Petrography of the Biotite-Hornblende Bearing Quartzo-Feldspathic Gneisses from *Dakshin Gangotri,* Schirmacher Hill, Antarctica

M.K. Kaul, S.K. Chakraborty and V.K. Raina

Geological Survey of India

ABSTRACT

The medium-grained biotite-hornblende bearing quartzo-feldspathic gneiss is oldest country rock present in the area, with a northwesterly trend and gentle dip (5° to 35°) towards south-west.

On the basis of megascopic characters the gneisses have been subdivided into 4 units, *viz.,* (A) microcline porphyroblastic gneiss, (B) porphyroblastic gneiss with mafic showing strong foliation, (C) garnet bearing porphyroblastic gneiss with pegmatite veins and (D) microcline bearing granoblastic gneiss with faint foliation. The units (A) and (B) are grouped as paragneisses and units (C) and (D) are grouped as migmatites.

These gneisses contain microcline, orthoclase, plagioclase, quartz, biotite and hornblende with granoblastic texture. Gneissosity has been defined by alternate arrangement of quartzo-feldspathic layers and mafic-rich layers.

The mineral assemblage is suggestive of regional metamorphism of quartzo-feldspathic sediments under the sillimanite-almandine-orthoclase subfacies of Fyfe *et al* (1958)

INTRODUCTION

The biotite-hornblende bearing quartzo-feldspathic gneiss is the oldest rock type in the present area and constitutes the country rock into which have been invaded all the other rock types. The gneissic rocks are distributed throughout the area.

The gneissic rocks are medium-grained, grey to pink coloured, consisting essentially of quartz, feldspar and mafic minerals. They are well foliated; foliation is produced by the parallel arrangement of the flakes of biotite and gneissosity is shown by the alternate layers of quartzo-feldspathic and mafic minerals.

In general, the gneissic rocks show a northwesterly trend. Minor variation in strike is noted in the south-western part of the area, where the trend varies from northeast to northwest. The foliation planes mostly dip gently (5° to 35°) towards southwest. At several places, a lineation is produced by the elongated prismatic mafic minerals, and it shows sub-parallel relation to the general strike of the gneissic rocks.

Veins of pegmatite with variable thickness ranging from a few inches to a few feet are injected into gneisses. These veins are contorted. The pegmatite veins show both conformable and cross-cutting relationship with the foliation of the gneissic rocks.

PETROGRAPHIC CHARACTERS

The gneisses are considered as a single rock type. Under the microscope the gneissic rocks show more or less similar characters but in the field they show some variations in the mode of occurrence. In the same exposure the mafic percentage increases across the strike, foliation is straight and well developed , gneissosity very prominent. On the basis of megascopic characters, these gneisses have been sub divided into four units

Biotite hornblende beanng quartzo-feldspathic gneisses

Migmatite	D Microcline rich granoblastic gneiss with faint foliation
	C Garnet porpbyroblastic gneiss with pegmatite veins
Gnesis	B Porphyroblastic gneiss with mafics showing strong foliation
	A Microclme porphyroblastic gneiss

The distribution of the rock types in shown in the geological map of the area (Paper 1)

A Microcline porphyroblastic gneiss

Megascopic characters : The specimens are light coloured, medium-grained in which porphy roblast of microcline occur within quartz feldspar biotite and hornblende Mostly biotite and at places amphiboles are arranged in parallel fashion producing strong foliation Quartzo feldspathic bands alternate with mafic- rich layers showing gneissose structure

Microscopic characters: The specimens consist of the following minerals

Microcline forms subidioblastic and short tabular to irregular grains with lobed boundaries It snows fine perthitic lamellae of albite (Fig 1) and hence is a microcline microperthite 2V as deter-mined on the Universal Stage is 75° to 85° It also shows cross hatched twinning and contains inclu-sions of quartz plagioclase biotite and zircon

Orthoclase forms subidioblastic and tabular grains It shows straight extinction with one of the cleavage set. 2V as determined on the Universal Stage is 69° It contains inclusions of quartz and biotite

Plagioclase forms subidioblastic and tabular grains Composition determined from maximum X 010 is An (andesine) Some grams show presence of zoning formed by an outer albite rim at their contact with potash feldspar It shows clouding due to fine dusty inclusions It also encloses quartz tnd biotite and is altered to sericite

Quartz grains are xenoblastic few with undulatory extinction It shows lobed and concavo convex contact and contains inclusions of apatite and zircon

Biotite is in elongated flakes it is pleochroic from greenish brown (X) to almost black (Y=Z) $X > Y$ Z N = 1657 ± .007 Parallel orientation of biotite flakes show strong foliation It contains inclusions of apatite sphene zircon and allanite

Hornblende forms subidioblastic short prismatic grains It is pleochroic with X = yellowish green Y = olive green to almost black Z = bluish green $Y > Z$ X N = 1 705 ± 003 and composi tion is Mg Fe Z C = 8 It shows lobed grain boundary and poikiloblasticallly encloses quartz apatite sphene and feldspar Elongated hornblende grains show parallelism with biotite grains and define the megascopic foliation

Apatite grains are idioblastic to subidioblastic prismatic elliptical and show high refractive index It occurs as inclusion within feldspar and biotite

Zircon forms idioblastic to sub idioblastic and six sided wedge shaped grains It shows high refractive index It occurs as inclusion within feldspar biotite and hornblende

Sphene is idioblastic, elongated grains and feebly pleochroic It shows high refractive index and occurs as inclusion within feldspar, biotite and hornblende

Allanite forms idioblastic to sub-idioblastic, yellowish orange coloured grains It shows straight extinction with respect to elongation It occurs as inclusion within feldspar, quartz and biotite It forms pleochroic haloes within biotite

Opaque ore is rare and forms xenoblastic, patchy grains It occurs as inclusion within biotite

Texture: The gneisses of this type are medium grained, inequigranular Elongated grains of biotite and hornblende are oriented in parallel fashion, exhibiting a strong foliation Feldspar and quartz grains are interlocked showing granoblastic texture Strong gneissose texture is produced by the alternation of mafic rich layers with quartz-feldspar rich layers

B. Porphyroblastic gneiss with mafics showing strong foliation

Megascopic characters The specimens are light coloured, medium-grained consisting essentially of plagioclase, potash feldspar, quartz, biotite and elongated amphibole Diffused microcline is present in patches or lenses Mafic percentage is higher than in previous group Mafics are strongly developed and segregated along planer surface Parallel alignment of mafic minerals exhibits a strong foliation Gneisses of this type are not migmatitic but some what feldspathised, and may have been deformed

Microscopic characters: The specimens consist of the following minerals

Microcline forms subidioblastic and elongated grains Grain boundaries are lobed Some specimens show fine perthitic lamellae and is therefore a microcline-microperthite $2V_X$ as determined on the Universal Stage is 74°, 74°, 89° It also shows cross-hatched twinning and inclusions of plagioclase, quartz (Fig 2) and biotite

Orthoclase forms subidioblastic grains It shows straight extinction with one of the cleavage set $2V_X$ is 68° It contains inclusions of quartz

Some specimens show simple twinning and fine perthitic lamellae Absence of orthoclase is noticed in some specimens

Quartz grains are xenoblastic, irregular, show lobed and concavo-convex contact It contains inclusions of ldioblastic plagioclase, biotite and sphene, at places occupies interstitial space between feldspar grains

Fig 1 Photomicrograph showing fine exsolved lamellae of albite within microcline (Between crossed nicols 61X)

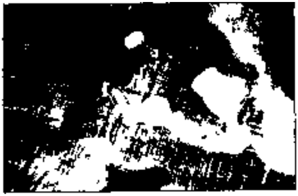

Fig 2 Photomicrograph showing inclusion of quartz within microcline (Between crossed nicols 20X)

Plagioclase forms subidioblastic and tabular to elongated grains, composition determined fiom maximum X 010 is An_{41} It shows zoning due to the presence of an outer albite rim at the contact with potash feldspar It contains submicroscopic to granular dusty inclusions and also inclusions of quartz microcline biotite and apatite Twinning is present in the outer albite rim in some specimens

Biotite is in elongated flakes, it is pleochroic with X = yellowish brown, Y = Z = dark brown, X < Y Z N = 1 657 ± 0 007 Few grains show pleochroism from colourless to deep brown Elongated flakes of biotite are oriented parallel to the foliation, contains inclusions of apatite, quartz and closely associated with hornblende and sphene

Hornblende forms subidioblastic to xenoblastic and short prismatic grains It is pleochroic with X = yellowish green, Y= Z = greenish black, Y Z > X, N_z = 1 695 ± 0 005 and composition is Mg Fe_9 Z c = 18° It is closely associated with biotite In all the specimens hornblende grains are arranged in a parallel fashion with biotite showing foliation It contains inclusions of quartz, plagioclase sphene, zircon, epidote and biotite

Apatite is idioblastic to subidioblastic and prismatic to elliptical grains, shows high refractive index and occurs as inclusion within quartz, feldspar, biotite and hornblende

Sphene forms subidioblastic and prismatic to elliptical grains, it is feebly pleochroic, colourless to pinkish brown occurs as inclusion within feldspar and biotite

Zircon is subidioblastic and six sided, and rhombic grains, occurs as inclusion within feldspar, biotite and hornblende

Epidote forms subidioblastic grains, colourless, fracture common and shows variegated inter ference colour It occurs within feldspar and biotite

Allanite grain is subidioblastic,shows pleochroism from pale brown to dark brown, interference colour masked by the body colour It forms black pleochroic haloes in biotite

Texture The rocks are medium grained, somewhat inequigranular Flakes of biotite and elongated hornblende are arranged in linear fashion forming strong foliation Quartz and feldspar rich layers alternate with biotite and hornblende rich layers showing gneissose texture Quartz and feldspar are interlocked, showing granoblastic texture

C Garnet bearing porphyroblastic gneiss with pegmatite veins (Migmatitic gneiss)

Megascopic characters The specimens of this group of gneisses are light coloured, medium grained and show a more or less similar mineralogical composition as in group A and B It differs from the previous groups in containing garnet as an essential mineral and in having stronger injection of or coarser crystallisation, or segregation of pegmatitic material which occurs as lenses or patches

Coarse grained microcline is segregated at places Pegmatitic veins cut across the foliation of the gneisses Parallel orientation of biotite and amphibole produces strong foliation At places mafic minerals are segregated along planer surfaces In some places biotite is concentrated and forms a sheath along the borders of quartz, feldspar patches and microcline lenses Quartzo-feldspathic bands alternate with mafic rich layers showing gneissose structure In some specimens porphyroblast of magnetite is surrounded by a halo of feldspar

Microscopic characters The specimens of this group consist of the following minerals

Garnet occurs as idioblastic to subidioblastic, six sided grains, non-pleochroic, pink coloured, fractures common, and isotropic Grains of garnet form granular aggregate It is closely associated with hornblende and at places surrounded by hornblende Some garnets completely enclose plagioclase, and contain inclusions of quartz (Fig 3) and opaque ore

Microcline forms subidioblastic to xenoblastic and short tabular grams with lobed gram boundaries It shows fine perthitic lamellae of albite, is therefore, a microcline microperthite It also shows cross-hatched twinning and contains inclusions of plagioclase, quartz and biotite At places it shows dusty alterations

Plagioclase forms subidioblastic tabular and poikiloblastic grains Composition determined from maximum X' 010 is An_{18} Some grains show presence of zoning formed by an outer albite rim at their contact with potash feldspar It contains intergrowth of fine lamellae of potash feldspar and hence is an antiperthite Submicroscopic to granular inclusions produce clouding

Quartz grains are granoblastic, few with undulatory extinction It shows lobed and concavo convex contact and contains inclusions of biotite and sphene It occurs as inclusion within garnet

Biotite is in elongated flakes it is pleochroic from greenish brown (X), to greenish black (almost dark-Y = Z), $X < Y \quad Z$, $N_y = 1\ 677 \pm\ 004$ Few grains are probably rich in phlogopite content showing pleochroism from very light yellowish brown (almost colourless) to deep brown Biotites, are haphazardly oriented but at places arranged in sub-parallel fashion showing weak foliation It contains inclusions of apatite, sphene and shows pleochroic halo around allanite

Hornblende forms subidioblastic and short prismatic grains It is pleochroic with X = light green, Y = almost black (almost opaque), Z = olive green, $Y > Z > X$, $N = 1\ 705 \pm\ 003$ and composition is Mg_2Fe $Z \quad c = 4$ Hornblende surrounds the plagioclase grains and is closely associated with biotite

Apatite grains are idioblastic to subidioblastic and elliptical to prismatic It occurs as inclusion within biotite and feldspar.

Sphene is subidiobkstic, subsquarish grains and feebly pleochroic from colourless to pinkish Sphene is enclosed by biotite and leldspar

Allanite is subidioblastic, pleochroic from light yellowish brown to brown It forms pleochroic haloes within biotite

Opaque ore occurs as xenoblastic grains within feldspar In some specimens opaque ore is ab sent but orthoclase is present

Orthoclase forms subidioblastic grains and shows straight extinction with one of the cleavage set It shows fine perthitic lamellae and hence it is a microperthite

Zircon grains are idioblastic, short prismatic It occurs as inclusion within quartz and feldspar

Texture The gneisses of this type are medium grained, inequigranular Elongated flakes of biotite are arranged in a sub-parallel fashion exhibiting weak foliation Feldspar and quartz grains are interlocked, showing granoblastic texture Gneissosity is present in some specimens where biotite rich layers alternate with quartzo feldspathic layers showing gneissose texture

D Microcline rich, granoblastic gneiss with faint foliation (Migmatitic gneiss)

Megascopic characters The specimens of this group of gneisses are pink coloured, medium grained This group is characterised by the absence of pegmatite veins

Fig.3. Photomicrograph showing inclusion of quartz in granet (plane polarized light, 61 X).

Fig 4 Photomicrograph showing prismatic hornblende clusters (Plane polarized 1ight 61 X).

At places microcline is segregated in patches or lenses Sub parallel orientation of biotite and elongated amphibole produces weak foliation At places mafic minerals are segregated along planer surface .Quartzo felspathic layers alternate with mafic rich layers showing weak gneissose structure

Microscopic characters The specimens of this group consist of the following minerals

Plagioclase forms subidioblastic to short tabular to elongated grains with crenulated grain boundaries Composition determined from the maximum X 010 is An_8 Some grains show presence of zoning formed by an outer albite rim at their contact with potash feldspar It contains inclusions of quartz biotite and hornblende It shows alteration to sericite and muscovite

Microline forms subidioblastic to xenoblastic short tabular prismatic and poikiloblastic grains with lobed grain boundanes It shows cross hatched twinning and contains inclusions of quartz and biotite At places it shows dusty alterations

Quartz grains are xenoblastic few with undulatory extinction It shows lobed and concavo con vex contact and occurs as inclusion within feldspar

Hornblende forms subidioblastic short prismatic and poikiloblastic grains towards quartz and feldspar (Fig 4) It is pleochroic with X = yellowish green Y= greenish black Z = bluish green $Y>Z>X$ $N = 1\ 705 \pm 003$ and composition is $Mg\ Fe_8$ Z c = 21° It alters to biotite and is closely associated with sphene zircon and apatite

Tremolite grains are few subidioblastic and fibrous It shows high refractive index It is altered to biotite and encloses zircon

Biotite is in elongated flakes it is pleochroic from yellowish brown (X) to greenish brown (Y = Z) $X < Y$ / $N = 1\ 667 \pm 004$ Biotite shows bending of flakes due to deformation and encloses feldspar and zircon It is closely associated with hornblende

Apatite froms idioblastic to subidioblastic and elliptical grains It occurs as inclusion within feldspar and hornblende

Sphene is subidioblastic and prismatic grain and is closely associated with hornblende

Zircon grains are idioblastic to subidioblastic six sided It is enclosed by biotite and hornblende

Allanite is xenoblastic, pleochroic from light brown to dark brown It is enclosed within opaque ore In some specimens allanite shows pleochroic halo in chlorite

Chlorite is in small elongated flakes, and pleochroic from light green to green It is closely asso ciated with biotite and encloses apatite and allanite It shows alteration along cracks

Epidote forms subidioblastic and prismatic grains, it is pleochroic from light pinkish brown to light green and shows higher order interference colour It is closely associated with feldspar

Opaque ore is xenoblastic and encloses plagioclase and allanite

Texture: The gneisses of this group are medium grained and somewhat inequigranular Biotite and hornblende grains are arranged in sub-parallel fashion exhibiting weak foliation Quartz and feldspar grains are interlocked showing granoblastic texture At places mafic rich layers alternate with quartzo-feldspathic layers producing gneissose texture

MODAL ANALYSIS

The modal analysis of the specimens from the different groups of gneisses were carried out and the results are presented in Table I The frequency distribution of the modal quartz plagioclase alkali feldspar ratio of several groups of gneisses are plotted in the triangular diagram X (Fig 5) representing quartz, plagioclase and alkali feldspar The figure shows a random scatter but maximum number of rocks are restricted to the central part near the minimum temperature region of the system quartz-albite-orthoclase, experimentally established by Tuttle and Bowen (1958)

Maximum concentration in the minimum temperature zone implies that either (*i*) the gneisses as observed are probably products of partial melting and migmatisation, 01 (*ii*) the original composition of these gneisses are such that they are very suitable to partial melt, *i. e.,* undergo anatexis Either of these two alternatives can explain the common occurrence of migmatitic rocks with these gneisses, presence of quartzo-feldspathic veins injected along the foliation planes of the gneisses and the presence of ptygmatic folding indicates plastic flowage during migmatisation

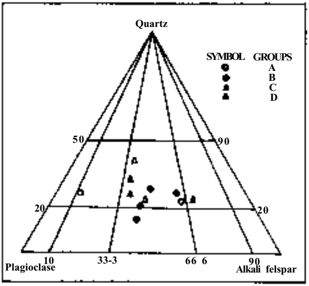

Fig 5 Quartz-Plagioclase-Alkali Feldspar diagram showing composition of different groups of gneisses

TABLE-I

Modal composition of the gneisses from Dakshin Gangotri, Antarctica.

Mineral	Group A		Group B				Group C			Group D	
	2	3	4	5	6	7	8	9	10	11	12
Microcline	17 7	86	26.5	18 1	33 0	12 8	21 4	17 5	19 2	23.1	45 0
Orthoclase	28 5	X	14.9	13 5	X	16.8	X	5.3	X	X	3.3
Plagioclase	24.3	55 6	24.8	32.0	45 6	39 3	30 0	37.5	33.0	37 3	21 1
Garnet	X	X	X	X	X	X	7.6	10 2	9 7	X	X
Quartz	20 8	23 2	24.8	26 0	13 4	18.5	35.1	20 6	20.2	29.1	21 0
Biotite	6 1	6.7	6 6	7 6	5.8	4.8	4 2	5.3	11.7	0 2	0 4
Hornblende	2.5	5 4	2 0	2 4	1.4	6 4	1 3	2.7	1 7	8.0	7.0
Apatite	0 1	0 1	0 1	0 1	0.3	0.1	0.4	X	X	0.4	0 4
Sphene	X	0 3	0 3	X	0 1	0 8	X	0.90	X	0 1	X
Zircon	X	0 1	X	X	0 4	0.5	X	X	0.4	0 1	0 4
Epidote	X	X	X	0.1	X	X	X	X	X	0 2	X
Allanite	X	X	X	0 1	X	X	X	X	0.1	X	X
Chlorite	X	X	X	X	X	X	X	X	X	1.5	X
Iron ore	X	X	X	0.2	X	X	X	X	2.0	X	X
Total	100.0	100 0	100 0	100 0	100.0	100.0	100 0	100 0	100 0	100 0	100 0

It is interesting to note the extensive distribution of gneisses in the diagram. This random scatter suggests a sedimentary origin of these gneisses and hence they can be termed as para-gneisses. These gneisses are not of igneous origin because ortho-gneisses may not show such random distribution, rather they are likely to be restricted in composition only to the central zone of the diagram.

PETROGENESIS

The biotite-hornblende bearing quartzo-feldspathic gneisses are the predominant rock types and constitute the country rock in the area. The present area consists of metasediments such as paragneisses and calc-silicate rocks.

Dominant theories suggested for these types of gneisses are: (*i*) crystallisation from magma, (*ii*) formation by fusion of pre-existing schist by solution and (*iii*) by granitisation (metasomatism by diffusion of emanations or magma).

The metamorphic gneisses of the area show two distinctly contrasting types, such as the least altered gneiss and the migmatitic gneisses. The least altered gneisses can also be termed as para-gneisses. They seem to have evolved from progressive metamorphism of sediments, that is, the rocks have possibly been little altered in bulk composition from the parent sedimentary rock. Paragneisses of the area are at places interlayered with calcsilicate rocks and migmatitic gneisses. Magascopically the para-gneisses are homogeneous in character, grey coloured and mottled in appearance showing granoblastic texture.

The second type, the migmatitic gneisses, are heterogeneous composite rocks consisting of biotite-hornblende bearing quartz-feldspathic gneisses with veins of pegmatitic material parallel to foliation of the gneisses Veins are ptygmatically folded Microcline occurs as stringers, and also as se gregations in patches within the gneisses The migmatitic gneisses may have been formed by anatexis of original gneisses (Winkler, 1965) Veins of quartzo-feldspathic material and segregation of mi crocline may have been produced by metamorphic differentiation, or due to injection of granitizing material from outside Presence of quartzo-feldspathic veins injected along the foliation planes of the gneisses and the presence of ptygmatic folding indicate plastic flowage during migmatisation Distribution of migmatitic rocks indicates that partial melting has taken place in one part of the area and their absence in the other part could be due to paucity of water or lack of suitable composition

Eskola (1948) suggested that granitisation of metamorphic rock of argillaceous origin is mostly first converted into migmatites and which may grade into almost homogeneous granites Characteristic of the metasomatic granitisation is the constant occurrence of intermediate stages and relict structure from earlier stages

The gneissic complex of the present area can be compared with the major paragneisses between Emeryville and Colton in Northwest Adirondack Mountain studied by Engel and Engel (1958) They stated that the gneiss seems to have evolved from a monotonous tuff or graywacke like sediments into a complex of little altered and variously granitised parts The least altered gneiss is probably formed from original sedimentary rock during progressive metamorphism The second type is produced by granitization of widely distributed parts of the least altered gneiss All gianitizing substances in the gneisses in the area of lowest temperature metamorphism (less than 550°C) appear to be introduced either laterally or from below These in areas of highest temperature metamorphism are partly introduced and partly derived locally from the gneiss The changes in texture and mineralogy in least altered gneiss accompanied by changes in its bulk chemical composition, are detectable at temperatures of metamorphism of about 550°C and are well defined at Colton The cause of the change is interpreted as a metamorphic *degranitization* or *basification* in which Si, K and H_2O are mobilized and partly liberated out, partly frozen into the rock as venitic migmatite

Petrographic studies on gneissic rocks from parts of Hazaribagh District and adjoining areas, show that a considerable volume of these were formed by metamorphism (with little or no metaso matism) of impure quartzo-feldspathic sediments A normal carbonate cemented sandstone (subgraywacke) can yield a gneiss composed of (volume percent) 23% quartz, 15% orthoclase, 43% plagioclase, 5% hornblende and diopside, 13% calcite by metamoiphism (De, 1964) It may be mentioned that pyroxene and free calcite are absent in the gneisses under study Similarity of the modal composition of these gneisses with the metamorphosed subgraywackes (De, 1964) indicates that the gneisses of the present area may also be of metasedimentary origin That they are of metasedimentary origin is clearly shown by the occurrence of paragneisses interlayered with calc-silicate rocks and probably also by the presence of round shaped quartz within feldspar and mosaic texture The gneisses in the present area have modal composition comparable to those found in the Adiron dack area and this also leads to the conclusion that these are paragneisses

The frequency distribution of the modal quartz plagioclase alkali feldspar ratio of all the groups of gneisses have been plotted in the triangular diagram representing quartz, plagioclase and alkali feldspar The largest number of these rocks are restricted to the adamellitic field near the minimum temperature region of the system quartz-albite-orthoclase, experimentally established by Tuttle and Bowen (1958) Maximum concentration of points representing composition of the gneiss at the minimum temperature zone indicates that either, (i) the gneisses as observed are largely pro ducts of partial melting and migmatisation of metamorphic gneisses, or (*ii*) the original composition of these gneisses are shown by these points, because of their location near the minimum temperature area, are such that they could partially melt, *i.e.,* undergo anatexis. Some gneisses show random scatter in the diagram and suggest a metasedimentary origin of these gneisses and hence they can be termed as paragneisses.

Mineral assemblage in the gneisses indicates that the gneissic rocks are produced by regional metamorphism of pelitic and quartzo-feldspathic sediments under the sillimanite-almandine-orthoclase sub-facies of the almandine-amphibolite facies of Fyfe, *et al.* (1958). Absence of muscovite in the gneisses indicates that metamorphism has not taken place under sillimanite-almandine-muscovite sub-facies because muscovite breaks down, in the presence of quartz, into sillimanite, orthoclase and water by the following reaction:-

$$\underset{\text{Muscovite}}{KAl_2(AlSi_3O_{10})(OH)_2} + \underset{\text{Quartz}}{SiO_2} \rightleftharpoons \underset{\text{Orthoclase}}{KAlSi_3O_8} + \underset{\text{Sillimanite}}{Al_2SiO_5} + H_2O$$

High water pressures are indicated by prevalence of hornblende and biotite in the gneisses. General absence of cordierite and andalusite shows that the almandine-amphibolite facies covers pressures far exceeding those of the hornblende-hornfels facies. Turner and Verhoogen (1960) concluded that the temperature of the upper limit of almandine-amphibolite facies may be near 700 or 750°C and in migmatitic complexes the higher grades must overlap the temperature of fusion of granite. The hornblende-granulite sub-facies represents the lower grade in the granulite facies.

REFERENCES

De, A, (1964) Metasedimentary origin of hornblende bearing gneisses of Chotanagpur. *Pio. Ind. Sci. Cong.,* Part III.

Engel, A.E.J, and C G. Engel (1958) Progressive metamorphism and granitisation of the major paragneisses, NW Adirondack Mountains, New York. *Bull. Geol. Soc. Amer,* V. 69, 1369-1414.

Eskola, P (1948) Nature of metasomatism in the process of granitisation. *Int. Geol. Cong. Rept. of the 18th Session,* Great Britain.

Fyfe, W.S., F J Turner and J. Verhoogen (1958) Metamorphic reactions and metamorphic facies. *Geol. Soc. Amer.,* Mem. 73.

Turner, F J and J. Verhoogen (1960). Second edition. Mc Graw Hill Book Company, Inc., 696 p.

Tuttle, O.F and N.L Bowen (1958). Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O, *Mem. Geol Soc. Amer.,* No. 74.

Winkler, H G.F. (1965). *Petrogenesis of Metamorphic Rocks* Springer-Verlag, New York, 220 p.