spectrometers (SP#) in CAMECA SX Five instrument. The following X-ray lines were used in the analyses: F-Kα, Na-Kα, Mg-Kα, Al-Kα, Si-Kα,P-Kα, K-Kα,Cl-Kα, Ca-Kα, Ti-Kα, Cr-Kα, Mn-Kα, Fe-Kα, Ni-Kα and Sr-Lα. Natural mineral standards: apatite, albite, halite, periclase, peridotite, corundum, wollastonite, orthoclase, rutile, chromite, rhodonite, celestite, barite, hematite, and synthetic Ni metal supplied by CAMECAAMETEK were used for routine calibration and quantification. Routine calibration, acquisition, quantification, and data processing were carried out using Sx SAB version 6.1 and SX-Results software of CAMECA. Tables 5.1–5.11 present representative EPMA data for various minerals.

5.3 Garnet

Garnet is a crucial mineral group in metamorphic rocks as it is used in various geothermobarometry models to evaluate the *P–T* conditions of the rocks and hence their genesis. The microprobe analysis of garnet (12 oxygen basis) from pelitic granulite, Garnet-biotite gneisses and amphibolites are listed in Table 5.1.

Garnet has the structural formula $X_3Y_2Z_3O_{12}$ (on a 12 oxygen basis), where X= (Fe^{2+}, Mn, Mg, Ca)$_3$, Y= (Al, Ti, Cr, Fe^{3+})2, and Z= (Si_3O_{12}).However, concerning the ideal formulae ($X_3Y_2Z_3O_{12}$), there are minor variations in X (2.837–3.1114), Y (1.919–2.104) and Z (3.00–3.07).

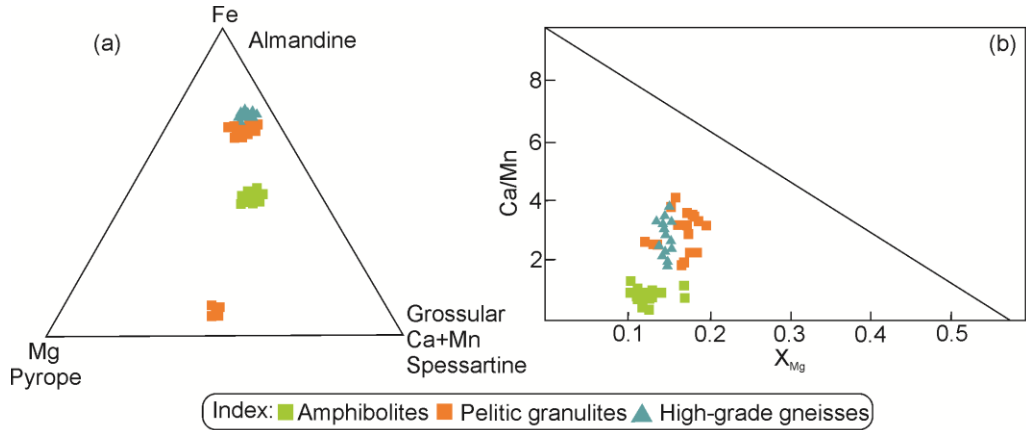

Figure 5.1 (a) Triangular diagram showing the variation in (spessartine + grossular)–almandine–pyrope end member compositions in the garnets from different rock types. (b) A plot of X_{Mg} vs Ca/Mn of garnets, from different rock types.

Garnets have a wide range of chemical composition, which depends on the mineral assemblage, bulk rock chemistry, and metamorphic condition. One of the most important characteristics of garnet is its complex crystal structure, and variation in temperature and pressure conditions plays an important role in the cation co-ordination number of the crystal structure, therefore increasing or decreasing in co-ordination number. Thus, the crystallizing state of garnet is reflected by its composition. Garnet from studied rocks comprises primarily of a solid solution of the end members almandine, pyrope, grossularite, and spessartine. The garnets consist of 2.21 to 74.09 mol% almandine, 6.55 to 49.65 mol% pyrope, 0.36 to 19.07

mol% grossularite, and 1.95 to 50.06 mol% spessartite in the studied rocks. The pyrope content of garnet from the different rock types indicates the following trend: pelitic granulites>garnet-biotite gneisses > amphibolites. The grossularite contents of garnet show the reverse trend: amphibolites> pelitic granulites>garnet-biotite gneisses. The analyzed garnets are plotted in the (Ca+Mn)–Mg–Fe^{2+} diagram (Fig.5.1a). All the garnet plots from the garnet-biotite gneisses and pelitic granulites and amphibolites fall in the almandine-grossartite-spessartite region, whereas some of the pelitic granulites show higher contents of pyrope and grossularite- spessartite. The X_{Mg} in the garnets from studied rocks varies from 0.10–0.28. This range may be attributed to Mn or Ca, which occupy the eight-fold co-ordination site in the garnet's crystal structure. The X_{Mg}vs Ca/Mn plots do not show any distinct correlation except that pelitic granulites and garnet-biotite gneisses are slightly higher in X_{Mg} and Ca+Mn content than amphibolites (Fig.5.1b).

5.3.1 Garnet zoning

The BSE image of the mapped garnet porphyroblast is shown in Figure 5.2a. The elemental X-ray map of garnet shows that garnet is rich in Fe, Al, and Si elements (Fig.5.2c,d&f) and has a depletion of Mg and Ca elements (Fig.5.2b&e). The garnet shows considerable variation in almandine, pyrope, grossular, and spessartine values from rim to rim (Fig.5.2g). The solid solution between the four end members controls the garnet compositional variation, and hence their compositional variation may be represented in terms of the four end members' independent factors. Almandine predominates in its composition. The X_{Alm} varies from 68.02 to 78.03. The almandine occurs more on the rims than on the core. The pyrope content varies from 8.64 to 17.90 and is considerably lower at the rims than at the core. The grossular and spessartine show a zigzag pattern mainly across the entire length of the garnet porphyroblast. A significant decrease in almandine and an increase in pyrope are seen from rim to mantle in the zoning profile of garnet due to compositional diffusion and transfer reactions between garnet and its surrounding minerals during cooling.

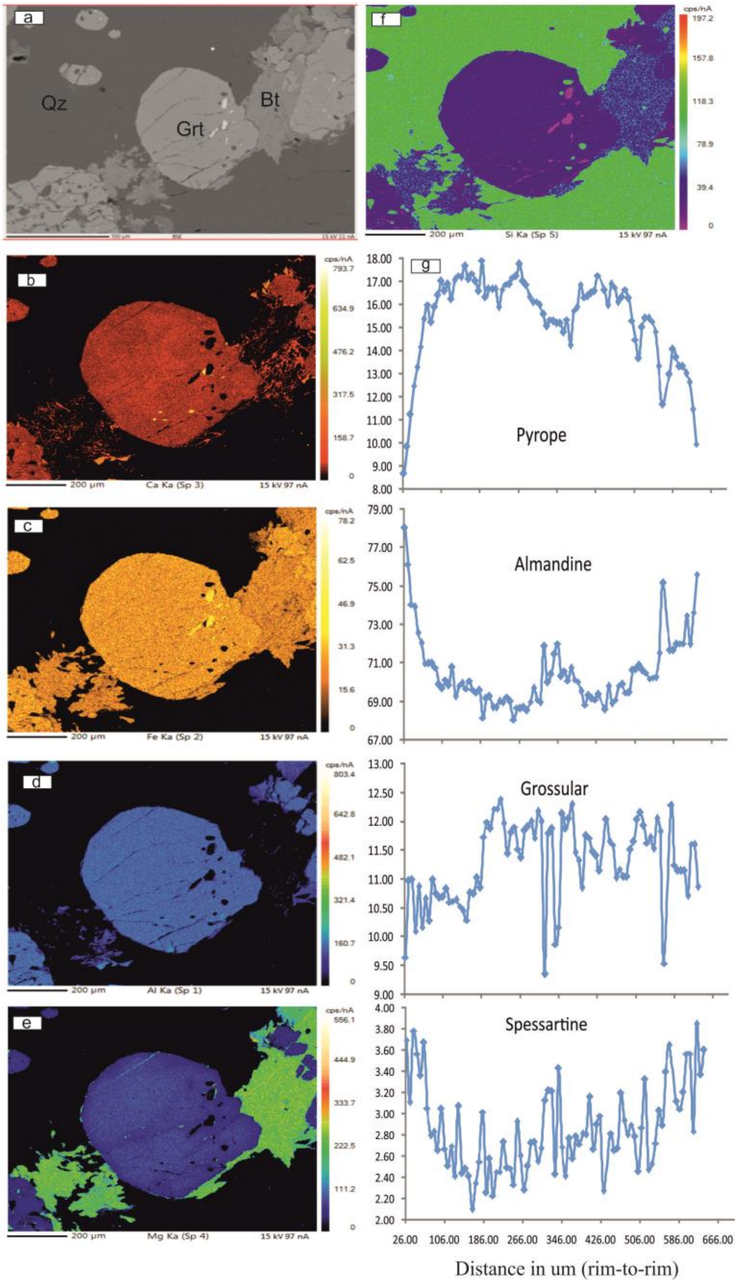

Figure 5.2 (a) BSE image of garnet porphyroblast, (b–f) Images of X-ray mapping of Ca, Fe, Al, Mg and Si in garnet porphyroblast; (f) X_{Alm}, X_{Py}, X_{Grs} and X_{Sps} variation along the garnet porphyroblast from rim to rim.

5.3.2 Ca & Mn content of garnet

The CaO-contents of the garnets are low, with 1.79 to 6.99 wt% in the studied rocks. The highest limit is observed in the garnets from the amphibolites and some samples of pelitic granulites, at least one in garnets from the high-grade gneisses and pelitic granulites.

Mn is highly variable in garnets, showing a wide range (0.027–0.106 p.f.u). The upper limit is found in the pelitic granulites.

5.4 Pyroxene

The name *pyroxene* is derived from the Greek word pyroxene, which was first introduced by Haüy (1801). *Pyroxene* is a combination of two words, which mean pyro-*fire* and xenos-*stranger*. It is an anhydrous single-chain silicate mineral found in igneous and metamorphic rocks. Poldervaart and Hess (1951) were the first to describe pyroxene nomenclatures based on $CaMgSi_2O_6$-$CaFeSi_2O_6$-$Mg_2Si_2O_6$-$Fe_2Si_2O_6$ (Diopside-Hedenbergite-Enstatite-Ferrosilite). Later, IMA/CNMMN (International Mineralogical Association/Commission on New Minerals and Mineral Names; Morimoto, 1988 and references therein) provided a series of recommendations and schemes for the classification nomenclature of pyroxenes. This nomenclature was later modified by Rock (1990). The first pyroxene (diopside) structure was determined by Warren and Bragg (1928). They established that the pyroxene structure is linked to the SiO_4 tetrahedral by sharing two oxygen atoms out of four by each tetrahedron, forming a single chain structure.

Cations surround this chain laterally in M1 and M2 sites. The site atom lies between the apices and the M2 site at the base of the SiO_3 tetrahedral chain. Further, pyroxene can be sub-grouped based on cation participation in M1 and M2 sites, mostly depending on variable parameters such as pressure and temperature. The co-ordination of oxygen at M1 site is fixed, i.e. octahedral, whereas at M2 site, it is variable according to the cation size, for instance, Mg in six-fold co-ordination; eightfold co-ordination for Na-Ca.

The representative analysis of orthopyroxenes from pelitic granulites, clinopyroxenes from amphibolites and their formula per unit calculated cations based on six oxygen basis, end-member Wo (Di+Hd), En and Fs and nomenclature of pyroxene are given in table 5.2

and 5.3 respectively. The recalculated formulae approximate the ideal formula: [(Mg, Fe^{2+}, Al, Ti, Mn, Ca)$_2$ (Si, Al)$_2$ O_6].

5.4.1 Orthopyroxene

The analyzed pyroxene are plotted in a triangular end member $CaSiO_3$-$MgSiO_3$–$FeSiO_3$ diagram (Fig.5.3).The plot shows that the orthopyroxenes of pelitic granulites are of clinoferrosilite composition and lie near the hypersthene, which is the solid solution between Mg and Fe end members of the orthopyroxene. The orthopyroxenes are mainly a solid solution of enstatite and ferrosilite having En (38.85–47.09) mol%, Fs (51.27–58.32) mol%, Wo (0.24–1.78) mol%, and Ac (0.21–1.41) mol% (Table 5.2). An essential feature of orthopyroxene chemistry is the Al content. This may be dependent on several factors: (a) host rock composition; (b) the composition of the coexisting mineral (Binns, 1962, 1969; Leelanandam, 1967); and (c) the pressure-temperature conditions of the formation (Dobretsov, 1968). The Al_2O_3 content of the orthopyroxenes varies from 1.521–2.663 wt%. The X_{Mg} values range between 0.40 and 0.47 and correspond to hypersthene. The Ca-content of orthopyroxene (0.007 to 0.033 p.f.u. based on 6 oxygen) is lower than that of clinopyroxene.

5.4.2 Clinopyroxene

The clinopyroxenes of amphibolites, when plotted in the triangular end member $CaSiO_3$-$MgSiO_3$–$Fe^{2+}SiO_3$ diagram, show two sets of data. Both are plotted in the diopside field, but one has more diopside content than the other. The clinopyroxenes from garnet-bearing amphibolites are mainly solid solution of wollastonite (47.31–48.45 mol%), enstatite (29.30–31.22 mol%), and ferrosilite (20.29–23.39 mol%) (Table 5.3). The calculated X_{Mg} value of clinopyroxene ranges from 0.59 to 0.65. It has a higher X_{Mg} content and a lower Al content than orthopyroxene. The clinopyroxenes from garnet absent amphibolites are mainly solid solutions of wollastonite (35.89–53.60 mol%), enstatite (23.85–40.53 mol%), and ferrosilite (11.29–39.34 mol%) (Table 5.3). The calculated X_{Mg} value of clinopyroxene ranges from 0.40 to 0.81. The Ca-content of the clinopyroxene varies between 0.736 and 1.050 p.f.u., suggesting evidence of high Ca content in clinopyroxene, a characteristic of amphibolites. The Al_2O_3 content in clinopyroxene varies between 0.38 and 0.99 wt%. The higher amounts of Al_2O_3 present reflect an increasing jadeite component, indicating higher pressures attained during metamorphism.

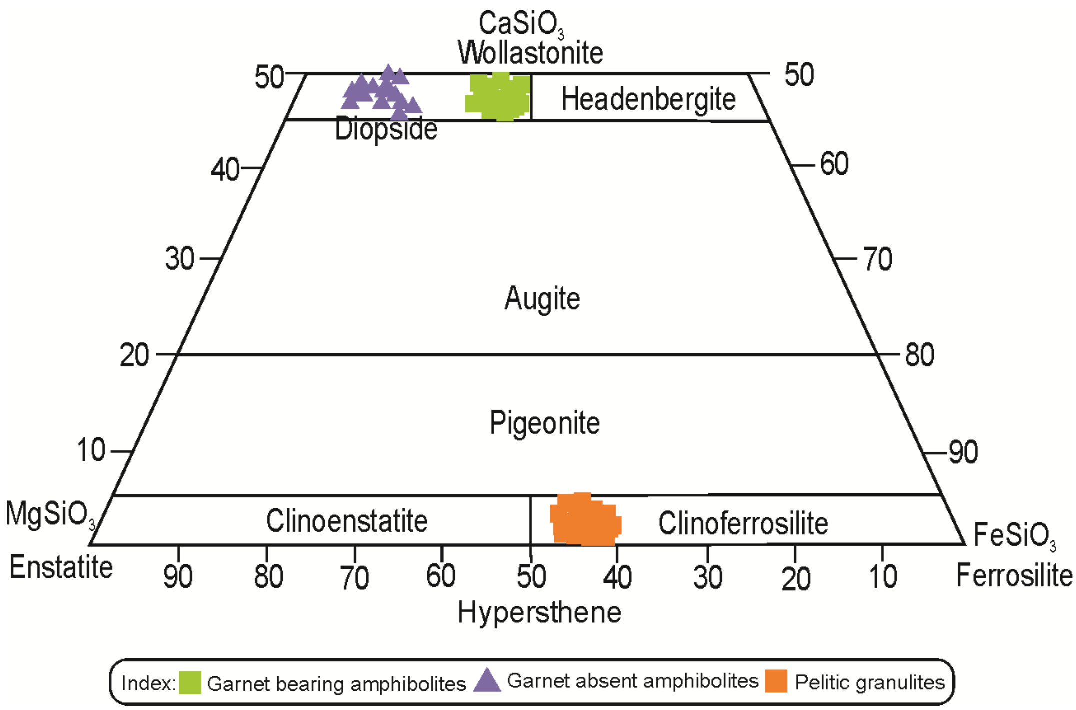

Figure 5.3 A $CaSiO_3$- $MgSiO_3$- $FeSiO_3$ composition diagram of proroxenes showing the plot of orthopyroxenes and clinopyroxenes from different rock types.

5.5 Amphibole

The word "*amphibole*" is derived from a Greek word introduced by Haüy (1801), which means an allusion to the minerals having a variety of compositions and appearances. The amphibole and pyroxene groups of minerals are chain silicates, whose classical work was described by Tschermak (1872). In 1961 Schaller recognized essential constituents of amphibole group mineral, which makes it different from pyroxene in the abundance of hydroxyl ions. Amphibole comprises (Si, Al)O_4 tetrahedral silicate linked to form a double chain and has a unit composition of Si_4O_{11}. The double chain silicates have two tetrahedra which lie at the inner and outer parts of each chain, T1 and T2, respectively, which are repeated along the C axis of the unit cell at an interval of approximately 5.3Å. Through double chain silicate, a hexagonal-shaped space is formed, which is usually linked by hydroxyl ions. The general formula of an amphibole is $\mathbf{A_{0\text{-}1}B_2C_5T_8O_{22}\ (OH,\ F)_2}$**;** where **A**-site is for large cations Na, K; **B**-site for the cation at M4 site Ca, Na; **C**-site for cations at M1, M2, M3 (usually medium-sized cation) sites; **T**-site those in tetrahedral T1 and T2 co-ordinated by O_3 (OH) in an octahedral manner. Amphibole is a common mineral found in both igneous and metamorphic rocks. It is a potential mineral to accurately measure the pressure of crystallization, metamorphism, and/or deformation, which can be deduced from total Al-in-amphibole that changes with pressure.

5.5.1 Classification of amphibole

Firstly, it is important to characterize the amphiboles, whether they are of *magmatic* or *metamorphic* origin. Leake (1965) suggested the criteria (Si and Al^{VI}atoms) fordifferentiating between igneous and metamorphic amphiboles with a maximum limit of Al^{VI}in amphibole, which increases with pressure, and beyond that, there may be someerrors in accuracy. Table 5.4 shows the microprobe analysis of amphiboles from amphibolites and their structural formula computed using 23 oxygen atoms. The structural formula of the analyzed hornblende corresponds to the general formula of calcic amphibole [(Ca, Na, K)$_{2\text{-}3}$(Mg, Fe, Cr, Mn, Al^{VI}, Ti)$_5$ (Si, Al^{IV})$_8O_{22}(OH)_2$]. The analyzed amphiboles from amphibolites are plotted in the leaks classification diagram; they all seize a place in the Tschermakite domain (Fig. 5.4a). The Alumina content of amphibole is dependent on (a) host rock composition, particularly $Al_2O_3/(Al_2O_3 + SiO_2)$ ratio (b) *P–T*conditions. Leak et al. (1965) proposed that the Al^{IV} content of amphibole increases with pressure. The amphibole from magmatic and contact metamorphic rocks generally has lower Al^{VI} and Si contents than amphibole in regionally metamorphosed rocks. The Al^{IV} and Al^{VI} content of amphibole varies from 1.453 to 1.875 and 0.0 to 0.478 p.f.u. respectively. The chemical composition of amphibole is expressed in 0.5 $[Al^{VI}–(Na+K)^{A}]$ vs $(Na+K)^{A}$ plot (Fig.5.4b) (Raase et al., 1986). The X_{Mg} ratio of amphibole ranges from 0.69-0.89. The hornblende's structural formulae clearly show an increase of X_{Mg} with an increase of Al^{IV} content (Fig.5.4c). The amphibole from the Mauranipur and Babina regions contains (p.f.u) Na = 0.276–0.497, K = 0.022–0.062, and Ti = 0.031–0.054. This indicates that these amphiboles have crystallized near the metamorphism's thermal peak under amphibolite facies.

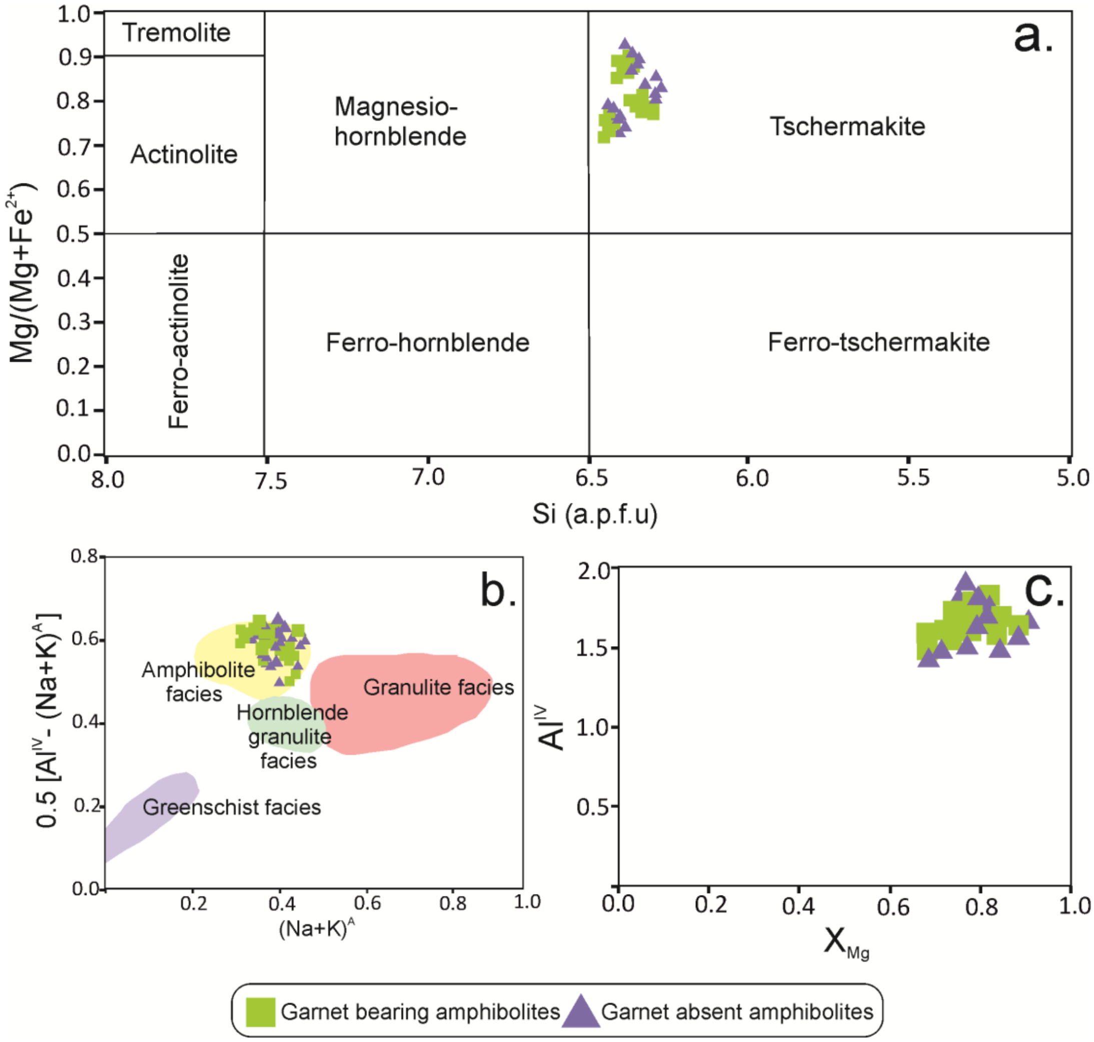

Figure 5.4 (a) Amphibole classification diagram (after Leaks et al., 1965) for the amphibolites of Bundelkhand craton. (b) Plot $0.5[Al^{IV}–(Na+K)^{A}]$ vs $(Na+K)^{A}$a.p.f.u for calcic amphibole from greenschist to granulite facies (after Raase et al., 1986) expressed as amphibolites of Bundelkhand craton belongs to amphibolites facies rock. (c) A plot of X_{Mg} vs Al^{IV} of amphibolites.

5.6 Cordierite

Cordierite is a magnesium-iron-aluminium cyclosilicate that forms when argillaceous rocks undergo contact or regional metamorphism. The stoichiometry approximates the ideal formula: $[(Mg, Fe^{2+})_2(Al_4Si_5O_{18})nH_2O]$. Iron in the cordierite is almost always present, and Mg-rich and Fe-rich cordierite show a solid solution between them. The cordierite structure accommodates molecular water with values of n commonly between 0.15 and 0.80 (Deer et al., 1986). The cordierite analyses show a summation between 94.035 to 99.053 wt%, suggesting that it may be hydrous, containing 0.947–5.965 wt% H_2O and gaseous species as cordierite has a wide channel site in the core of its six-membered ring structure that may hold molecular H_2O, CO_2, and to a lesser extent, other volatile molecules like CH_4, N_2, and Ar. (e.g. Schreyer and Yoder, 1964; Gibbs, 1966; Le Breton and Schreyer, 1993; Harley et al., 2002). It is now well accepted that cordierite's molecular water content is a function of P and T (Newton and Wood, 1979; Mukhopadhyay and Holdaway, 1994; Carey, 1995). Table 5.5 lists the cordierite analyses and structural formulas based on 18 oxygen.

The X_{Mg} varies between 0.61 and 0.69. The cordierite microprobe studies show only limited and irregular zoning, indicating varied dominance of the action of small-scale cation exchange with inclusion, diffusion, and continual re-equilibration with matrix grains after nucleation. Insignificant amounts of Na_2O and K_2O are commonly present, ranging from 0.319 to 0.643 wt% and 0.013 to 0.066 wt%, respectively. Thompson et al. (2002) suggest that K content increases with temperature and decreases with water content. Thus, it can be inferred that the water content in cordierite will be below based on the depletion of K in cordierite.

5.7 Mica

The mica minerals are phyllosilicates, commonly found in igneous, metamorphic, and sedimentary rocks. It is mainly composed of two tetrahedral silicon sheets between which an octahedrally co-ordinated cation exists. An additional OH-(hydroxyl ion) is associated and completes the sandwiched octahedral cations. These octahedral cations coordination are either in the form of brucite layer $Mg_3(OH)_6$ or in gibbsite layer $Al_2(OH)_6$. Micas have the general chemical formula $X_2Y_{4\text{-}6}Z_8O_{20}(OH,F)_4$, where X stands for K, Na, Ca, Ba, Rb, Cs; Y stands for Al, Mg, or Fe, Mn, Cr, Li; and Z stands for Si or Al but also Fe^{3+} and Ti^{4+}.

The mica group is further subdivided based on the number of Y ions present into 4 and 6 di-octahedral (muscovite) and tri-octahedral (biotite) classes, respectively. However, mica can be sub-classified as *common mica* in which K or Na are dominant ions in X, whereas if a Ca ion is present, it is known as *brittle mica*. In trioctahedral mica, the number of Y ions equals three atoms. Depending upon prevailing Physico-chemical conditions and the nature of melt, sometimes K in the X site may be replaced by Ba, Rb, or Cs; therefore, the total sum of X sites in the formula may be more than unity.

5.7.1 Biotite

The analytical electron microprobe data of biotite from pelitic granulites, high-grade gneisses and amphibolites, with their structural formula (calculated based on 11 oxygen), are presented in Table 5.6. The structural formula approximated the ideal formula of biotite: $[(K, Na, Ca)(Al^{VI}, Mg, Fe, Mn, Ti)_3(Si, Al^{IV})_4O_{10}(OH)_2]_{.2}$.

The biotite is composed of annite $[K_2Fe_6(Si_6Al_2O_{20})(OH)_4]$, siderophyllite $[K_2Fe_5Al(Si_5Al_3O_{20})(OH)_4]$, phlogopite $[K_2Mg_6(Si_6Al_2O_{20})(OH)_4]$, and eastonite $[K_2Mg_5Al(Si_5Al_3O_{20})(OH)_4]$.The biotites' analyses display a wide range of X_{Mg} (0.31 to 0.61). The wide range of variation indicates the following trend of X_{Mg} in biotites; pelitic granulites (0.38 to 0.61) > amphibolites (0.45 to 0.49) >garnet-biotite gneisses (0.31 to 0.44) >. The Al^{IV} content of biotites from all studied rock samples varies from 2.402 to 2.960 p.f.u.

In the triangular diagram Mg–(Fe+Mn) – Ti (Fig.5.5a), the plot of biotite is lying between Mg and (Fe+Mg) line. The plot of biotites from different rocks shows a decrease of

Ti with an increase of Mg, suggesting preferential substitution of Mg by Ti in the octahedral layer. In Mg – (Fe+Mn) – (Al^{IV}+Ti) (Fig.5.5b), a plot of biotite depicts the decrease of (Al^{IV}+Ti) with an increase in Mg, indicating that Al^{VI}+Ti substitutes Mg relative to Fe.

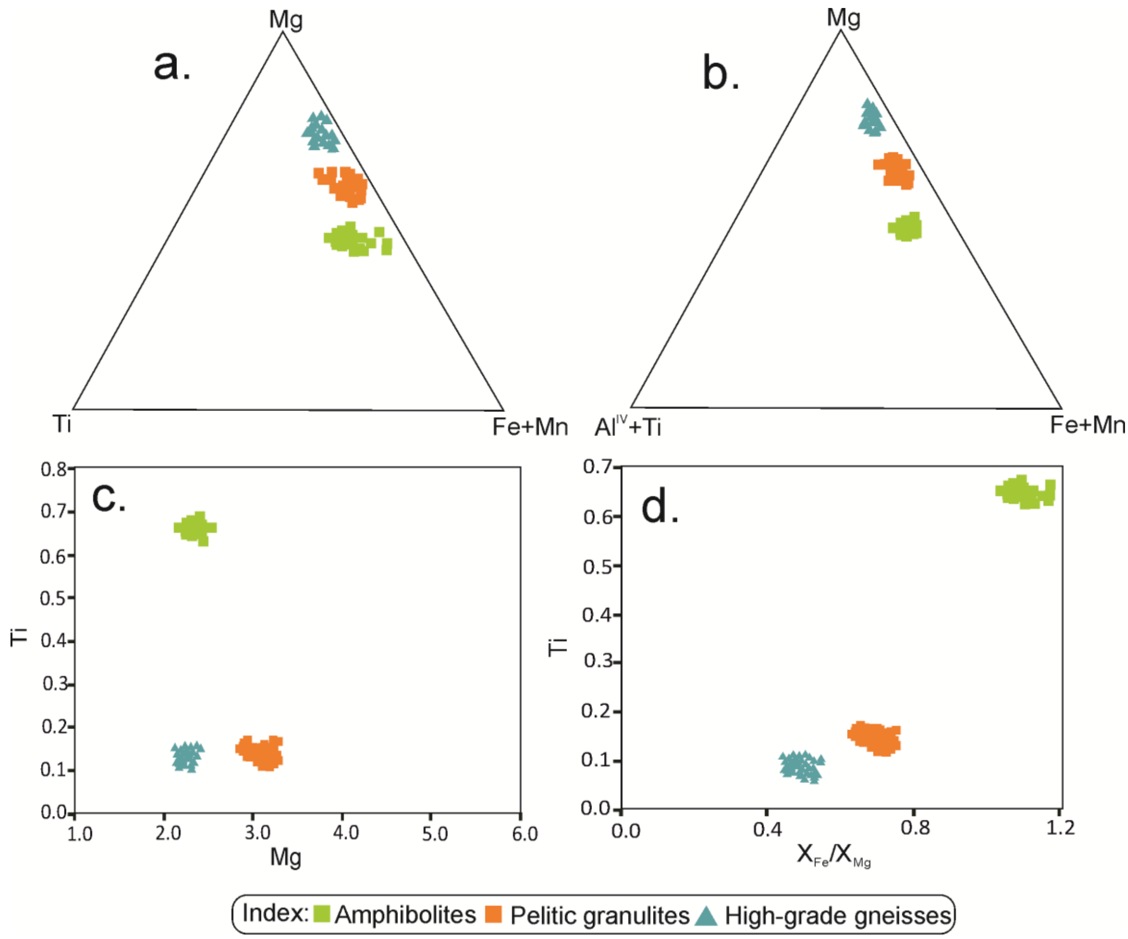

Figure 5.5 (a) A plot of microprobe analyses of biotites from different rock type in Mg- Ti -(Fe+Mn) diagram. (b) A plot of microprobe analyses of biotites from different rock type in Mg-(Al^{IV}+Ti) - (Fe+Mn) diagram. (c) A plot of Ti vs Mg showing negative trend. (d) A plot of X_{Fe}/X_{Mg}vs TiO_2 showing linear relationship.

5.7.1 TiO_2 content

The TiO_2 content of biotite is very significant in estimating the rock's metamorphic grade (Engel and Engel, 1960; Kwak, 1968; Guidotti, 1970). In the Bundelkhand region's analyzed biotites, the amount of TiO_2 in biotite from the amphibolites is higher than in pelitic granulite and high-grade gneisses. The TiO_2 content of biotite from high-grade gneisses ranges from 1.41–1.99 Wt% and in pelitic granulites from 1.00–1.95 Wt%. The high content of (more than 5 Wt%) TiO_2 in biotite from amphibolites, although the low content of TiO_2 in various rocks may be due to their formation, was observed during retrogression. The plots of Ti vs Mg (Fig.5.5c) and Ti vsX_{Fe}/X_{Mg} (Fig.5.5d) show a negative and linear correlation, respectively.

5.8 Feldspar

The original name of feldspar was *feldtspat*, which refers to the presence of the spar (spath) in a tilled field (Swedish; feldt or falt) overlying granite, rather than the German word "Fels", meaning rock. The feldspar group of minerals is ubiquitous in most of the studied lithounits. Indeed, feldspar is termed as quaternary feldspar because of the inclusion of celsian (Ba-feldspar) in addition to the common end-members orthoclase (Or)-albite (Ab)-anorthite (An). Feldspars are expressed in two different binary solutions: solid solution between albite and orthoclase, known as the alkali feldspars ($NaAlSi_3O_8$–$KAlSi_3O_8$) and solid solution between albite and anorthite, known as the plagioclase feldspars ($NaAlSi_3O_8$–$CaAl_2Si_2O_8$).

The triangular $NaAlSi_3O_8$–$KAlSi_3O_8$–$CaAl_2Si_2O_8$ diagram (Fig.5.6) demonstrates the chemical variation in feldspar from studied rock types. The feldspars of pelitic granulites and amphibolites are of andesine composition, whereas the feldspars of high-grade gneisses are of labradorite composition. The representative microprobe analyses and structural formulae of plagioclase and k-feldspar (calculated based on 32 oxygen) are shown in Table 5.7. The plagioclases of all the studied rock samples are solid solutions of Ab (37.41-60.15) mol%, An (40.04-63.39) mol% and Or (0.01-0.75) mol%. The X_{Ca} = [Ca/(Na+Ca+K)] ratio range from 0.40 to 0.59 for pelitic granulites, from 0.45 to 0.63 for high-grade gneisses and from 0.01-0.75 for amphibolites. The plagioclase is unzoned. The recalculation of the general formula of plagioclase $(Ca, Na, K)_2(Al, Si)_8O_{16}$ shows a persistent deficiency of larger cations. They suggested that the deficiency may be explained through deviation from ideal plagioclase stoichiometry towards a higher siliceous solid solution, for example, in pure albite through the virtue of substitution Si = Na, Al, and in anorthite through Si = Al, 0.5Ca. Plagioclase contains minor amounts of total iron as FeO. In the feldspar, smaller six co-ordinate divalent cations are impossible on crystal structure ground. Fe is likely present as Fe^{3+} substituting Al^{3+} or possibly due to extremely fine inclusion of opaque in plagioclase which could not be identified under microprobe.

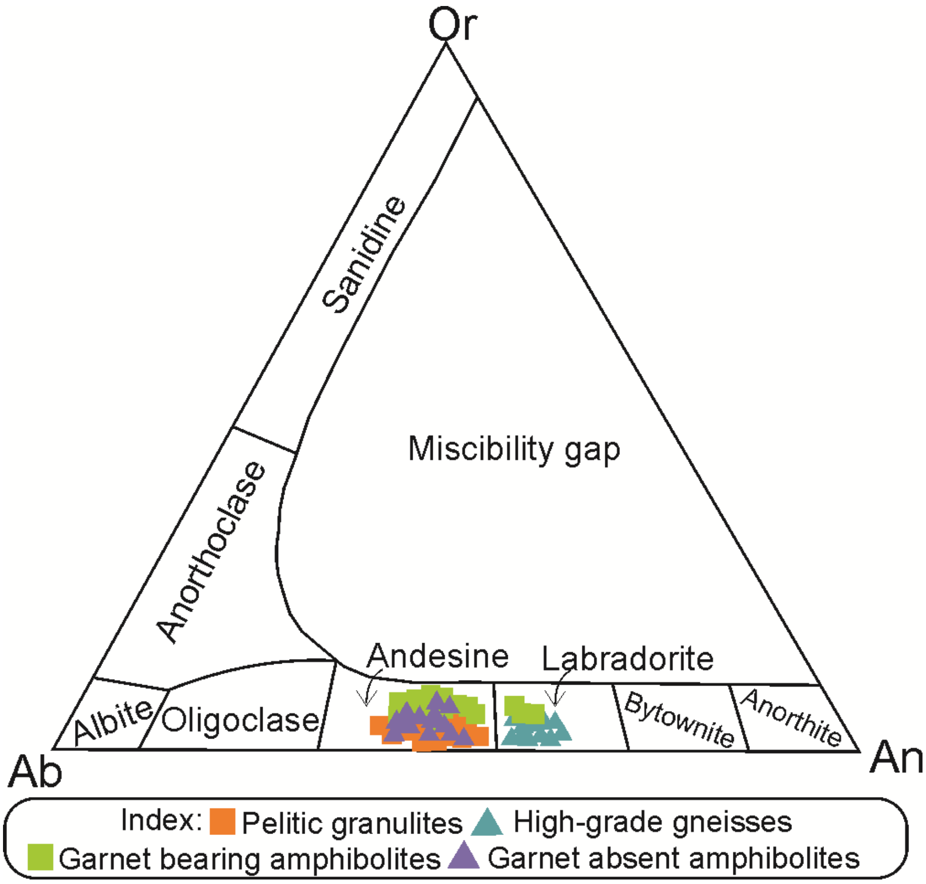

Figure 5.6 Triangular $NaAlSi_3O_8$ - $KalSi_3O_8$ - $CaAl_2Si_2O_8$ diagram showing plots of alkali feldspar and Plagioclase feldspar.

5.9 Opaque

These include ilmenite and magnetite. Ilmenite from the granulites and amphibolites is presented in Table 5.8. It approximates the ideal formula $(Fe, Mg, Mn)_2Ti_2O_6$. The structural formulae of ilmenite have been calculated on a six oxygen basis. The structural formula deviates slightly from the ideal formula. The total Fe as Fe^{2+} has been analyzed; the deficiency at Ti-site or the presence of more than two divalent cations suggests the presence of Fe^{3+} in significant amounts. Thus ilmenite calculated on six oxygen was normalized to 4 cations to estimate Fe^{3+} and Fe^{2+} (Bohlen and Essene, 1977) from the formula: Fe^{3+}=12–[2(Fet+Mn+Mg)+3(Al+Cr)+4(Ti)].

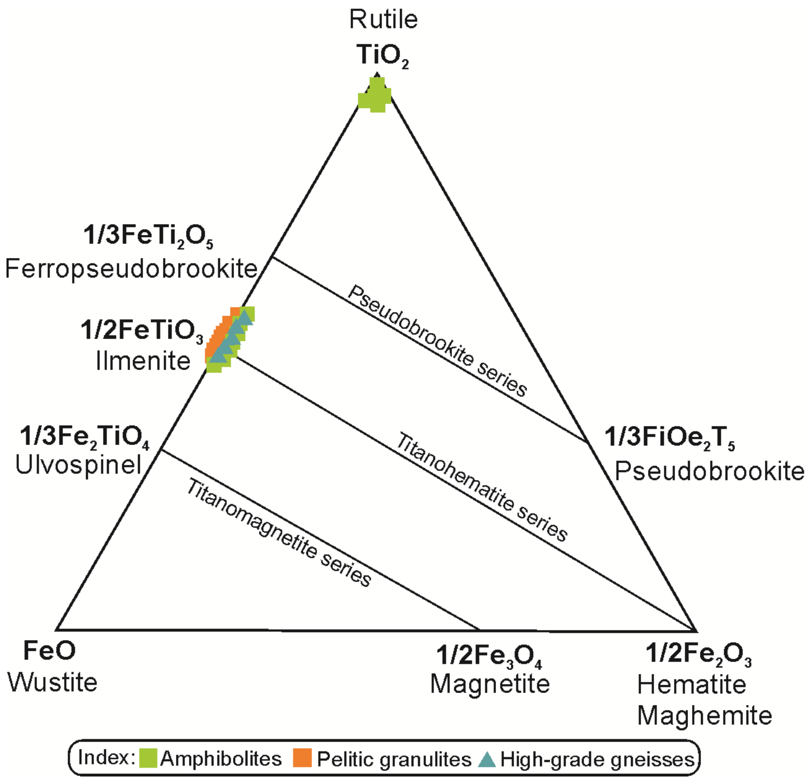

Figure 5.7 Triangular diagram for ilmenite and magnetite (modified from Buddington and Lindsley, 1964).

The calculated structural formulae of ilmenite suggest a significant amount of hematite solid solution in ilmenite in most of the samples. Thus, this ilmenite may be better termed hemoilmenite if Fe^{3+} is present in significant amounts. Fe^{3+} varies from 0.004 to 0.075 p.f.u. All the analyzed ilmenites have been plotted in the triangular TiO_2-FeO-Fe_2O_3 diagram (Fig.5.7). The plots of ilmenites from gneisses and granulites lie between TiO_2 and FeO. Compositionally, ilmenites of amphibolites are magnesian–mangaonilmenites (MgO: 0.010–0.046 wt% and MnO: 0.496–1.197 wt%) and ilmenites of pelitic granulites are (MgO: 0.402–0.051 wt% and MnO: 0.402–0.805 wt%).

5.10 Epidote

Representative chemical compositions of analyzed epidote based on 25 oxygens for the amphibolites are listed in Table 5.9. Epidote is present as inclusions within the amphibole and clinopyroxene in amphibolites. The values of X_{Al} [X_{Al}=Al/(Al+Fe^{3+})] ranges from 0.84-0.85. The values of X_{Fe} [X_{Fe}=Fe/(Fe+Al)] varies from 0.15–0.16. All epidotes belongs to clinozoisite–epidote–piemontite series dominated by clinzoisite (83.39–84.97 mol%) having epidote (14.71–16.08 mol%) and piemontite (0.24–0.72). Fe_2O_3 varies from 12.85–14.11 wt%. The triangular plot for the epidote end member shows that the epidotes from both the samples are of clinozoisite composition (Fig. 5.8).

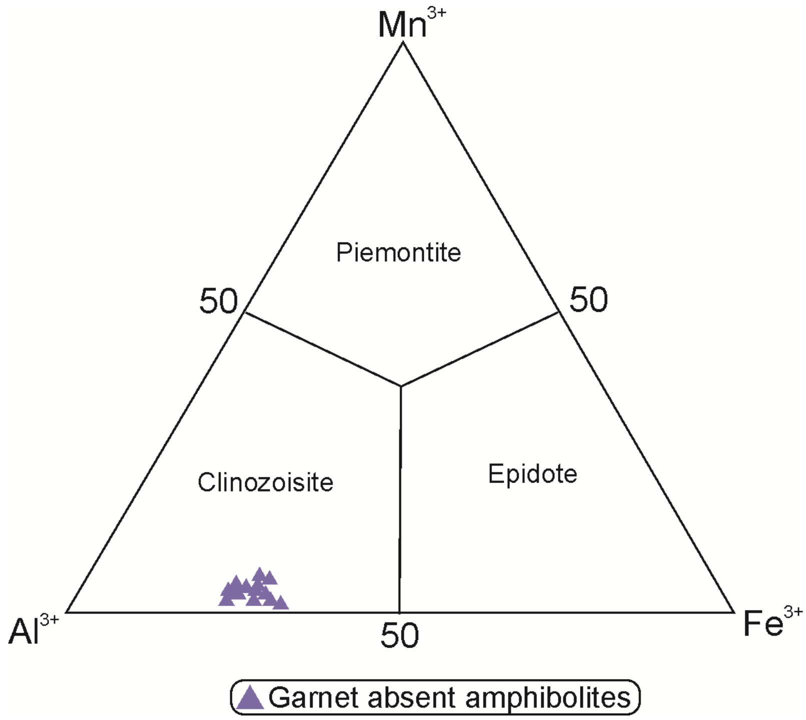

Figure 5.8 Triangular diagram for epidotes from amphibolites (after Tarantola et al. 2019).

5.11 Chlorite

Chemical analyses of chlorites were carried out on microprobe, and structural formulas (calculated based on 14 oxygen) are given in Table 5.10. The ideal formula of chlorite can be described as; [$(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2\cdot(Mg,Fe)_3(OH)_6$] (repeating unit).

The analyzed data for chlorite from amphibolites and pelitic granulites has been plotted in the X_{Mg} vs. Si (Fig. 5.9) diagram of chlorite classification. Here, chlorites of pelitic granulites fall in the Brunsvigite field, whereas chlorites of amphibolites fall in the Ripidolite domain. Chlorite contains Fe^{2+} and Fe^{3+}, and in some of the chlorite grains, Fe^{3+} predominates over Fe^{2+}. Also, Al^{IV} and Al^{VI} found in these rocks lie between 1.97-3.11 and 0.84-1.64 pfu, respectively. BaO is found in a trace amount. The X_{Fe}values for amphibolites are higher (0.67–0.69) than the X_{Fe} values for pelitic granulites.

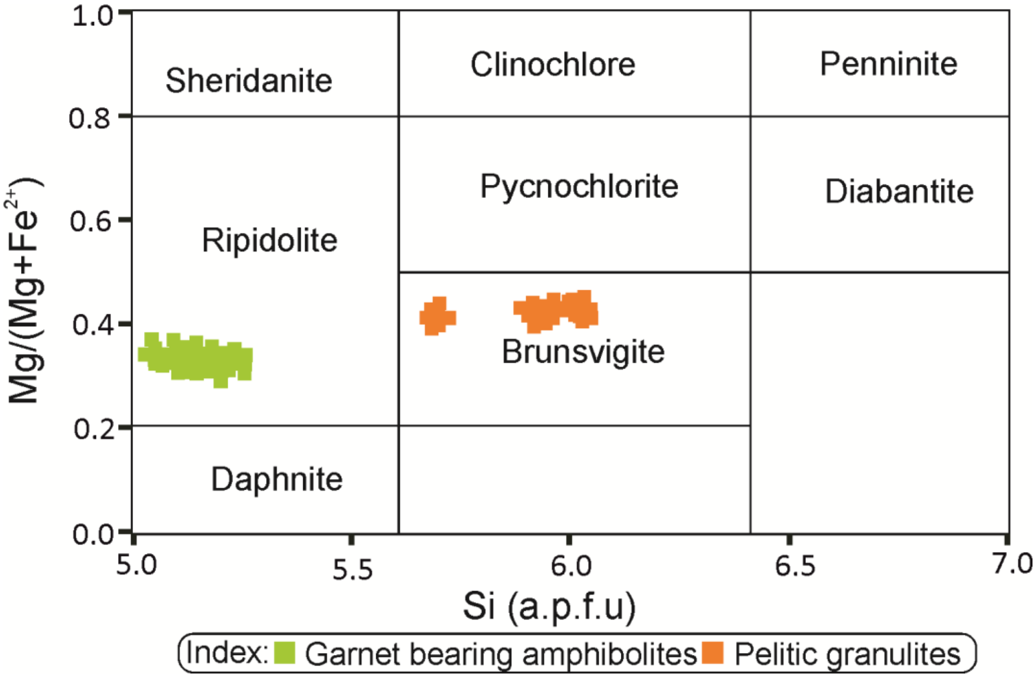

Figure 5.9 Chlorite classification diagram of different rock types (after Hey, 1954).

5.12 Sillimanite

The electron microprobe data of the sillimanite and their structural formulae (calculated based on 10 oxygen) from pelitic granulites is presented in Table 5.11. The composition is relatively pure Al_2SiO_5. The most common ion replacing aluminium in the sillimanite structure is the ferric ion, while other elements, viz. Ti, Cr, Ca, K, Na, and Mn are in minimum amounts. The Al-content ranges between 3.897 and 3.960 p.f.u. sillimanite includes minor amounts of Cr and Fe. Total Fe as Fe^{2+} has been analyzed. The Cr and Fe content vary from 0.001 to 0.002 p.f.u. and 0.018 to 0.03 p.f.u., respectively.

Table 5.1 Chemical analysis and structural formulae (on the basis of 12 Oxygen) of garnet from pelitic granulites.

Sample	PM-1							K-2		
Domain	56	57	53-R	62-R	37-C	59-C	63-C	61/1	64/1	65/1
SiO_2	37.324	37.344	37.311	37.418	37.304	37.349	37.373	36.554	36.558	38.954
TiO_2	0.051	0.101	0.038	0.021	0.057	0.084	0.027	0.101	0.000	0.121
Al_2O_3	20.957	21.062	20.763	20.561	20.561	20.880	20.319	21.020	20.832	19.020
Cr_2O_3	0.006	0.031	0.000	0.000	0.070	0.000	0.000	0.000	0.000	0.005
FeO	30.425	30.214	32.684	32.292	31.713	29.556	31.433	32.898	31.834	32.898
MnO	1.332	1.322	1.485	1.908	0.880	1.322	1.457	1.269	1.119	1.457
MgO	3.393	3.079	2.368	2.453	4.252	3.742	3.927	2.425	3.215	2.564
CaO	6.185	6.201	5.017	5.393	4.348	6.764	5.537	5.187	6.112	5.329
Total	**99.689**	**99.397**	**99.691**	**100.04**	**99.185**	**99.725**	**100.110**	**99.458**	**99.691**	**100.347**
Si	2.975	2.989	3.005	3.002	2.986	2.966	2.970	2.948	2.923	3.117
Al^{IV}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ΣZ	2.975	2.989	3.005	3.002	2.986	2.966	2.970	2.978	2.923	3.117
Al^{VI}	1.970	1.987	1.971	1.945	1.941	1.955	1.903	1.999	1.963	1.794
Ti	0.003	0.006	0.002	0.001	0.003	0.005	0.001	0.006	0.000	0.007
Cr	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Fe^{3+}	0.078	0.026	0.013	0.049	0.076	0.108	0.160	0.091	0.193	0.000
ΣY	2.051	2.019	1.986	1.995	2.024	2.068	2.064	2.096	2.156	1.801
Fe^{2+}	1.950	1.996	2.188	2.118	2.037	1.855	2.029	2.128	1.935	2.202
Mn	0.090	0.089	0.102	0.129	0.060	0.089	0.098	0.087	0.076	0.099
Mg	0.403	0.367	0.274	0.283	0.537	0.463	0.554	0.291	0.383	0.303
Ca	0.529	0.532	0.434	0.464	0.376	0.575	0.471	0.449	0.523	0.457
ΣX	2.972	2.984	3.008	3.004	2.990	2.962	3.122	2.955	2.917	3.061
X_{Mg}	**0.17**	**0.16**	**0.10**	**0.11**	**0.21**	**0.20**	**0.22**	**0.12**	**0.17**	**0.12**
Pyrope	13.213	12.193	9.401	9.597	16.862	14.430	15.966	9.554	12.315	9.899
Almandine	66.492	67.176	72.857	70.979	68.917	63.941	66.697	72.850	68.424	71.937
Grossularite	17.344	17.674	14.366	15.198	12.264	18.730	14.351	14.741	16.817	14.930
Spessartite	2.951	2.957	3.376	4.225	1.957	2.899	2.986	2.856	2.444	3.234

Table 5.1 contd.

Sample	M-9									
Domain	91	92	93	94	95	96	105	106	107	108
SiO_2	37.570	37.424	36.904	36.482	36.329	36.287	36.465	36.781	36.875	36.285
TiO_2	0.074	0.054	0.000	0.056	0.061	0.112	0.070	0.069	0.001	0.079
Al_2O_3	20.964	21.060	21.378	20.572	20.376	21.559	20.982	20.561	20.122	20.593
Cr_2O_3	0.000	0.000	0.179	0.000	0.000	0.000	0.000	0.042	0.054	0.083
FeO	32.787	32.783	32.645	34.280	34.961	34.783	35.731	33.958	36.106	34.793
MnO	0.400	0.517	0.349	0.683	1.043	0.991	0.889	0.930	0.922	1.876
MgO	5.988	6.228	6.337	5.576	4.676	3.768	3.546	4.820	3.639	3.629
CaO	1.913	1.798	2.014	1.867	2.160	2.084	2.264	2.344	2.511	2.430
Total	**99.722**	**99.898**	**99.863**	**99.538**	**99.625**	**99.629**	**99.957**	**99.541**	**100.249**	**99.806**
Si	2.973	2.953	2.906	2.908	2.911	2.913	2.929	2.941	2.957	2.919
Al^{IV}	0	0.000	0.011	0.000	0.247	0.000	0.000	0.003	0.003	0.005
ΣZ	2.973	2.953	2.917	2.908	3.158	2.913	2.929	2.944	2.960	2.924
Al^{VI}	1.955	1.959	1.985	1.933	1.925	2.041	1.986	1.938	1.902	1.953
Ti	0.004	0.003	0.004	0.004	0.004	0.007	0.004	0.004	0.000	0.005
Cr	0	0.000	0.011	0.000	0.247	0.000	0.000	0.003	0.003	0.005
Fe^{3+}	0.094	0.132	1.191	0.246	0.071	0.126	0.149	0.172	0.182	0.198
ΣY	2.053	2.094	3.191	2.183	2.247	2.174	2.139	2.117	2.087	2.161
Fe^{2+}	2.076	2.031	1.958	2.039	2.096	2.209	2.251	2.099	2.240	2.143
Mn	0.027	0.035	0.023	0.046	0.071	0.067	0.061	0.063	0.063	0.128
Mg	0.706	0.733	0.744	0.663	0.559	0.451	0.425	0.574	0.435	0.435
Ca	0.162	0.151	0.170	0.160	0.185	0.179	0.194	0.201	0.216	0.209
ΣX	2.971	2.950	2.895	2.908	2.911	2.906	2.931	2.937	2.954	2.915
X_{Mg}	**0.25**	**0.27**	**0.28**	**0.25**	**0.21**	**0.17**	**0.16**	**0.21**	**0.16**	**0.17**
Pyrope	49.16	47.71	30.83	45.64	44.97	48.99	49.59	47.80	49.65	47.55
Almandine	2.21	3.08	18.86	5.45	6.72	2.75	3.24	3.93	4.04	4.38
Grossularite	0.64	0.82	0.36	1.02	1.50	1.46	1.33	1.41	1.38	2.76
Spessartite	48.31	48.79	50.06	48.36	47.49	47.51	46.50	47.53	45.62	46.62

Table 5.1 contd. (from garnet-biotite gneisses)

Sample	M-1A					M1-A1				
Domain	25	26	32	38	45	27	28	31	58	52
SiO_2	37.955	37.544	37.631	37.974	37.905	37.057	36.932	37.137	36.563	36.857
TiO_2	0.028	0.036	0.059	0.043	0.068	0.042	0.054	0.049	0.135	0.090
Al_2O_3	20.844	20.959	20.769	20.460	20.947	21.156	20.933	20.814	20.471	20.565
Cr_2O_3	0.000	0.000	0.000	0.070	0.000	0.000	0.000	0.000	0.000	0.000
FeO	32.485	33.381	33.637	33.594	33.313	33.207	33.481	33.993	30.705	31.167
MnO	1.560	1.584	1.369	1.024	1.527	1.327	1.394	1.405	1.246	1.362
MgO	3.544	3.447	3.753	3.458	3.461	3.294	3.272	2.643	3.941	3.666
CaO	3.340	3.870	3.259	3.734	3.075	4.590	3.935	4.080	6.631	6.204
Total	**99.775**	**100.838**	**100.503**	**100.356**	**100.294**	**100.706**	**100.000**	**100.126**	**99.719**	**99.921**
Si	3.033	2.979	2.994	3.029	3.022	2.964	2.957	2.982	2.989	2.963
Al^{IV}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ΣZ	3.033	2.979	2.994	3.029	3.022	2.944	2.957	2.982	2.989	2.963
Al^{VI}	1.963	1.960	1.948	1.924	1.969	1.981	1.976	1.970	1.920	1.949
Ti	0.002	0.002	0.004	0.002	0.004	0.002	0.003	0.003	0.008	0.005
Cr	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Fe^{3+}	0.000	0.080	0.059	0.012	0.000	0.132	0.104	0.060	0.252	0.114
ΣY	1.965	2.042	2.011	1.942	1.973	2.115	2.083	2.033	2.180	2.068
Fe^{2+}	2.171	2.135	2.179	2.229	2.220	2.074	2.138	2.222	1.791	1.849
Mn	0.106	0.106	0.092	0.069	0.103	0.089	0.094	0.096	0.084	0.093
Mg	0.422	0.407	0.445	0.410	0.411	0.389	0.390	0.316	0.467	0.430
Ca	0.286	0.329	0.277	0.319	0.262	0.382	0.338	0.351	0.565	0.525
ΣX	2.985	2.977	2.993	3.027	2.996	2.934	2.960	2.985	2.907	2.967
X_{Mg}	**0.16**	**0.16**	**0.17**	**0.16**	**0.16**	**0.16**	**0.15**	**0.13**	**0.20**	**0.18**
Pyrope	14.137	13.314	14.581	13.491	13.718	12.69	12.73	10.38	14.78	14.13
Almandine	72.730	72.457	73.329	73.741	74.099	71.95	73.17	74.94	64.67	66.27
Grossularite	9.581	10.762	9.076	10.497	8.745	12.46	11.03	11.53	17.89	16.60
Spessartite	3.551	3.467	3.014	2.270	3.438	2.90	3.07	3.15	2.66	2.93

Table 5.1 contd. (from amphibolites)

Sample	**B-6**									
Domain	56	57	58	59	60	61	62	82	83	84
SiO_2	38.309	38.003	37.037	38.088	37.195	37.701	37.546	37.625	37.997	38.146
TiO_2	0.102	0.048	0.066	0.050	0.032	0.032	0.077	0.104	0.054	0.065
Al_2O_3	18.419	18.829	19.646	18.754	19.994	18.909	19.832	18.358	19.996	18.905
Cr_2O_3	0.139	0.090	0.052	0.064	0.000	0.115	0.177	0.133	0.119	0.179
FeO	28.070	26.457	25.733	26.216	25.476	25.944	29.010	25.675	24.283	25.756
MnO	6.191	8.693	8.765	8.889	8.875	9.315	7.665	9.895	7.135	8.666
MgO	1.908	1.792	1.796	1.690	2.111	2.840	2.242	1.865	2.894	2.337
CaO	6.527	6.029	6.750	6.007	5.460	5.400	3.238	6.998	6.736	6.013
Total	**99.665**	**99.940**	**99.844**	**99.759**	**99.142**	**100.256**	**99.785**	**100.653**	**99.213**	**100.066**
Si	3.003	3.073	2.988	3.087	3.018	3.024	3.000	3.022	3.050	3.069
Al^{IV}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ΣZ	3.003	3.073	2.988	3.087	3.018	3.024	3.000	3.022	3.050	3.069
Al^{VI}	1.858	1.795	1.869	1.792	1.912	1.788	1.868	1.738	1.893	1.793
Ti	0.006	0.003	0.004	0.003	0.002	0.002	0.005	0.006	0.004	0.004
Cr	0.009	0.006	0.003	0.004	0.000	0.008	0.011	0.008	0.008	0.011
Fe^{3+}	0.014	0.047	0.142	0.023	0.050	0.155	0.114	0.198	0.000	0.050
ΣY	0.029	0.056	0.149	0.030	0.052	0.165	0.130	0.212	0.012	0.065
Fe^{2+}	1.887	1.742	1.594	1.754	1.678	1.586	1.825	1.527	1.630	1.683
Mn	0.425	0.595	0.599	0.610	0.609	0.633	0.630	0.674	0.485	0.591
Mg	0.231	0.216	0.216	0.204	0.255	0.340	0.267	0.224	0.346	0.281
Ca	0.567	0.523	0.584	0.522	0.475	0.464	0.277	0.602	0.580	0.519
ΣX	3.110	3.076	2.993	3.090	3.017	3.023	2.999	3.027	3.041	3.074
X_{Mg}	**0.11**	**0.11**	**0.12**	**0.10**	**0.13**	**0.18**	**0.13**	**0.13**	**0.18**	**0.14**
Pyrope	7.39	6.92	6.89	6.55	8.31	10.70	8.58	6.95	11.38	8.99
Almandine	60.85	57.28	55.37	57.08	56.34	54.78	62.29	53.49	53.60	55.47
Grossularite	18.15	16.75	18.63	16.77	15.49	14.60	8.90	18.67	19.07	16.61
Spessartite	13.60	19.05	19.11	19.60	19.86	19.92	20.24	20.90	15.95	18.92

Table 5.2 Chemical analysis and structural formulae (on the basis of 6 Oxygen) of Orthopyroxene from pelitic granulites.

Sample	**PM-1**					**PM-5**				
Domain	20-C	23-C	39-C	29-R	41-R	24	30	47	50	60
SiO_2	50.583	51.056	51.005	50.656	50.567	50.176	50.880	50.230	50.873	50.923
TiO_2	0.021	0.058	0.03	1.409	0.254	0.161	0.029	0.085	0.176	0.116
Al_2O_3	1.967	1.521	1.838	2.418	2.231	2.663	2.555	2.605	2.270	2.642
FeO	29.906	30.899	30.844	31.603	32.254	30.894	30.396	30.172	30.084	29.532
MnO	0.637	0.654	0.661	0.227	0.478	0.080	0.443	0.375	0.364	0.714
MgO	14.862	13.977	13.615	12.388	12.354	14.523	14.379	14.861	14.273	14.377
CaO	0.715	0.763	0.782	0.455	0.689	0.494	0.515	0.354	0.387	0.803
Na_2O	0.357	0.236	0.338	0.215	0.312	0.335	0.332	0.237	0.213	0.256
K2O	0	0.005	0.011	0.013	0	0.054	0.000	0.000	0.005	0.067
Total	**99.048**	**99.1688**	**99.124**	**99.384**	**99.139**	**99.379**	**99.530**	**98.918**	**98.646**	**99.430**
Si	1.977	2.000	1.999	1.980	1.992	1.958	1.977	1.963	1.990	1.977
Al^{IV}	0.023	0.000	0.001	0.020	0.008	0.042	0.023	0.037	0.010	0.023
Ti	0.001	0.002	0.001	0.041	0.008	0.005	0.001	0.002	0.005	0.003
Al^{VI}	0.068	0.070	0.083	0.091	0.096	0.081	0.094	0.083	0.095	0.098
Fe^{3+}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe^{2+}	0.980	1.019	1.018	1.051	1.073	1.011	0.993	0.990	0.994	0.966
Mn	0.021	0.022	0.022	0.008	0.016	0.003	0.015	0.012	0.012	0.023
Mg	0.866	0.816	0.795	0.722	0.726	0.845	0.833	0.866	0.832	0.832
Ca	0.030	0.032	0.033	0.019	0.029	0.021	0.021	0.015	0.016	0.033
Na	0.027	0.018	0.026	0.016	0.024	0.025	0.025	0.018	0.016	0.019
K	0.000	0.000	0.001	0.001	0.000	0.003	0.000	0.000	0.000	0.003
Total	3.993	3.979	3.979	3.949	3.971	3.992	3.982	3.987	3.971	3.978
End member										
X_{Wo}	1.56	1.68	1.73	1.05	1.56	1.09	1.14	0.78	0.87	1.78
X_{En}	45.01	42.80	42.00	39.76	38.85	44.57	44.13	45.54	44.50	44.40
X_{Fs}	52.02	54.58	54.91	58.30	58.32	53.00	53.41	52.73	53.77	52.79
X_{Ac}	1.41	0.94	1.36	0.90	1.28	1.34	1.33	0.94	0.86	1.03
X_{Mg}	**0.47**	**0.44**	**0.44**	**0.41**	**0.40**	**0.46**	**0.46**	**0.47**	**0.46**	**0.46**

Table 5.2 contd.

Sample	**M-9**									
Domain	112	113	114	115	116	135	136	137	138	139
SiO_2	51.960	51.780	51.689	51.490	51.603	50.333	49.715	50.689	49.787	49.560
TiO_2	0.003	0.018	0.046	0.051	0.042	0.060	0.037	0.057	0.074	0.082
Al_2O_3	2.942	2.205	2.613	2.345	2.076	2.400	2.765	2.506	2.730	2.495
FeO	29.296	29.822	30.049	30.252	30.966	30.793	31.261	29.917	29.784	31.804
MnO	0.339	0.470	0.248	0.404	0.391	0.614	0.575	0.732	0.445	0.497
MgO	14.965	15.058	14.895	14.929	14.386	14.498	14.829	15.181	15.583	14.450
CaO	0.204	0.160	0.158	0.107	0.117	0.441	0.352	0.388	0.546	0.483
Na_2O	0.051	0.055	0.059	0.074	0.086	0.139	0.088	0.103	0.116	0.113
K2O	0.014	0.000	0.025	0.037	0.048	0.033	0.042	0.000	0.033	0.028
Total	**99.772**	**99.595**	**99.782**	**99.730**	**99.854**	**99.309**	**99.663**	**99.572**	**99.097**	**99.510**
Si	1.992	1.998	1.990	1.989	1.997	1.967	1.942	1.966	1.943	1.945
Al^{IV}	0.008	0.002	0.010	0.011	0.003	0.033	0.058	0.034	0.057	0.055
Ti	0.000	0.001	0.001	0.001	0.001	0.002	0.001	0.002	0.002	0.002
Al^{VI}	0.125	0.098	0.108	0.095	0.092	0.078	0.069	0.081	0.069	0.061
Fe^{3+}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe^{2+}	0.953	0.973	0.979	0.987	1.013	1.011	1.022	0.976	0.973	1.044
Mn	0.011	0.015	0.008	0.013	0.013	0.020	0.019	0.024	0.015	0.017
Mg	0.855	0.866	0.855	0.860	0.830	0.845	0.864	0.878	0.907	0.846
Ca	0.008	0.007	0.007	0.004	0.005	0.018	0.015	0.016	0.023	0.020
Na	0.004	0.004	0.004	0.006	0.006	0.010	0.007	0.008	0.009	0.009
K	0.001	0.000	0.001	0.002	0.002	0.002	0.002	0.000	0.002	0.001
Total	3.957	3.965	3.964	3.970	3.967	3.986	3.998	3.984	3.998	4.000
End member										
X_{Wo}	0.46	0.36	0.35	0.24	0.26	0.97	0.77	0.85	1.19	1.05
X_{En}	46.71	46.42	46.14	45.97	44.45	44.34	44.84	46.17	47.09	43.70
X_{Fs}	52.62	53.00	53.27	53.49	54.94	54.14	54.05	52.57	51.27	54.81
X_{Ac}	0.21	0.22	0.24	0.30	0.35	0.55	0.34	0.41	0.45	0.44
X_{Mg}	**0.47**	**0.47**	**0.47**	**0.47**	**0.45**	**0.46**	**0.46**	**0.47**	**0.48**	**0.45**

Table 5.3 Chemical analysis and structural formulae (on the basis of 6 Oxygen) of Clinopyroxene from amphibolites.

Sample No.	**MM-1**					**BB-1**				
Domain	4	5	6	7	8	13	14	15	16	17
SiO_2	49.220	49.550	48.890	47.450	49.385	48.250	48.740	47.240	48.560	48.495
TiO_2	0.140	0.120	0.160	0.100	0.130	0.100	0.150	0.180	0.160	0.125
Al_2O_3	0.490	0.550	0.770	0.500	0.520	0.600	0.990	0.550	0.470	0.795
Cr_2O_3	0.090	0.080	0.080	0.100	0.085	0.100	0.070	0.020	0.010	0.085
FeO	23.790	21.200	23.260	21.340	22.495	22.300	23.150	24.160	22.780	22.725
MnO	0.220	0.330	0.230	0.240	0.275	0.300	0.230	0.450	0.340	0.265
MgO	8.120	10.110	8.290	11.430	9.115	9.920	8.450	8.790	9.220	9.185
CaO	17.220	17.650	17.660	18.520	17.435	17.560	17.560	18.220	18.050	17.560
Na_2O	0.120	0.130	0.110	0.020	0.125	0.100	0.100	0.010	0.120	0.100
K_2O	0.000	0.020	0.010	0.000	0.01	0.000	0.010	0.020	0.010	0.005
Total	**99.410**	**99.740**	**99.460**	**99.700**	**99.575**	**99.230**	**99.450**	**99.640**	**99.720**	**99.340**
Si	1.964	1.950	1.949	1.885	1.957	1.924	1.942	1.903	1.933	1.933
Al	0.023	0.026	0.036	0.023	0.024	0.028	0.046	0.026	0.022	0.037
Cr	0.003	0.002	0.003	0.003	0.092	0.003	0.002	0.001	0.000	0.140
Ti	0.004	0.004	0.005	0.003	0.003	0.003	0.004	0.005	0.005	0.003
Fe^{+3}	0.070	0.113	0.094	0.290	0.004	0.179	0.100	0.234	0.166	0.004
Fe^{+2}	0.719	0.578	0.676	0.402	0.648	0.553	0.665	0.564	0.582	0.609
Mn	0.007	0.011	0.008	0.008	0.009	0.010	0.008	0.015	0.011	0.009
Mg	0.483	0.593	0.493	0.677	0.538	0.590	0.502	0.528	0.547	0.546
Ca	0.736	0.744	0.754	0.788	0.740	0.750	0.749	0.786	0.770	0.750
Na	0.009	0.010	0.009	0.002	0.010	0.008	0.008	0.001	0.009	0.008
K	0.000	0.001	0.001	0.000	0.001	0.000	0.001	0.001	0.001	0.000
Total	4.019	4.031	4.025	4.082	4.025	4.050	4.027	4.064	4.046	4.038
End member										
X_{Wo}	36.35	36.31	37.11	36.38	36.33	35.89	36.89	36.95	36.91	36.38
X_{En}	23.85	28.94	24.24	31.25	26.43	28.21	24.70	24.80	26.24	26.48
X_{Fs}	39.34	34.26	38.23	32.30	36.76	35.53	38.03	38.21	36.41	36.76
X_{Ac}	0.46	0.48	0.42	0.07	0.47	0.37	0.38	0.04	0.44	0.37
X_{Mg}	**0.40**	**0.51**	**0.42**	**0.63**	**0.45**	**0.52**	**0.43**	**0.48**	**0.48**	**0.47**

Table 5.3 contd.

Sample No.	**B-6**					**K-1**				
Domain	142	143	144	145	146	23	24	25	26	27
SiO_2	52.267	51.989	52.343	52.128	52.166	50.243	52.468	52.982	51.356	52.225
TiO_2	0.160	0.124	0.196	0.142	0.160	0.158	0.19	0.145	0.174	0.168
Al_2O_3	0.980	0.865	0.453	0.923	0.659	0.702	0.382	0.481	0.592	0.432
Cr_2O_3	0.012	0.002	0.046	0.007	0.024	0.1	0.03	0.022	0.065	0.026
FeO	12.435	11.998	11.045	12.217	11.522	9.672	6.458	8.263	8.065	7.361
MnO	1.698	1.724	1.646	1.711	1.685	0.67	0.98	0.56	0.825	0.77
MgO	9.978	10.354	10.962	10.166	10.658	13.467	14.89	11.124	14.179	13.507
CaO	22.423	23.589	23.672	23.006	23.631	25.232	24.539	25.986	24.886	25.263
Na_2O	–	0.010	0.012	0.005	0.011	–	0.05	0.06	0.025	0.055
K_2O	0.165	0.192	0.173	0.179	0.183	0.16	0.18	0.19	0.17	0.185
Total	**100.118**	**100.847**	**100.548**	**100.483**	**100.698**	**100.404**	**100.167**	**99.813**	**100.336**	**99.990**
Si	1.993	1.974	1.984	1.983	1.979	1.898	1.958	1.999	1.928	1.962
Al	0.007	0.026	0.016	0.017	0.021	0.054	0.017	0.001	0.035	0.019
Cr	–	–	0.001	–	0.001	0.003	0.001	0.001	0.002	0.001
Ti	0.005	0.004	0.006	0.004	0.005	0.004	0.005	0.004	0.005	0.005
Fe^{3+}	–	0.024	0.012	–	0.018	0.066	0.042	–	0.059	0.027
Fe^{2+}	0.398	0.356	0.337	0.389	0.346	0.234	0.158	0.261	0.191	0.202
Mn	0.055	0.055	0.053	0.055	0.054	0.021	0.031	0.018	0.026	0.025
Mg	0.567	0.586	0.619	0.577	0.603	0.758	0.828	0.626	0.794	0.757
Ca	0.916	0.960	0.961	0.938	0.960	1.021	0.981	1.050	1.001	1.017
Na	–	0.001	0.001	–	0.001	–	0.004	0.004	0.002	0.004
K	0.008	0.009	0.008	0.009	0.009	0.008	0.009	0.009	0.008	0.009
Total	3.986	4.007	4.004	3.997	4.006	4.068	4.033	3.993	4.050	4.028
End member										
X_{Wo}	47.31	48.41	48.45	47.87	48.43	48.60	48.00	53.60	48.30	50.05
X_{En}	29.30	29.57	31.22	29.44	30.40	36.10	40.53	31.93	38.29	37.24
X_{Fs}	23.39	21.98	20.29	22.67	21.13	15.30	11.29	14.24	13.32	12.51
X_{Ac}	0.00	0.04	0.04	0.02	0.04	0.00	0.18	0.22	0.09	0.20
X_{Mg}	**0.59**	**0.62**	**0.65**	**0.60**	**0.64**	**0.76**	**0.84**	**0.71**	**0.81**	**0.79**

Table 5.4 Chemical analysis and structural formulae (on the basis of 23 Oxygen) of amphibole from amphibolites.

Sample No.	MM-1					BB-1				
Domain	5	6	7	8	12	9	10	11	14	17
SiO_2	43.399	43.564	43.618	43.656	44.736	44.814	43.659	44.333	43.956	43.716
TiO_2	0.410	0.393	0.421	0.495	0.414	0.399	0.431	0.440	0.476	0.347
Al_2O_3	14.219	14.315	14.875	13.411	12.931	12.196	16.079	13.039	13.099	14.833
FeO	12.109	12.135	11.947	14.207	13.345	13.498	11.576	12.509	13.773	12.132
MnO	0.256	0.098	0.061	0.183	0.122	0.098	0.110	0.073	0.158	0.183
MgO	11.890	12.128	12.572	12.303	12.502	12.933	12.330	12.605	11.809	11.833
CaO	11.646	11.683	11.915	11.639	11.481	11.735	11.443	11.682	11.985	11.840
Na_2O	1.381	1.586	1.327	1.622	1.370	1.389	1.499	1.420	1.346	1.286
K_2O	0.181	0.171	0.196	0.179	0.177	0.173	0.191	0.139	0.248	0.209
Total	**95.490**	**96.072**	**96.931**	**97.694**	**97.078**	**97.236**	**97.318**	**96.240**	**96.849**	**96.379**
Si	6.373	6.360	6.283	6.291	6.448	6.463	6.231	6.451	6.420	6.357
Al^{iv}	1.627	1.640	1.717	1.709	1.552	1.537	1.769	1.549	1.580	1.643
Al^{vi}	0.833	0.823	0.808	0.569	0.645	0.536	0.936	0.687	0.675	0.899
Ti	0.045	0.043	0.046	0.054	0.045	0.043	0.046	0.048	0.052	0.038
Fe^{+3}	0.612	0.594	0.733	0.953	0.855	0.867	0.792	0.698	0.623	0.577
Fe^{+2}	0.875	0.888	0.706	0.759	0.753	0.761	0.590	0.824	1.060	0.898
Mn	0.032	0.012	0.007	0.022	0.015	0.012	0.013	0.009	0.020	0.023
Mg	2.603	2.640	2.700	2.643	2.686	2.781	2.623	2.734	2.571	2.565
Ca	1.832	1.827	1.839	1.797	1.773	1.813	1.750	1.821	1.875	1.845
Na	0.393	0.449	0.371	0.453	0.383	0.388	0.415	0.401	0.381	0.363
K	0.034	0.032	0.036	0.033	0.033	0.032	0.035	0.026	0.046	0.039
X_{Mg}	**0.75**	**0.75**	**0.79**	**0.78**	**0.78**	**0.79**	**0.82**	**0.77**	**0.71**	**0.74**

Table 5.4 contd.

Sample No.	B-6					K-1				
Domain	142	143	144	145	146	23	24	25	26	27
SiO_2	52.267	51.989	52.343	52.128	52.166	50.243	52.468	52.982	51.356	52.225
TiO_2	0.160	0.124	0.196	0.142	0.160	0.158	0.19	0.145	0.174	0.168
Al_2O_3	0.980	0.865	0.453	0.923	0.659	0.702	0.382	0.481	0.592	0.432
Cr_2O_3	0.012	0.002	0.046	0.007	0.024	0.1	0.03	0.022	0.065	0.026
FeO	12.435	11.998	11.045	12.217	11.522	9.672	6.458	8.263	8.065	7.361
MnO	1.698	1.724	1.646	1.711	1.685	0.67	0.98	0.56	0.825	0.77
MgO	9.978	10.354	10.962	10.166	10.658	13.467	14.89	11.124	14.179	13.507
CaO	22.423	23.589	23.672	23.006	23.631	25.232	24.539	25.986	24.886	25.263
Na_2O	–	0.010	0.012	0.005	0.011	–	0.05	0.06	0.025	0.055
K_2O	0.165	0.192	0.173	0.179	0.183	0.16	0.18	0.19	0.17	0.185
Total	**100.118**	**100.847**	**100.548**	**100.483**	**100.698**	**100.404**	**100.167**	**99.813**	**100.336**	**99.990**
Si	1.993	1.974	1.984	1.983	1.979	1.898	1.958	1.999	1.928	1.962
Al	0.007	0.026	0.016	0.017	0.021	0.054	0.017	0.001	0.035	0.019
Cr	–	–	0.001	–	0.001	0.003	0.001	0.001	0.002	0.001
Ti	0.005	0.004	0.006	0.004	0.005	0.004	0.005	0.004	0.005	0.005
Fe^{3+}	–	0.024	0.012	–	0.018	0.066	0.042	–	0.059	0.027
Fe^{2+}	0.398	0.356	0.337	0.389	0.346	0.234	0.158	0.261	0.191	0.202
Mn	0.055	0.055	0.053	0.055	0.054	0.021	0.031	0.018	0.026	0.025
Mg	0.567	0.586	0.619	0.577	0.603	0.758	0.828	0.626	0.794	0.757
Ca	0.916	0.960	0.961	0.938	0.960	1.021	0.981	1.050	1.001	1.017
Na	–	0.001	0.001	–	0.001	–	0.004	0.004	0.002	0.004
K	0.008	0.009	0.008	0.009	0.009	0.008	0.009	0.009	0.008	0.009
Total	3.986	4.007	4.004	3.997	4.006	4.068	4.033	3.993	4.050	4.028
End member										
X_{Wo}	47.31	48.41	48.45	47.87	48.43	48.60	48.00	53.60	48.30	50.05
X_{En}	29.30	29.57	31.22	29.44	30.40	36.10	40.53	31.93	38.29	37.24
X_{Fs}	23.39	21.98	20.29	22.67	21.13	15.30	11.29	14.24	13.32	12.51
X_{Ac}	0.00	0.04	0.04	0.02	0.04	0.00	0.18	0.22	0.09	0.20
$\mathbf{X_{Mg}}$	**0.59**	**0.62**	**0.65**	**0.60**	**0.64**	**0.76**	**0.84**	**0.71**	**0.81**	**0.79**

Table 5.5 Chemical analysis and structural formulae (on the basis of 18 Oxygen) of Cordierite from pelitic granulites.

Sample	**M-9**											
Domain	90	98	99	117	118	119	120	121	122	123	124	125
SiO_2	47.890	48.445	48.161	48.064	47.730	47.606	47.652	48.695	49.457	48.049	48.087	47.668
Al_2O_3	31.493	31.451	31.692	30.990	30.938	30.889	31.368	30.334	30.764	31.410	31.195	30.914
FeO	7.953	8.197	7.859	9.011	8.189	8.966	7.750	8.924	6.674	7.973	8.193	8.578
MnO	0.108	0.081	0.068	0.028	0.096	0.027	0.001	0.035	0.068	0.041	0.089	0.061
MgO	7.697	7.803	7.619	7.927	7.896	8.123	7.794	7.784	8.223	7.799	7.850	8.009
CaO	0.069	0.014	0.019	0.001	0.022	0.026	0.012	0.032	0.002	0.013	0.018	0.024
Na_2O	0.580	0.408	0.403	0.425	0.338	0.319	0.440	0.457	0.643	0.424	0.373	0.329
K_2O	0.066	0.017	0.033	0.027	0.000	0.017	0.024	0.013	0.022	0.021	0.008	0.008
Total	**95.858**	**96.416**	**95.853**	**96.471**	**95.209**	**95.990**	**95.041**	**96.273**	**95.853**	**95.728**	**95.812**	**95.600**
Si	5.060	5.086	5.077	5.068	5.078	5.046	5.066	5.138	5.181	5.076	5.082	5.062
Al	3.922	3.891	3.937	3.851	3.879	3.859	3.930	3.772	3.798	3.910	3.885	3.869
ΣZ	8.982	8.977	9.013	8.919	8.956	8.904	8.996	8.910	8.979	8.986	8.967	8.930
Fe^{2+}	0.703	0.720	0.693	0.794	0.728	0.795	0.689	0.787	0.585	0.704	0.724	0.762
Mn	0.010	0.007	0.006	0.002	0.009	0.002	0.000	0.003	0.006	0.004	0.008	0.006
Mg	1.213	1.221	1.197	1.246	1.252	1.284	1.235	1.224	1.284	1.228	1.237	1.268
∑Y	1.925	1.948	1.896	2.043	1.989	2.081	1.924	2.015	1.875	1.936	1.969	2.035
Ca	0.008	0.002	0.002	0.000	0.003	0.003	0.001	0.004	0.000	0.001	0.002	0.003
Na	0.119	0.083	0.082	0.087	0.070	0.066	0.091	0.093	0.131	0.087	0.076	0.068
K	0.009	0.002	0.004	0.004	0.000	0.002	0.003	0.002	0.003	0.003	0.001	0.001
ΣX	3.985	3.983	3.881	4.177	4.051	4.232	3.944	4.129	3.883	3.963	4.017	4.142
Total	12.967	12.959	12.894	13.095	13.007	13.137	12.940	13.039	12.862	12.950	12.983	13.072
X_{Mg}	**0.63**	**0.63**	**0.63**	**0.61**	**0.63**	**0.62**	**0.64**	**0.61**	**0.69**	**0.64**	**0.63**	**0.62**

Table 5.6 Chemical analysis and structural formulae (on the basis of 22 Oxygen) of biotite from pelitic granulites

Sample	PM-1					M-9				
Domain	56	21	86	87	88	83	84	85	86	97
SiO_2	32.842	33.826	32.144	33.876	33.315	36.040	35.898	36.141	36.395	37.658
TiO_2	1.624	1.658	1.954	1.712	1.921	1.053	1.038	1.094	1.004	1.390
Al_2O_3	16.917	16.997	17.153	17.808	17.796	17.526	16.567	15.371	16.612	16.827
FeO	25.859	24.563	25.396	23.851	23.533	16.294	16.798	17.320	16.481	15.689
MnO	0.001	0.000	0.108	0.000	0.076	0.053	0.052	0.134	0.067	0.000
MgO	8.766	9.075	11.362	10.759	10.985	13.597	14.385	13.901	14.191	13.178
CaO	0.212	0.294	0.131	0.057	0.148	0.153	0.202	0.312	0.348	0.067
Na_2O	0.312	0.395	0.078	0.112	0.195	0.293	0.351	0.180	0.126	0.265
K2O	8.230	8.588	6.686	6.800	6.880	8.186	8.207	8.953	8.424	8.118
Cl	0.007	0.025	0.027	0.057	0.052	0.065	0.098	0.016	0.020	0.085
F	0.125	0.164	0.186	0.090	0.206	1.193	1.107	1.149	1.125	1.426
Total	**95.103**	**95.834**	**95.224**	**95.139**	**95.107**	**94.452**	**94.703**	**94.570**	**94.791**	**94.702**
Si	5.213	5.295	5.040	5.235	5.166	5.494	5.482	5.574	5.539	5.694
Al^{IV}	2.787	2.705	2.960	2.765	2.834	2.506	2.518	2.426	2.461	2.306
ΣZ	8.000	8.00	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{VI}	0.378	0.430	0.209	0.478	0.418	0.643	0.464	0.367	0.519	0.692
Ti	0.194	0.195	0.230	0.199	0.224	0.121	0.119	0.127	0.115	0.158
Fe^{2+}	3.432	3.215	3.329	3.082	3.051	2.077	2.145	2.234	2.097	1.984
Mn	0.000	0.000	0.014	0.000	0.010	0.007	0.007	0.017	0.009	0.000
Mg	2.075	2.118	2.656	2.479	2.539	3.090	3.275	3.196	3.220	2.970
ΣX	6.092	5.97	6.439	6.240	6.243	5.938	6.010	5.941	5.960	5.804
Ca	0.036	0.049	0.022	0.009	0.025	0.025	0.033	0.052	0.057	0.011
Na	0.096	0.120	0.024	0.033	0.059	0.086	0.104	0.054	0.037	0.078
K	1.666	1.715	1.337	1.340	1.361	1.592	1.599	1.761	1.635	1.566
ΣY	1.798	1.88	1.383	1.383	1.444	1.703	1.736	1.867	1.729	1.654
Cl	0.002	0.007	0.007	0.015	0.014	0.017	0.025	0.004	0.005	0.022
F	0.063	0.081	0.092	0.044	0.101	0.575	0.535	0.560	0.541	0.682
X_{Mg}	**0.38**	**0.40**	**0.44**	**0.45**	**0.45**	**0.60**	**0.60**	**0.59**	**0.61**	**0.60**

Table 5.6 contd. (from pelitic granulites and amphibolites**)**

Sample	**M-9**				**B-6**					
Domain	121	122	123	124	149	150	151	152	153	154
SiO_2	35.279	35.669	35.637	36.935	35.969	36.473	35.771	34.722	35.789	35.845
TiO_2	1.382	1.313	1.280	1.275	5.647	5.660	5.547	5.507	5.613	5.790
Al_2O_3	17.385	17.689	16.935	16.749	13.623	13.597	14.864	13.787	13.854	13.908
FeO	17.921	16.813	17.845	17.326	20.061	19.195	20.140	20.701	19.905	20.674
MnO	0.054	0.053	0.171	0.013	0.057	0.057	0.000	0.000	0.000	0.029
MgO	14.467	12.921	13.853	13.273	10.194	10.194	9.353	9.799	10.367	10.954
CaO	0.019	0.000	0.000	0.000	0.279	0.162	0.108	0.207	0.234	1.008
Na_2O	0.173	0.190	0.156	0.140	0.374	0.293	0.285	0.455	0.443	0.261
K2O	8.835	8.723	8.933	8.730	9.096	9.341	9.051	9.969	9.572	7.348
Cl	0.058	0.060	0.032	0.047	0.019	0.017	0.018	0.018	0.015	0.004
F	1.096	1.342	1.255	1.182	0.164	0.196	0.230	0.179	0.125	0.161
Total	**96.667**	**94.772**	**96.097**	**95.669**	**95.482**	**95.185**	**95.367**	**95.343**	**95.918**	**95.983**
Si	5.321	5.458	5.415	5.588	5.529	5.598	5.494	5.412	5.487	5.446
Al^{IV}	2.679	2.542	2.585	2.412	2.468	2.402	2.506	2.533	2.503	2.490
ΣZ	8.000	8.000	8.000	8.000	7.998	8.000	8.000	7.944	7.990	7.937
Al^{VI}	0.411	0.647	0.448	0.574	0.000	0.058	0.184	0.000	0.000	0.000
Ti	0.157	0.151	0.146	0.145	0.653	0.653	0.641	0.646	0.647	0.662
Fe^{2+}	2.260	2.151	2.267	2.192	2.579	2.464	2.587	2.698	2.552	2.627
Mn	0.007	0.007	0.022	0.002	0.007	0.007	0.000	0.000	0.000	0.004
Mg	3.253	2.947	3.138	2.993	2.336	2.333	2.141	2.277	2.370	2.481
ΣX	6.088	5.904	6.022	5.905	5.575	5.515	5.553	5.620	5.569	5.773
Ca	0.003	0.000	0.000	0.000	0.046	0.027	0.018	0.035	0.038	0.164
Na	0.051	0.056	0.046	0.041	0.111	0.087	0.085	0.138	0.132	0.077
K	1.700	1.703	1.732	1.685	1.784	1.829	1.773	1.982	1.872	1.424
ΣY	1.753	1.759	1.777	1.726	1.941	1.943	1.876	2.154	2.042	1.665
Cl	0.015	0.015	0.008	0.012	0.005	0.004	0.005	0.005	0.004	0.001
F	0.522	0.649	0.603	0.566	0.079	0.095	0.112	0.088	0.061	0.077
X_{Mg}	**0.59**	**0.58**	**0.58**	**0.58**	**0.48**	**0.49**	**0.45**	**0.46**	**0.48**	**0.49**

Table 5.6 contd. (from garnet-biotite gneisses)

Sample	**M1-A1**					**M-1A**				
Domain	72	99	100	21	22	43	49	57	22	44
SiO_2	33.283	33.484	33.147	33.826	33.312	34.833	34.736	34.848	34.112	34.708
TiO_2	1.509	1.988	1.767	1.558	1.537	1.683	1.602	1.956	1.637	1.411
Al_2O_3	16.417	16.204	16.494	16.397	16.549	16.944	16.791	16.900	16.249	16.784
FeO	26.597	27.377	26.736	22.563	23.559	22.831	23.951	23.490	23.559	23.450
MnO	0.023	0	0	0	0.114	0.001	0.000	0.058	0.114	0.000
MgO	6.75	6.974	7.103	9.885	9.914	9.075	9.967	9.143	9.314	9.630
CaO	0.043	0	0.107	0.094	0.064	0.060	0.257	1.805	0.264	0.157
Na_2O	0.778	0.092	0.089	0.095	0.152	0.234	0.575	0.210	0.352	0.336
K2O	7.31	8.923	8.169	8.988	7.903	9.079	6.915	6.467	9.603	9.024
Cl	0.097	0.087	0.076	0.025	0.013	0.022	0.022	0.000	0.013	0.014
F	0.108	0.187	0.078	0.064	0.063	0.228	0.125	0.198	0.163	0.232
Total	**92.914**	**95.317**	**93.765**	**93.494**	**93.18**	**95.305**	**95.152**	**95.423**	**95.621**	**96.023**
Si	5.395	5.348	5.341	5.372	5.309	5.435	5.389	5.388	5.363	5.395
Al^{IV}	2.605	2.652	2.659	2.628	2.691	2.565	2.611	2.612	2.637	2.605
ΣZ	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{VI}	0.531	0.398	0.473	0.441	0.418	0.551	0.460	0.467	0.373	0.469
Ti	0.184	0.239	0.214	0.186	0.184	0.197	0.187	0.227	0.194	0.165
Fe^{2+}	3.605	3.656	3.602	2.996	3.14	2.979	3.107	3.037	3.097	3.048
Mn	0.003	0	0	0	0.015	0.000	0.000	0.008	0.015	0.000
Mg	1.631	1.661	1.706	2.34	2.356	2.111	2.306	2.107	2.183	2.231
ΣX	5.954	5.953	5.996	5.963	6.113	5.858	6.072	5.872	5.88	5.930
Ca	0.007	0	0.018	0.016	0.011	0.010	0.043	0.299	0.044	0.026
Na	0.244	0.029	0.028	0.029	0.047	0.071	0.173	0.063	0.107	0.101
K	1.511	1.818	1.679	1.821	1.607	1.807	1.369	1.275	1.926	1.789
ΣY	1.763	1.846	1.725	1.866	1.665	1.888	1.584	1.637	2.08	1.916
Cl	0.027	0.024	0.021	0.007	0.003	0.006	0.006	0.000	0.003	0.004
F	0.055	0.095	0.04	0.032	0.032	0.113	0.006	0.097	0.081	0.114
X_{Mg}	**0.31**	**0.31**	**0.32**	**0.44**	**0.43**	**0.41**	**0.43**	**0.41**	**0.41**	**0.42**

Table 5.7 Chemical analysis and structural formulae (on the basis of 8 Oxygen) of Plagioclase from pelitic granulites.

Sample	**PM-1**					**M-9**				
Domain	6	11	12	19	74	102	103	104	105	106
SiO_2	56.603	55.451	55.916	55.127	54.001	56.815	58.328	57.144	56.979	57.572
Al_2O_3	26.955	26.979	26.962	27.957	22.294	26.546	25.568	26.392	26.469	26.057
FeO	0.029	0	0	0.274	0.421	0.180	0.151	0.209	0.195	0.166
CaO	8.979	9.539	9.758	10.121	16.366	8.463	8.821	8.676	8.569	8.642
Na_2O	6.921	6.975	6.561	6.169	5.75	7.115	7.139	6.778	6.946	7.127
K_2O	0.094	0.002	0.096	0.012	0.876	0.057	0.015	0.019	0.038	0.036
Total	**99.581**	**98.946**	**99.293**	**99.66**	**99.707**	**99.175**	**100.021**	**99.216**	**99.195**	**99.598**
Si	2.554	2.527	2.536	2.495	2.520	2.572	2.616	2.583	2.578	2.594
Al	1.434	1.449	1.441	1.491	1.226	1.416	1.352	1.406	1.411	1.384
Fe^{+2}	0.001	0.000	0.000	0.010	0.016	0.007	0.006	0.008	0.007	0.006
Ca	0.434	0.466	0.474	0.491	0.818	0.410	0.424	0.420	0.415	0.417
Na	0.606	0.616	0.577	0.541	0.520	0.624	0.621	0.594	0.609	0.623
K	0.005	0.000	0.006	0.001	0.052	0.003	0.001	0.001	0.002	0.002
Total	5.034	5.057	5.034	5.030	5.153	5.034	5.019	5.012	5.023	5.026
An	41.54	43.04	44.87	47.52	58.84	39.54	40.54	41.39	40.45	40.04
Ab	57.94	56.95	54.60	52.41	37.41	60.15	59.38	58.51	59.34	59.76
Or	0.52	0.01	0.53	0.07	3.75	0.32	0.08	0.11	0.21	0.20
X_{Ca}	**0.42**	**0.43**	**0.45**	**0.48**	**0.59**	**0.40**	**0.41**	**0.41**	**0.40**	**0.40**

Table 5.7 contd. (from garnet-biotite gneisses).

Sample	**M1-A1**					**M-1A**				
Domain	65/ 1	66 / 1	101/ 1	102 / 1	39/ 1	37	41	47	107	109
SiO_2	55.877	52.861	53.077	51.682	57.589	53.361	54.487	53.947	52.694	54.693
Al_2O_3	27.526	29.260	29.417	30.587	25.954	27.094	23.767	27.171	27.340	23.740
FeO	0.162	0.653	0.100	0.151	0.153	0.216	0.037	0.025	0.174	0.000
CaO	9.649	11.656	12.082	13.140	9.947	13.851	14.839	13.683	13.099	15.984
Na_2O	6.352	4.842	4.921	4.288	6.032	5.194	6.732	4.591	6.339	5.058
K_2O	0.086	0.112	0.057	0.132	0.054	0.036	0.047	0.043	0.052	0.068
Total	**99.652**	**99.384**	**99.654**	**99.980**	**99.729**	**99.752**	**99.908**	**99.460**	**99.698**	**99.543**
Si	2.524	2.413	2.413	2.351	2.592	2.444	2.513	2.465	2.422	2.523
Al	1.465	1.574	1.576	1.640	1.377	1.462	1.292	1.463	1.481	1.291
Fe^{+2}	0.006	0.025	0.004	0.006	0.006	0.008	0.001	0.001	0.007	0.000
Ca	0.467	0.570	0.588	0.640	0.480	0.680	0.733	0.670	0.645	0.790
Na	0.556	0.429	0.434	0.378	0.526	0.461	0.602	0.407	0.565	0.452
K	0.005	0.007	0.003	0.008	0.003	0.002	0.003	0.002	0.003	0.004
Total	5.024	5.017	5.018	5.022	4.984	5.057	5.144	5.008	5.122	5.060
An	45.42	56.72	57.38	62.40	47.53	59.47	54.80	62.08	53.18	63.39
Ab	54.10	42.64	42.29	36.85	52.16	40.35	44.99	37.69	46.57	36.30
Or	0.48	0.65	0.32	0.75	0.31	0.18	0.21	0.23	0.25	0.32
X_{Ca}	**0.45**	**0.57**	**0.57**	**0.62**	**0.48**	**0.59**	**0.55**	**0.62**	**0.53**	**0.63**

Table 5.7 contd. (from amphibolites).

Sample	**MM-1**				**BB-1**				**B-6**			
Domain	37	38	39	40	144	142	149	150	21	22	23	24
SiO_2	56.533	56.126	56.238	55.377	55.076	54.378	55.392	55.931	57.821	57.362	57.029	57.591
Al_2O_3	25.166	27.243	27.310	27.384	27.575	27.776	26.696	25.792	25.691	26.237	26.262	25.964
FeO	0.470	0.000	0.000	0.000	0.000	0.000	0.130	0.420	0.160	0.120	0.080	0.140
CaO	9.921	9.577	9.238	9.871	11.410	12.105	9.443	9.956	9.815	8.764	9.824	9.290
Na_2O	6.922	6.647	6.741	6.752	5.531	5.194	7.332	6.318	6.474	6.982	6.484	6.928
K_2O	0.060	0.036	0.075	0.083	0.021	0.064	0.034	0.041	0.017	0.226	0.042	0.122
Total	**99.072**	**99.629**	**99.602**	**99.467**	**99.614**	**99.516**	**99.028**	**98.457**	**99.978**	**99.691**	**99.721**	**100.034**
Si	2.580	2.535	2.538	2.512	2.496	2.473	2.527	2.562	2.599	2.585	2.572	2.589
Al	1.353	1.450	1.453	1.464	1.473	1.489	1.436	1.393	1.361	1.394	1.396	1.376
Fe^{+2}	0.018	0.000	0.000	0.000	0.000	0.000	0.005	0.016	0.006	0.005	0.003	0.005
Ca	0.485	0.463	0.447	0.480	0.554	0.590	0.462	0.489	0.473	0.423	0.475	0.447
Na	0.612	0.582	0.590	0.594	0.486	0.458	0.649	0.561	0.564	0.610	0.567	0.604
K	0.003	0.002	0.004	0.005	0.001	0.004	0.002	0.002	0.001	0.013	0.002	0.007
Total	5.052	5.032	5.032	5.055	5.011	5.013	5.080	5.023	5.003	5.030	5.015	5.028
An	44.06	44.24	42.92	44.49	53.21	56.09	41.50	46.44	45.54	40.45	45.47	42.28
Ab	55.63	55.56	56.67	55.07	46.68	43.55	58.32	53.33	54.36	58.31	54.30	57.06
Or	0.32	0.20	0.41	0.45	0.12	0.35	0.18	0.23	0.09	1.24	0.23	0.66
X_{Ca}	**0.44**	**0.44**	**0.43**	**0.44**	**0.53**	**0.56**	**0.42**	**0.46**	**0.46**	**0.40**	**0.45**	**0.42**

Table 5.8 Chemical analysis and structural formulae (on the basis of 4 Oxygen) of Ilmenite from pelitic granulite and amphibolites.

Sample	**PM-1**						**MM-1**		**BB-1**	
Domain	13	26	29	30	62	65	14	20	21	27
SiO_2	0.044	0.000	0.000	0.000	0.000	0.000	0.230	0.007	0.031	0.000
TiO_2	49.885	49.264	49.916	49.087	49.435	49.086	49.874	50.151	51.152	51.103
Al_2O_3	0.000	0.006	0.029	0.011	0.000	0.000	0.066	0.000	0.011	0.137
FeO	45.909	46.510	46.353	46.682	46.579	47.413	45.307	44.824	45.460	45.003
MnO	0.805	0.475	0.485	0.753	0.526	0.402	0.888	1.084	1.197	0.496
MgO	0.000	0.051	0.003	0.021	0.000	0.000	0.039	0.020	0.010	0.046
CaO	0.034	0.092	0.116	0.192	0.086	0.142	0.050	0.092	0.092	0.148
Na_2O	0.007	0.048	0.011	0.044	0.018	0.008	0.037	0.001	0.043	0.090
K_2O	0.000	0.076	0.031	0.043	0.038	0.033	0.024	0.002	0.004	0.072
Cr_2O_3	0.000	0.233	0.211	0.208	0.079	0.118	0.005	0.050	0.046	0.187
V_2O_3	2.329	2.630	2.657	2.563	2.614	2.637	2.309	2.325	2.333	2.526
NiO	0.000	0.392	0.224	0.196	0.238	0.084	0.042	0.000	0.000	0.238
TOTAL	**99.011**	**99.777**	**100.037**	**99.802**	**99.613**	**99.922**	**98.871**	**98.555**	**100.379**	**100.045**
Si	0.001	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.001	0.000
Ti	0.955	0.937	0.947	0.932	0.942	0.931	0.956	0.965	0.967	0.970
Al	0.000	0.000	0.001	0.000	0.000	0.000	0.002	0.000	0.000	0.004
Fe^{3+}	0.039	0.061	0.044	0.075	0.058	0.081	0.026	0.020	0.016	0.004
Fe^{+2}	0.938	0.922	0.933	0.910	0.928	0.918	0.940	0.939	0.939	0.954
Mn	0.017	0.010	0.010	0.016	0.011	0.009	0.019	0.023	0.025	0.011
Mg	0.000	0.002	0.000	0.001	0.000	0.000	0.001	0.001	0.000	0.002
Ca	0.001	0.002	0.003	0.005	0.002	0.004	0.001	0.003	0.002	0.004
Na	0.000	0.002	0.001	0.002	0.001	0.000	0.002	0.000	0.002	0.004
K	0.000	0.002	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.002
Cr	0.000	0.005	0.004	0.004	0.002	0.002	0.000	0.001	0.001	0.004

Table 5.9 Chemical analysis and structural formulae (on the basis of 25 Oxygen) of Epidote from amphibolites.

Domain	**MM-1**			**BB-1**			**MM-2**					
	45	46	47	48	48	50	55	56	57	58	59	60
SiO_2	35.043	36.439	35.368	36.295	36.545	36.522	36.667	35.741	35.832	36.533	36.367	36.606
TiO_2	0.085	0.099	0.112	0.117	0.099	0.034	0.039	0.092	0.114	0.066	0.108	0.069
Al_2O_3	23.517	23.733	24.471	23.688	23.357	24.130	23.952	23.625	24.079	23.744	23.710	23.654
Fe_2O_3	13.886	13.899	13.744	12.845	14.106	13.204	13.679	13.892	13.294	13.655	13.372	13.893
MnO	0.281	0.147	0.098	0.122	0.208	0.110	0.123	0.214	0.110	0.159	0.134	0.166
MgO	0.287	0.000	0.000	0.000	0.000	0.000	0.000	0.144	0.000	0.000	0.000	0.000
CaO	23.314	22.466	22.554	23.046	22.767	23.113	22.704	22.890	22.800	22.940	22.756	22.735
Na_2O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K_2O	0.008	0.018	0.006	0.014	0.018	0.010	0.049	0.013	0.010	0.014	0.016	0.034
Total	**96.421**	**96.800**	**96.352**	**96.127**	**97.100**	**97.124**	**97.212**	**96.610**	**96.239**	**97.112**	**96.464**	**97.156**
Si	6.141	6.308	6.158	6.289	6.326	6.272	6.307	6.225	6.224	6.299	6.299	6.317
Al	0.011	0.013	0.015	0.015	0.013	0.004	0.005	0.012	0.015	0.009	0.014	0.009
Ti	4.857	4.842	5.021	4.837	4.765	4.883	4.855	4.849	4.929	4.825	4.840	4.810
Fe^{3+}	0.916	0.905	0.900	0.837	0.919	0.853	0.885	0.910	0.869	0.886	0.871	0.902
Mn	0.042	0.022	0.014	0.018	0.031	0.016	0.018	0.032	0.016	0.023	0.020	0.024
Mg	0.075	0.000	0.000	0.000	0.000	0.000	0.000	0.037	0.000	0.000	0.000	0.000
Ca	4.377	4.167	4.207	4.278	4.222	4.252	4.184	4.271	4.243	4.237	4.222	4.203
Na	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K	0.002	0.004	0.001	0.003	0.004	0.002	0.011	0.003	0.002	0.003	0.004	0.007
Total	16.420	16.260	16.317	16.278	16.280	16.283	16.265	16.340	16.298	16.282	16.269	16.273
Cz	83.53	83.93	84.59	84.97	83.39	84.89	84.32	83.73	84.78	84.15	84.45	83.86
Ep	15.75	15.69	15.17	14.71	16.08	14.83	15.37	15.72	14.94	15.45	15.21	15.72
Pie	0.72	0.37	0.24	0.31	0.53	0.28	0.31	0.55	0.28	0.41	0.34	0.42
X_{Al}	0.84	0.84	0.85	0.85	0.84	0.85	0.85	0.84	0.85	0.84	0.85	0.84
X_{Fe}	**0.16**	**0.16**	**0.15**	**0.15**	**0.16**	**0.15**	**0.15**	**0.16**	**0.15**	**0.16**	**0.15**	**0.16**

Table 5.10 Chemical analysis and structural formulae (on the basis of 28 Oxygen) of Chlorite from amphibolites.

Sample	**B-6**								
Domain	64	65	66	67	68	69	70	71	72
SiO_2	25.732	26.139	25.680	23.739	24.263	24.898	25.576	25.135	25.483
TiO2	0.042	0.025	0.000	0.050	0.057	0.047	0.134	0.074	0.071
Al_2O_3	18.187	18.836	18.234	17.695	17.212	17.046	18.082	18.322	18.256
Cr_2O_3	0.038	0.112	0.075	0.087	0.124	0.112	0.100	0.013	0.137
FeO	28.072	29.825	28.203	28.687	28.632	29.710	28.095	29.592	29.465
MnO	1.024	0.728	1.045	1.078	0.973	0.868	0.894	0.810	0.869
MgO	12.086	11.830	11.796	12.356	12.485	12.395	12.099	11.404	11.803
CaO	0.000	0.039	0.025	0.050	0.034	0.000	0.101	0.053	0.158
Na_2O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K_2O	0.013	0.000	0.021	0.023	0.000	0.041	0.006	0.000	0.033
BaO	0.016	0.028	0.026	0.022	0.000	0.027	0.000	0.000	0.000
F	0.000	0.000	0.001	0.000	0.000	0.001	0.075	0.000	0.000
Cl	0.000	0.008	0.006	0.049	0.000	0.008	0.020	0.000	0.000
Total	**85.209**	**87.568**	**85.112**	**83.835**	**83.780**	**85.152**	**85.183**	**85.403**	**86.274**
Si	5.182	5.225	5.189	4.892	4.997	5.111	5.153	5.143	5.150
Al^{iv}	2.818	2.775	2.811	3.108	3.003	2.889	2.847	2.857	2.850
Al^{vi}	1.578	1.731	1.610	1.306	1.282	1.332	1.528	1.641	1.580
Ti	0.006	0.004	0.000	0.008	0.009	0.007	0.020	0.011	0.011
Cr	0.006	0.018	0.012	0.014	0.020	0.018	0.016	0.002	0.022
Fe^{+2}	7.333	7.197	7.342	7.713	7.677	7.590	7.325	7.430	7.361
Mn	0.175	0.123	0.179	0.188	0.170	0.151	0.153	0.140	0.149
Mg	3.628	3.525	3.553	3.796	3.833	3.793	3.634	3.478	3.556
Ca	0.000	0.008	0.005	0.011	0.008	0.000	0.022	0.012	0.034
Na	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K	0.006	0.000	0.011	0.012	0.000	0.022	0.003	0.000	0.017
Ba	0.003	0.004	0.004	0.004	0.000	0.004	0.000	0.000	0.000
F	0.000	0.000	0.001	0.000	0.000	0.001	0.096	0.000	0.000
Cl	0.000	0.005	0.004	0.034	0.000	0.005	0.014	0.000	0.000
X_{Fe}	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.68**	**0.67**

Table 5.10 Contd. (from amphiboites and pelitic granulites)

Sample	**B-6**				**M-9**						
Domain	77	78	79	80	124	125	126	127	128	129	130
SiO_2	24.357	24.821	25.103	24.533	31.040	32.898	33.894	32.969	33.896	32.967	33.277
TiO2	0.036	0.051	0.044	0.048	0.053	0.038	0.024	0.045	0.031	0.038	0.038
Al_2O_3	16.235	17.478	18.535	17.215	14.526	14.567	13.268	14.546	13.917	13.897	14.120
Cr_2O_3	0.086	0.025	0.137	0.075	0.000	0.000	0.015	0.000	0.008	0.008	0.005
FeO	30.498	30.183	29.471	29.119	20.294	19.798	20.225	20.046	20.012	20.259	20.106
MnO	0.935	0.739	0.939	0.997	0.053	0.052	0.074	0.052	0.063	0.063	0.060
MgO	10.916	12.924	11.783	12.081	17.597	17.385	18.986	17.491	18.186	18.292	17.989
CaO	0.000	0.067	0.016	0.076	0.153	0.202	0.214	0.178	0.208	0.184	0.190
Na_2O	0.000	0.000	0.000	0.000	0.293	0.351	0.326	0.322	0.339	0.309	0.323
K_2O	0.000	0.006	0.025	0.023	0.186	0.207	0.194	0.197	0.201	0.190	0.196
BaO	0.009	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.056	0.000	0.019	0.000	0.193	0.107	0.178	0.150	0.143	0.185	0.159
Cl	0.000	0.000	0.002	0.012	0.065	0.098	0.079	0.082	0.088	0.072	0.081
Total	**83.127**	**86.293**	**86.074**	**84.188**	**84.452**	**85.703**	**87.477**	**86.077**	**87.090**	**86.465**	**86.544**
Si	5.191	5.044	5.087	5.063	5.693	5.928	6.011	5.933	6.029	5.915	5.959
Al^{iv}	2.809	2.956	2.913	2.937	2.307	2.072	1.989	2.067	1.971	2.085	2.041
Al^{vi}	1.356	1.332	1.601	1.350	0.912	1.083	0.844	1.077	1.002	0.917	0.999
Ti	0.006	0.008	0.007	0.007	0.007	0.005	0.003	0.006	0.004	0.005	0.005
Cr	0.015	0.004	0.022	0.012	0.000	0.000	0.002	0.000	0.001	0.001	0.001
Fe^{+2}	7.794	7.552	7.394	7.640	6.759	6.514	6.458	6.492	6.415	6.534	6.480
Mn	0.169	0.127	0.161	0.174	0.008	0.008	0.011	0.008	0.010	0.010	0.009
Mg	3.468	3.915	3.560	3.717	4.811	4.670	5.019	4.692	4.822	4.892	4.802
Ca	0.000	0.015	0.004	0.017	0.030	0.039	0.041	0.034	0.040	0.035	0.036
Na	0.000	0.000	0.000	0.000	0.208	0.245	0.224	0.225	0.234	0.215	0.224
K	0.000	0.003	0.013	0.012	0.087	0.095	0.088	0.090	0.091	0.087	0.089
Ba	0.001	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
F	0.075	0.000	0.025	0.000	0.223	0.122	0.200	0.170	0.161	0.210	0.180
Cl	0.000	0.000	0.002	0.008	0.041	0.060	0.047	0.050	0.053	0.044	0.049
X_{Fe}	**0.69**	**0.66**	**0.68**	**0.67**	**0.58**	**0.58**	**0.56**	**0.58**	**0.57**	**0.57**	**0.57**

Table 5.11 Chemical analysis and structural formulae (on the basis of 10 Oxygen) of Sillimanite from pelitic granulites.

Sample	**M-9**									
Domain	7	8	9	10	11	12	13	14	15	16
SiO_2	38.58	38.21	37.84	37.05	37.16	38.12	37.89	37.27	38.16	38.23
TiO_2	0	0	0	0	0	0	0	0	0	0
Al_2O_3	62.15	61.25	61.1	61.48	62.18	61.52	61.84	62.11	62.27	61.64
Cr_2O_3	0.032	0.026	0.031	0.029	0.018	0.024	0.017	0.034	0.045	0.041
FeO	0.52	0.58	0.51	0.57	0.48	0.47	0.42	0.59	0.67	0.39
Total	100.28	100.07	99.48	99.13	99.84	100.13	100.17	100.00	101.15	100.30
Si	2.026	2.063	2.055	2.021	2.012	2.056	2.043	2.016	2.041	2.058
Ti	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Al	3.948	3.897	3.910	3.953	3.968	3.910	3.929	3.959	3.924	3.910
Cr	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002
Fe	0.023	0.026	0.023	0.026	0.022	0.021	0.019	0.027	0.030	0.018
Total	5.999	5.988	5.989	6.002	6.003	5.988	5.992	6.004	5.996	5.987