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POLYPHASE DEFORMATIONS IN THE PRECAMBRIAN ROCKS OF THE CENTRAL PART OF THE SCHIRMACHER HILLS, EAST ANTARCTICA

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Abstract

The central part of the Schumacher Hills have suffered repeated phases of deformations. Five generations of deformations (D_1- D_5) have been delineated. D_1 and D_2 deformations took place under granulite facies conditions. The dominant deformation, D, took place under amphibolite facies conditions. D_3 foliations are further deformed by two later generations of open and upright folds. Multiple phases of ductile shearing took place in continuation with the last three deformations.

Introduction

The rocks of the Schirmacher Hills in the Queen Maud Land has been repeatedly deformed and metamorphosed. The general deformation history was studied by earlier workers (Sengupta 1986, 1988, 1991, 1993, 1994; Stackebrandt et al. 1988, Paech' and Stackebrandt 1995, Rameshwar Rao, D. 2000, Rameshwar Rao, D. et al. 2000, Ravikant, V. and Kundu, A. 1998). The early two generations of deformations took place under granulite facies conditions (Sengupta, 1988, 1993). However, the dominant deformation of the area, D_3, formed under the amphibolite facies condition. There are rare occurrences of the signature of D_1 deformation in the central part of the Schirmacher Hills. D_2 foliations are found within the pyroxene granulite and enderbite. In most places, D_2 and D_3 foliations are subparallel. They can only be distinguished in places where both granulitic and amphibolitic facies rocks are preserved. The D_3 foliations are further deformed by two generations of later events , D_4 and D_5.

The present work is concentrated within the central part of the Schirmacher Hills. An attempt has been made to revise the earlier geological map in the scale 1: 12,500. In the following section we describe various macroscopic and mesoscopic structures and their relation with the large-scale deformations.

Lithology

The main lithological units found in the study area, from east to west, are banded gneiss; interbanded pyroxene granulite and augen gneiss, garnet-biotite gneiss; interlayered calc sillicate-khondalite-pyroxene granulite-granite gneiss; and augen gneiss (Fig.l).

Banded gneiss consists of alternate bands of mafic granulites and enderbite/charnockite. The thickness of individual band ranges from a few centimetres to a few metres. Interbanded pyroxene granulite and augen gneiss occurs within the central part of the study area. There was also emplacement of enderbite parallel to this banding. Calc silicate layers of about 2-metre thickness are found within this rock unit. Garnet-biotite gneiss are medium to coarse grained. Interlayered calc sillicate-khondalite-pyroxene granulite-granite gneiss forms a most deformed unit in the northwest part of the study area. In general, the granite gneiss runs parallel to the khondalite bands. However in some places they are at an angle to the general gneissic foliation. Mafic granulites occur both as bands and rotated blocks within the granite gneiss. Augen gneiss occurs at the extreme northwest part of the study area. It contains large augen of both K-feldspar and plagioclase. The average size of the augen is 2 cm. There are occurrences of isolated pods of massive mafic bodies within the garnet-biotite unit (Fig.l).

Augen gneiss and interlayered calc-khondalite unit also occur as rock types in the northern nunatak of the Schirmacher Hills. The interlayered calc-khondalite unit occurs as a thin zone towards south with a sheared contact between augen gneiss and the interlayered calc-khondalite unit in the nunatak.

Macroscopic and Mesoscopic folds

The dominant deformation in the central part of the Schirmacher Hills is associated with D_3 deformation. The foliation associated with this deformation is D_3 foliations. The general strike of D_3 foliation is east-west with a moderate dip towards south. D_3 folds are present only in mesoscopic scale (Fig.2). The D_3 folds are isoclinal, inclined to nearly reclined with well-developed axial planar foliation. The axial plane of D_3 folds are marked by biotite and hornblende grains in mafic rocks and quartz and feldspar in granitic rocks. The mineral lineation is generally parallel to the D_3 fold hinges. The D_3 foliations have an average strike of 75° with a southerly dip of 24((Fig.3). The average orientation of fold hinges and mineral lineation is 18° towards 220° (Fig.4). The mineral assemblages that mark the axial plane of D_3 fold indicate that this deformation took place under amphibolite facies metamorphic conditions.

The axial plane of D_3 folds have been deformed by D_4 fold with northeasterly striking steep axial surfaces (Fig.5) and southwesterly trending fold hinges parallel to or at low angle to D_3 hinges. TheD_4 folds are thus co-axial with D_3 folds. The interference of D_3 and D_4 folds produces hook-shaped outcrop patterns (Fig.6). In the study area, a macroscopic fold has been delineated by the systematic variation in strike of thin bands of calc silicate. This fold is found in the central part of the study area (Fig.1). The opposite limbs of the macroscopic fold show asymmetric S- and Z- shaped folds. The presence of these asymmetrical folds indicates that this map-scale fold is a buckle fold. The foliation within the thick unit of pyroxene granulite and augen gneiss also shows systematic variation of strike. However, the bands of pyroxene granulite and augen gneiss do not show asymmetric folds in the limb region of the macroscopic fold. A vertical cross section (Fig.7) along AA/ (shown in Fig.1) is made across the hinge of the macroscopic fold. It shows an open and upright fold with steep axial surface. The dip of the foliation on the either limb of the macroscopic fold converges towards each other thereby indicating that it is a synform. The contour diagram of the foliation poles shows a fold axis with a plunge of 18° towards 208° with the strike of axial plane trending 28° with subvertical dip (Fig.8 a and b). The axes of the mesoscopic folds have an average value of 15° towards 223° indicating thereby that they are synchronous and belong to the same deformation. Since these folds deform the regional D_3 foliations, they must be later than D_3 folds and can be grouped as D_4 folds. The orientations of the axial plane and fold axis of the macroscopic fold along with the field relations indicate that this is a D_3 fold. The mineral lineation in this area is essentially parallel to the regional fold axis. The contour diagram of lineation of this area shows that the lineation plunges 20° towards 246° (Fig. 8b), subparallel to the D_3 and D_4 fold hinges.

Another set of open upright fold, D_5 is found with axial plane striking east-west with subhorizontal fold axis. The D_5 folds are mostly present in mesoscopic scales. However, the regional variation in the amount of dip of D_3 foliations from moderately dipping towards both south to north through subhorizontal orientation, (Fig. 8a) may be due to the superimposition of large scale D_5 folds on the dominant D_3 foliation .

Figure 9 shows a D_5 fold in calc - khondalite unit. A pegmatite vein is cutting across the hinge of D_5 fold hinge subparallel to the axial plane of this fold.

Shear Zones :

There are three generations of shear zones found within this study area.

(1) Layer parallel shear zones.
(2) North - easterly cross cutting shear zones
(3) East-west cross cutting shear zones.

Layer parallel shear zones:

Layer parallel shear zones are found along the contact of augen gneiss and calc khondalite intercalated units. Shear foliations are parallel to the regional D_3 foliation. Shear sense indicators show that there was a thrust type of movement in the NE direction along this shear zones. There was profuse development of sheath folds within this shear zones (Sengupta and Bose, 1997).

North Easterly striking shear zones:

Northeasterly striking shear zones ranges from mesoscopic scale to the map scale. Numerous north easterly shear zones are found throughout the study area with the emplacement of pegmatite along it. In most cases foliation drag of the host gneiss near the shear zone borders indicates that the movement along the shear zones are dextral.

The map scale northeasterly shear zone occurs in the eastern part of the study area along the southeastern limb of the macroscopic D_4 fold (Figs.l and 7). The width of this shear zone is about 800 metres. It cut across the width of the Schirmacher Hills. The mylonitic foliation within this shear zone strikes 60°; the clip varies from subvertical to 60° towards southeast. The pitch of the mylonitic lineation varies from subhorizontal to 20° from southwest (Fig. 12). This indicates a strong strike slip movement along this shear zone. Since this wide shear zone cuts across a number of rock units, the mylonites within the shear zone show a variety of compositions. Hence, this shear zone is designated as mylonitic gneiss.

The different rock types found within the shear zones are pyroxene granulite, augen gneiss and garnet-biotite gneiss. Pyroxene granulite bodies within the shear zone occurs as isolated lenses with their long axis parallel to the mylonitic foliation. However, the foliation within the pyroxene granulite show diverse orientations. On the outcrops, the strike of the pyroxene granulite foliation ranges from N-S to E-W making a distinct angle with the mylonitic foliation. The easterly striking pyroxene granulite foliation with a moderate dip towards south may represent the unrotated part of the preexisting pyroxene granulite bands. Augen gneiss occurs as thin discontinuous bands within this shear zone. The foliation within the augen gneiss is parallel to the mylonitic foliation.

Towards the northeastern part a later ductile shear zones cut across this wide shear zones. This narrow shear zone also produced mylonite. The mylonitic foliation along this shear zone strikes 120° with a dip of 70° towards north and the lineation pitches 24° from west. Shear sense indicators in the section parallel to the lineation and the foliation drag of the mylonitic gneiss indicate the thrust sense of movement. There was emplacement of aplite vein within this narrow shear zone. The central portion of the aplite vein is undeformed with a little effect of shearing along its border.

East - West cross cutting shear zones:

Map-scale E-W cross cutting shear zones are found within the central zone of the study area. The length of the shear zone is about 3 Km. and its average width is 15 metres. This shear zone is mostly concentrated along a calc-granulite layer. However, it also dissected the augen gneiss, calc - gneiss and pyroxene granulite bands. The augen gneisses show excellent development of mylonites along this' shear zones. Within the shear zones, protomylonites, orthomylonites and ultramylonites occur depending on the intensity of the shear strain. There was also development of sheath folds with strongly curved hinge lines within the calc-granulite band.

In some places the pyroxene granulites occur as massive, competent bodies around which the mylonitic foliation swerves (Fig. 10). However, in other instances, the pyroxene granulites are somewhat foliated; the foliation within the pyroxene granulites is at high angle to the mylonitic foliation in such places. In such cases the foliation within the pyroxene granulite has the orientation of 136° strike with a dip of 30° towards south indicating thereby that the block has been bodily rotated. The mylonitic foliation around the pyroxene granulite is subvertical with a trend of 114°. In this case, the strain has been concentrated mostly along less competent quartzo-feldspathic rocks. However, in general, pyroxene granulite bands are sheafed with foliation subparallel to the mylonitic foliation outside the bands. The sheared pyroxene granulite shows intense development of hornblende at the expense of pyroxenes. The final product is hornblende schist with a few remnants of pyroxene grains.

The contour map of the mylonitic foliations and lineations indicate that the average mylonitic foliation trends 70° with a dip of 60° towards south. The mylonitic lineation shows an average plunge of 24° towards 234° (Fig. 11). This shear zone has been further dissected and displaced sinisterly by NW - SE trending fault in the central part of the study area. There was emplacement of coarse grained pegmatite along the fault.

Summary

The structural features present in the central part of the Schirmacher Hills indicate multiple episodes of folding and ductile shearing. The early deformations, D_1 and D_2, took place under granulite facies conditions. The dominant deformation within the study area is D_3 The D_3 deformation took place under amphibolite fades condition. The D_3 folds are isoclinal, inclined to nearly reclined with fold axis plunging moderately towards southwest. This deformation also includes development of shear zones parallel to the D_3 foliation. These layer-parallel shear zones have a thrust sense of movement towards NE.

The later deformations produced two sets of open upright folds, D_4 and D_5. These folds developed by the folding of D_3 foliation. The D_4 folds are with axial planes striking NE with a steep dip. The fold axes plunge moderately towards SW. These D_4 folds are coaxial with D_3 isoclinal folds. The presence of S-shaped and Z-shaped asymmetric folds at opposite limbs of a macroscopic D_4 fold indicates that D_4 fold is a buckle fold. Since the NE-trending cross-cutting shear zones occur along the limb of the D_4 folds with mylonitic foliation subparallel with the axial planes of the D_4 folds, these shear zones must have developed in continuation of the D4 deformation. The last deformation in the area is D_5, which produced horizontal folds with subvertical axial planes trending E - W. The general undulation of the regional foliation and variation of dip from subhorizontal to moderate clip towards both south and north with easterly strike is the result of D_5 deformation. The E-W cross-cutting shear zones, which cut across the NE trending shear zones, may be related to the D5 deformation.

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Figure Captions :

Fig. 1. Lithological map of the central part of the Schirmacher Hills, East Antarctica.

Fig. 2. D3 fold on interbanded mafic granulite and augen gneiss. Axial planar foliation marked by long axes of the feldspar augen.

Fig. 3. Contours of 437 foliation (D_3) poles in the central part of the Schirmacher Hills with 0.2-1.1-2.3-4.6-6.9-11.5-16-18-20 percent.

Fig. 4.. Contours of a total of 297 D_3 stretching lineations in the central part of the Schirmacher Hills with 16.83-13.13-9.76-6.4-3.03-0.33 percent.

Fig. 5. Open upright D_4 fold in khondalite. There is a development of crenulation cleavage parallel to the axial surface of the fold.

Fig. 6. Interference of D_3 and D_4 giving rise to hook shaped outcrop. Note that later fold is open and upright.

Fig. 7. Vertical cross-section showing D_4 fold in the central part of the

Schumacher Hills. A thin easterly striking shear zone cuts across the fold in the central part. The southern limb of the synform is truncated by the northeasterly striking wide shear zone with subvertical mylonitic foliation.

Fig.8. (a) Contours of 96 foliation (D_3) poles in the central part of the Schirmacher Hills around the map-scale D_4 fold with 1.04-2.08-5,2-8.33-10.41-12.5-14.58-16.66 percent, (b) Contours of a total of 64 D_3 stretching lineation in the same area with 18.75-15.62-12.5-7.81-3.12-1.56 percent.

Fig.9. The D_5 fold deforms the banding and foliation parallel shear zone. Emplacement of granite at an angle to the regional foliation. On the right hand, side the pegmatite band occur subparallel to the axial plane of the D_5 fold.

Fig. 10. Swerving of easterly trending cross-cutting mylonitic foliation around a massive body of pyroxene granulite.

Fig. 11. Contour of 30 mylonitic foliation (S) poles with 20-10-3.33 percent and contour of 28 mylonitic lineation (L) with 3.84-7.69-15.38 percent of easterly trending cross-cutting shear zone in the central part of the Schirmacher Hills.

Fig.12. Contour of 26 mylonitic foliation (S) poles with 26.92-19.23-11.53-3.84 percent and contour of 32 mylonitic lineation (L) with 18.75-15.62-9.37-3.12 percent of wide NE shear zone in the central part of the Schirmacher Hills.

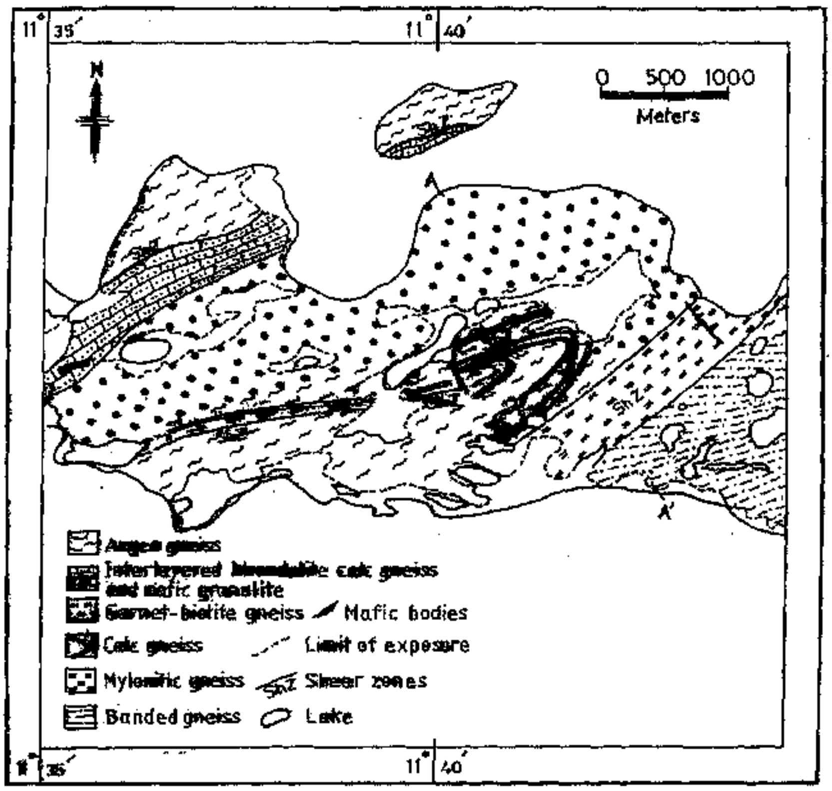

11° 35′
11° 40′
N
0 500 1000
Meters
A
A′
Garnet-biotite gneiss
Mafic bodies
Calc gneiss
Limit of exposure
Mylonitic gneiss
Shear zones
Banded gneiss
Lake

Fig 1

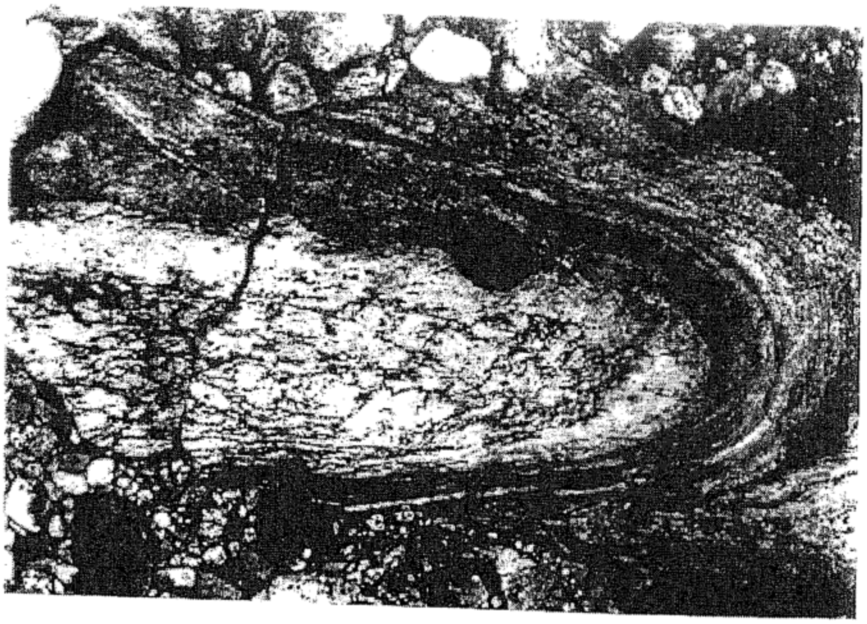


Fig.2

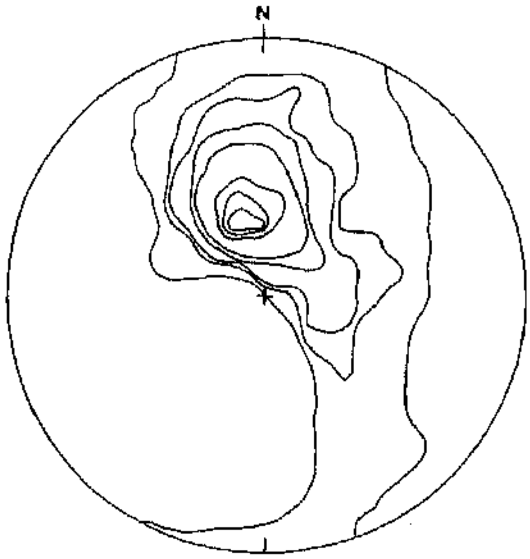


Fig. 3

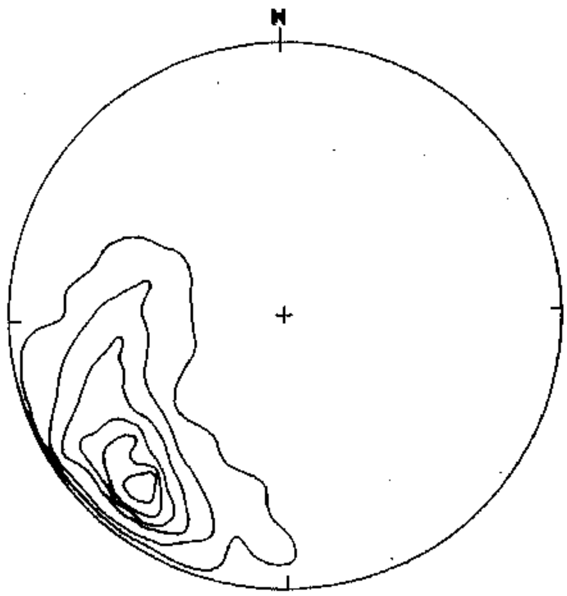
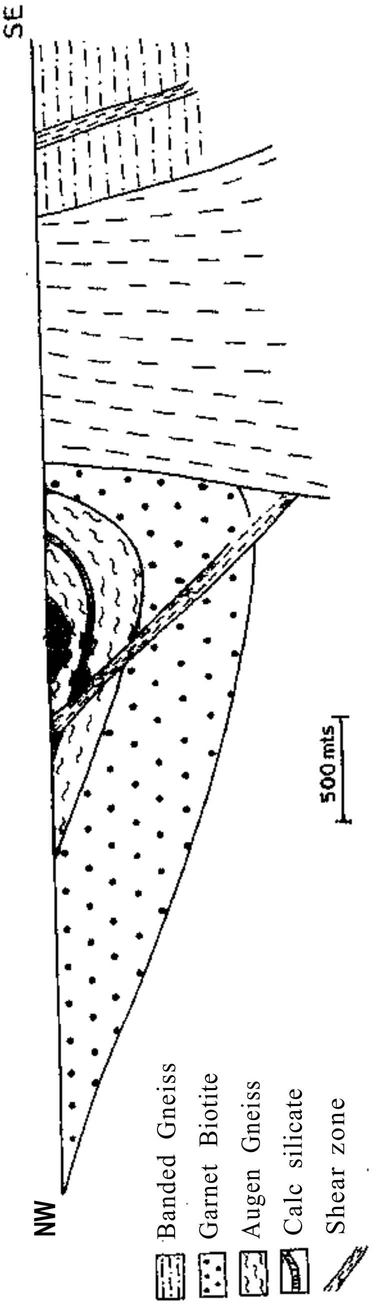


Fig.4

Fig.5

Fig.6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NW
500 mts
Banded Gneiss
Garnet Biotite
Augen Gneiss
Calc silicate
Shear zone

Fig.7

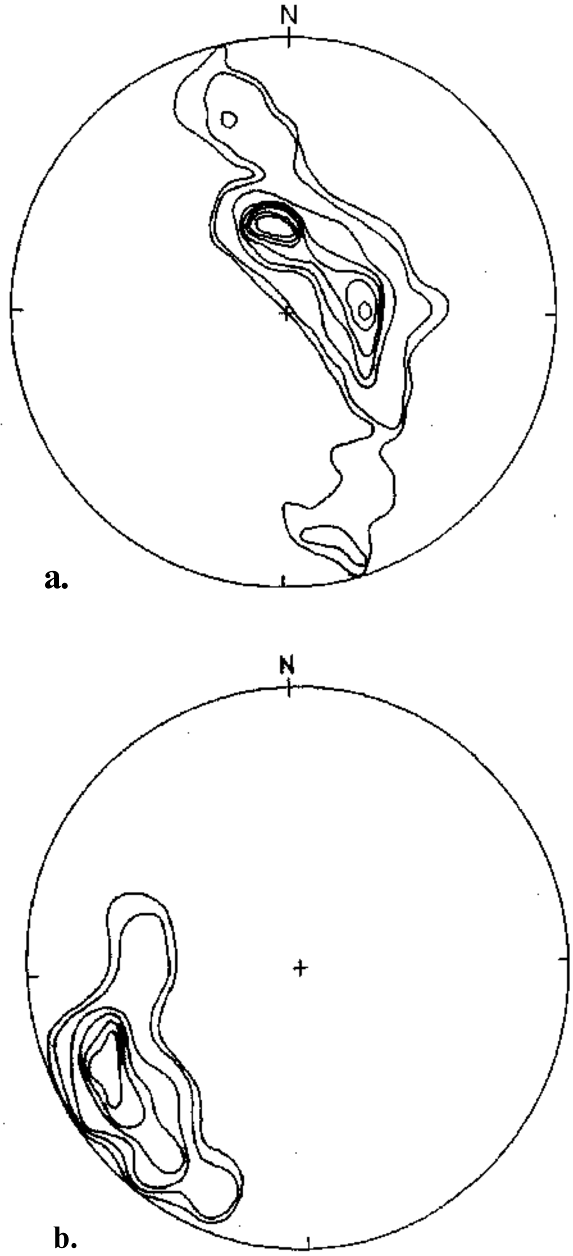

Fig. 8

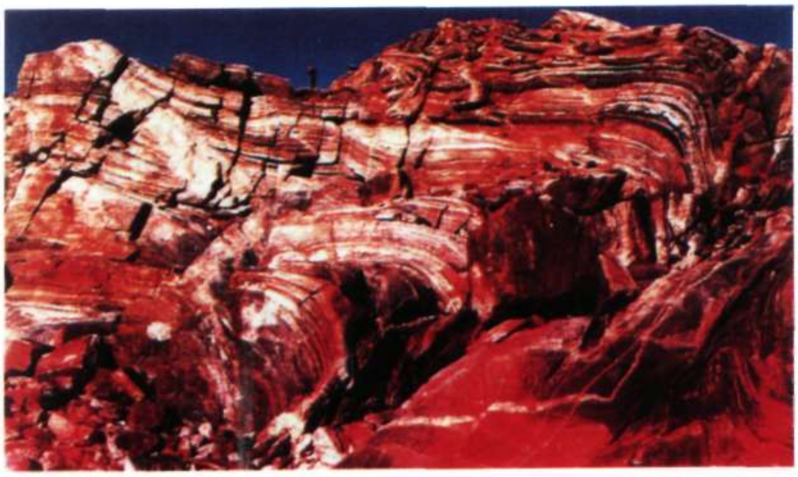

Fig. 9

Fig. 10

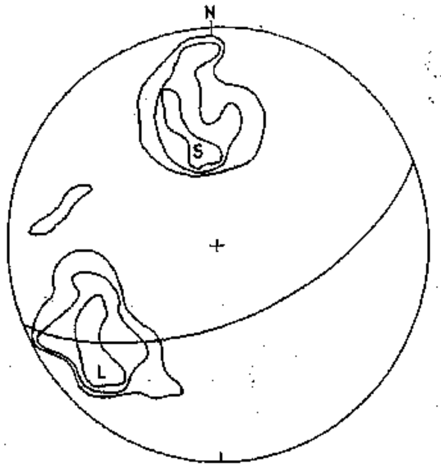

Fig. 11

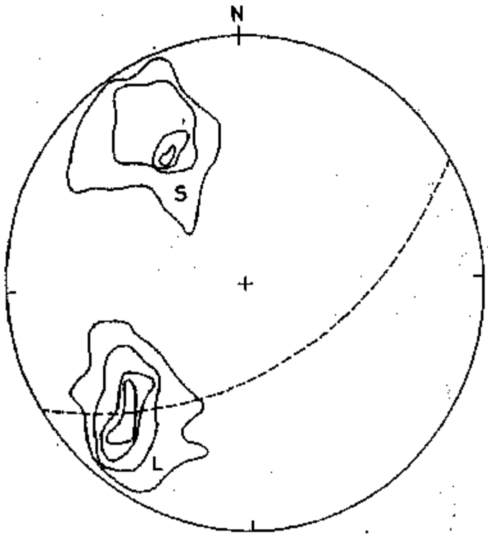

Fig.12