MODE OF EMPLACEMENT OF TWO CATAZONAL GRANITE PLUTONS IN THE BIHAR MICA BELT

by P. MUKHOPADHYAY, *Department of Geology, Presidency College, Calcutta*

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The mode of emplacement of two catazonal Precambrian granite plutons of Gawan-Singho area in the Bihar Mica Belt in eastern India has been studied. The principal rock types around Singho are: sillimanite-garnet-muscovite-biotite-quartz schist; quartzite; amphibolite; and gneissose adamellitic granite. The metamorphites belong to the almandine-amamphibolite facies and two generations of folds are recognized on the basis of geometric styles of the folds and orientation of various structural elements. The earlier set of folds is tight to isolclinal with sharp hinges and plunges generally at a low angle unaffected by second-generation folds, whereas later generation folds are open to tight with broad, rounded hinges and they plunge at moderate to high angles mainly towards ESE.

The adamellitic granite bodies are coarse-grained and made of quartz, k-feldspar, plagioclase, biotite (hornblende) with local porphyritic structure occupying the cores of second-generation folds and were emplaced display two synkinematically with the second-generation folding. They sets of foliation and two sets of lineation, the earlier set being of primary origin. The forceful upward swirling motion of the magmatic mush caused the observed domical pattern of the earlier set of foliation within the granite bodies. Subsequent to the emplacement of granite bodies there were regional broad warpings about steep subvertical axes, presumably related to the upward push of the rising granitic bodies.

INTRODUCTION

THE INVESTIGATED AREA (Fig. 1) forms a part of the famous Bihar Mica Belt (cf. Survey of India Topo Sheet nos. 72H/14 and 72 L/2) of the Indian Shield. This is a hilly region except at the east-central part where the topography is generally flat to rolling. The dominant rocks of this area are mica schist, quartzite, amphibolite and gneissose adamellitic granite. The last-named rock forms three distinct plutons, viz., Gawan, Kalapahar and Banresar plutons. The mean modal compositions of the Gawan and Kalapahar bodies are given in Table I. Pegmatite bodies of varying dimensions occur within the metamorphites and the granites; some of the pegmatites within the metamorphites contain large books of mica. Fine grained sandstone of presumed Gondwana age (gentle dip varying from 5° to 15°) overlies the metamorphites in the south-eastern part of the area.

A large portion of the Bihar Mica Belt was first mapped systematically by L.A N. Iyer (1939-1944) but this map is as yet unpublished. Mahadevan and Maithani (1961) classified the mica pegmatites of Bihar Mica Belt into (*a*) homogeneous bodies,

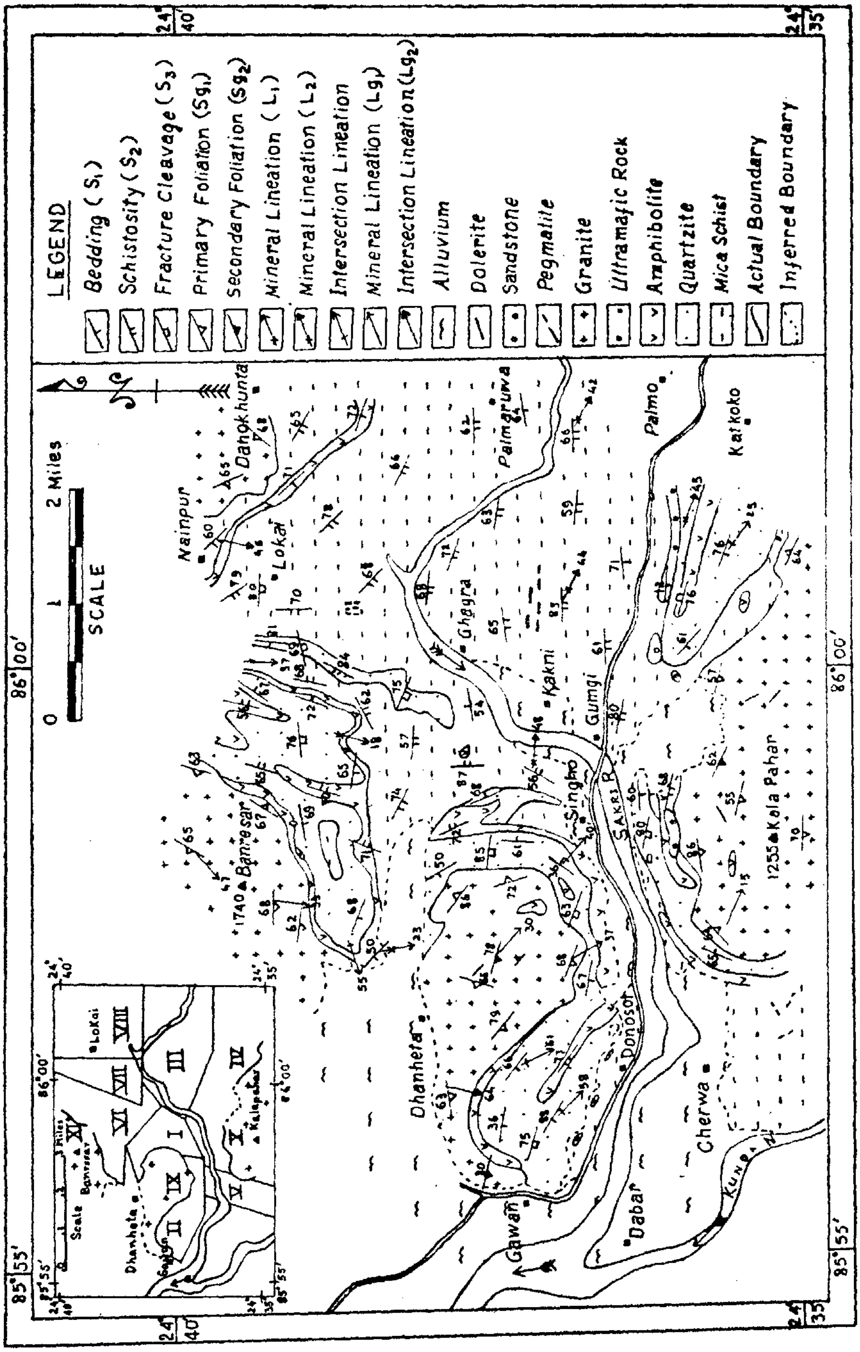

FIG. 1. Geological map of the Gawan-Singho area, Giridih district, Bihar. Inset shows the location of the structurally homogeneous sectors.

TABLE I

Average volume percent modes of granites

Name of the mineral	Gawan Granite (average of 30 samples)	Kalapahar Granite (average of 10 samples)
Quartz	32.72 (5.34)	34.78 (5.16)
Potash feldspar	33.98 (7.01)	33.28 (6.89)
Plagioclase	22.45 (4.86)	21.26 (4.42)
Biotite	6.58	7.89
Non-opaque accessories (include apatite, epidote, zircon and sphene)	0.41	0.44
Opaque minerals	1.42	0.95
Colour Index	10.81 (3.29)	10.61 (1.82)

Figures in brackets give the standard deviation.

(*b*) zoned bodies and (*c*) composite bodies. They also recognized two types of granitic rocks, viz., (*i*) strongly to mildly foliated and lineated gneisses, porphyritic in places, but mostly non-porphyritic and occurring as phacolithic sheets along noses and limbs of folds, and (*ii*) massive equigranular types forming sub-elliptical boss-like bodies, foliated along their margins with the country rocks. The southern part of the present investigated area including parts of the Kalapahar Granite was mapped by B. Ghosh (1971). Amongst other workers who worked on various aspects in different parts of the belt are Roy *et al.* (1939); Sen and Saha (1961); Saha *et al.* (1968); B. Chattopadhyay and A. K. Saha (1974), and N. Chattopadhyay (1975).

STRUCTURES OF THE METAMORPHITES

Three sets of planar surfaces have been found within the metamorphites. Bedding (S_1) is recognized by compositional and colour banding, schistosity (S_2) is defined by parallel arrangement of coarse flaky mica and is generally parallel to sub-parallel with S_1, and fracture cleavage (S_3) is defined by close-spaced fracture planes and parallelism of elongate quartz grains. The overall trends of S_3 is WNW-ESE which cuts across S_1 and S_2. Linear structures include, mineral lineation defined by preferred dimensional orientation of mica flakes, elongated quartz grains, acicular hornblende crystals etc., intersection lineation defined by intersection of $S_1(\simeq S_2)$ and S_3 planes, "pebble" elognation lineation defined by a parallel linear arangement of elongated quartzo-feldspathic pebbles (Fig. 2), striping lineation which is defined by stripes of dark coloured minerals on S_2 and lastly crumpling lineation (rare) restricted within the mica schist and is defined by parallelism of small-scale fold axes of the second generation. All these lineations are classified into two groups ; (*i*) Earlier lineation (L_1) parallel to the axes of the first-generation folds; and (*ii*) Later lineation (L_2) parallel to the axes of the second-generation folds.

The mesoscopic structures show varying degrees of inhomogeneity due to superposition of two generations of folds (Fig. 3). In the first phase S_1 was folded with the development of axial plane schistosity (S_2) whose axes plunge at moderately low angle in various directions and the lineation (L_1 is subparallel to the axes of these folds which are tight, nearly isoclinal and nearly upright folds. They have more or less sharp hinges and long limbs. In the second phase, S_1 and S_2 were simultaneously folded and axes of these folds plunge at moderate to high angles mainly towards SES with the axial plane designated by S_3. The lineations (L_2) are parallel to the axes of later folds. The second generation folds are mostly open to tight, isoclinal and reclined in places.

On the stereograms of the structures, the deviations of the poles to S_1 and S_2 from the great cirlce tend to lie on small circles about a steep plunging axis. The spread of the poles is apparently due to later warping.

Well-developed early mesoscopic folds on S_1 with the axial plane foliation S_2 are found in many places, such as in a nala just north of the Kariatary Mica Mines. Here S_3 cuts across the folds which have a moderate southerly plunge; another outcrop showing early folds was found about 3/4 km. NNE of the village Donosot (Fig. 4). These folds have high amplitude/wavelength ratio (approximately 4:1). The early fold axes in this sector (II) plunge 60° towards N51° and later fold axes plunge 50° towards N140° (Fig. 5*a* & *b*). The late folds here have a low amplitude/wavelength ratio 2:1 and fracture cleavage (S_3) is subparallel to the axial plane of such folds. Another set of mesoscopic late folds was found about 3 km. SSE of village Cherwa. The early folds in this sector (V) plunge 49° towards N167° and later fold axes plunge 60° towards N28° (Fig. 5*c* & *d*).

Five megascopic folds were recognized in this area of which two are early folds with the axial traces trending approximately N—S and rest are late folds with the trends of the axial traces varying from WNW-ESE to WSW-ENE. A megascopic synform of first-generation is found to the east of the Gawan Granite. This is a moderately tight fold plunging 22° towards N184° while the later fold axes in this sector (I) plunge 52° towards N110° (Fig. 5*e* & *f*). Another megascopic synform of second-generation is present NE of the Kalapahar pluton and south of the Gawan Granite. This inclined fold has a broad hinge and it is nearly isoclinal. The early fold axes in the sector (IV) NE of the Kalapahar pluton plunges 56° towards N171° and that of the later plunges 50° towards N123° (Fig. 5*g* & *h*). In the northern part of the present area, a regional first fold whose NNE-SSW axial trace is parallel to the planar structure S_2 is probably refolded by a regional second fold with WSW-ENE axial trace with S_3 parallel to the axial trace of the second fold. The second fold is synform which is an isoclinal, overturned fold with broad hinge. In the east-central part, only minor broad warpings on $S_2(\simeq S_1)$ is present with fold axis in this sector (III) plunging 45° towards N128° (Fig. 5*i*).

Structures of the Gawan Granite and the Kalapahar Granite

The Gawan Granite is broadly oval shaped in plan whereas Kalapahar Granite has a folded lensoid shape. They are surrounded by a group of metamorphites and alluvium. The granite bodies, in general, show a concordant relationship with the surrounding country rocks, though there is local evidence of discordance. The western part of Kalapahar Granite occurs along the core of a synform whereas the Gawan

FIG. 2. Photograph showing "pebble" elongation lineation in quartzite (1 km. NNW of the Singho Mica Mine).

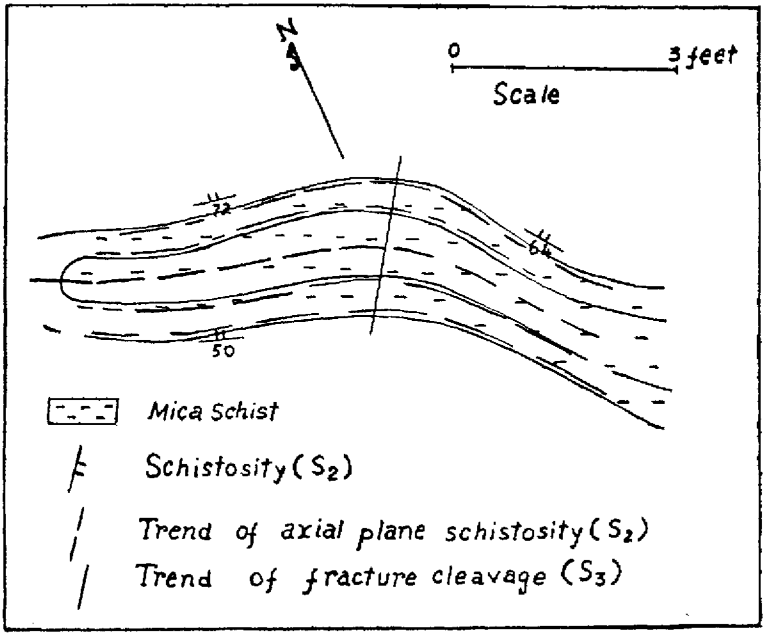

FIG. 3. Exposure map showing superposition of structures produced by two generations of folding within mica schist (3 km. SSE of village Cherwa).

FIG. 4. Photograph showing early fold within quartzite about 3/4 km NNE of village Donosot.

Granite and the eastern part of Kalapahar Granite occur along the hinge of antiformal closures with S_1 ($\simeq S_2$) of the adjacent metamorphites plunging at moderate angle towards ESE.

Two sets of foliation are recognized in the granite bodies and they belong to two generations, as follows : (*a*) Sg_1, defined by parallel arrangement of elongated potash feldspar and of relatively coarse grains of biotite, elongated quartz and hornblende prisms; and (*b*) Sg_2, defined by parallelism of thin biotite flakes, sheared quartz and feldspar grains; Sg_2 truncates Sg_1 at places.

Two types of lineations are as follows : (*a*) Lg_1, formed by linear arrangement of flaky biotite, hornblende prisms and elongated potash feldspar on Sg_1, and (*b*) Lg_2, formed by intersection of Sg_1 and Sg_2.

The following evidences indicate that Sg_1 was caused by magmatic flow :

(*i*) Foliation (Sg_1) is parallel to the contact of the granite bodies; (*ii*) The tendency of Sg_1 to swerve sharply in conformity with the walls of the bodies; (*iii*) Sg_1 formed by parallelism of subhedral/euhedral tabular grains of potash feldspar; and (*iv*) Conical distribution of Sg_1 in the stereograms for the different sectors (IX & X) of the granites (Fig. 5*j* & *k*). (cf. Sen & Saha 1961; and Chattopadhyay & Saha 1974).

The trend of Sg_1 varies from place to place and is parallel to the contact near the border region, even where the contact shows sharp bends. Minor discordances (such as, western part hf Gawan Granite and southern part of Kalapahar Granite) appear where the granite boundary swerves sharply leaving the country rocks abutting against the wall. The trends of Sg_1, in case of Gawan Granite is nearly N-S in the western

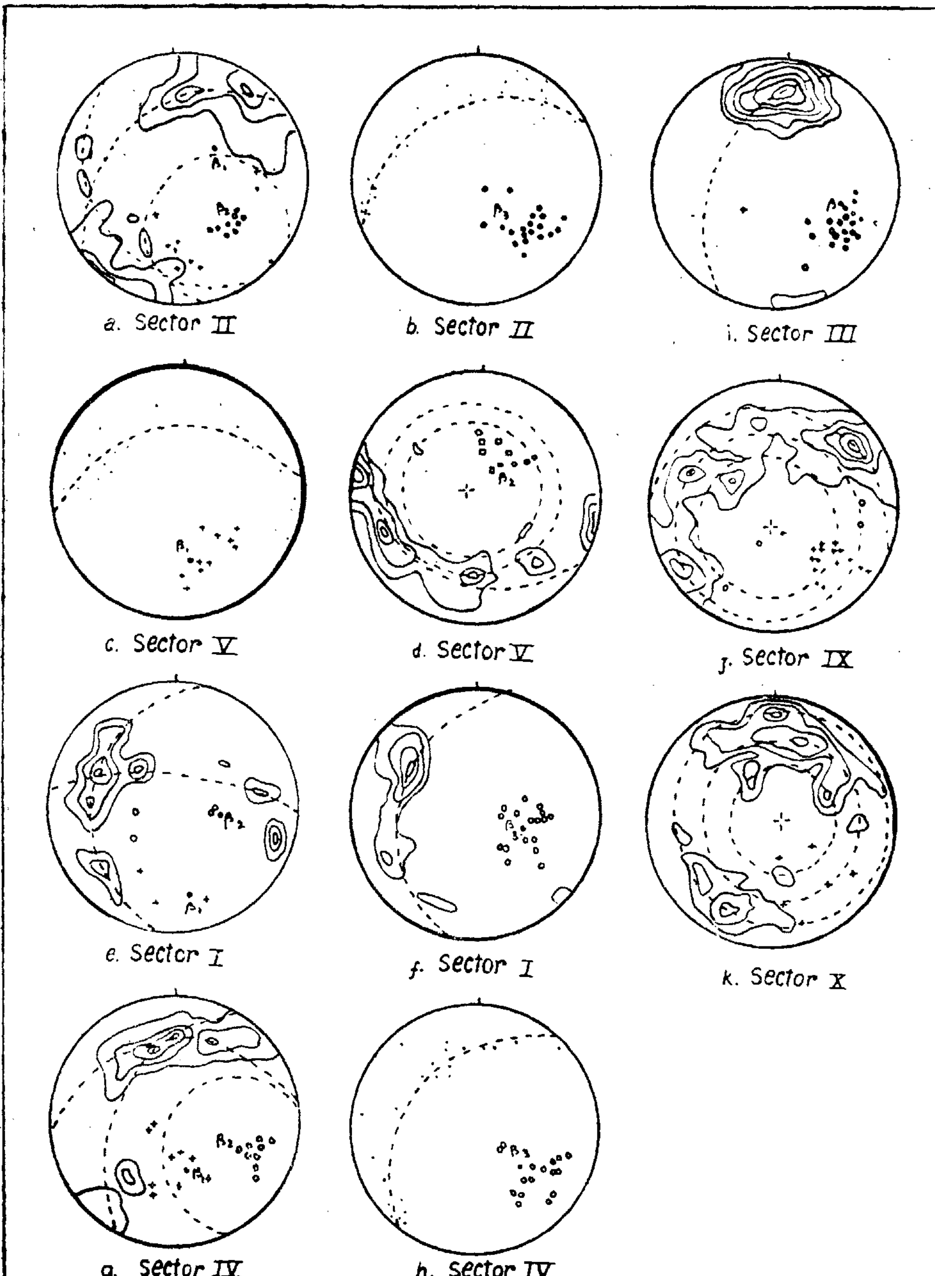

FIG 5. Equal area plots of the structural elements of sectors I to V, IX and X. (*a*) contours 7%, 5%, 3%, 1%, per 1% area of 106 S_1 poles; β_1 : 60°→N51°; β_2: 50°→N140°. (*b*) 22 poles to S_2; β_3: 50→N152°:. (*c*) 24 poles to S_1; β_1: 49°→N167°. (*d*) Contours 9%, 8%, 6%,4%, 2%, per 1% area of 83 poles to S_2; β_2 : 60°→N28°. (*e*) Contours 7%, 5%, 3%, 2% per 1% area of 72 poles to S_1; β_1 : 22°→N184°; β_2 60°→N100°. (*f*) Contours 10%, 7%, 5%, 3% per 1% area of 47 poles to S_2; β_3 : 52°→N110°. (*g*) Contours 8%, 6%, 4%, 2% per 1% area of 81 poles to S_1; β_1 : 56°→N171°; β_2 : 40→N116°. (*h*) 26 poles to S_2; β_3 : 50°→N123°. (*i*) Contours 17%, 12%, 7%, 5%, 3%, 1% per 1% area; 18 poles to S_1 & 86 poles to S_2; β_3: 45°→N128°. (*j*) Contours 9%, 7%, 5%, 3%, 1% per 1% area of 116 poles to Sg_1; Cone axis 78°→N181°; Flow lines: 40°→N125°. (*k*) Contours 5%, 3%,2%, 1% per 1% area of 103 poles to Sg_1; Cone axis : 83°→N74° ; Flow lines : 42°→N120°.

Symbols: Dot represents pole to S_1 and S_2 *solid circle* represent fold axes, *plus* sign represents L_1 and Lg_1 type lineations, *blank circle* represents L_2 and Lg_2 type lineations, *square* represents mesoscopic fold axis and *dotted plus* represents cone axis (warp axis).

and eastern part and gradually changes through NW-SE to WNW-ESE near the northern and southern margin. The trends of Sg_2 are subparallel with the S_3 of the metamorphites. Sg_2 is well developed in the eastern and western part of the Gawan Granite and only western part of the Kalapahar Granite trending ESE and ENE; and dip in most cases, is southerly at steep angle. Sg_2 is discordant with the wall of the granite and is of secondary origin.

In the case of Gawan Granite, the Lg_1 type of mineral lineation trending approximately SE is the most well developed and the amount of plunge varies from 6° towards E30°S to 73° towards E61°S; the angle between Lg_1 and Lg_2 varies from 20° to 50°. In the Kalapahar Granite, Lg_1 plunges at various directions (mostly SSE).

Only three exposures of the Gawan Granite and one exposure of the Kalapahar Granite (about 3/4 km. NNW of Sewadhab) have been found to show inclusions of amphibolite. In a rotated inclusion of amphibolite (about 1½ km. WNW of the village Singho) the attitude of foliation (S_2) is N110°/65°S, while that in the adjacent granite (Sg_1) is N220°/65°SE. The angle between the two plane is therefore, about 70°.

There are few dolerite dykes running parallel or oblique to the foliation but small pegmatite bodies containing a little small-sized muscovite are approximately concordant with Sg_1. There is a prominent set of joints, subperpendicular to Sg_1, in the Gawan Granite.

All the above evidences suggest that Sg_1 probably developed during the time of consolidation and Sg_2 probably developed after the complete consolidation. The granite body was probably emplaced during the fold movement of second generation. S-pole diagrams for these granite bodies show several incomplete concentric girdles of Sg_1 which suggest the shape of the intrusive body to be a conical or dome shaped one and the girdle axis indicates the general direction of movement of the magma body. Occurrence of such small-circle girdles of primary foliation poles in bodies of intrusive granite were noted by Saha (1959) and others. In Gawan Granite the mean attitude of flow lines (lg_1) is oblique to the general direction of the movement of the magma body, as determined from the relationship between the cone axis and the flow lines. Here girdle axis indicates the general direction of movement of the magma body. In case of Gawan Granite the relationship of mean attitude of flow lines (Lg_1) with the cone axis for the primary foliation (Fig. 5*j*) is as follows :

Cone axis	78°⟶N181°
Flow lines	40°⟶N125°

The oblique relationship between the mean attitude of flow lines (Lg_1) and cone axis may be expected in case of magma body, where the lineation is not generally expected to be parallel to the overall flow direction except near the margins (cf. Balk 1937).

The trend of Sg_2 in the granite bodies is generally E-W with variations from ENE-WSW to WNW-ESE and is subparallel with the S_3 of the adjacent metamorphites. The structural differences of the Kalapahar Granite with the Gawan Granite are listed below (Table II).

TABLE II

Structural differences between the Kalapahar Granite and the Gawan Granite

Kalapahar Granite	Gawan Granite
1) It has a folded lensoid shape.	1) It is approximately oval shaped.
2) The granite body has a phacolithic structure.	2) It has an approximately domical structure.
3) The granite body occurs in the core of a synform and an antiform with S_1 ($\simeq S_2$) of the adjacent country rocks plunging at moderate angle towards ESE.	3) The granite body occupies the core of an antiform on the S_1 ($\simeq S_2$) of the metamorphites plunging at moderate angle towards ESE.
4) The attitude of the cone axis is 83°→N74° and average Lg_1 plunges 42°→N120° (Fig. 5*k*).	4) The attitude of the cone axis is 78°→ N181° and average Lg_1 plunges 40°→ N125° (Fig. 5*j*).
5) Lg_2 plunges mainly towards east with variation from ESE to ENE.	5) Lg_2 plunges in various directions varying from ENE to SSW.

CONCLUSION

The structural study reported here indicates that the metamorphites of Gawan-Singho area were folded by F_1-fold movement to give rise to tight to isoclinal folds with sharp hinges with development of related axial plane schistosity (S_2). Subsequent to this another fold movement (F_2) was superposed on it with development of axial plane cleavage (S_3). F_1, indicates the first generation of folding and F_2, the second generation of folding. During this F_2-folding, Gawan Granite and Kalapahar Granite were emplaced along the core and limbs of the later folds as the secondary foliation (Sg_2) in granites are sub parallel with the S_3 of the metamorphites. So the granites are post-kinematic with respect to F_1-folding but synkinematic with respect to F_2-folding.

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