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ANALYSIS OF LARGE SCALE SUPERPOSED FOLDING IN A MIGMATITE TERRAIN.

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ABSTRACT

In the "hook syncline" of central Rajasthan, India, the large metasedimentary bands of early Precambrian age, considered to form synclinal cores in the older basement gneisses, represent extensively migmatized palaeosomes. The curious, hook-shaped double closures in the map pattern of these palaeosomes are due to a superposition of tight upright folds with NS-striking axial planes on isoclinal reclined folds plunging westward, a feature duplicated in numerous examples in hand specimen and outcrop. The later folds, which vary in style from open in the southeast to isoclinal in the northwest, have caused a wide scattering in the orientation of the axes and axial planes of the first set of folds. Although the later folds always trend NS, they range in plunge from subhorizontal to vertical, depending on their location in the limbs and hinges of the early folds. Flexure modified by flattening and flow seems to have been the dominant mechanism in the evolution of the folds. Migmatization, which has transgressed the stratigraphic levels, is broadly synkinematic with the first deformation.

The style and orientation of the folds of the two systems are mutually incompatible in any single deformation plan. The increase in the intensity of the second deformation westward near the contact of the younger Precambrian (Proterozoic) Delhi System of rocks suggests that it is connected with the Delhi orogeny, whereas the first folding on an EW trend is linked with an earlier orogeny, hitherto unrecognized in Rajasthan.

INTRODUCTION

Analysis of large scale structures of migmatites involved in superposed folding is beset with difficulties. As foliations and lineations in regions of superposed deformations vary without any apparent pattern from outcrop to outcrop, within a single outcrop, and sometimes even in a single hand specimen, this seemingly erratic behaviour may be taken to mean mobilization, rheomorphism, anatexis or local magmatic flow. Even where a rigorous structural analysis of these supposed "wildmigmatites" is possible within a group of largely continuous outcrops (Berthelsen, Bondesen and Jensen, 1962), the analysis loses its precision and the interpretation its incontrovertibility when a coherent picture is sought from isolated groups of outcrops. In these instances, the only elegant method to unravel the large scale structure is provided where folded metasedimentary layers are traceable for long distances in the migmatites (Ghosh and Naha, 1962). Set against the map pattern of these palaeosomes, structural data help in geometrical analysis of migmatites with as much rigour as of sedimentary or parametamorphic rocks whose bedded geometry has been retained. The Precambrian migmatite terrain between Gam Gurha ($25^{o}00'N : 73^{o}39'E$) and Ghata ($25^{o}08'N : 73^{o}43'E$) in the Udaipur district of central Rajasthan, India, provides a unique opportunity for such a study. In a region of superb exposures two bands of quartzite and marble in intricately folded attitude in the gneissic host render the large scale architecture of the migmatites abundantly clear.

In the Precambrian gneissic terrain north of Nathdwara in central Rajasthan (Fig. 1) large metasedimentary bands of pelitic, psammitic and calcareous composition are outcropping. According to Heron (1953), the Banded Gneissic Complex, represented by migmatites, forms the basement, upon which rest the successively younger Aravalli pelitic and psammitic, and the Raialo calcareous rocks. With a pronounced unconformity the Delhi parametamorphics of younger Precambrian (Proterozoic) age lie on these older Precambrian rocks. Between Gam Gurha and Ghata, the marbles of supposed Raialo age trace an intricate fish hook pattern with double closures in the migmatite milieu. Heron named this structure the "hook syncline" as the younger marbles were considered to form the fold-core, flanked by the older gneisses. The regional deviation of the formational boundaries from NNE to NE "Aravalli trend" for nearly 500 square miles in the "hammer-head syncline" just east of the present tract (Fig. 1; see also Heron, 1953, p. 171-178) suggests that the "hook syncline" forms part of a much larger structural unit (Naha,

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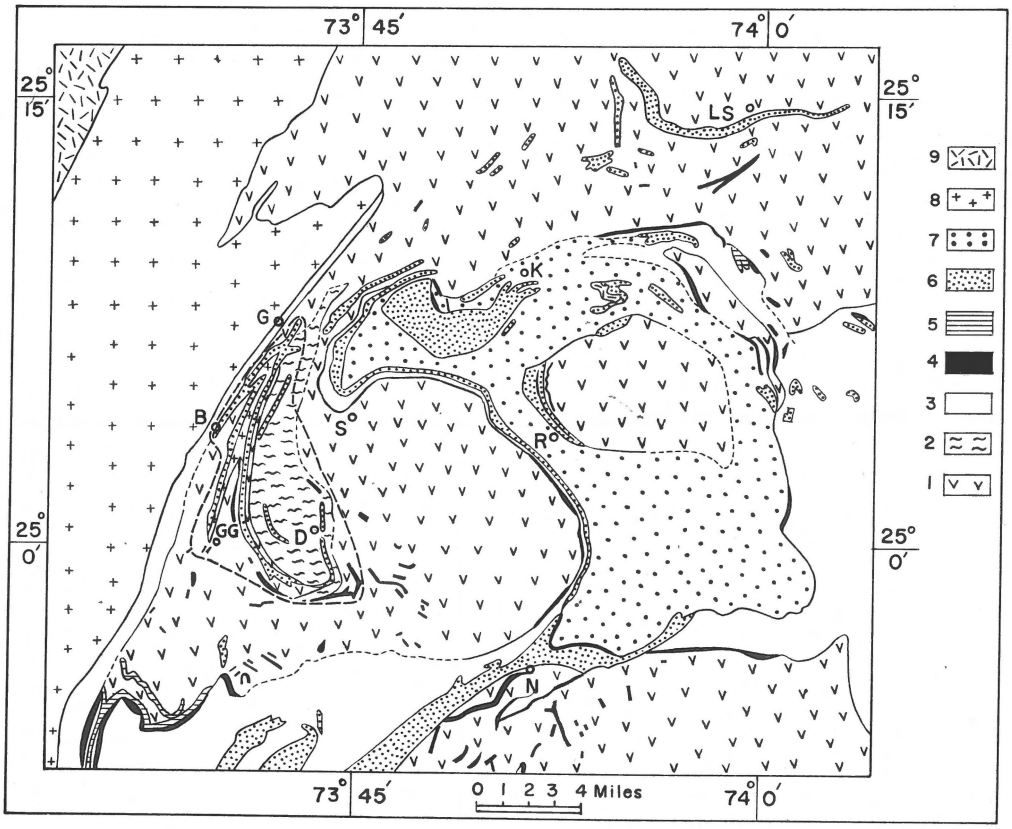


Fig. 1 - Regional setting of the area studied (slightly modified from Heron, 1953, Pl. 38).
1. Pre-Aravalli gneiss and schist; 2. Pre-Aravalli granite; 3. Aravalli phyllite and biotite schist; 4. Aravalli quartzite; 5. Aravalli limestone; 6. Raialo marble; 7. Raialo garnet-biotite schist; 8. Delhi para-metamorphics; 9. Post-Delhi granite. B - Bargula, D - Darwal, G - Ghata, GG - Gam Gurha, K - Kelwa, LS - Lawa Sardargarh, N - Nathdwara, R - Rajnagar, S - Sangat.

Chaudhuri and Bhattacharyya, 1966; Naha, Chaudhuri and Mukherji, 1966; Chaudhuri, 1966; Mukherji, 1966). All the mappable inclusions of the metasedimentaries in the gneissic terrain covered by Figure 1 were taken by Heron to represent synclinal tips of the Aravalli, Raialo and rare Delhi metamorphics in the older gneisses. Large scale mapping of the metasedimentary inclusions in the migmatites of the "hook syncline" and geometrical analysis of more than 16,000 compass readings of foliation, axial planes of folds, fold axes and other linear structures have aided in elucidating the structural geometry in scales from inches to miles, in tracing the history of movements, and in analyzing the way in which the deformation plan fits the orogenic model suggested for the Rajasthan Precambrian rocks up to this date.

Migmatite, marble, quartzite, calc-silicate rock and amphibolite are the main rock types. Of these, the amphibolites could not be separately mapped since they occur as numerous bands of varying dimensions throughout the migmatite country. The calc-silicate rocks are a local facies variant of the quartzite and have, therefore, been grouped with the latter in the geological map (Fig. 2).

Marbles, the predominant metasedimentary rocks, are moderately to coarsely crystalline with calcite forming nearly 80% of the volume. Talc-tremolite marble, forsterite marble (altering to serpentine marble) and very rare diopside marble are the various types. They range from equigranular rocks with equant, polygonal calcite grains forming a mosaic texture, to strongly inequigranular rocks with flat lenticular calcite grains showing a marked di-

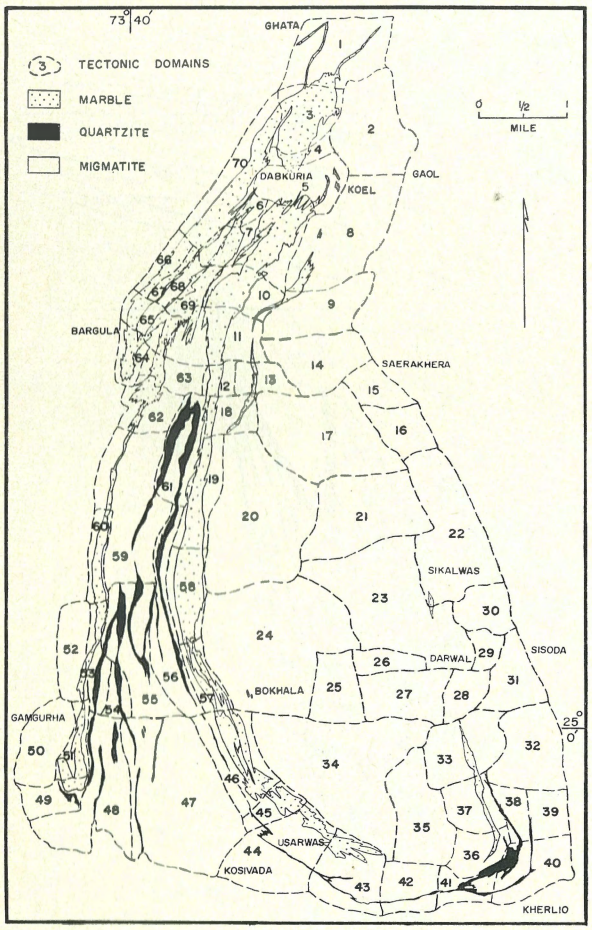


Fig. 2 - Geological map of Gam Gurha-Ghata showing the tectonic domains.

mensional parallelism. Postcrystalline deformation is indicated by bent cleavage and twin lamellae and by faulted twins.

Quartzites contain more than 80% of quartz in the most dominant type, either muscovite or amphibole being the other main constituent. The minor constituents are biotite, altered feldspar, apatite, epidote, sphene, calcite and tourmaline. Cataclasites have occasionally been noted.

Calc-silicate rocks are fine grained, nearly equigranular, granulitic, with quartz, calcite, epidote, tremolite, hornblende, diopside, calcic plagioclase, scapolite, sphene, biotite and apatite as the mineral constituents. Tremolite, diopside and hornblende occur in bands alternating with quartz-feldspar rich layers.

Amphibolites of both schistose and granulitic varieties contain hornblende, andesine-labradorite, quartz and occasional garnet. They often grade to impure marble or calc-silicate rock, a relation which points to a sedimentary parentage. These rocks have been extensively migmatized, with hornblende bordered by biotite and epidote in the migmatized zones.

Migmatites, the predominant plutonic rocks in the area, are represented mainly by banded gneisses, streaky gneisses and augen gneisses with myriads of parametamorphic inclusions, besides the large continuous marble and quartzite bands. They consist mainly of quartz, microcline and acid plagioclase, with biotite, chlorite, muscovite, hornblende, epidote, sphene, garnet, tourmaline, apatite, zircon and ore minerals in variable proportions. Heron mapped a separate unit, the Darwal granite "boss", in part of the area (Fig. 1). The present study, however, shows that this granite is inseparable from the migmatites of the Banded Gneissic Complex sensu stricto in mineral content, texture and structural setting, and must therefore have evolved along with them. The migmatites representing the Banded Gneissic Complex and the Darwal granite are considered to have been formed by migmatization of pre-existing metasedimentary rocks at different stratigraphic levels, synkinematically with the first deformation (Naha, Chaudhuri and Mukherji, 1967).

STRUCTURES IN HAND SPECIMEN AND OUTCROP

Structural elements

Foliation: Only one dominant foliation is determinable in this area. It is invariably parallel to the fine-scale stratification in the metasedimentary bands and to the formational boundary of the thicker bands of contrasting composition, curving as it does round the hinges of folds marked by these bands. This bedding foliation is traced by colour bands and compositional bands in the quartzites, marbles and calc-silicate rocks. Quartz-feldspar-rich and hornblende-rich layers in the migmatites mark the migmatitic foliation. Micas and amphiboles are oriented parallel to the foliation.

Even when the foliation seemingly runs straight for a considerable distance, detailed observations show very tight to isoclinal small folds on the foliation in numerous instances throughout the area (Fig. 3b). For a large part the foliation is parallel to both the limbs and the axial planes of the folds. Only in the sharp hinges does the foliation curve accordantly with the folding. This feature becomes spectacular wherever the rocks show a striking variation in composition and colour. In marbles, in particular, the apparently unfolded layers show rootless folds with floating hinges when quartzose impurities are present. In a regional sense, therefore, the foliation is now a transposed one. It is also obvious that the present thickness of the formations does not represent that of the original sediments. Very rarely an axial plane foliation cutting across the hinges

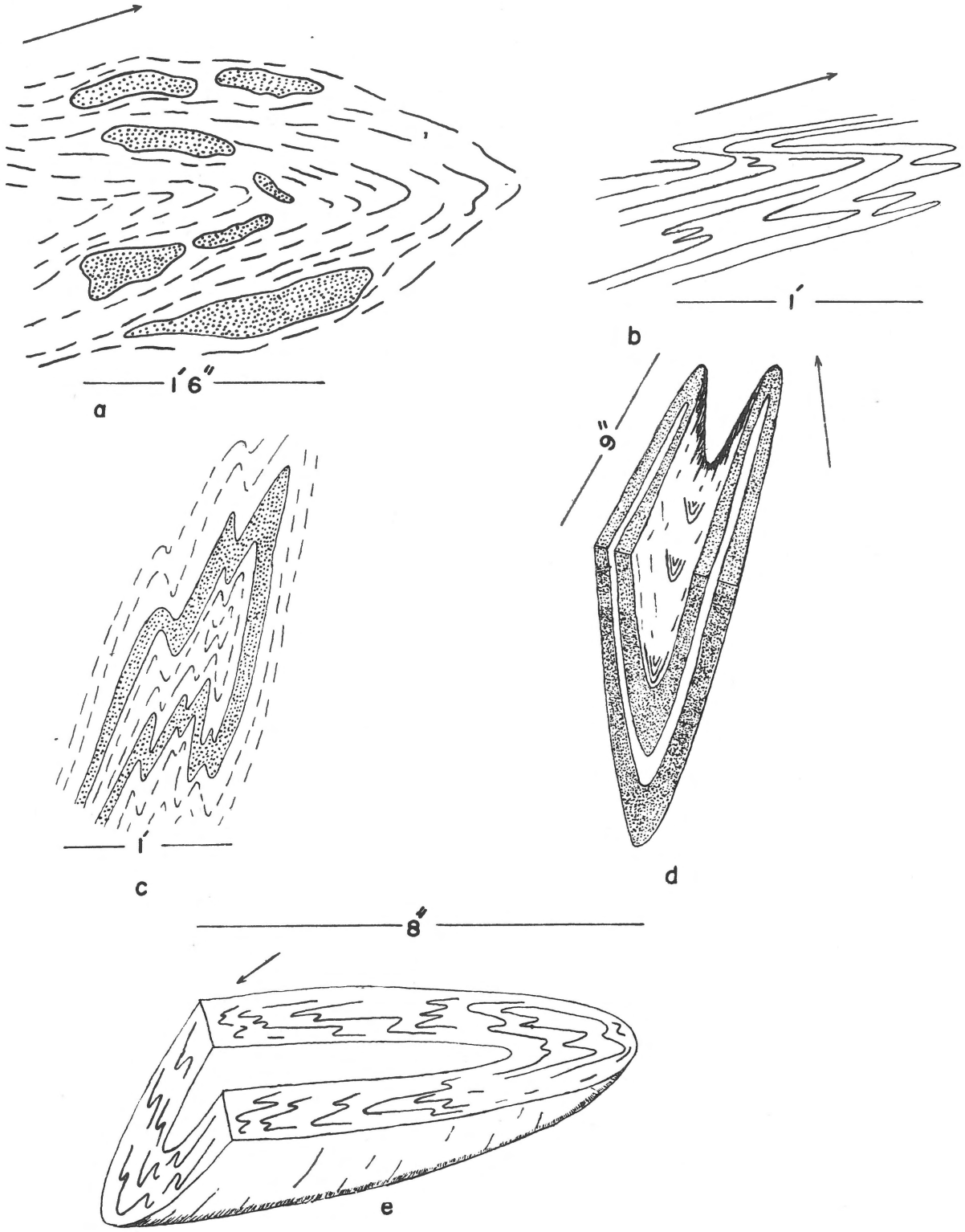


Fig. 3 - Style of folds.
a, migmatite involved in early folding; feldspathic layers disrupted to form rods, domain 21. b, disharmony in migmatite affected by first folding, domain 15. c, double closure because of superposed folding displayed by feldspathic layer in migmatite, domain 55. d, reclined fold affected by tight upright folding; the bent hinge of the early fold plunges east and west in the two limbs of the later fold, domain 63. e, isoclinal folds of two generations in migmatite showing parallelism of two sets of axial planes in a major part of the structure and variation in axial plunge of the later fold, domain 63.

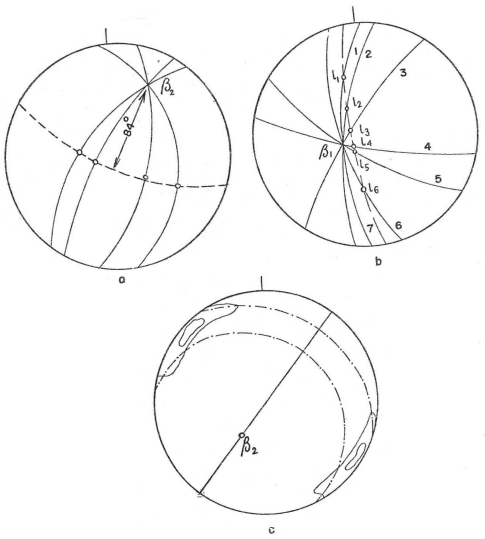


Fig. 4 - Generalized stereograms showing the effect of later folding on early lineations and β axes.
a, stereogram showing early mullions (open circles) in a small circle around the later fold axis (β_2); data from station 2 in Table 1. b, diversely oriented foliation planes (1-6) because of folding around β_1 affected by folding on a subvertical axial plane (7); l_1-l_6 are the resultant lineations (cf. Fig. 15, domain 56). c, stereogram showing an elongated maximum of s-poles around an early fold axis refolded on β_2; the s-poles will fall within the zone marked by the two arcs.

of isoclinal folds has been noted in the migmatites.

Folds: Folds of different size are the dominant structures in this area. Two sets of folds differing from each other in style and orientation are present. The first set is very tight to isoclinal with a high amplitude as compared to wave length (Pl. 1b, 1c, 1d; Fig. 3a, 3b). The folds have sharp hinges, and in many instances, the two limbs are so close to each other that the trace of the fold is lost if the hinge zone is obscured. Intrafolial folds (Turner and Weiss, 1963, p. 116-117) have been noted, particularly in migmatites and marbles. Disharmony with reversals of curvature in the hinge area is the rule (Fig. 3b); excellent examples of disharmonic folds are seen in the migmatites. Small crenulations in the hinge zones of larger folds are common. The folds are concentric rather than similar with respect to the hinges. In their overall geometry, however, they simulate the flattened flexure folds of Ramsay (1962a). Folds with rootless hinges have often been noted. Though varying widely in plunge, these folds often trend westward (except in the southeastern part), with the axial planes striking NS in the majority of cases. They are therefore reclined in style, the strike of the axial planes being normal to the trend of the fold axes (Turner and Weiss, 1963, p. 119; Fleuty, 1964, p. 486-487). The dips at the hinges are almost vertical while the dips at the limbs correspond to the axial plunge. Because of extreme flowage the marbles show very irregular profiles of folds though the axis remains constant.

The folds of the second set are sharply contrasting; they range from very open to isoclinal folds (Pl. 2a, 2b, 2c), the tightness of the folds increasing from southeast to west and northwest. The axial planes of these folds are subvertical to vertical, and unlike the reclined folds they maintain a constant NS strike. The trend of the folds is therefore constant though the plunge varies widely (Pl. 2a and 2c). Disharmony at the hinges is shown by these folds too.

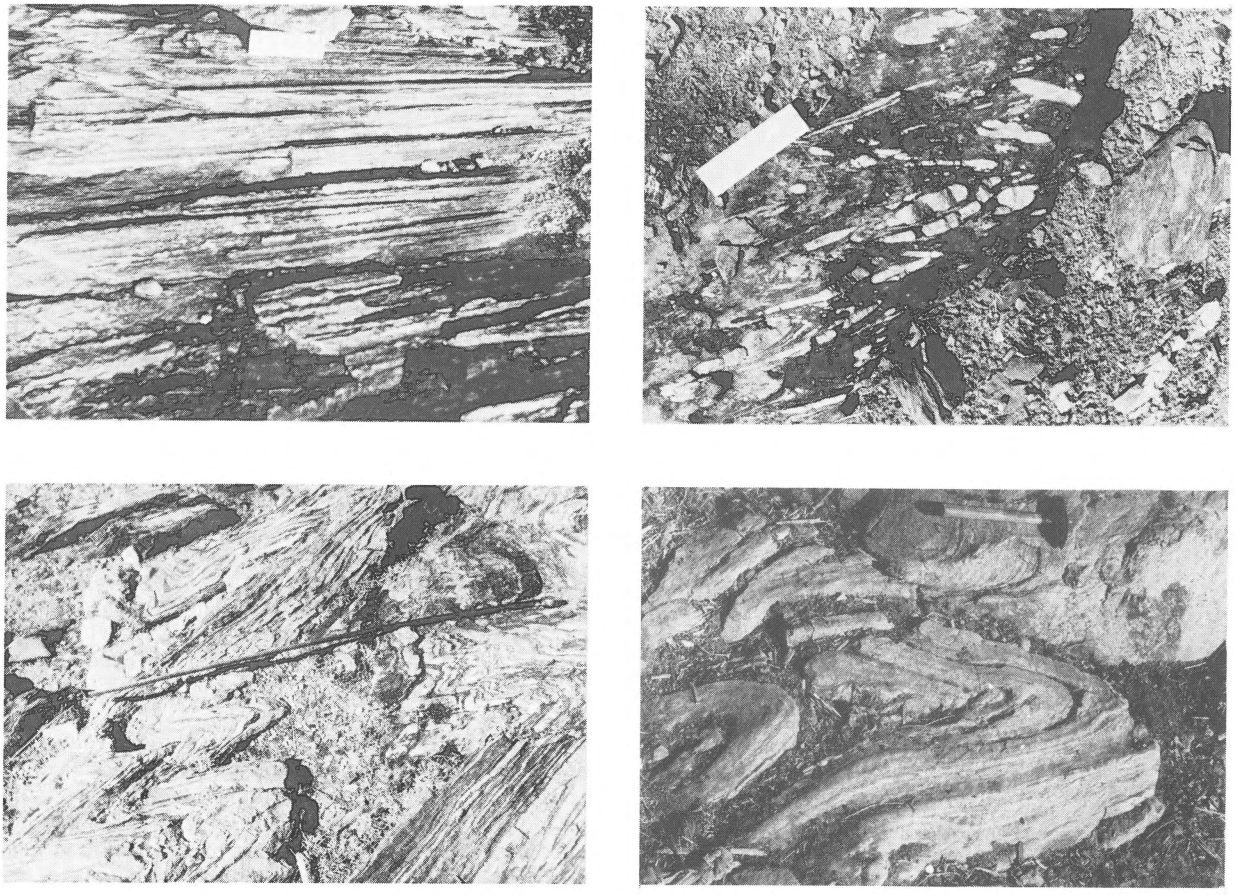
Both sets of folds follow the competency law, the folds being larger in more competent and smaller in less competent beds.

Mullions: Mullions form one of the most pervasive structures here (Pl. 1a). They are fold mullions (cf. Wilson, 1961, p. 510-514) with minutely curved cylindrical surfaces giving a ridge-like appearance. They range in length from less than an inch to several feet. Cross joints normal to the mullions are very well developed. The mullions are invariably parallel to the adjacent fold axis, and indeed, in cross section many of the mullions show traces of reclined or upright folds. Two sets of mullions corresponding to the two types of folds and intersecting at high angles are sometimes present. In migmatites, in particular, very well developed mullions occasionally obscure the foliation, and the rocks resemble pencil gneisses. Bent mullions have been noted in a number of instances.

Rodding: Cylindrical, rod-like bodies of quartz and feldspar are particularly well developed in the migmatites (Pl. 1b, Fig. 3a). Their main elongation is along the axes of either the reclined or the upright folds. Striking examples are seen where feldspathic layers or quartzose veins oriented parallel to the foliation are acutely folded and finally torn to give rise to rods.

Mineral lineation: Although less common than the preceding types, lineation due to parallelism of hornblende and bundles of biotite, and occasionally of garnet porphyroblasts, is noticeable in the amphibolites within migmatites. A linear orientation of tremolite prisms is seen in marbles, whereas quartzites sometimes show parallel slivers of quartz. Feldspar "eyes" in the augen gneisses often mark a prominent lineation. All mineral lineations are parallel to the mullions and fold axes in the neighbourhood.

Puckering: Sharp microcorrugations of chevron style are sometimes seen in the schistose amphibolites and mica-rich migmatites. Most of these structures generally trend NS.



Pl. 1 - Mullion, rodding and early folds.
a. Subhorizontal mullion in migmatite from domain 31.
b. Quartz rods in amphibolite, formed by acute early folding and disruption; domain 52.
c. Reclined fold in migmatite, exposed tape 44 inches; domain 47.
d. Very steeply plunging early folds in migmatite; early mullions bent around the hinge of a later fold are seen near the handle of the hammer; domain 54.

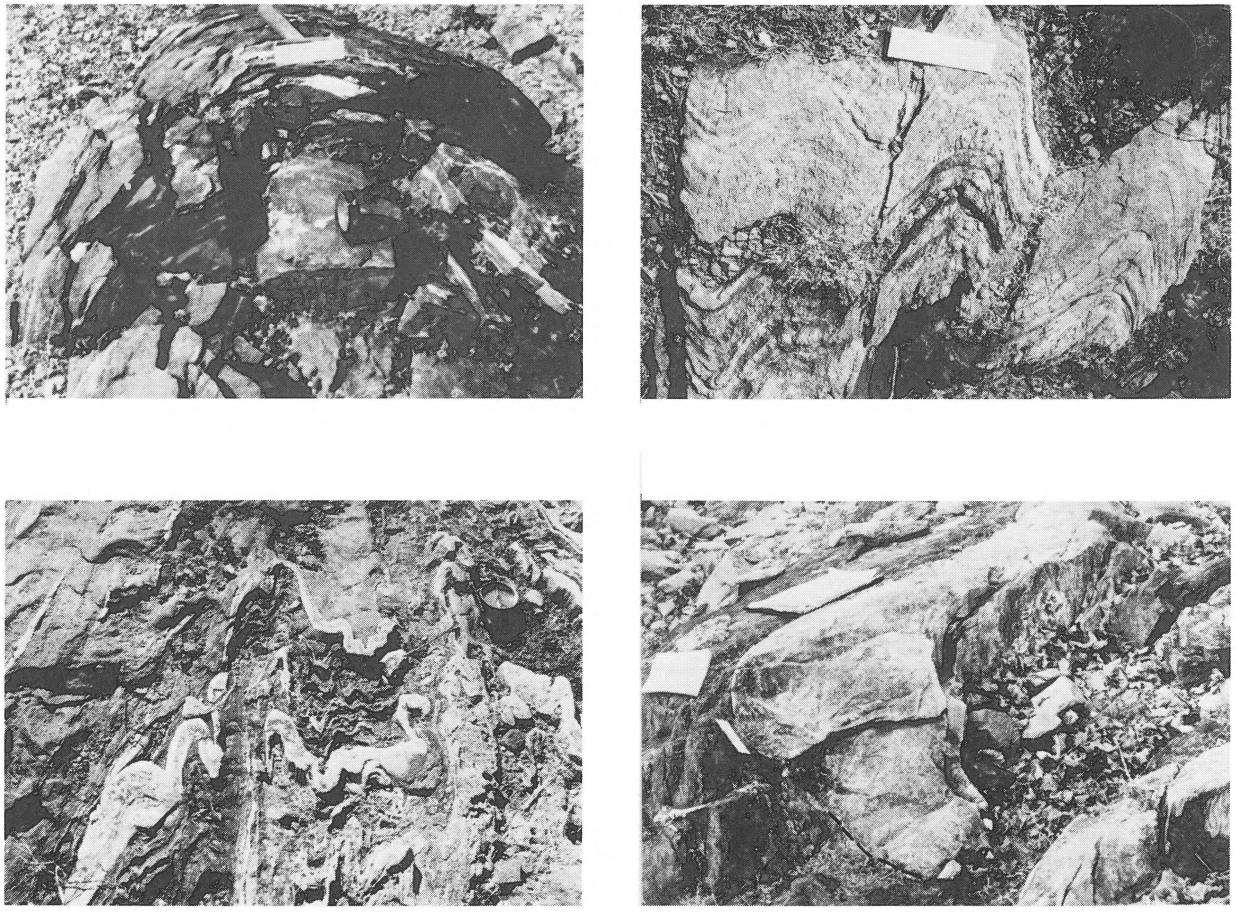
Boudinage: Boudins are rare in this area. They are seen mainly in the marbles and occasionally in the migmatites. In marbles the quartz-rich parts form boudins while the calcareous material flows plastically into the necking points. The boudin lines are parallel to fold axes.

Striation: On the foliation surfaces of the quartzose migmatites, calc-silicate rocks and quartzites, striations less than a tenth of an inch in height resembling slickenside groovings have been noted in a few instances. They also are parallel to the local fold axes.

Joints: Joints nearly normal to the mullions and to the axes of both sets of folds are extensively developed. These joints often show tensional gaps which provide excellent opportunity for studying folds in profile. Radial fan joints containing the fold axes have occasionally been seen in the hinge zones of folds.

Relation between the folds of contrasted styles

Figures 5 through 8 bring into bold relief the extreme variation in orientation of the reclined and the upright folds. While there is a wide divergence in trend and plunge of folds even in a single outcrop, a distinct difference exists in the behaviour of the folds of contrasted styles. Although the upright folds show a great variation in plunge from subhorizontal to vertical sometimes within a few feet, the trend largely remains constant, maintaining a N to NNE direction. In sharp contrast are the reclined folds which show an extreme divergence both in trend and plunge. Another fact needing re-emphasis is that, while the reclined folds are practically isoclinal throughout the area, the upright folds vary from open in the southeast through tight to almost isoclinal ones in the west and northwest. Total disappearance of these folds further



Pl. 2 - Later folds.
a. Very open later fold in amphibolite, showing slight variation in the axial plunge; domain 14.
b. Tight later fold with gentle plunge; calc-silicate rock from domain 59.
c. Tight later folding on steep axis; steep mullions seen near the clinometer; migmatite from domain 47.
d. Axis of a later fold subvertical at the hinge of an early isoclinal fold in marble from domain 5.

to the east of the present tract (Naha, Chaudhuri and Mukherji, 1966; Naha, Chaudhuri and Bhattacharyya, 1966) suggests a spatial variation in the intensity of the upright folding. No such variation has been deciphered in the reclined folds which have been recorded in a region covering nearly 500 square miles (Fig. 1). This in itself suggests that the upright folds are later than the reclined ones. Wherever the two sets of folds are associated, they show certain significant relations:

(1) The hinges of the westerly trending reclined folds (with associated mullions) are bent by upright folds on NS-striking axial planes, the hinges of the reclined folds plunging down the dip of either limb of the upright folds. Consequently, the reclined folds plunge eastward or westward on the two limbs of the open upright folds (Fig. 3d). As the upright folds become isoclinal, the axes of the reclined folds on the two sets of limbs move closer (Fig. 3e; Pl. 3b, 3c, 3d).

(2) The tighter the upright folding, the closer the axial surfaces of the reclined folds move toward those of the upright ones. When the upright folds become isoclinal, the distinction between the axial surfaces of the two sets is lost, except at the hinges of the upright folds. Here the two sets of axial surfaces intersect at high angles, the dip of the axial planes of the reclined folds corresponding to the axial plunge of the upright folds (Fig. 3d, 3e; Pl. 3b, 3c, 3d).

(3) The hinge zones of the reclined folds, however, leave important traces of deformation. While for a major part of the folds, the axes of the upright folds are low to moderate in plunge, at the hinge zone of the reclined folds involved in upright folding the axial plunge of the upright folds is almost vertical (Fig. 3d, 3e; Pl. 2d, 3b, 3c, 3d).

(4) Though the axes of both the sets of folds may

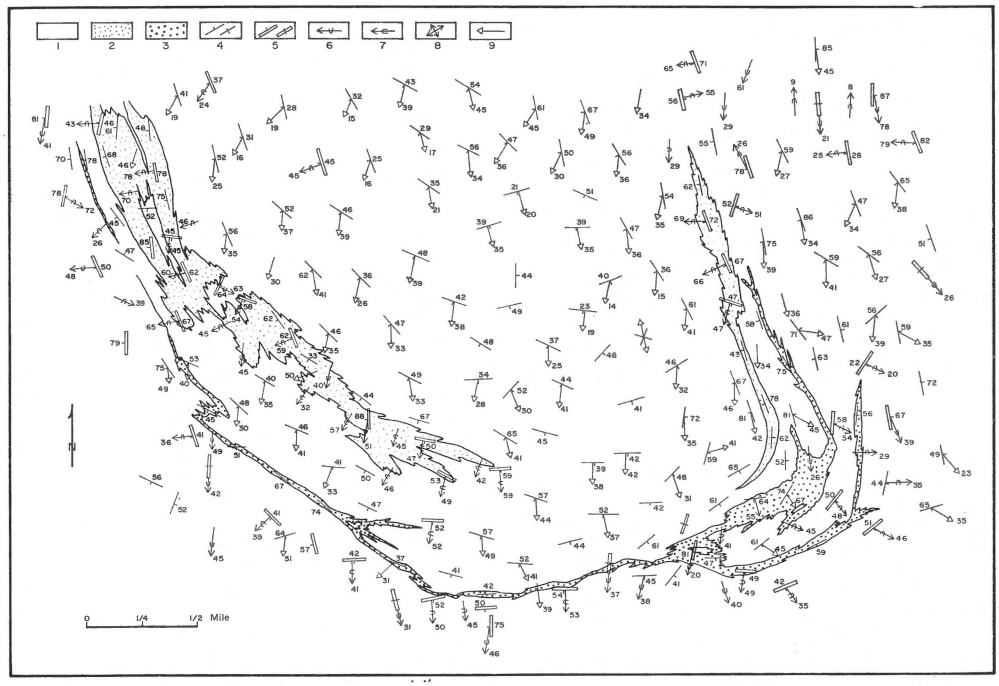


Fig. 5 - Map of the Bokhala-Usarwas-Darwal fold. 1. Migmatite; 2. Marble; 3. Quartzite; 4. Foliation; 5. Axial plane of fold; 6. Axis of reclined fold; 7. Axis of upright fold; 8. Axis of vertically plunging fold; 9. Other linear structures, mostly mullions and roddings, with some mineral lineations.

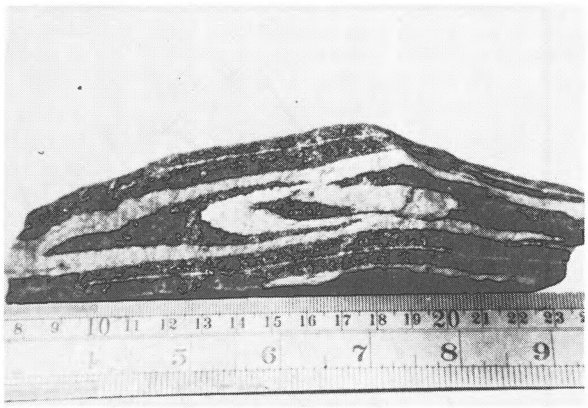
vary from outcrop to outcrop, they show a typical angular relation when seen together. At selected points where mesoscopic upright folds have a constant orientation, they bear a constant angle ($\neq 90^{o}$) with the axes of the reclined folds and associated mullions (Fig. 4a; Table 1). As Table 1 shows, at any one point the early mullions form a small circle around the axes of the upright folds. This proves convincingly that the upright folds are later, that the variation in the attitude of the reclined folds is due to superposed folding, and that the upright folds have formed by flexural slip (cf. Weiss, 1959; Ramsay, 1960; Naha, Chaudhuri and Bhattacharyya, 1966, p. 215, Fig. 4, Table 1).

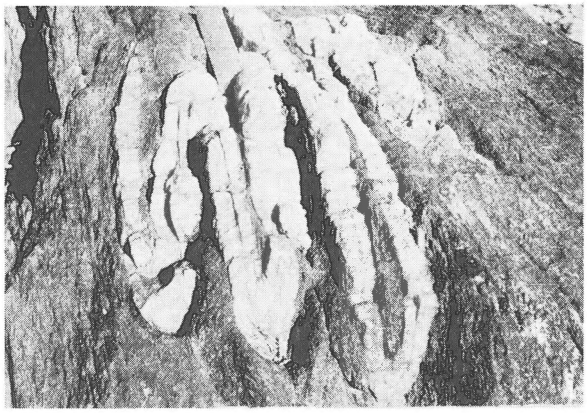
The geometry of superposition in the present terrain together with the variation in the axial orientation of folds of both the generations is shown in Fig. 3c, 3d, 3e and Plate 3, examples like which are abundant throughout the area. Analyses by Weiss and Mclntyre (1957), Weiss (1959), Ramsay (1960) and McBirney and Best (1961) have shown that in superposed folding, the axes of the later folds will be parallel to the intersection of the already folded s-surfaces with the axial plane of the later fold system. In the present instance, the superposition of upright folds with NS-striking axial planes on reclined isoclinal folds with their axial surfaces and limbs striking N to NNE would result in a dispersion of the later fold axes in the following manner:

(a) In the limb regions of the early folds the later axial planes are subparallel to the foliation planes in strike, though not in dip; as a result, the later fold axes plunge gently to moderately (the sides in Fig. 3d and 3e).

(b) In the hinge zones of the reclined folds, in contrast, the axial plunge of the later folds is nearly vertical, as here the subvertical axial planes of the later generation intersect subvertical foliation surfaces. This can be clarified by referring to Figure 4b. Here, plane 7 (the later axial plane) causes a subvertical plunge of the later fold (l_4) at the hinge of the early fold (plane 4), while in the limb areas (planes 1 and 2) the axial plunges of the later fold are moderate (see also Fig. 3d, 3e). The greater the tilt of the later axial planes from vertical, the greater will be the dispersion of the later fold axes not only in plunge but also in trend even on a mesoscopic scale. A number of limbs and hinges of the early reclined folds would result in a large variation in the axial plunge of the later folds even in a single outcrop, leading finally to the 'eyed' folds of Ramsay (1962b).

It follows from the foregoing analysis that in a zone where the mesoscopic early folds are not easily demonstrable, a steep plunge of the later folds would locate the hinge areas of early folds, while the zones with low to moderate plunge of later folds would suggest that a set of parallel limbs of early folds with hinge zones of insignificant extent









Pl. 3 - Superposed folds.
a. Superposed fold in migmatized amphibolite from domain 63, the front surface showing fish-hook pattern.
b. Isoclinal folding of two generations in quartz vein in migmatite from domain 20; the termination at the top left corner is due to the hinge of an early fold.
c. Reclined isoclinal folds in migmatite from domain 63 involved in upright isoclinal folding. Axis of upright fold subhorizontal near the scale; hinge of an early fold exposed in the topmost part.
d. Details of the central part of Pl. 4c, showing the refolded fold (cf. Fig. 3d); top surface shows the profile of the early fold, whereas the front surface shows the profile of the later fold.

has been involved in later folding. Extreme variation in the plunge of the later folds would point to a number of hinges and limbs of mesoscopic early folds, though they may not be recognizable now (cf. Naha, Chaudhuri and Bhattacharyya, 1966, p. 216).

LARGE SCALE STRUCTURES

Map pattern of the metasedimentary palaeosomes

The quartzite and marble bands in the gneissic host trace out clearly the large scale architecture of this migmatite terrain. A cursory examination of outcrops, particularly of the quartzites in a major part of the area, would at first suggest numerous small disjointed bands strewn in a N to NNE direction within the banded gneisses. The mesoscopic structures, however, run counter to such a pattern, and large scale tracing of the bands confirms the picture gathered from hand specimens and outcrops. For the quartzites and marbles with subparallel trends merge finally in acute closures suggesting very tight to isoclinal plunging folds with the axial planes striking N to NNE (Fig. 2, 6-8, 17).

The only sector where the map pattern deviates significantly from this generalization is in the southeast (Fig. 2, 5). Here about $1\frac{1}{2}$ mile south southeast of Darwal, a quartzite band starts off in a SSE trend, and turning through SSW and W finally trends NNW north of Kosivada. In this arcuate pattern of a typically open fold with NS trace of the axial plane, however, evidences of the aforesaid isoclinal folds are present. All the bands here are made up of more than one limb of a fold, and they often bifurcate for some distance (e.g., northwest of Kherlio). The axial planes of these isoclinal folds, subparallel to

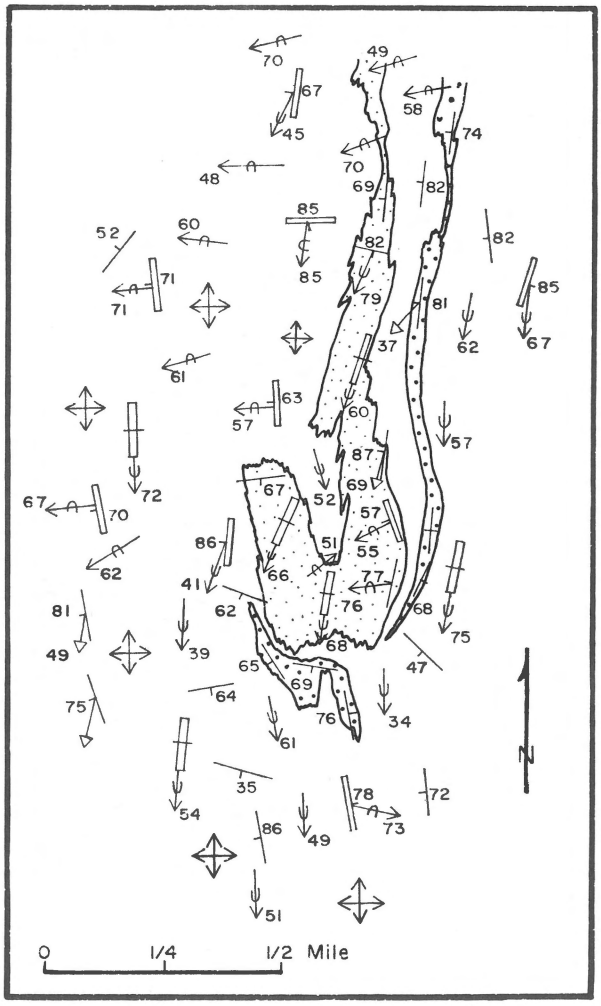


Fig. 6 - Map of the Gam Gurha fold; symbols as in Fig. 5.

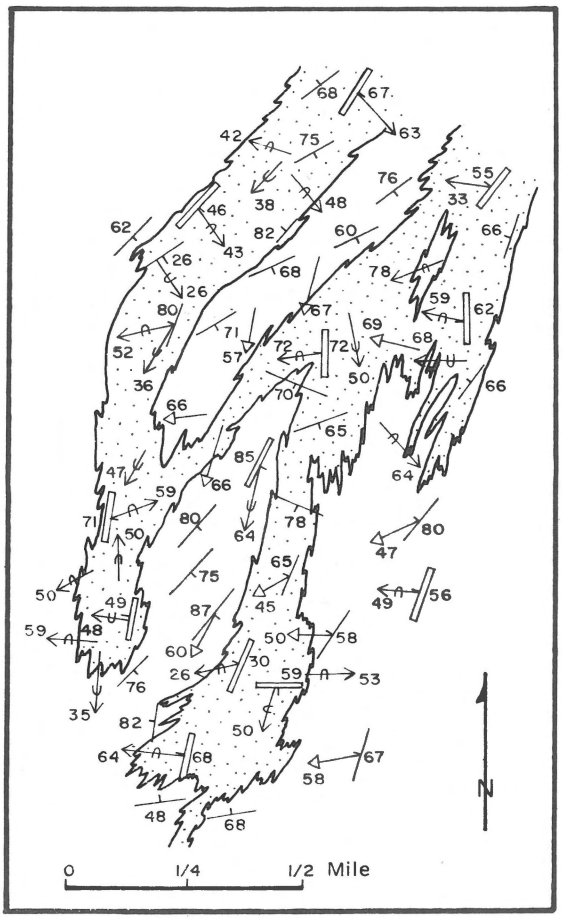


Fig. 7 - Map of the Bargula fold; symbols as in Fig. 5.

the trends of the bands, show an identical arcuate swing, finally becoming NS west of Bokhala. The large open fold between Kherlio and Kosivada is, therefore, quite different in style and orientation from the isoclinal folds, the axial planes of which have been involved in open folding here. An identical map pattern is shown by the extremely serrated marble horizon in the inner side of the closure traced by the quartzite.

From west of Bokhala the subparallel NNE to N trend mentioned earlier is maintained; the quartzite band traces a number of large folds bent upon themselves and closing northward and southward. The subparallel limbs, the acute fold hinges and the hook-shaped double closures - all these features of the quartzites in the western part of the area (Gam Gurha-Bokhala-Ghata) are shown in much more grandiose scale by the marble band because of its greater persistence and flowage during deformation. These map patterns are duplicated in numerous folds on a mesoscopic scale. They also can therefore be taken to indicate folding of axial planes of early folds with the two sets of axial surfaces subparallel.

The map pattern of the metasedimentary inclusions thus emphasizes the following features: (i) Presence of tight to isoclinal folds about variably plunging axes on a large scale; (ii) overall NNE to N trace of the axial surfaces for a major part of the terrain; (iii) open folding on a NS-striking axial plane in the southeastern part, flexing the limbs and axial planes of the isoclinal folds; and (iv) tight axial plane folding with the two sets of axial surfaces subparallel for a large part of the area between Gam Gurha and Ghata. Further, the folded marble band continuing westward from the southerly closure at Gam Gurha and eastward from the southerly closure at Kosivada forms a "mirror-image" type pattern, also suggesting an interference of fold systems (cf. White and Jahns, 1950; Reynolds and Holmes, 1954; Ramsay,

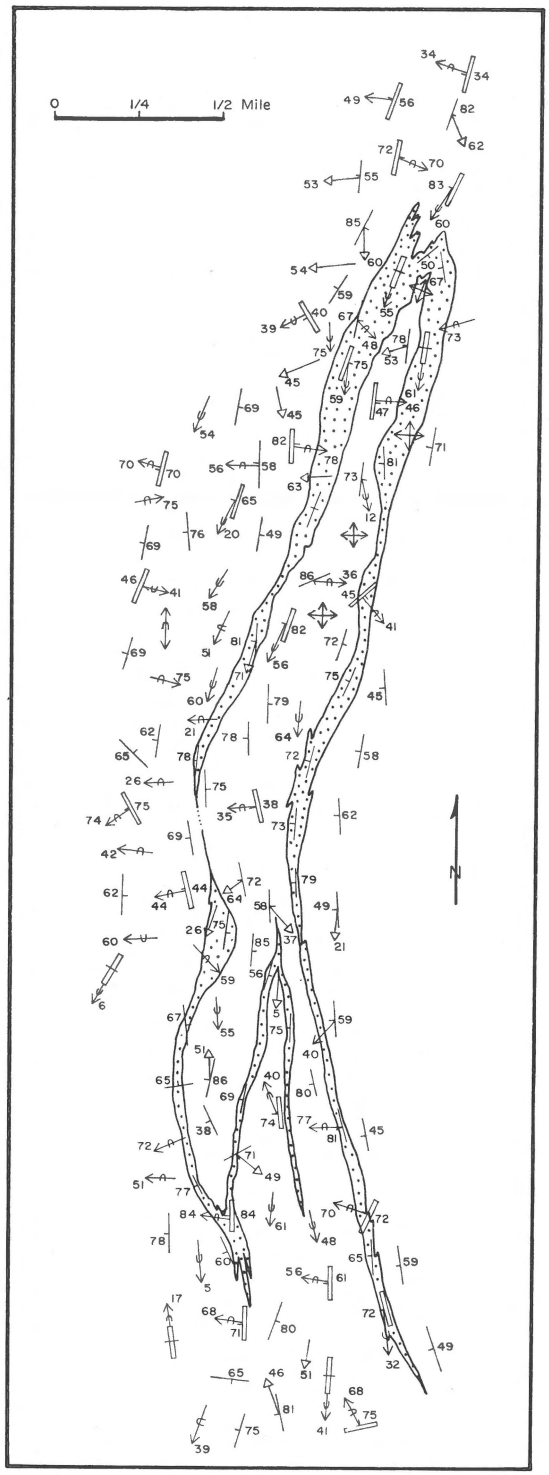


Fig. 8 - Map of the hook-shaped fold east of Bargula-Gam Gurha; symbols as in Fig. 5.

TABLE 1 - Angles between the later fold axes (β_2) and the early mullions on single fold surfaces at selected points.

Station No.	Attitude of β_2	Angle between β_2 and early mullions					
1.	72/N186	24	22	21			
2.	20/N27	83	84	84	84		
3.	22/N183	70	71	75			
4.	23/N4	81	81	84			
5.	23/N197	75	73	74			
6.	30/N357	77	74	77			
7.	25/N200	60	58	58			
8.	24/N41	60	61	61			
9.	43/N184	11	15	11	12		
10.	31/N208	64	59	66	66	62	
11.	36/N195	88	84	85			
12.	40/N207	61	59	61			
13.	44/N200	73	76	76	72	76	77
14.	53/N214	85	82	80			
15.	62/N182	90	83	82			
16.	51/N201	84	82	85			
17.	46/N202	75	77	81	75	76	82
18.	51/N201	67	64	63	66	64	
19.	25/N195	85	83	86			
20.	20/N175	36	36	39	37		
21.	3/N193	57	59	60			
22.	7/N182	21	26	25	29		
23.	39/N16	80	79	80			
24.	41/N161	38	39	38	42	37	
25.	52/N123	56	58	58			
26.	45/N24	87	88	87			
27.	25/N346	38	38	36			
28.	83/N137	44	46	46			

1962b; O'Driscoll, 1962, 1964; Naha, Chaudhuri and Bhattacharyya, 1966).

Structural geometry

Geometry of foliation planes: The refolded folds on a mesoscopic scale suggest a non-cylindrical character for the folds of larger scale as well. This is confirmed by the apparently haphazard orientation of nearly 12,000 foliation planes here. The strike direction of the vertical foliation and the dip direction of the planes with minimum dips - both indicators of the axial trend (Wegmann, 1929) - betray a total lack of regularity. Thus for structural analysis, the whole area was divided into 70 tectonic domains, each with either a statistically parallel foliation, or one well defined fold axis (β), or two identifiable fold axes (β and β). A large number of domains are tectonically imhomogeneous. The s-pole diagrams of selected tectonic domains exemplifying the different types discussed below are shown in Figs. 9 and 10. The linear structures from all the 70 domains are plotted in Figs. 11 through 16.

(1) Significance of point maxima: A point maximum of s-poles indicates a set of parallel foliation planes. This points to either an unfolded area, or the limb or hinge zone of a fold, or a set of isoclinal folds with the limbs dominant and the hinges insignificant. Innumerable tight to isoclinal small folds in this terrain suggest that a point

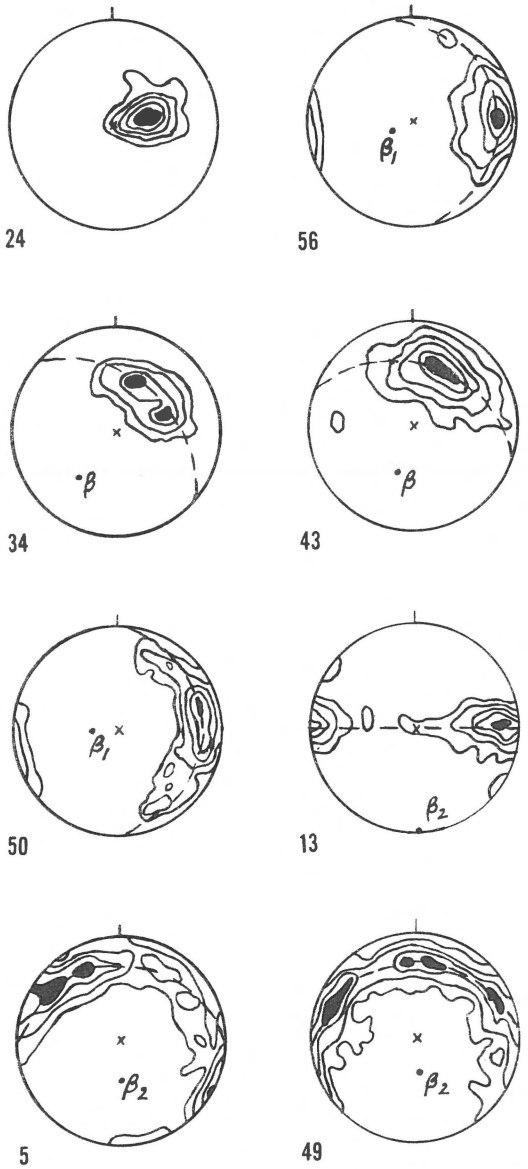


Fig. 9 - Geometry of foliation planes in selected tectonic domains. Domain numbers indicated in each diagram: 24. 250 poles, contours: 0.4-4-8-16-24%. 56. 147 poles, contours: 0.7-2-6-12-20%. 34. 164 poles, contours: 0.7-3-9-11%; β_1 and β_2 coincident. 43. 242 poles, contours: 0.4-1.2-4-8-12%; β_1 and β_2 coincident. 50. 70 poles, contours: 1.5-3-7-13-19%. 13. 63 poles, contours: 1.5-3-8-11-24%. 5. 202 poles, contours: 1-2-4-6%. 49. 166 poles, contours: 0.6-1.8-3.6-4.8%.

maximum in the s-pole diagram of any domain would indicate isoclinal fold-limbs rather than one limb of a fold. Domains 21 and 24 are examples of isoclinal folds of this type. Domains with elongated maximum or partial girdle would point either to very gentle warps or to very tight folds with sharp hinges (cf. Ramsay, 1964, Fig. 10). For reasons mentioned above the elongated maxima from domains 25, 34, 39, 42, 43, 44, 56, 57, 67 and 68 suggest very tight folding.

(2) Significance of girdle fabrics: Girdle fabrics unequivocally point to folding, the axis of the girdle being the fold axis. In the present instance, the position of the maxima within the girdles is significant in the following sense:

(a) If the strike of the dominant foliation deduced from the position of the maximum is parallel to the trend of the β axis, the fold is upright (or inclined if not strictly parallel) or a maximum number of readings have been taken from the hinge zone of a reclined fold. In the former case the trend of the fold axis will be parallel to the strike of the axial plane (which is generally NS except in the southeast), whereas in the latter case the two will be normal to each other. Domains 2, 4, 5, 13-17, 26, 29-31, 49 and 64 are all examples of upright folding with respect to β_2.

(b) If the strike of the dominant foliation is normal to the trend of the β axis, it signifies either that a majority of readings is from the hinge of an upright fold or that the fold is a reclined one. This also can be checked from the orientation of the axial planes. The trend of the fold axis is nearly parallel to the strike of the axial plane in the first case, whereas in the latter the two are at right angles. In this area with dominant NS strike of axial planes, β_1 axes plunging W or E would suggest reclined folding. In the southeast the β axes ($\beta_1 = \beta_2$) plunging southward with the axial planes and dominant foliation EW in a number of domains also indicate reclined folding. Domains 9, 25, 27, 28, 34, 36, 39-44, 50, 52, 56, 57, 60, 66, 67 and 69 are examples of reclined folding (all with respect to β_1, with β_2 coinciding with reoriented β_1 in some domains like 27, 28, 34, 41-44).

(c) There is no well defined girdle but the spread suggests that an elongated point maximum or partial girdle has been rotated around another axis (β_2 in Fig. 4c). This would indicate a superposed deformation on a macroscopic scale, the pole of the poorly developed girdle coinciding with the axis of later folding. The later axial planes in these instances become the plane of symmetry of the s-pole diagrams so long as the axial planes are vertical with constant strike. Domains 1, 3, 6-8, 10-12, 18-20, 22, 23, 32-33, 35, 37, 38, 45, 46, 48, 51, 58, 59, 61-63, 65, and 70 provide examples of this type of superposed folding.

It follows from (b) and (c) that a well defined girdle around a β, which is an axis of superposed folding, would suggest a point maximum before the second folding; this would indicate in the present instance isoclinal folding of the first generation, the hinge zones being insignificant. Also, elongated maxima (or partial girdles) around later axes in the western part in contrast with well defined girdles in the east point to tight later folding to the west (compare 59 and 65 with 7 and 13, Figs. 9 and 10).

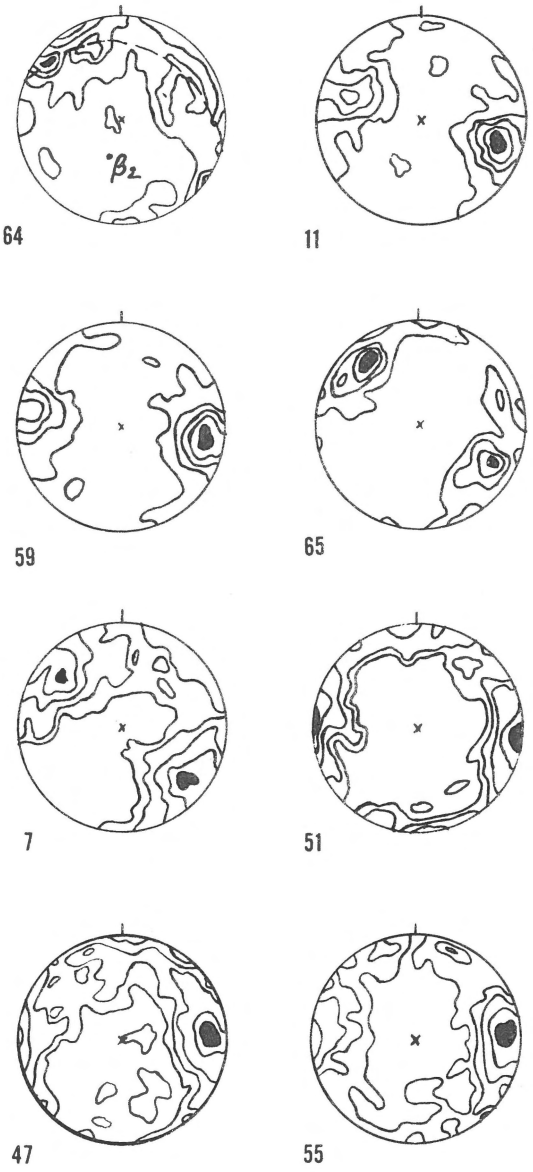


Fig. 10 - Geometry of foliation planes in selected tectonic domains. 64. 96 poles, contours: 1-3-6-11%. 11. 311 poles, contours: 0.3-2-4.2-7-15%. 59. 344 poles, contours: 0.3-2-4-8-14%. 65. 228 poles, contours: 0.9-3.1-5.3-7%. 7. 414 poles, contours: 0.3-0.5-2-4-6%. 51. 129 poles, contours: 0.8-1.5-2.5-7-9%. 47. 324 poles, contours: 0.3-0.7-2-8-11%. 55. 270 poles, contours: 0.4-0.8-2.2-5.2-12%.

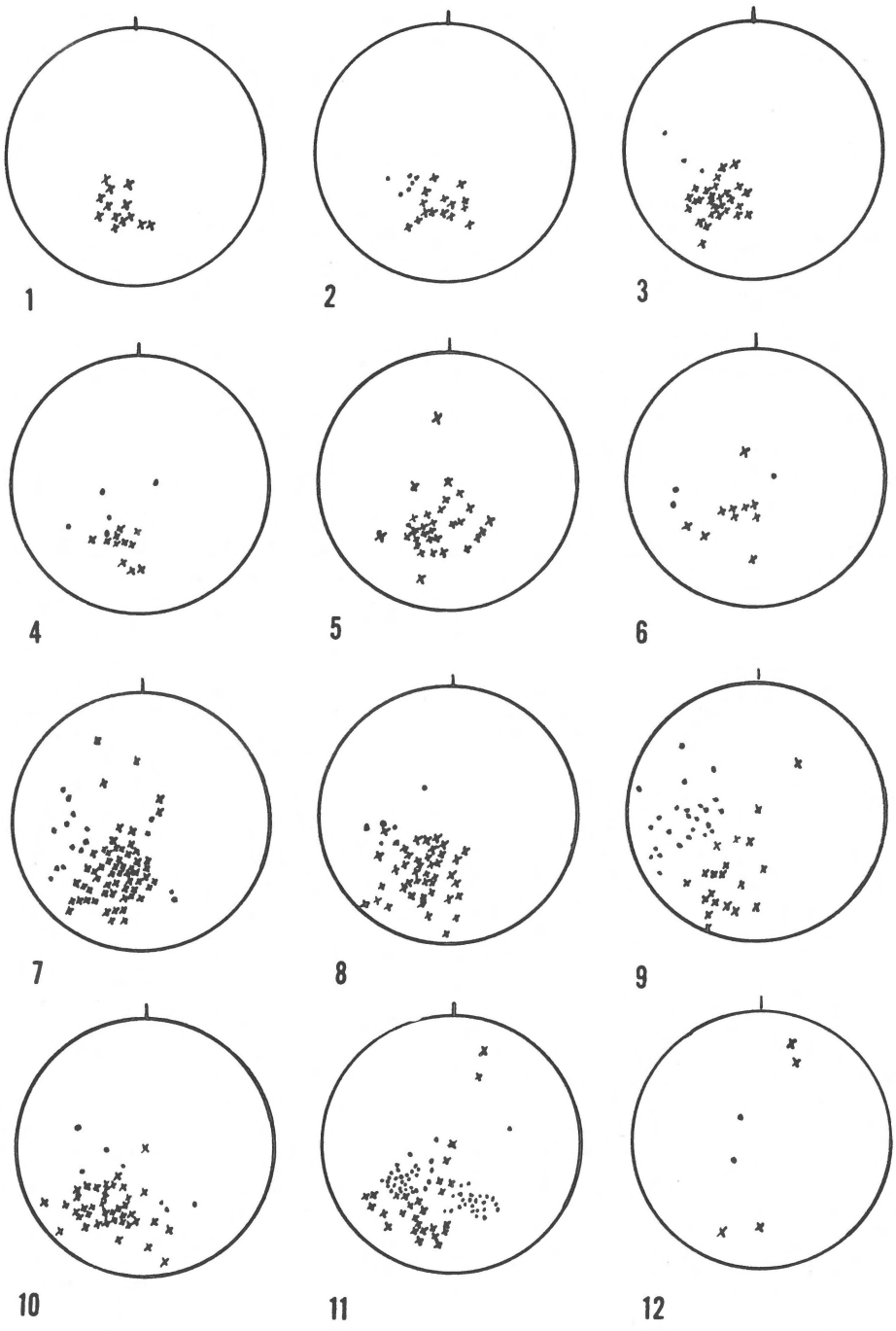
(d) Totally inhomogeneous domains where no girdles can be drawn suggest that the hinges and limbs of early folds with diversely oriented foliation have been involved in later folding (domains 47, 53, 54, 55). This can be understood by referring to Fig. 4b discussed earlier. The later fold axes (l_1-l_6) vary widely in plunge because of the diverse attitude of planes 1-6. Around each of the later fold axes the foliation planes are rotated. There is no longer any trace of an early girdle, nor is there a unique later axis.

Geometry of axial planes of folds: The axial plane folding seen on a small scale, and suggested by the map pattern on a larger scale, is corroborated by the varying attitude of the axial planes of the mesoscopic folds. Plots of the poles of the axial planes of 1048 small folds throughout the area fail to show any meaningful pattern. Figures 5 through 8, however, show that while the upright folds almost always have a NS axial strike, the axial planes of the reclined folds vary widely in strike and dip, the variation being most marked in the southeastern part. If the whole area is divided into two sectors, one covering the southeastern part between Kherlio and Kosivada (domains 32-47) and the other containing the rest of the region, and if the axial planes of the reclined and upright folds are plotted separately for these two sectors, certain characteristic patterns emerge:

(a) The poles of the axial planes of the early reclined folds from the southeastern sector fall in a well defined girdle with β plunging N 178°E, around which cluster the β_2 axes for the domains in this sector (Fig. 17, inset c). The diagram is also broadly symmetrical about the modal orientation of the later axial planes here (taken from Fig. 17, inset d). This proves that the axial planes of the early folds have been involved in symmetrical open folding on a large scale around the macroscopic later folds axes (β_2) in this sector. The axial planes of the later folds are however parallel, maintaining a NS strike and vertical dip (Fig. 17, inset d).

(b) The axial planes of the later folds in the rest of the area also show a uniform attitude with a N2°E strike and vertical dip (Fig. 17, inset b), so that they are parallel throughout the region. The axial planes of the early folds in the western part show, in contrast, a wide variation, the main concentration indicating steep westerly dips (Fig. 17, inset a). An ill defined girdle with the β axis plunging moderately southward and included in the zone of β_2 axes for domains in this sector shows that here also the varying attitude of the axial planes of the early folds is caused by later folding. A comparison of insets a and c of Figure 17 corroborates the suggestion that the western part of the terrain has been involved in later folding which is much tighter than in the southeastern part.

It therefore follows that although there is a dominance of folds with northerly and southerly closures, the map conceals large scale folds of very different styles, one set being reclined and the other upright. The apparently simple map pattern is due to the parallelism of strikes of the two sets of axial planes, which are N to NNE for a major part of the area (Fig. 17). The clue to the complexity of these macroscopic folds is provided by the s-pole diagrams showing rotation of

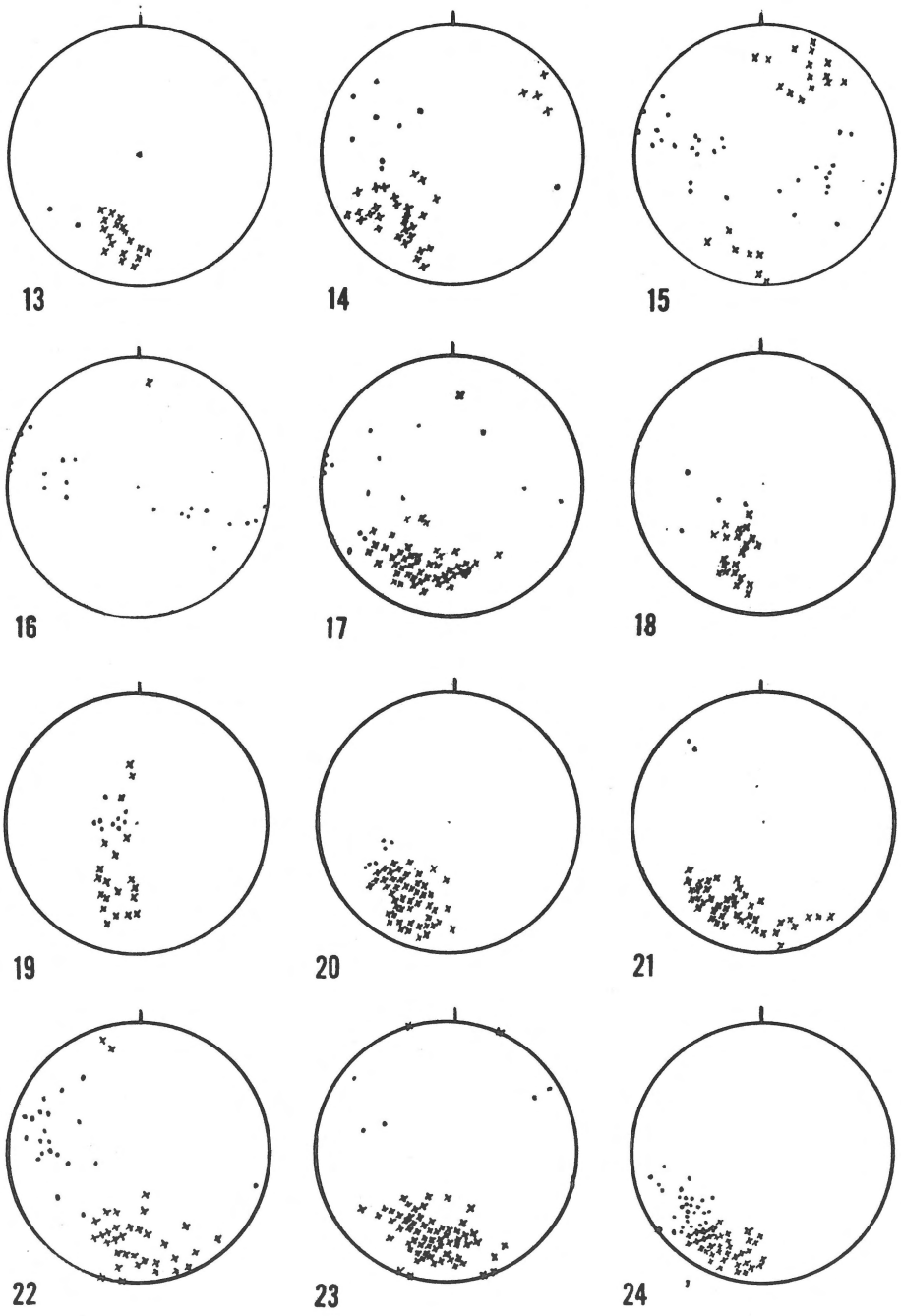


Figs. 11-16 - Geometry of linear structures in different tectonic domains. Domain numbers indicated in each diagram. Dot - early lineation, cross - later lineation. In domains 25, 27 and 34 (Fig. 13), early and later lineations are coincident and have therefore been shown by the same symbol.

early folds on a large scale, and by bent hinges and double closures of folds in hand specimen (Fig. 3c, 3d, 3e; Pl. 3).

Geometry of fold axes: The macroscopic fold axes (β), like the linear structures on a smaller scale, show seemingly haphazard distribution which at first baffles any analysis. For a rigorous analysis of this variation, the linear structures from each domain have been plotted in Figures 11 through 16 and compared with β axes from the corresponding domains (some of which are shown in Figs. 9 and 10). The following points emerge from this geometrical analysis:

(a) In some of the domains the axes of reclined



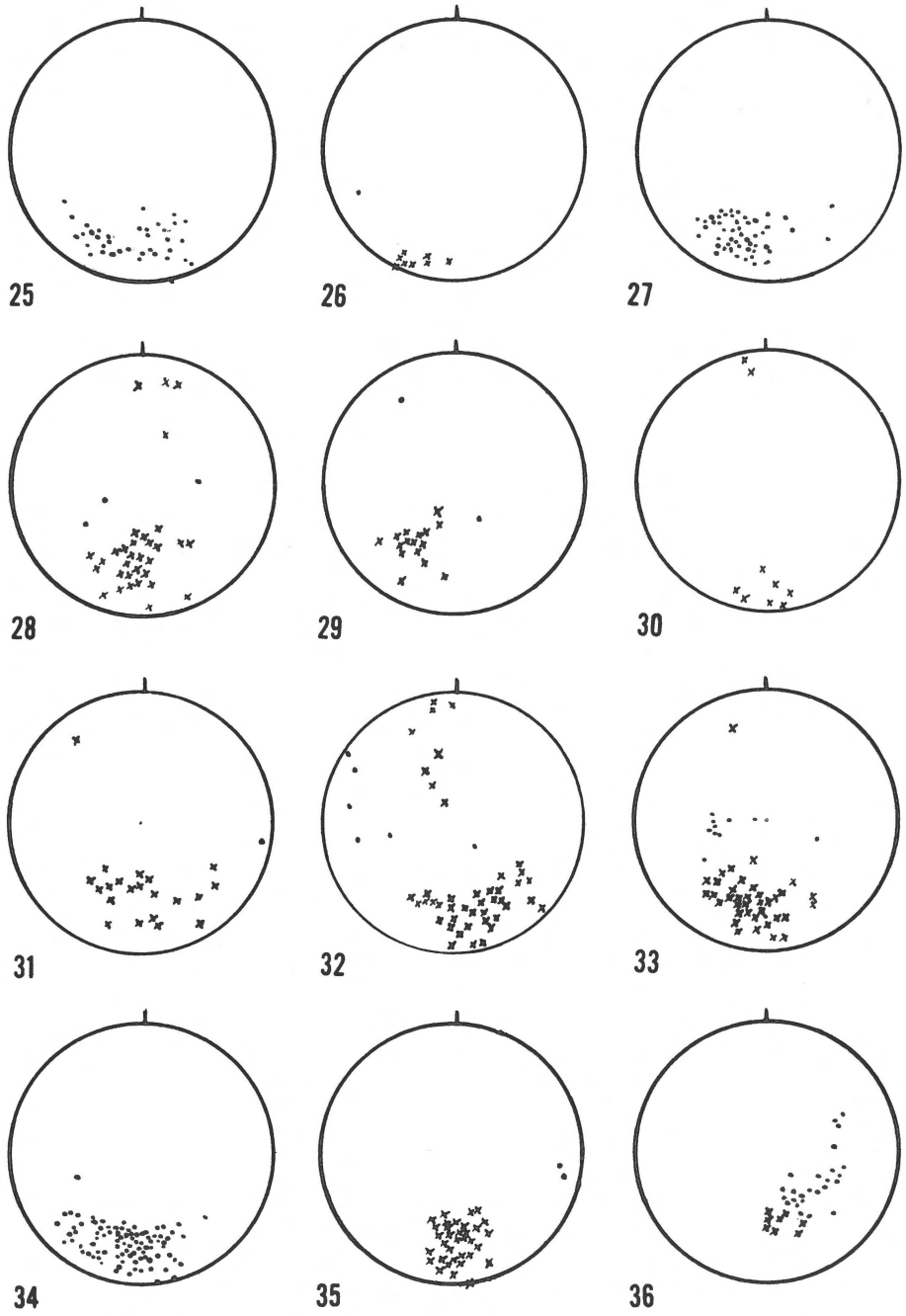
folds and associated linear structures cluster around β_1 while in others the dominant linear structures are the upright folds and related mullions clustering around β_2.

(b) The early lineations show a wide dispersion in many domains; the later ones, however, are still concentrated around β_2.

(c) Extreme variation in plunge of the later folds from horizontal to vertical is noticed in some domains (particularly 47, 48, 53, 55, 56, 58 and 59).

(d) Whereas the early linear structures and β_1 axes vary widely both in plunge and trend, the later folds and lineations vary in plunge only, the trend remaining N to NNE. As discussed in connection with mesoscopic structures, this constancy in trend is due to subvertical dip and constant strike of the axial planes of the later folds.

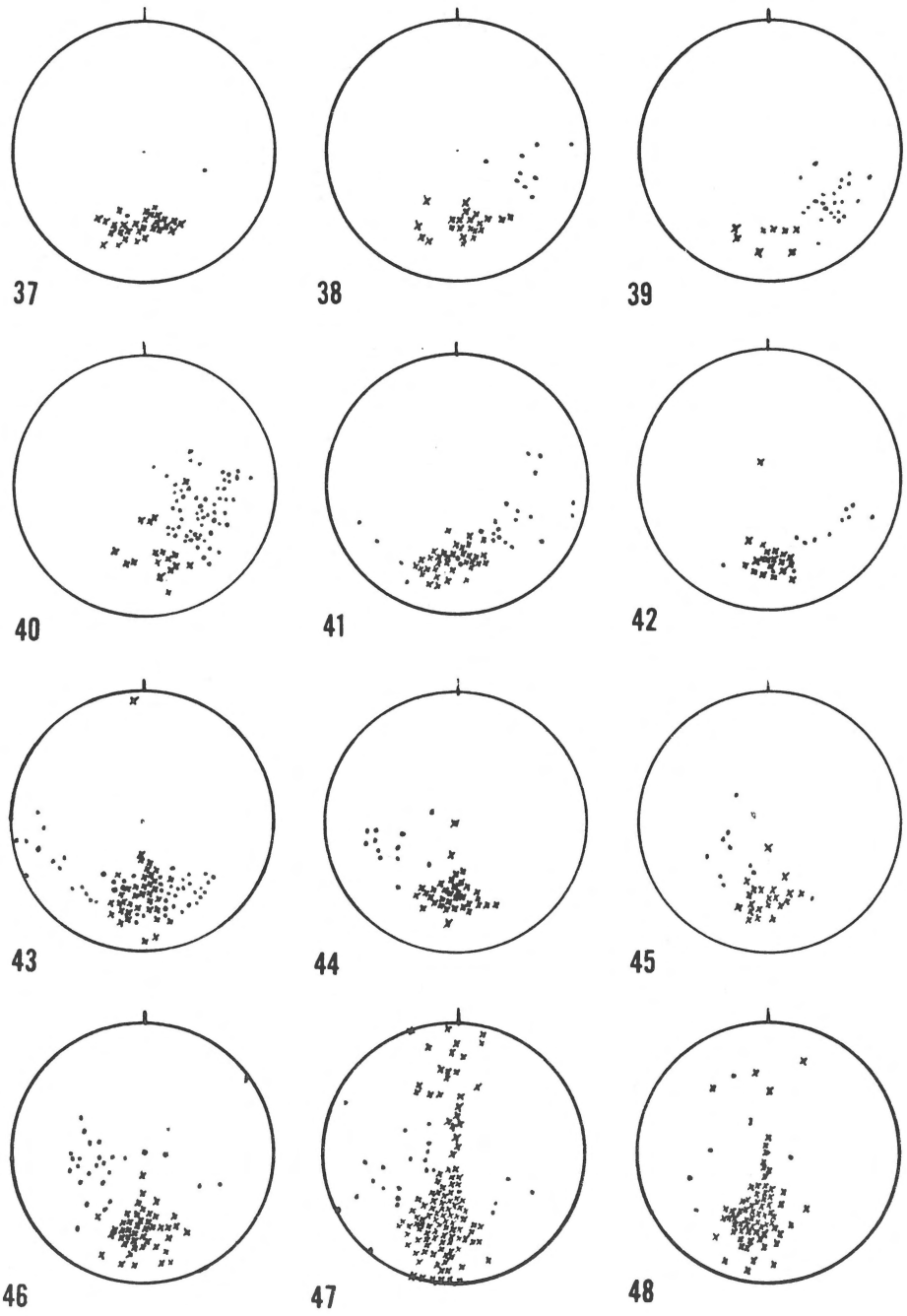
(e) Extreme variation in the axial plunge of the



later folds of different scales is caused by the geometry of superposition analyzed earlier (Fig. 4b). Domains with a number of hinges and limbs of macroscopic folds of earlier generation will be inhomogeneous, and will show a diversity in plunge of the later folds (e.g., domains 47, 53, 54, 55).

The β_2 axes from different domains have been plotted in Fig. 17 (insets a and c). A majority of them plunge SSW to S while only a few plunge in the northeast quadrant. β_{1l} axes from the southeastern part (e.g., domains 34 and 43 in Fig. 9), in general, plunge at a gentler angle than from the rest of the area (e.g., domains 50 and 56 in Fig. 9), where a number of them are almost vertical. This is because the early folds plunge down the dip of the limbs of the later folds. Consequently, the more open the later folding, the gentler the plunge of β_1; β_1 becomes steeper in plunge as the later folds tighten. This variation in plunge then is a measure of the tightness of the later folds and confirms that these folds are more open in the southeastern part.

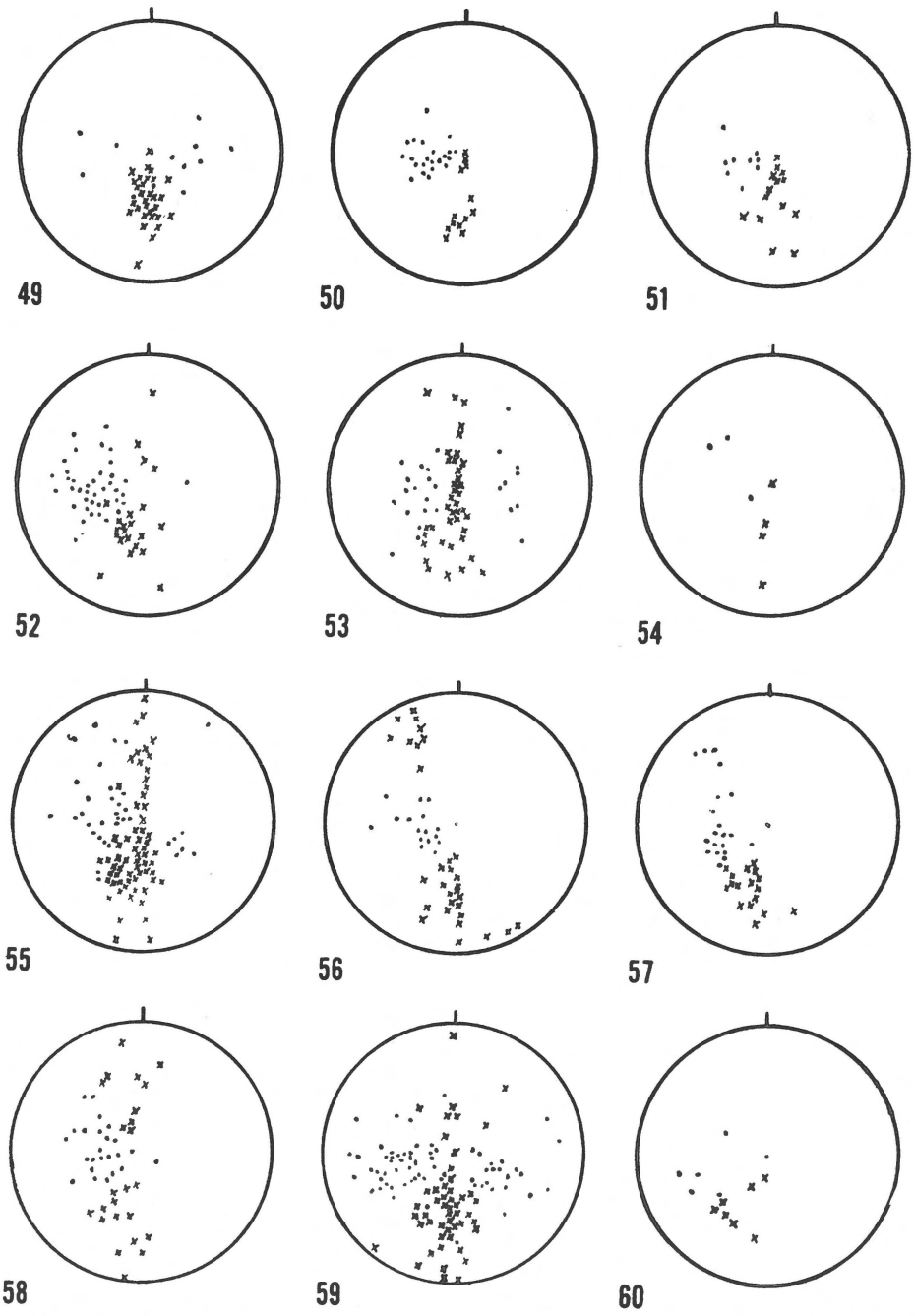
In a number of domains with well defined β_2 axes,



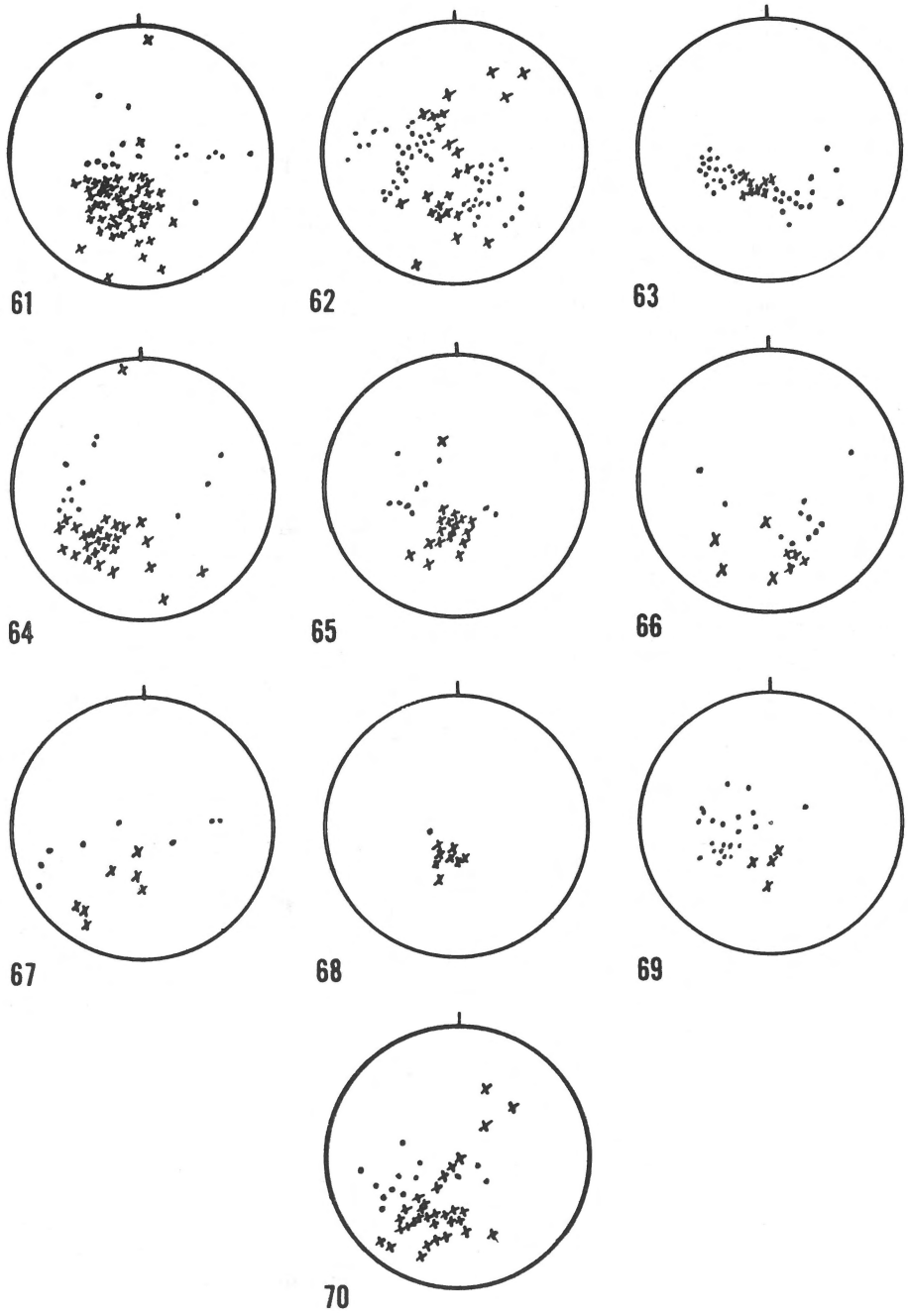
the early linear structures (and sometimes identifiable β_1 axes in divergent attitude) fall in a small circle around β_2, suggesting flexural slip mechanism for the second folding on a macroscopic scale.

Geometry of individual folds: The superposed deformations of varying style and intensity are exemplified on a large scale by some of the mappable folds.

Bokhala-Usarwas-Darwal fold: In the southeastern part of the area (domains 32-46) occurs a large open later fold with southerly plunge, traced by the arcuate bands of quartzite and marble; they trend from SSE near Bokhala through E and NE to NNW near Darwal, where the large structure is lost in the migmatites (Fig.5). Both the metasedimentary bands show isoclinal folding on the scale of the map, with the axial planes of the early folds turning in a semicircular arc together with the bedding planes.



Concomitantly, the axes of the early folds and associated linear structures are dispersed from ESE near Kherlio, through SSE and S in the broad hinge of the later fold, to SSW and SW near Bokhala. The later axial planes strike NS with subvertical dips, the later fold axes plunging moderately to steeply southward (β: 48/N178°E in Fig. 17, inset c). In the hinge zone of the later fold (domains 27, 34, 35, 41-44) the axes of the early folds are reoriented parallel to those of the later folds, so that the southerly plunging folds are also reclined isoclines here. Neither in the marble nor in the quartzite band do the two formational contacts with the migmatites represent two stratigraphic levels; they belong to the same horizon which is folded and occasionally disrupted. Migmatites on either side of the quartzite and marble are of the same generation, of the same structural setting, and are physically connected, with the metasediments engulfed in the migmatites. The evidence, therefore, does not sup-



port Heron's contention that the core of the fold is occupied by an older granite body.

Gam Gurha hinge: The sharp southerly closure of the marble band with the western limb terminating northward in domains 49-51 (Fig. 6) may apparently suggest that the marble has thinned because of facies variation and/or migmatization. But a large number of steep to vertical later folds here confirms the presence of a major hinge of a reclined early fold. Axial plunge ranging from horizontal to vertical indicates that a series of limbs and hinges of early folds of lesser dimension has been affected by later folding. The s-pole diagrams of all the three domains show steep macroscopic fold axes. But whereas in domain 50 β_1 plunges westward and in domain 49 β_2 plunges southward, domain 51 shows an ill-defined peripheral girdle indicating a subvertical B (Figs. 9 and 10). They suggest that the major fold was originally a reclined isocline plunging WSW to W with a digitated hinge

closing southward. This has been bent back northward by a later fold with NS striking axial plane. The southerly closure, therefore, represents the hinge of the later fold; the northward termination of the western limb of this fold, in contrast, represents the hinge of the early fold rotated through 180° (Fig. 17 and 18).

Bargula Closure: This closure in domain 64 (Fig. 7) is marked by a thickened hinge of the marble band with a not very well defined β_2 (Fig. 10). The dominant foliation planes subparallel to the axial plane indicate tight later folding on a set of foliations which were statistically parallel after the first folding. The later fold axes, though showing a slight dispersion, do not range in plunge from subhorizontal to vertical like the Gam Gurha fold, pointing to the absence of any hinge of an early fold on a large scale. Because of tight later folding the early axial planes coincide with the later ones for some distance. In a deeper tectonic level in domain 65, the s-pole diagram suggests a partial girdle on β_1, rotated by the later axis (Fig. 10). Paucity of the poles of foliation near the strike of the later axial plane also suggests tight second folding.

Dabkuria hinges: The very serrated hinges around Dabkuria in domains 4-7 are due to the combined effect of both system of folds, the axial planes of the early folds having been sharply folded (Fig. 17). Domains 4 and 5 show a fairly well defined girdle around β_2, indicating a subparallel set of foliation planes before the second folding. Domains 6 and 7, in contrast, show very ill-defined girdles, suggesting that both hinges and limbs of early folds have been involved in later folding. A wide range in the plunge of the later folds, from low to very steep, strengthens this suggestion.

Hook-shaped fold east of Bargula-Gam Gurha: The complex fold pattern (Fig. 8) traced by the quartzite band in the migmatites from east of Gam Gurha to east of Bargula (domains 53, 54, 55, 56, 59, 61 and 63) is the most spectacular of all the large scale structures in this region. All the fold-limbs run nearly NS for miles on end and are joined by sharp hinges indicating plunging isoclinal folds. An extreme variation in plunge of the later folds in almost all the domains here proves that a number of hinges and limbs of early folds have been affected by later folding. Examples of bent hinges of mesoscopic early folds with their axial planes involved in isoclinal folding are legion (Fig. 3d, 3e; Pl. 3a, 3c). Domain 56 with an elongated maximum around a subvertical β_1 (Fig. 9) records the vestige of reclined isoclinal early folding. No other domain shows a unique β, but domains 59, 61 and 63 suggest that a partial girdle around β_1 has been rotated by β_2. The quartzites in domain 47, 48, 54 and 53 almost certainly represent the same band folded, thinned, disrupted and migmatized. The geometry of folding here is strikingly different from the open later fold in the southeastern part. The small folds in hand specimen and outcrop from this sector are studies in miniature of the large scale folding here.

Summary of structural geometry

(1) Although for a major part of the area the metasedimentary bands run N to NNE, the sharp closures on the map, extensive variations in dip and strike of foliation, and innumerable mesoscopic folds point to the presence of tight plunging folds on a large scale. Only in the southeast an open fold is suggested by the arcuate map pattern.

(2) The northerly and southerly closures on the map conceal folds contrasting in style and orientation, and separated in time. The early folds are isoclinal and reclined, the fold axes plunging westward down the dip of their axial planes when not reoriented by later folding. On these, upright folds with NS-striking axial planes have been superimposed, the intensity of the second folding increasing westward.

(3) There is no unique macroscopic fold axis for the area as a whole. Large scale folds, like their small scale counterparts, vary widely in axial orientation. They coincide with the earlier or the later axes (β_1 or β_2), or show non-cylindrical character. The axial plunges are generally moderate to steep.

(4) Extensive evidence of superposed folding on all scales is provided by hinges of small scale reclined folds, refolded on subvertical axial planes striking NS; by outcrops showing subhorizontal to vertical plunge of later folds within tens of feet; by maps showing "mirror-image" type patterns and double closures; and by dispersion of point maxima or girdles of s-poles around β_1, by rotation on β_2.

(5) In the southeastern sector the reclined folds have been involved in open folding. The axes and the axial planes of the early folds have been dispersed, the former changing in plunge from ESE in the eastern limb through S at the hinge to WSW in the western limb of the later fold.

(6) In a major part of the tract, however, the later folds are much tighter. The two sets of axial surfaces coincide for greater distances as one moves further to the west. All the hinges of the early folds have been extensively modified by refolding.

(7) Whereas the axial planes of the early folds are acutely folded, the later axial planes have a constant NS strike and subvertical dip throughout the area (Fig. 17).

(8) The early folds vary widely in plunge because of the second deformation. In contrast, the variation in the plunge of the later folds is due to the non-parallel attitude of the foliation surfaces which have been involved in the second folding. Particularly striking examples of the variation in plunge of the later folds are seen in the central part of the region.

(9) The "hook syncline", so termed by Heron

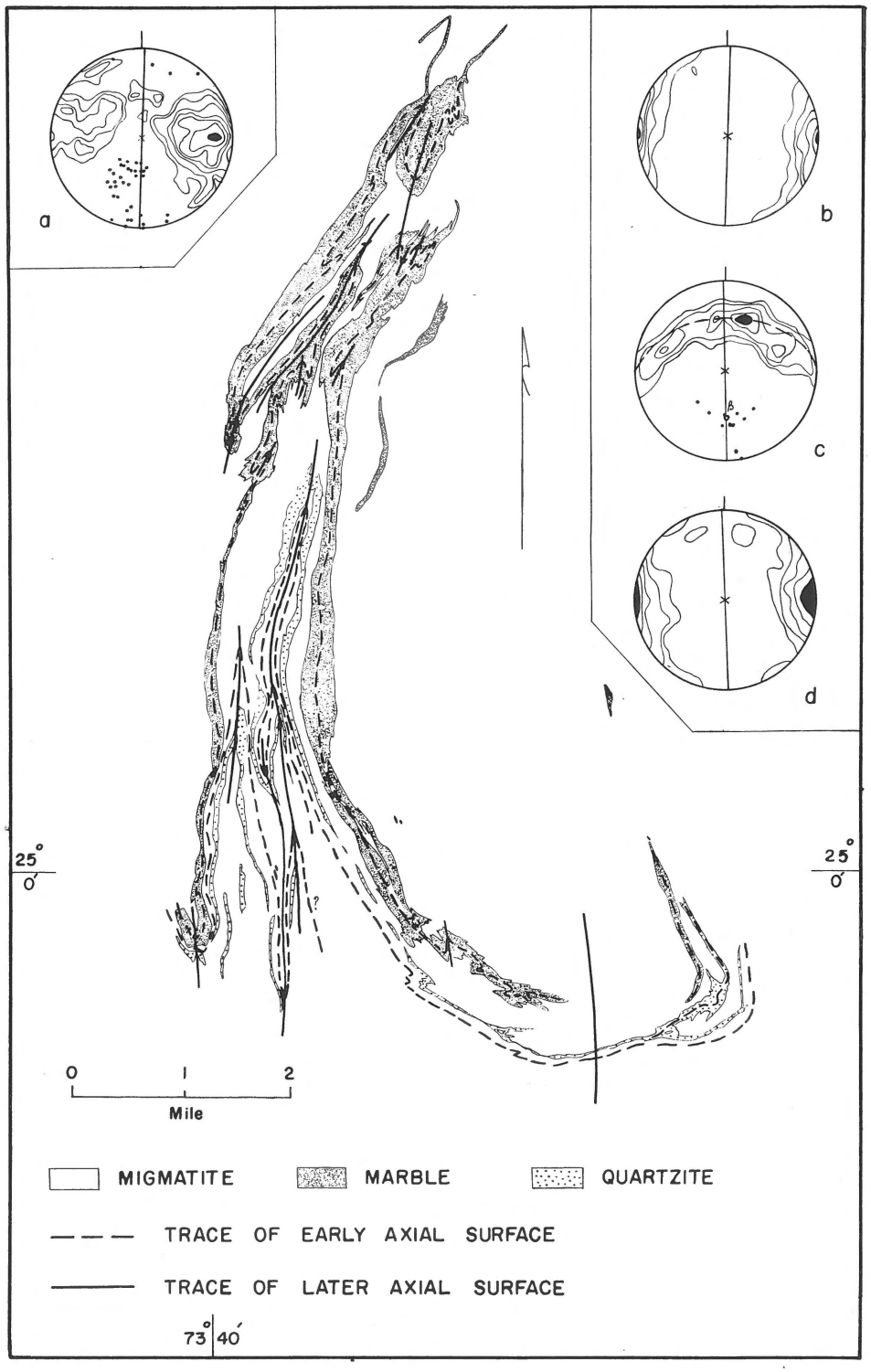


Fig. 17 - Map and stereograms showing axial plane folding in the area.
Insets: a, 252 poles of axial planes of early folds in domains 1-31 and 48-70, contours: 0.5-1-2-3-4-6-8%. The modal orientation of the later axial planes and the β_2 axes from the same sector shown. b, 433 poles of axial planes of later folds in the sector shown in a, contours: 1-3-6-10-15-19%. c, 143 poles of axial planes of early folds in domains 32-47, contours: 0.7-2.1-4.2-6.3-8.4%. The modal orientation of the later axial planes and the β_2 axes from the same sector shown. d, 220 poles of axial planes of later folds from the sector shown in c, contours: 0.5-1-4-7.3-18.2%.

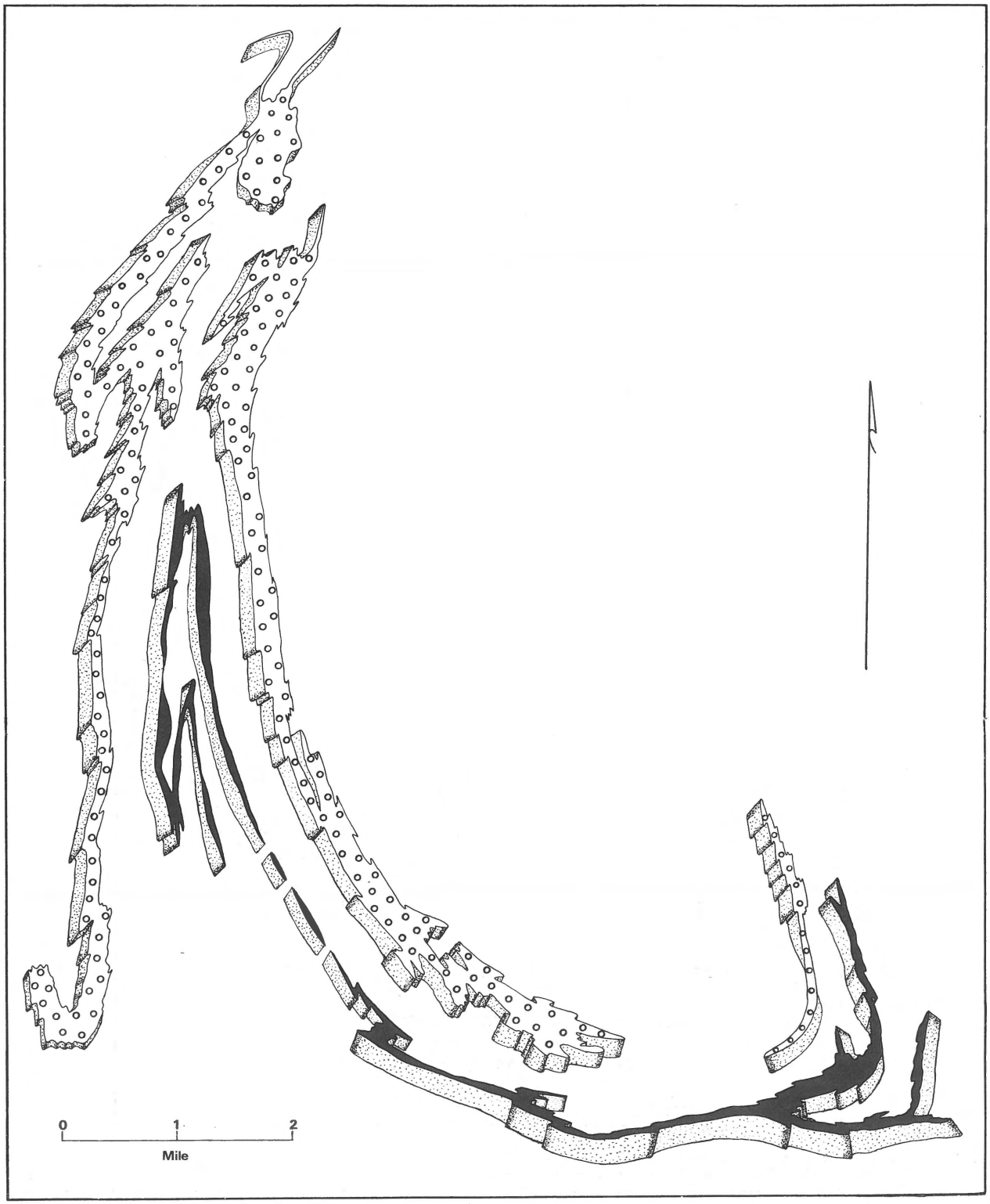


Fig. 18 - Generalized block diagram depicting the geometry of the large scale folds. One quartzite band (black) and one marble band (with circles) shown.

after the map pattern of a marble band within the banded gneisses (Fig. 1, details slightly different as seen from Fig. 2 and 17), owes its shape to superposed folding on divergent axes, the two sets of axial surfaces being subparallel in strike for a considerable distance. In regions of tight later folding this has resulted in subparallel fold-limbs and double closures.

(10) The use of the terms "anticline" and "syncline" in describing these folded folds is hazardous. In the absence of any primary top-and-bottom feature the almost neutral reclined folds, refolded into antiforms and synforms, offer no clue to the original stratigraphic sequence - a pre-requisite for the terms anticline and syncline. Even the terms "antiform" and "synform" cannot be applied in the zones of subvertical axial plunge where there is a plunge reversal through the vertical.

It is obvious from the structural geometry that in this terrain of complex folds of different generations, no conventional vertical section or tectonic profile would clarify the structure. The geometry of the folds can be better visualized by referring to the generalized block diagram (Fig. 18).

MOVEMENT HISTORY

First deformation

The reclined isoclinal folds on bedding foliation are the earliest structures. The ubiquitous bedding foliation, absence of axial plane foliation, disharmonic folds, folds following the competency rule, concentric fold style in the vicinity of the hinges, and congruous drag folds within larger folds - all of these evidences suggest that the folds were initiated by flexural slip. In some instances quartz veins are located in the cores of the folds, suggesting zones of low pressure. This strengthens the case for flexural slip folding as in slip folds the hinges are not kinematically different from the limbs. At the same time, the folds are extremely flattened with a high amplitude to wave length ratio. Shortening normal to and flowage along the axial plane at right angles to the fold axis must, therefore, have contributed to the shaping of the folds. Longitudinal stretching is proved by the universal development of joints normal to fold axes, and by mullions and roddings strongly elongated compared to their cross section.

In many of the fold hinges, however, extensive crumples with constant axes indicate that interplanar flexural slip cannot explain all the details of fold geometry, as slip is nil at the hinges of folds. Shortening without attendant slip (buckle folding - Turner and Weiss, 1963, p. 473) would explain these folds.

In domains where the early folds have not been significantly reoriented by later folding, the axes (β_1) plunge moderately to steeply westward, with the axial planes striking NS. For a large stretch of country east of the present tract, the later folding is much less in intensity or is totally absent. The folds here trend EW, generally with a gentle westerly plunge (Naha, Chaudhuri and Mukherji, 1966). With this as the original attitude of the early folds, an unrestricted transport in a NS direction in a horizontally bedded series seems to have been the style of deformation at the first stage. As the later folding has affected already folded surfaces, cylindrical fold units of the second generation are bound to be smaller than the first set (cf. Weiss, 1959, p. 98). The westerly plunge of the large early folds, therefore, could not have developed due to tilt by later folding. In that event, the gentle plunge of the first set of folds must have developed simultaneously with the first folding.

Second deformation

Incontrovertible evidences for superposition of folding on different scales have already been cited. Disharmonic folds, absence of transverse foliation cutting across the folds, and folds following the competency law suggest a flexural slip origin for the second set of folds also. Conclusively evidence of flexural slip folding is provided by the early B-mullions unrollable with respect to the axes of the later folds (Table 1). The same relation is seen on larger scales in some domains where the early lineations in various orientations move in small circle paths around β_2 axes.

Flexural slip on a series of isoclinal reclined folds with sharp hinges and gentle plunge involves interplanar slip on a set of parallel planes except at the hinges. The assumption of rectilinear axes of later folds in a terrain affected by superposed folding is now known to be untenable (Turner and Weiss, 1963 especially p. 496). It has been proved that the orientation of the later fold axes does not immediately depend on the stress pattern causing the later movement but on the intersection of the later axial planes with the already folded foliation. The wide variation in the axial plunge of the later folds in one domain or even in a single outcrop is, therefore, not caused by very complex local folding but by the geometrical relations obtained in the hinges and limbs of the early folds.

The NS strike and vertical dip of the axial planes of the later folds point to a horizontal squeezing in an EW direction on an orthorhombic movement plan during the second deformation. The two movement pictures - unrestricted transport from N (or S) and horizontal compression along an EW axis - do not fit in any single plan of deformation. Undoubted evidences of superposed folding and the spatial variation in the intensity of the later folding suggest a significant time gap between the two episodes of deformation.

Within one mile of the western border of the present terrain the rocks of the younger Precambrian (Proterozoic) Delhi System crop out (Fig. 1). Reconnaissance in these rocks has failed to show any structure corresponding to the early fold system of the present area. This, together with the gradual decrease in intensity and final disappearance of the folds of the second system eastward, lends weight to the suggestion that the later deformation is connected with the Delhi orogeny (Naha, Chaudhuri and Mukherji, 1966; Naha, Chaudhuri and Bhattacharyya, 1966). In that event, the first deformation is to be linked with a much older movement impulse affecting the Banded Gneissic Complex, probably the oldest orogenic episode in Rajasthan and one of the oldest in the Precambrian of India.

COMMENTARY ON STRATIGRAPHIC RELATIONS

Although the retention of bedded geometry in the folded quartzite and marble bands seems to offer a unique opportunity for working out the "ghost stratigraphy" in the migmatitic environs here, the lack of primary top-and-bottom features in the metasediments poses difficulties in elucidating the stratigraphic relations between the marbles and the quartzites. This difficulty has been enhanced by the special geometry of the folds here. In this terrain of neutral, isoclinal reclined folding there is no way to determine which closure was anticlinal and which synclinal before recumbency. Any chance of erecting the sequence by finding the zones of local upright folding of the first generation has dwindled further by the superposition of a series of upright folds, with the early folds involved in later antiforms and synforms. So, we have to be guided by the geological history for unravelling the stratigraphic relations here.

The following points are of special significance for elucidating the broad stratigraphic relations among the metasedimentary rock groups and their gneissic host:

(a) All the rock groups show a structural continuity throughout the area.

(b) The schists and limestones of supposedly Delhi age shown to occur between Dabkuria and Gam Gurha (Fig. 1) are shred-like inclusions of mica schists in various stages of migmatization. Amphibolites, calc-silicate rocks, marbles and quartzites are also present in the migmatites here. There seems to be no reason, therefore, to separate this patch from the other parts of the Banded Gneissic Complex.

(c) The "Darwal granite", taken by Heron as a pre-Aravalli bosslike intrusive, is not a separate entity. It is similar to the gneissic complex in its composition, texture and structure, and is physically connected with the latter in certain sectors.

(d) The migmatites mapped as Banded Gneissic Complex and pre-Aravalli granite are a granitized pile of metasediments. The migmatization is broadly synkinematic with the first deformation.

(e) The migmatite front represented by the contact of the Banded Gneissic Complex does not follow any stratigraphic horizon. All the metasedimentary rocks have been migmatized to varying degree during the formation of the gneisses.

The gneissic complex, therefore, evolved after the sediments had been laid down. If these sediments belong to the Aravalli and Raialo groups as Heron suggests, the Banded Gneissic Complex has to be post-Raialo in age (cf. Crookshank, 1948, p. 109; Sharma, 1953, p. 4-6). Alternatively, the whole suite of sediments belongs to an older sequence now forming a part of the gneissic complex. An undoubted unconformity between the Aravalli rocks and the "Sarara inlier" (equivalent to the gneissic complex) south of Udaipur (Heron, 1953, p. 76-77; Poddar, 1965), and the contrasted lithology between the metasedimentary rocks here and the Aravalli rocks of the type area near Udaipur (Poddar and Mathur, 1965) support the second alternative.

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