Mineralogical Variation in the Gneisses from *Dakshin Gangotri,* Antarctica

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ABSTRACT

Mineralogical variations in the gneisses *of Dakshin Gangotri* was studied by determination of R.I. by liquid immersion method, optic axial angle measurement, determination of composition of plagioclase by the help of a universal stage and determination of composition of biotite and hornblende from R.I. (Ny and Nz).

All the gneisses consist of microcline (and/or) orthoclase, plagioclase, quartz, biotite, hornblende and opaques.

The plotting of $2V_X$ of microcline and orthoclase against frequency shows two different peaks occupied by different ranges of $2V_X$; with a gap in between. Orthoclase shows $2V_X$ ranging between 70°-75° and microcline ranging between 80°-85°.

Degree of disorder of Al/Si distribution suggests that orthoclase is partly ordered monoclinic $K(AlSi)_2Si_2O_8$ and microcline is fully ordered triclinic $KAlSi_3O_8$ and as a result of order-disorder type of transition, both orthoclase and microcline co-exist in these gneisses.

INTRODUCTION

Geological mapping has been carried out around the Indian Research Station *Dakshin Gangotri* (Lat. 74° 45'S, Long. 11°37'E), which is on the Schirmacher Range of Antarctica. The dominant rock type present is the biotite-hornblende bearing quartzo-feldspathic gneiss which is the country rock in which are intruded dykes and sills of pegmatite, metadolerite, amphibolite and melasyenite. The biotite-hornblende bearing quartzo-feldspathic gneiss is further sub-divided on field and petrographic basis into the following four units:

D. Microcline rich granoblastic gneiss with faint foliation (Migmatitic gneiss).
C. Garnet porphyroblastic gneiss with pegmatite veins (Migmatitic gneiss).
B. Porphyroblastic gneiss with mafics showing strong foliation.
A. Microcline porphyroblastic gneiss.

The petrography of these units of gneisses have been described elsewhere. A general account of the mineralogical variation only is given here and an attempt has been made to trace the significance of such variation.

PETROGRAPHIC METHODS

Refractive index was determined by liquid immersion method on a crushed fraction. The indices of the liquids have been previously checked with a refractometer. The optic axial angles were determined by the Universal Stage by direct measurement of the two optic axes. The obtained values of the optic axial angles were corrected for difference in refractive indices between those of the glass hemisphere and the mineral.

Composition of the plagioclase was determined on the basis of maximum extinction on the Universal Stage on albite twin lamellae perpendicular to 010, using the method of maximum symmetrical extinction and using the curve constructed by Hess (1960). Only Universal Stage data have been used.

Composition of biotite and hornblende were determined from the refractive indices (N_y and N_z) respectively by using the curves of Deer *et al.* (1965).

MINERALOGY

The gneisses consist of microcline (and/or) orthoclase, plagioclase, quartz, biotite, hornblende and opaque ore as the essential mineral constituents.

Alkali feldspars present in the gneisses are of two types, namely, orthoclase and microcline. They have been identified under the petrographic microscope by the following criteria: (*i*) section of orthoclase perpendicular to 010 gives straight extinction indicating monoclinic nature; (*ii*) microcline shows cross hatched twinning and untwined microcline shows inclined extinction.

The optic axial angle ($2V_x$)of microcline and orthoclase have been measured by the Universal Stage. A histogram has been prepared by plotting $2V_X$ against frequency (Fig.1). The graph shows two different peaks occupied by different ranges of $2V_X$ (Table I.). There is a gap between the two peaks. Orthoclase shows $2V_x$, ranging between 70°-75° and microcline ranging between 80°-85°. Therefore, the Universal Stage determinations indicate the presence of orthoclase and microcline in these gneisses. Both orthoclase and microcline are present in the same specimen.

TABLE I

Optic axial angle of alkali feldspars in gneisses.

UNITS	**A**	B	C	D
Optic Axial Angles (2V)	69 75 81 82 85	68° 74° 74° 89°	83° 83° 85°	63° 68° 73° 74° 77° 86° 89°

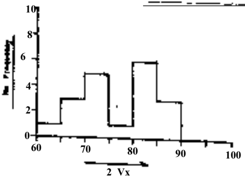

Fig 1 Histogram showing range of 2Vx of Alkali Feldspar (Orthoclase and Microcline) in gneisses

Degree of disorder of Al/Si distribution suggest that orthoclase is partly ordered monoclinic, $K(AlSi)_2$ Si_2O_8 and microcline is fully ordered triclinic, $KAlSi_3O_8$. Ordered microcline can be formed from disordered orthoclase (Deer *et al*., 1965). Hence as a result of order-disorder type of transition, a gradual transformation occurs due to which both orthoclase and microcline coexist in these gneisses.

From studies of granulites of Lapland, Eskola (1952) concluded that the first stage of alteration of the clear orthoclase into microcline appears in the form of undulating extinction. Gradually, appearance of fine twin lamellae in the crystal of orthoclase leads to its transformation into cross hatched microcline.

Microcline generally forms subidioblastic, short tabular to elongated prismatic grains. Microcline shows fine perthitic lamellae of albite and therefore, is a microcline microperthite. The exsolution lamellae of albite are produced by unmixing from an originally homogeneous feldspar at the subsolidus temperature (highest temperature of solvus is 660°C) during cooling. Cross hatched twinning is very common to microcline but untwinned microcline are also present. Microcline shows lobed grain boundaries and contains inclusions of circular to sub-circular quartz, plagioclase, biotite, hornblende, zircon, sphene, apatite and small granules of opaque ore. Koschmann (1960) suggested from the presence of inclusion of plagioclase in microcline, that, in the paragenesis of gneisses studied by him plagioclase is older than microcline and also replaced by microcline. At places it shows dusty alterations.

Orthoclase is in the form of subidioblastic, prismatic grain and shows straight extinction with one of the cleavage set on 001 orientation. Orthoclase generally enclose quartz, apatite, biotite, sphene and opaque ore. Dusty alteration is common.

Plagioclase forms subidioblastic to xenoblastic short tabular, elongated prismatic and poikilitic grains with lobed grain boundaries. Maximum extinction angle of plagioclase determined on the Universal Stale X' 010 in the zone normal to 010 varies from 17.5 to 26 (Table II) and corresponding composition ranges between $An_{35.5}$ to An_{18} (andesine). Normally plagioclase shows lamellar twinning but untwinned plagioclase is also commonly seen. It is characterised by the presence of zoning formed by an outer albite rim where the plagioclase grain is in contact with the potash feldspar; this albite rim may have been formed by exsolution and diffusion of the albite component and of the adjacent potash feldspar during slow cooling as suggested by Tuttle (1954). Plagioclase in some specimen of group C contains intergrowth of fine lamellae of potash feldspar and hence is an antiperthite. Clouding is very common phenomenon in plagioclase of gneisses. Plagioclase is intensely clouded due to dusty granular inclusions and also show alteration to sericite and muscovite.

TABLE II

Optical properties of plagioclase in gneisses.

Group	X' 010 as determined in the zone normal to 010, on Universal Stage	Anorthite content	Average anorthite content
A	22°, 22.5°, 23°, 23.5°	41, 41.5 42.5 44	42.5
B	21°, 22°, 22°	39,41,41	40
C	20°, 20°, 20°	38, 38, 38	38
D	26°, 26°, 26°	48, 48, 48	48

Quartz is xenoblastic, a few with undulatory extinction Quartz is characterised by lobed and concavo convex contact. Generally, rounded to subrounded grains of quartz are enclosed within plagioclase microcline and often orthoclase Quartz contains inclusions of biotite, hornblende, sphene apatite and also in places small grains of plagioclase and microcline

Biotite is in elongated flakes Generally pleochroism varies from light yellowish brown (X) to dark brown (Y=Z) and N_y ranges between 1.655±0.003 to 1.658±0.002 (Table III) in groups A and B When it is pleochroic with X = greenish black to almost opaque, N_Y ranges from 1.667 ±0.005 to 1677 ± 0.004 in groups B, C and D Group B shows both higher and lower refractive indices Migmatitic gneisses have higher refractive index. It has been found that the refractive index of biotite is related to its composition Refractive index generally shows an increase with increasing iron content but is also affected appreciably by other substitutions (increase with Mn and T_1 and decrease with P) as shown bv Deer *et al* (1965) Principal factors which influence colour are TiO_2 content and the ratio Fe O /FeO+Fe O High TiO content gives a reddish brown colour while high ferric iron gives green Intermediate proportions of Ti and Fe^3 result in yellowish or grenish brown colourations High iron content may be inferred from the high values of refractive index such as N_y = 1.667 ± 000"i to 1 677 ± 0 004 Few grains of biotite in some specimens of group C are probably rich in phlogopite content showing pleochroism from light yellowish brown (almost colourless) to dark brown At places biotite shows bending of flakes due to deformation Parallel orientation of the elongated flakes of biotite form the foliation in these gneisses Biotite shows pleochroic haloes around allanite and also zircon at places

TABLE III

Optical properties of biotite in gneisses

* T	Scheme of pleochroism		Refractive index (N_y)
\	Greenish brown	Almost black	1 667 ± 0 005
\	light brown	Dark brown	1 667 ± 0 003
B	Yellowish brown	Dark brown	1 657 ± 0 007
B	Light brown	Almost black	1 671 ± 0 004
C	Greenish brown	Greenish black	1 677 + 0 004
C	Yellowish brown	Dark brown	1 657 ± 0 007
D	Yellowish brown	Greenish brown	1 677 ± 0 004

Horneblende forms subidioblastic, short prismatic and poikiloblastic grains. It is pleochroic with X = light yellowish green to light green, Y = olive green to greenish black, Z = dark green, N varies from 1.695 ± 0.005 to 1.697 ± 0.005 (table IV) in groups A, B and C. Hornblende of groups A, B, C and D shows different reactive indices and change in colour of pleochroism In these groups Z direaction shows bluish green to almost opaque and NZ is 1.705 ±0.003 It has been found that groups of migmatitic gneisses have high refractive index of hornblende Both lower and higher refracter indices are shown by groups A B and C The refractive indices of hornblende are influenced by composition such as presence of Mg, Fe , Fe+3 content and are also to a certain extent by Mn and Ti content which is present in a very minor amount in the hornblende structure the relationship between the refractive indices and chemical composition expressed as 100 Mg (Mg + Fe+2 + Fe+3 + Mn) ratios has indicated that refractive indices of hornblende increases with increase in Fe (both Fe+2, Fe+3) content Hornblende showing N from 1.695 ± 0.005 to 1.697 ± 0.005 contains $Mg_{41\ 31}$ and $Fe_{59\ 63}$

TABLE IV

Optical properties of hornblende from gneisses of Dakshin Gangotri, Antarctica

Group	Scheme of pleochroism			Absorption	Z C	Refractive Index (N_z)	Composition
	X	Y	Z				
A	Yellowish green	Olive green to almost black	Bluish green	Y>Z>X	8°	1 705±0 003	$Mg_{32}Fe_{68}$
A	Yellowish green	Green	Dark green	Z>Y>X	18°	1 697±0 005	$Mg_{37}Fe_{63}$
B	Yellowish green	Greenish black	Greenish black	Y>Z>X	18°	1 695±0 005	$Mg_{41}Fe_{59}$
B	Yellowish green	Almost black	Bluish green	Y>Z>X	23°	1 705±0 003	$Mg_{32}Fe_{68}$
B	Pale yellowish green	Greenish black	Dark green	Y>Z>X	26°	1 697±0 005	$Mg_{37}Fe_{63}$
C	Light green	Almost black	Olive green	Y>Z>X	4°	1 705±0 003	$Mg_{32}Fe_{68}$
C	Yellowish green	Greenish black	Dark green	Y>Z>X	10°	1 697±0 005	$Mg_{32}Fe_{63}$
D	Yellowish green	Greenish black	Bluish green	Y>Z>X	21°	1 705+0 003	$Mg_{32}Fe_{68}$

With increase in iron content refractive index gradually increases and hornblende with N_z = 1 705 ±0 003 consists of Mg_{32} Fe_{68} (Fe represents Fe^{+2} + Fe^{+3} + Mn)

Z C mostly lies in between 17° to 30° but in some specimens it is extremely low, 4° only Hornblende shows sharp content with the other grains and at places alters to biotite Elongated grains of hornblende are arranged in parallel fashion with biotite showing the foliation

Opaque ore is present in all the groups of gneisses Opaque ore forms subidioblastic to xenoblastic, octahedral, barshaped small granular grains Dusty specks of opaque ore form clouding in plagioclase Generally, it occurs as inclusion in feldspars, hornblende and biotite

In a large number of specimens, plagioclase show clouding by dusty inclusions Clouding of plagioclase is a very common phenomenon in the gneisses of the present area Plagioclase are clouded due to presence of numerous minute dark particles distributed throughout the crystal

The particles which produce clouding, generally, consists of granular dusty opaque ore, but other minerals when large enough has been identified as biotite, hornblende may also be present in clouded plagioclase The particles producing this clouding, occur as dust like specks, short rods or thin hair like growths and needles and are variable in size Clouding is usually slight but at times very pronounced, rendering crystals nearly opaque

The distribution of the particles is somewhat variable, the dusty particles are randomly distributed throughout the crystal but in some cases are concentrated in the core of the crystal leaving outer margin clear and devoid of any particles In some plagioclase the fine dusty inclusions are oriented parallel to albite twin plane or are aligned parallel to the cleavage set In some plagioclase, trails of fine dusty inclusions produce clouding

Clouding observed in the plagioclase of these gneisses is similar to those observed by Poldervaart and Gilkey (1954) They have shown that slight clouding is probably due to exsolution (during slow cooling) of iron dissolved in the plagioclase crystal lattice, but more intense clouding may be produced by diffusion of iron and other extraneous material into the crystal after its formation They suggested that in clouded plagioclase crystals there are minute surface of physical discontinuity which provide suitable passage for diffusion of material into and out of the crystals. Clouding occurs in unmixed plagioclase of intermediate composition and intense clouding has not been observed in either albite or anorthite. Conditions for clouding of plagioclase in a rock according to these authors are (*i*) the existence of an adequately high temperature for a sufficient length of time, (*ii*) the presence of an aqueous pore fluid and (*iii*) the presence of iron bearing minerals in the original rock. These conditions may or may not be realised in thermal or regional metamorphism,

To the authors it seems quite impossible for plagioclase to be clouded by dusty inclusions mainly in the core leaving clear margin by diffusion during metamorphism. Clouding is more probably produced during metamorphism as a result of exsolution of iron originally incorporated in the plagioclase at the time of its formation. Clouded plagioclase clearly can not form the sole criterion for thermal or regional metamorphism.

REFERENCES CITED

Deer,W.A, R Howie and J Zussman(1965) *Rock Forming Minerals, Vol* 2,3 & 4. Longmans Green and Co. Ltd ,374 pp. 270 pp , 435 pp respectively

Eskola, P (1952) On the granulites of Lapland *Amer Jour Sci,* Bowen Volume, p. 133-171.

Hess, H H (1960) Still Water Igneous Complex, Montana *Mem Geol Sur Amer.,* V 80

Koschmann, A.H. (1960) Mineral paragenesis of precambrian rocks in the Tenmile Range, Coloiado *Bull Geol Soc.Amer.,*

Poldervaart, A and A.K Gilkey (1954) On clouded plagioclase. *Amer Miner,* 39, 75-91

Tuttle, O F (1954) Origin of the contrasting mineralogy of extrusive and plutonic salic rocks. *Jour Geol,* 60, 107.