Chapter 4

METAMORPHISM AND PHASE PETROLOGY

4.1 INTRODUCTION:

It has been realized that the mineral assemblages of metamorphic rock may reflect the approach of chemical equilibrium during the crystallization. The distribution of elements in the coexisting minerals should be systematic if they attained chemical equilibrium. These crystallized minerals also show a systematic chemical variation in their composition. Such variation in their mineral chemistry indeed reflects the physical conditions of metamorphism and the mineral parageneses reflect a unique phase compatibility relation in the P-T space.

The analysis of co-existing minerals and the phase compatibility relationships in pertinent system have been used to provide data about nature and tendency of equilibrium and also help to deduce the P-T-X conditions during metamorphism. Thus, we can find out unique pigeonhole on the basis of mineral paragenesis depicted in the petrogenetic grids, which provide information’s about the metamorphic evolution. Today the concept of petrogenitic grid is too advanced in comparison to Bowen (1940), who firstly proposed the concept of grid with univariant reaction curves bounding all the conceivable divariant mineral assemblages for a particular bulk chemical composition.

In the following paragraphs an attempt has been made to discuss the mineral parageneses, P-T conditions and phase compatibility relationships of different assemblages obtained from the petrography, textural relationship. The phase petrology and involved metamorphic reactions of different metamorphism along with the fluid inclusion data generated for these assemblages.

4.2 CHEMOGRAPHIC RELATIONSHIP:

The rocks of BnGC, exposed around Nathupura and other places of the study area comprise biotite gneisses, granite-gneisses, tonalite gneisses, trondhjemite gneisses, hornblende-biotite gneisses and amphibolites. These Archaean rocks were tectonically deformed and metamorphosed and subsequently emplaced by different
episodes of gray granitoids (Fig.-2.3). The detailed petrographic study on different foliation planes with chronological events of deformations reveal at least two phases of metamorphism in BnGC. The early phase metamorphism was very high-grade as evident by complete absence of prograde muscovite, chlorite, kyanite, talc, actionlite and epidote etc. minerals and presence of sillimanite, perthite, and diopside minerals. The presence of tonalite-gneisses and their intermingled relationship with other gneisses in the field points that regional metamorphism in the central part of Bundelkhand area was coterminous with migmatites and gray granite. The geochronological study points the formation of TTG around 3300 Ma (Mondal et al 2002). Since the crystallized minerals of the metamorphics are aligned on S₁ and S₂ planes developed during the D₁ deformation D₂ phase and have similar structural trend of TTG, therefore, it can be concluded that a tectonothermal event should be at Mid-Archaean for the first phase of metamorphism of BnGC. Basu (2002), Sharma (1988) and Singh et al (2007) have also been suggested similar views. The second episode of metamorphism in the TTG & granite gneisses of BnGC is mainly confined to the shear zones and is low grade to very low grade may be possibly contemporaneous to east-west trending shear zone. This may be considered as retrograde event. The mylonitised and sheared rocks has been recorded from the gneisses, granite, migmatites, amphibolites and hornblende, biotite gneisses. During the mylonitisation, the chlorite-biotite microcline-albite-quartz and chlorite-biotite-epidote, chlorite-chloritoide-magnetite garnet–Chlorite –muscovite-quartz, muscovite chlorite –magnetite- feldspar-quartz assemblages were developed in shear zones trending in E-W direction and are related to D4 deformation (Table-2.6.)

The first phase of metamorphism possibly initiated at deformation D1. In general, rocks associated with the F1, F2, and F3 folds observed in the gneisses are responsible for the development of gneissic foliation in the pelitic, psammatic and mafic rocks which are defined by the orientation of flaky minerals and elongated plagioclase and needles of magnetite. This episode of metamorphism is further subdivided into two stages (i) formation of gneisses and amphibolites (ii) anatexitic migmatite, granite-gneisses, granulites, tonalite, and trondhjemite. The detailed mineral assemblages of gneisses and amphibolites are listed in detailed in chapter III.
(i) Biotite–K-feldspar-perthite-quartz.

(ii) Biotite-plagioclase-K-feldspar-antiperthite quartz.

(iii) Garnet-biotite-K-feldspar-quartz.

(iv) Biotite–K-feldspar-perthite-sillimanite-quartz

Assemblages in amphibole-biotites and hornblende- biotite gneisses:


(iii) Hornblende – clinopyroxene – plagioclase - quartz.

(iv) Hornblende - plagioclase - K - feldspar - quartz.

The TTG rocks which includes both tonalite and Trondhjemite-rocks, content significant amount of K-feldspar, antiperthite, plagioclase, perthite, biotite, and quartz with minor amount of illmanite, apatite, zircon, sphene, spinel etc. The muscovite and clinopyroxene are completely absent in TTG. The hornblende has been noticed in minor amount in most of the TTG rocks.

The gneiss contains mainly biotite, quartz, plagioclase and K-feldspars. The zircon and apatite are present in the significant amount in all the rock samples. The perthite and antiperthitic texture are also present in the gneisses. The garnet and sillimanite minerals reported by earlier workers from the Kabrai area (Saxena 1961) could not be obtained from the present investigated area. The absence of the garnet and sillimanite from Kabrai area may be possibly due to composition variation and excavation of outcrop. It is very significant that muscovite as prograde or retrograde phase is completely absent from the gneisses.

The minerals assemblages of these rocks can be portrayed in AKF diagram (Fig.-4.2) and explained through six components in the KFMASH system. The AKF diagram shows three phases fields of garnet – biotite and K – feldspar. The K-feldspar – biotite join defines the two-phase field for non-garnetiferrous gneisses. The mineral assemblages of tonalite and trondhjemite gneisses may be treated in CaO,
Na$_2$O, K$_2$O, FeO, MgO, SiO$_2$, Al$_2$O$_3$ and H$_2$O (CNKF MASH) system and portrayed in the AFM diagram (Reinhardt Projection) with FeO and MgO as separate component and as plagioclase. Thus the phase compatibility relationship can be better represented by AFM projection from plagioclase (Fig.-4.3). The advantage of this projection is that the tie line connects hornblende, clinopyroxene and biotite composition of the three coexisting phases form triangle, enclosing the field of composition of three mineral associations having the fixed composition. The common presence of hornblende-clinopyroxene-biotite phase for amphibolite may be due to large field with variation in the bulk composition of amphibolite rock and these coexisting minerals may be considered as continuous reaction in the CFMASH system between hornblende and biotite at variable pressure and temperature(Fig.-4.3). The presence of corroded biotite in the hornblende and clinopyroxene, and similarly presence of corroded hornblende in the biotite and clinopyroxene from the hornblende- biotite gneisses discussed in the chapter III may be attributed to the breakdown of the biotite and hornblende by the following continuous reaction in CFMASH system and portrayed in AFM diagram (Fig.-4.3).

\[
\text{Biotite}_1 + \text{Hornblende}_2 = \text{Biotite}_2 + \text{Hornblende}_1
\]

\[
\text{Clinopyroxene} + \text{Biotite} + \text{plagioclase} = \text{hornblende} + \text{K- feldspar} + \text{V}
\]

The absence of garnet mineral from all the hornblende-biotite gneisses and biotite-gneisses may be due to either low silica content or due to strong retrograde metamorphism of hornblende biotite-gneisses or in appropriate fluid activity. The absence of garnet from these gneisses may be considered due to the non-availability of appropriate bulk composition and high K$_2$O and Al$_2$O$_3$.

The enclaves of amphibolites are very common in the gneisses. Sometimes they are co folded with biotite gneisses. The petrography studies reveal that talc, epidote, tremolite, chlorite, actinolite, etc. are completely absent, while diopside, calcite, plagioclase, hornblende are present as medium to coarse grained texture. The absence of garnet from the basic gneisses may be due high MgO, K$_2$O and low Al$_2$O$_3$. The common presence of plagioclase, hornblende, and diopside assemblages can be explained in three-phase field of ACF diagram (Fig.-4.1) in CFMASH system. The
other compatible assemblages viz. hornblende-plagioclase-magnetite ± quartz and diopside – hornblende – magnetite ± quartz can be also explained in ACF diagram in six component system of CFMASH system.

4.3 P-T CONDITION:

The detailed petrographic study revealed that at least two phases of metamorphism took place in Bundelkhand gneissic Complex. The early phase metamorphism (M₁) was high-grade as evident by complete absence of prograde muscovite, chlorite, kyanite, actinolite, tremolite, talc and epidote minerals and presence of cordierite, garnet, sillimanite, perthite, diopside, hornblende, anthophyllite and gedrite minerals. The presence of tonalite-gneisses and their intermingled field relationship with other gneisses point out that regional metamorphism was more or less contemporaneous with TTG. On the basis of observed mineral assemblages of MnGC rocks of Study area a pterogenetic grid has been constructed in the KFMASH system (Fig4.4) involving the Grt, Bio, Sill, Crd, Mus, Kfs, qtz. Four invariant points and The metastable points have been obtained in the AKF diagram in the KFMASH system and a prograde path have been suggested.

The different observed mineral assemblages viz. garnet-biotite-sillimanite-K-feldspar (Fig.4.3), biotite-garnet-K-feldspar-plagioclase-quartz (Fig. 4.2) and hornblende-clinopyroxene-plagioclase-magnetite-quartz (Fig.4.3) of the high-grade metamorphic rocks of Bundelkhand massif reveal that the rocks of Bundelkhand Basement gneissic Complex belong to upper amphibolite to granulite facies. The P–T conditions obtained from different geothermobarometric models (Singh et al 2007) reveal that all the above-mentioned mineral assemblages in gneisses were developed between 650° C to 725° C temperature and 5 to 6 kbar pressure (Fig 4.4).

4.4 FLUID INCLUSION:

4.4.1 Introduction:

Fluid inclusions are nothing but the small quantities of fluid trapped with in the mineral during the process of crystal growth. They represent actual sample or the only samples of fluid existing at the time of formation of a mineral and its growth.
This data can be used to reconstruct the geological history of a rock in combination with other features like textures and mineralogy. Thus the fluid inclusion study provide important clues in understanding the geological processes viz, the P-V-T-X (pressure, temperature, density, composition) of the rocks and the fluid that formed or traversed the rock in the geological past. There are different types of inclusions observed in mineral viz., fluid inclusion, solid inclusion, melt inclusion, gaseous inclusion.

Fluid inclusions are present as small amount of liquid vapour and gas phases or mixture of these phases. In the granite-gneisses and quartz reef the inclusion are trapped at the time of mineral formation or outwards during the change in geological condition. To understand the genetic condition of gneisses and granite of the Mahoba area, fluid inclusion study were carried out in the quartz crystals.

The small fluid filled vacuoles are present in quartz crystals. These fluid filed vacuoles are observed with a standard petrographic microscope. In the gneisses apatite and quartz in the granite rocks the quartz crystals are considered to be suitable for an investigation of the inclusion. The study shows that mineral contains many excellent fluid cavities (Fig 4.5-4.10). The inclusions reach up to 120cm in length. The inclusion are spheroidal orbalat in shapes in the gneisses (Fig-4.11-4.16). While inclusion are larger in shape in granite comparison to the gneisses. The granitic inclusions are elongated, and prismatic mode of formation of inclusion.

Various scheme of classification have been proposed. The most useful and widely applicable classification of fluid inclusion is proposed by Roebber (1976) which categorized the inclusion into primary (p), secondary (s), and pseudo secondary (ps) on the basis of their origin.

The laboratory grown crystals size, abundance and distribution of inclusion are principally a function of growth kinetics and the stability of various growing faces. The natural, processes leading to the growth and re-crystallization of minerals are diverse and complex during these processes variety of inclusion trapped in crystal which can be easily identified in the ten minerals viz. quartz, fluorite, halite, calcite, apatite, dolomite, sphalerite, barite, topaz, and casseterite. The fluid feature common
to all these minerals is that they are transparent and lightly coloured which, of course, is the most fundamental prerequisite for any optical study of inclusion. The overall abundance and distribution of inclusion in a single crystal depend partly on the primary growth condition and partly on the post crystallization history of the samples. Fluid inclusion shapes are highly variable and are partly controlled by the crystallography of the host minerals.

**Mode of formation of primary inclusion:**

Primary inclusion – most of the crystals grow or recrystalise in a fluid medium of any kind. During crystals growth or growth irregularities may result for trapping of small portion of the fluid in solid crystals. Such irregularities may be sealed off during growth of surrounding part of the host crystals, yielding primary inclusion (p). Primary inclusion from the granitic rocks of the study area are large prismatic and elongated in shape (plate-4.12). But in the gneisses rock the primary inclusion are usually spheriodal and oblate in shape (plate-4.35). The size of primary inclusion varies from rocks. Most of the primary inclusions are biphase (L+V) i.e. liquid + vappour phase inclusion (plate-4.29).

Secondary inclusions (s); the inclusion formed by any process after crystallization of the bulk of the host minerals. Secondary inclusions are formed by the two processes. (a) from ductile deformation (b) from brittle deformation.

The trapped fluid into these deformation lamellae may be sealed during recrysalization of the host grains commonly, after the healing process is completed. This result the formation of rows of inclusions having regular spacing with the plane with in the grains (plate-4.39).

Pseudosecondary (PS) inclusion are those that are trapped along a fractures developed in the crystals during its growth, instead of being trapped as primary inclusion in the rim of the crystals.

The choice of significant inclusions are exceedingly valuable in extracting the appropriate thermobarometry and compositional information. This is because of the possible presence of several generation of inclusion in the one sample.
It is worth to described that inclusions with sign of leakages, necking down or those adjacent to the crakes are not suitable for getting reliable data. Therefore such inclusions were not included in text. The temperature of trapping can be estimated by the heating of the sample to the point at which the bubbles disappear i.e. the temperature of homogenization. This marks a minimum temperature of formation of the minerals, provided no leakages, exists.

4.4.2 Method of sample preparation:

To calibrate the genetic condition of different type of granite, quartz reef gneisses of study area the fresh sample were collected for the fluid inclusion study. The chosen samples of fluid inclusion interest are rich in transparent minerals like quartz and apatite and taken from the various locations to cover the nature of fluid in the study area.

4.4.2.1 Sowing and Grinding:

After cutting, ideally with a small diameter saw, the surface is hand ground angles plate using progressive fierge grade of silicon carbide (sic) grit. The final grade should be at least 800 (FScale).

4.4.2.2 Polishing:

Hand polishing is carried out using a soft, napped polishing Nylone cloth mounted on a rotary lapping machine. Zirconium powder are used from the polishing of slide one side of polishing takes the 15 to 20 minuets, and the grain size is 0.3μm

Reverse Mounting is essential after polishing for the fluid study. Therefore the sample mounted with the polished face down on to a glass microscope slide using a low melting point dental was once removed and polished by zorconiu power followed by polishing on zylene. The slide cleaned, using acetone or Alcohol or zylene. At the end the slide is cleaned by the fresh water. Dip the slide in fresh water in 10 to 20 minutes. The fluid inclusion slide should be doubly polished and the thickness should be section of 0.1 to 1.0mm in thickness.

Final stage of reserve mounting of the slide are (0.5 to 1mn) are thick, once removed the slide in hot plate can be clean using acetone or Alcohol and fresh water,
petrological microscope, low magnification lenseses (25 x power) identity the primary, secondary and pseudo secondary inclusion in granite wafers. The best-procedure to identifying the inclusion in the wafers to scan the sample using a low to moderate magnification. Inclusion of average size (10 in micron) will usually appears as small dark speaks or group of trails of speaks with in the small because of the strong internal reflection. The objective should then be change to one of the higher power at the same time raining the sub stage condenser close to the specimens. This should reduced the internal reflection and with an appropriate adjustment of the focus. The inclusion should be clearly visible. In the primary inclusion are large in size. They are trapped in quartz crystals in disseminated forms and primary stage of mineral formation. But the secondary inclusion are trapped at the stage of secondary intergrowth of minerals formation. They are trapped in fractures secondary inclusion are small in size they are aligned in particular directions.

4.5 FLUID INCLUSION PETROGRAPHY:

Fluid inclusion petrography is used in the determination of inclusion shapes, size, phase proportion (like monosphase, biphase), determination of degree of fill, length and width of the inclusion, types of inclusion (L+V+G+S) and abundances and distribution of the inclusion. The fluid petrography is also useful in growth zones, relationship to the crystal faces and traces the cleavages direction. The optical examination of fluid inclusion are used in determination of either metastable inclusions, heterogeneous trapping, leakage and daughter inclusion identification and necking down inclusion, their relation with other inclusion and with the host grain suggest the type and origin of the inclusion and also the relative chronology.

4.6 FLUID IN GNEISSES:

Thermodynamics concept and experimental work suggest that mineral stability is the guidelines, factors to understand mineral reaction in metamorphic. Apart from P and T, the action of chemically active fluids is also important factor, because they promote or inhibit metamorphic reactions. Although metamorphic system is described as subsolides or solids state that virtually contains several types of a fluid phases. In
the Bundelkhand gneissic rocks, the fluid inclusion petrography indicates that
gneisses consisting orthoclase, quartzs and apatite have appreciable amount of fluid
inclusion. They provide important insight into the composition of the fluid present,
when the minerals grains formed. The experimental study reveal a variation in
composition and density, with respect to change in the P-T conditions of
metamorphism and thus help to record the uplift/extensional history of a metamorphic
terrane.

Most of the primary fluids of the gneisses are rounded and trabular in shape
and are usually biphase (L+V) in nature. The gas bubble trapped in fluid use to under
the influence of gravity or due to thermal gradient with in the inclusion, when the
temperature go down most of the gneisses inclusion are sink down and shows the
hazy texture. Keeping this advantage, the heating and freezing stage are run to
determine the phase change at appropriate time. The useful qualitative and semi
quantitative composition data have been obtained. The determination of composition
and density of fluid inclusion in largely based on a comparison of the behaviour of the
inclusion. The cooling experiment was done below -150°C. The primary fluid the
inclusion of gneisses are found to freezeed consisting at -120°C all the bobbles upto
-120°C. That is shown by hazy texture, the heating initiated after super cooling and
various kind of change texture were noted at several temperature. In the gneisses
primary inclusion of the gneisses rocks melt different melting temperature. study on
linkam heating and freezing stage suggested of primary inclusion of the gneisses
rocks are dominated by H2O-NaCl, H2O-Na2CO3 system. The temperature clathrate
melting of H2O-NaCl;-MgCl2 also noted in several samples that indicate at 1.1°C
temperatures.

4.7 DENSITY OF FLUID INCLUSION :

The relative volume of liquid and gas phases are determined at room
temperature (using geometrically regular inclusions), and if the composition of the
fluid inclusion is known, the density of the homogeneous inclusion can be determined
using various P-V-T data. Determination of the density of the inclusion, the length
and width of the liquid and bobble were calculated using the software of linkam. On
the basis of calculated length and width of the inclusion the degree of fill of the inclusion has been determined. The data of degree of fill, shape, size length and width, eutectic point taken into considerate for interpretation of fluid composition. The software has facility two plots the density and salinity diagram on the basis of these given values. The gneissic rock yield the different system inclusion for various type of shows which depends on length and width and also values of degree of fill and the basis of these values the plot the density and salinity diagram (table-4.1).

4.8 FLUID IN PINK GRANITE:

The fluid inclusion signatures in quartz of granite can also provide some compositional evidence for syn to post magmatic fluid. The later may provide evidences of major hydrothermal activity and tectonic related events in the upper crust. It is important to distinguish primary and secondary inclusion to known the temperature and chemical environment during minerals growth. Tuttle (1949), pointed that the primary inclusion is useful for tectanothermal event. He also empases that the presence and attitude of secondary inclusion are essential that can be useful to structural geologist to interprete the tectonics of the area. Fluid inclusion signature in granitic has been used to find the chemical composition fluid during and after the crystalization of granitic magma of Bundelkhand magmatites (BnGC).

The secondary fluid provide evidence of major hydrothermal convection and tectonic related events in upper crust. The Bundelkhand pink granitoid consist quartz as major minerals constituent besides the rock consist the biotite–hornblende magnatite – rutile – pottash feldspar, minerals. The minerals are medium to coarse grained. The mermekite textures are also found in many thin sections of pink granite rock. The coarse crystal of quartz have been selected for the preparation of fluid inclusion.

Most of the inclusions in the granitic rocks are biphase (L+V). In the granite rock primary inclusions are rounded and elliptical in shape. Some places they are cylindrical in shape. At the room temperature inclusion are light greenish in colour. But freezing stage inclusion are sinking down and they gives the purple colour. At 70°C all the (L+V) phase are freeze out and both the phases are mixed, when return to
heating stage melting of Ice will start and first bubble are developed at the -11.0^\circ C. The eutectic point of suggested that most of the inclusion are related to H\textsubscript{2}O-KCl system. But some inclusions are developed at -35^\circ C. They give H\textsubscript{2}O-NaCl-MgCl system. The clathrate of the H\textsubscript{2}O-KCl system is -1.8^\circ C. In the case of H\textsubscript{2}O-NaCl- MgCl system temperature is +21.5^\circ C. The density calculation of these inclusions based on length and width of the inclusions, plot the density diagram in P-V-T-X software field and diagram.

4.9 FLUIDS IN GRANITES:

Fluid inclusion signature in quartz of the granite rock can provide direct compositional evidence for syn and post magmatic fluids. The secondary fluid can provide evidences of major hydrothermal convection and tectonic related events in the upper crust. It is important to distinguished primary and secondary inclusion because of the poacity to determining the temperature and chemical environment during mineral growth. Secondary inclusion further allow us to reconstruct part of the history of a crystal.

The granite consist the quartz biotite hornblende magnetite rutile orthoclase plagioclase and microcline are the major minerals of the pink granite. Fluid inclusion signature in quartz can provide direct compositional evidence for syn and post magmatic fluid in granite.

Two type of inclusions have been identified in the Bundelkhand granites. The size bubble is a first observation followed volatile content of the inclusion petrography of fluid inclusion. Volatile rich melt fluid may also be present with in the bubble. The density of a fluid phase that depend on the pressure and temperature at the time of trapping. The best procedure is to scan the sample using a low to moderate magnification. Inclusion of average size (15 in microns) will usually appear as small dark specks or group of trails of specks with in the sample because of strong internal reflection. They are biphase (L+V) in nature. The biphase nature of the inclusion are easily separate out. The fluid are an aqueous solution and a vappour bubble. The primary inclusion are biphase in nature. They occurred randomly but the secondary inclusions are aligned in the particular direction. They are small in length. Some
places the pseudosecondary inclusion are also noted. The quartz crystal in the granite rock are euhedral in shape white to light green in colour. The inclusion in the crystal are moderate relief mineral. Most of the primary inclusion found in the quartz are rounded and elliptical in shape, but some place they are cylindrical in shape.

The primary inclusion they are transparent to light green in colour at the room temperature that changes to dark green to purple in colour at cooling. At the room temperature the inclusion consist of liquid + vappour (L+V) two phase. On gradual cooling they developed the solid ice phase. Freezing stage the vappour phase is disappear and all the crystal are freeze out. All the crystal are freeze out and the quartz crystal show the green to purple colour the crystal are shink down at -120$^\circ$C. Gradual heating lead to melting of solid phases at the temperature. Which is the tripple point (L+V+S) phase. Complete melting of solid phase give to liquid and vapour (L+V) and the inclusion envolved along the two phase (L+V) univariant line. When the solid phase change to liquid crystal phase show many change in their shape and texture and colour. At the freezing stage colour of the fluid is purple to brown but lowering of temperature give the green to transparent in colour.

Again lowering the temperature the clathrate melting will be appear. At the room temperature appear vapour phase will moved in the liquid phase, zig –zag movement of the vapour phase are present in the clatherate melting. Again increasing the temperature above the 300$^\circ$C the water will pass from the microscope and found the Th (Temperature of Homogenization).

Secondary monophase biphasel aqueous inclusion range in shape from irregular to elongated and tabular. At the room temperature inclusion consist of monophase with low degree of fill. Lowering of temperature result in the formation of hydrohalite and ice at temperature between -54$^\circ$C. On the gradual heating melting of hydrohalite and ice takes place at -30$^\circ$C which is the vappour saturated eutectic point of H$_2$O Nacl system. Final ice melting is observed in the temperature range of -120c, -4$^\circ$C .The density and degree of fill and salinity are calculated by the PVTX software.
Table: 4.1: Fluid phase system in the study area

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Rock type</th>
<th>No. of Experiment</th>
<th>Type of Inclusion</th>
<th>Shape</th>
<th>Degree of fill</th>
<th>Tm</th>
<th>Density</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO₄-12</td>
<td>Pink granite</td>
<td>1</td>
<td>L+V</td>
<td>Rounded</td>
<td>0.83996</td>
<td>-12.3</td>
<td>0.999</td>
<td>H₂O-NaCl</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>L+V</td>
<td>Ellipse</td>
<td>0.9956</td>
<td>-34.8</td>
<td>0.997</td>
<td>H₂O-NaCl-MgCl₂</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>L+V</td>
<td>Cylindrical</td>
<td>0.94405</td>
<td>-17.3</td>
<td>0.998</td>
<td></td>
</tr>
<tr>
<td>MO₄-4</td>
<td>Pink granite</td>
<td>1</td>
<td>L+V</td>
<td>Rounded</td>
<td>0.9556</td>
<td>-11.0</td>
<td>0.997</td>
<td>-H₂O-KCl</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>L+V</td>
<td>Rounded</td>
<td>0.17500</td>
<td>-17.3</td>
<td>0.997</td>
<td>-H₂O-KCl</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>L+V</td>
<td>Rounded</td>
<td>0.4405</td>
<td>-11.5</td>
<td>0.998</td>
<td>-H₂O-KCl</td>
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<td>MO₄-276</td>
<td>Gneisses</td>
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<td>L+V</td>
<td>Ellipse</td>
<td>0.8719</td>
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<td>0.996</td>
<td>H₂O-NaCl</td>
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<tr>
<td></td>
<td></td>
<td>2</td>
<td>L+V</td>
<td>Ellipse</td>
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<td>-21.8</td>
<td>0.997</td>
<td>Na₂CO₃H₂O-NaCl</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Na₂CO₃</td>
</tr>
<tr>
<td>MO₄-184</td>
<td>Gneisses</td>
<td>1</td>
<td>L+V</td>
<td>Trabular</td>
<td>0.91134</td>
<td>-30</td>
<td>0.997</td>
<td>KCl</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>L+V</td>
<td>Trabular</td>
<td>0.94019</td>
<td>-21.8</td>
<td>0.997</td>
<td>H₂O-NaCl</td>
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<tr>
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<td>3</td>
<td>L+V</td>
<td>Trabular</td>
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<td>0.999</td>
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</tr>
<tr>
<td>BU/PM/183</td>
<td>Gneisses</td>
<td>1</td>
<td>L+V</td>
<td>Rounded</td>
<td>0.8828</td>
<td>-36.3</td>
<td>0.997</td>
<td>H₂O-Na₂CO₃</td>
</tr>
</tbody>
</table>
Fig 4.1: The phase compatibility relation for amphibolites portrayed in ACF diagram. The solid circles represent the observed mineral assemblages in the

Fig 4.2: Phase relation of biotite gneisses, tonalite, garnetiferous gneisses and TTG are shown in AKF diagram in the KFMASH system. The solid circles represent the observed mineral assemblages in the study area.
Fig 4.3: The phase relation ship for the biotite gneisses, Biotite- hornblende gneisses and amphibolites, and BnGC group of rocks in the A'F'M' projection diagram “Projection from plagioclase in the tetrahedron AKFM in the system Na2O – K2O – CaO – FeO – Al2O3 – SiO2 (NACFMASH) proposed by Reinard 1967”. The solid circles represent the observer minerals assemblages.
Fig. 4.1: P-T conditions of metamorphism as represented by experimentally determined equilibria of the reactions. The triangle (R) represents the stability field of amphibolite facies, and the triangle (M) represents the stability field of granulite facies. The shaded box represents the P-T of the metamorphism. For the rocks of the Buurkhanland Complex (BGC) and (ii) M2, the rocks of Bundukhan Metamorphics and Metasediments (BM) differ from the different.

12. Thomson (1982). The shaded box represents the P-T of the metamorphism. (i) M1 for the rocks of Bundukhan Complex (BGC) and (ii) M2 for the rocks of Bundukhan Metamorphics and Metasediments (BM).
Fig 4.4: Petrogenetic grid in the KFMASH system for the pelitic rocks of BnGC group of Mahoba area. Arrow represents the P-T path.
Fluid inclusion textures from the rocks of Mahoba area at various temperature.
Fluid inclusion textures from the Pink Granite of Mahoba area at different heating temperature.
Fluid inclusion textures from the rocks of Mahoba area at various temperature.
Fluid inclusion textures for the pink granite of Mahoba area at various temperature.
Fluid inclusion textures from gneiss of Mahoba area at various temperature.
Fluid inclusion textures from gneissic rock of Mahoba area at various temperature.
Fluid inclusion textures from gneissic rock of Mahoba area at various temperature.
Fluid inclusion textures from gneissic rock of Mahoba area at various temperature.
Fluid inclusion textures for the pink granite of Mahoba area at various temperature.
Fig 4.59

Fig 4.60