THE KINEMATIC SIGNIFICANCE OF SMALL-SCALE STRUCTURES FROM A PART OF SINGHBHUM THRUST-BELT, CENTRAL SINGHBHUM, EASTERN INDIA

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The wide zone of shearing demarcating the thrust-belt in central Singhbhum is characterized by the presence of a single set of shear planes (*ab*-plane). The dominant linear structures present on these planes—mineral lineation, streaking, grooving, major axis of deformed pebbles and axis of small-scale folds and puckers—are all parallel to striae on slickensides, and thus indicate the direction of tectonic transport. The small-scale folds in the direction of tectonic transport appear to have formed due to non-collinear movements; while the deformed pebbles indicate that they were stretched and flattened on the same surface. The *c*-axes of quartz, measured from quartzites affected by mylonitization, form girdles with their axes parallel to mineral lineation in the shear-zone. The thrust was not clean-cut in nature, but was manifested by mylonitization and shearing of the rocks distributed over a wide region. The attitudes of some of the overturned folds on the shear planes, flexing *a*-lineations, suggest an oblique-slip movement during shearing.

INTRODUCTION

The Singhbhum thrust-belt (shear-zone) is one of the most spectacular geological features in the east Indian Precambrian terrains. It is an arcuate belt with northward convexity, and runs for more than 180 km along the southern limb (Fig. 1) of the Iron-ore Series anticlinorium ('geo-anticline' of Dunn 1929; Dunn and Dey 1942). The general descriptions of the thrust-belt have been given by Dunn and Dey (*op. cit.*) in their classic memoirs. In recent years several workers have made intensive studies along small tracts of this thrust-belt (Banerji 1959, 1962; De 1954, 1957; Naha 1954, 1956, 1958, 1959, 1965; Roy 1964, 1966*a*, *b*; Sarkar 1964).

Within the area described here [between Narainpur (22° 45′; 86° 00′) and Sindhukopa (22° 44′; 86° 03′)] in central Singhbhum, west of Jamshedpur, the thrust is marked by a wide zone of shearing represented by mylonites and other sheared rocks. The main purpose of the present paper is to describe the small-scale structures associated with the thrust and to analyse their kinematic significance.

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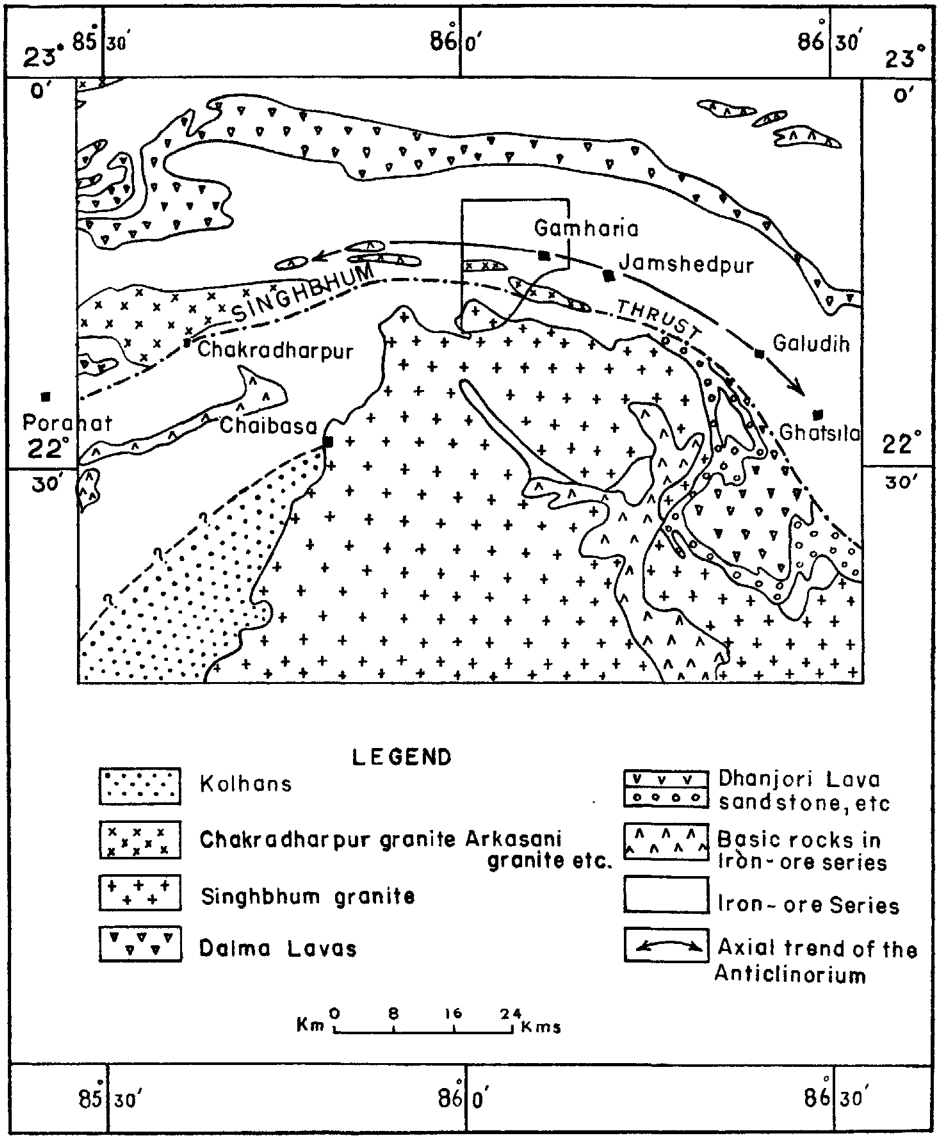

FIG. 1. Regional setting of the area (modified from Dunn and Dey 1942, Plate 40; and Sarkar and Saha 1963, Fig. 32). The area studied is shown in the frame.

EVIDENCES OF SHEARING

The metamorphics in the anticilinorium comprising rocks of the Iron-ore Series abruptly pass in to a strip of sheared rocks south of the Tatanagar-Chakradharpur Railway line (Fig. 2). The pelitic rocks present in this shear-zone show all the stages of cataclasis. Extreme mylonitization has often led to complete destruction of the porphyroblasts with reduction of materials to

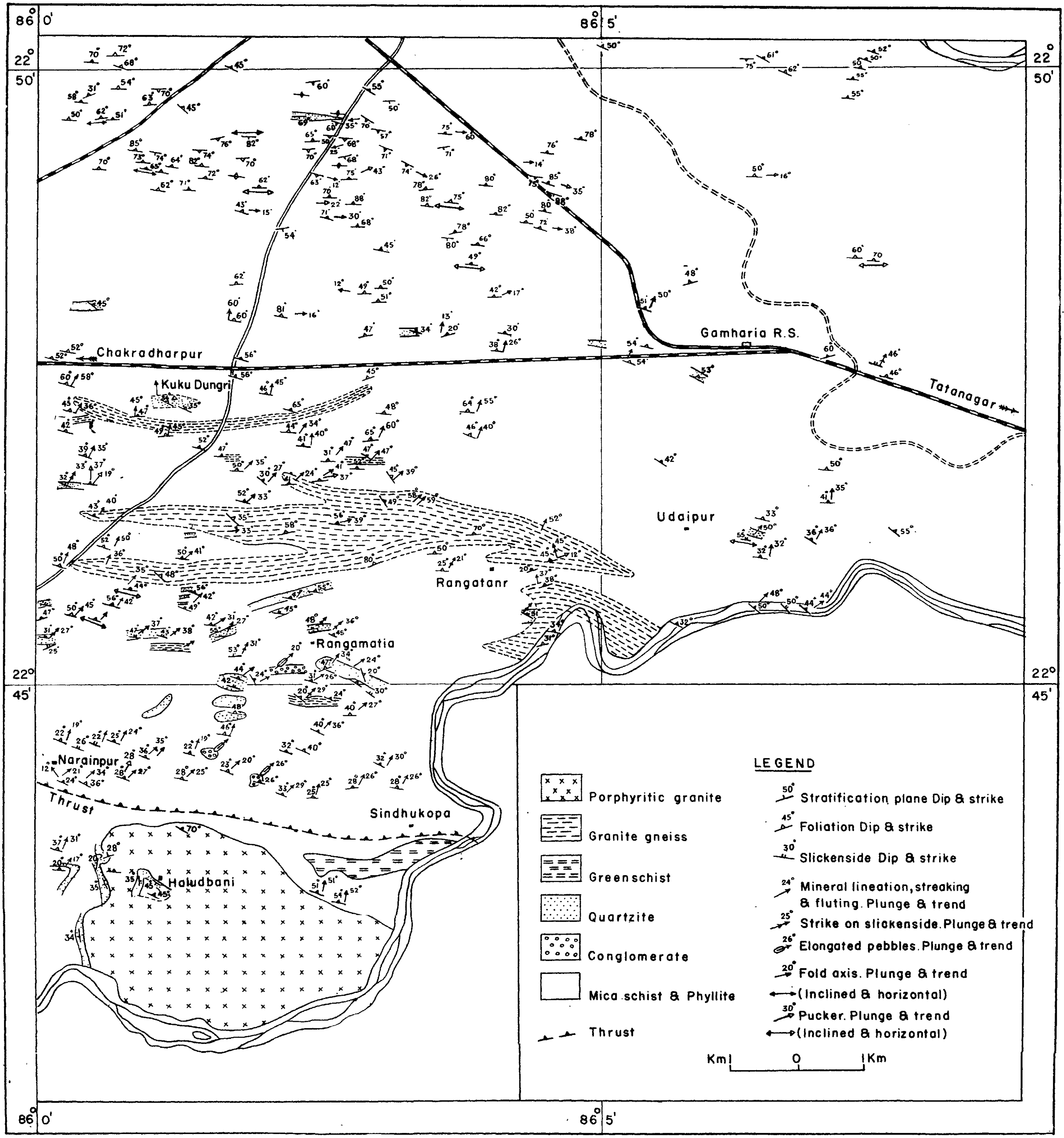

FIG. 2. Geological map around Gamharia Railway Station, central Singhbhum, Bihar.

ultramylonitic pastes (Roy 1964). Frequently there are well-developed bands formed by alternations of quartzose and micaceous layers (Fig. 3A). The mica-rich layers are generally more crystalloblastic than the quartzose counterparts which are predominantly cataclastic. The total effect is the development of 'mylonite-gneiss' as described by Quensel (1916).

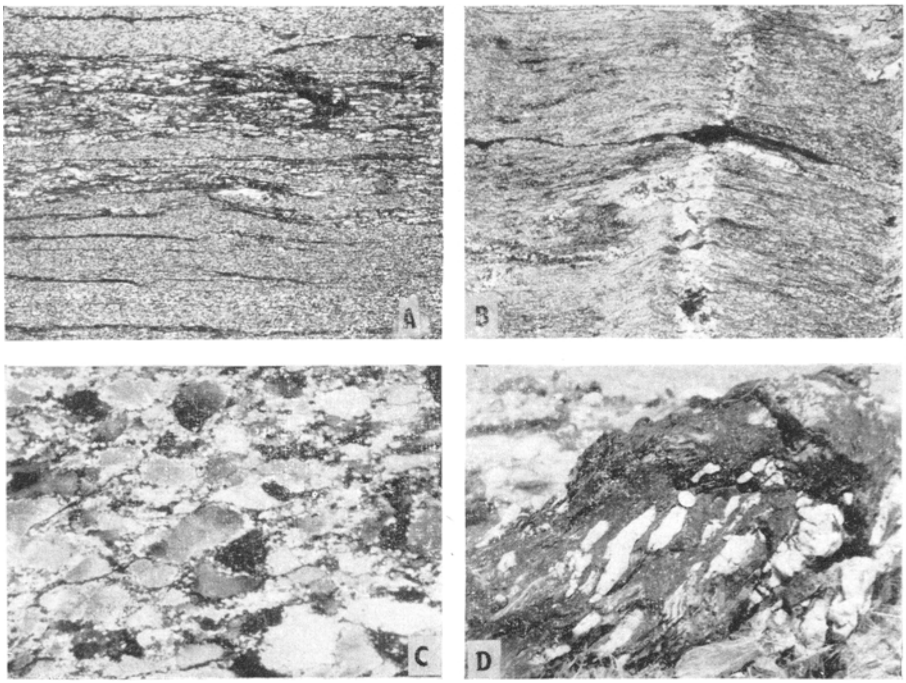

FIG. 3. (A) Mylonite-gneiss showing alternations of mica-rich and quartzose layers. The mica-rich bands show recrystallization in contrast to ultramylonitic pastes in the quartzose layers. ×5. (B) Mildly folded quartzite-mylonite penetrated by a quartz vein along the axial zone. ×5. (C) Spindle-shaped porphyroclasts of quartz showing dimensional orientation parallel to the major axis of stretched pebbles. Rangamatia. ×8. (D) Flattened lenses of quartz veins parallel to the shear planes in mica schist. Kuku Dungri.

In slightly less sheared rocks, the porphyroblasts of staurolite, kyanite and garnet display strong post-crystalline deformation (Roy 1966*a*). The grains are fractured and rotated, thrown into folds and kink bands, and the cleavages in many instances have been accentuated by intra-crystalline gliding (Read 1937; Naha 1956). The intense retrogression of the porphyroblastic schists often produced diaphthorites in the zone of strong shearing (Roy 1966*b*).

The quartzites in the shear-zone have been mylonitized and have developed prominent slickensides (Fig. 4A). Some of the quartz veins within the mica-schists are deformed to thinner slices (Fig. 4B) with surfaces being polished and striated. The extreme fineness of the grains, as seen in the ultramylonites, and the strong preferred lattice orientation in mylonites and blastomylonites indicated a high degree of penetrative deformation (Kvale 1945, p. 202).

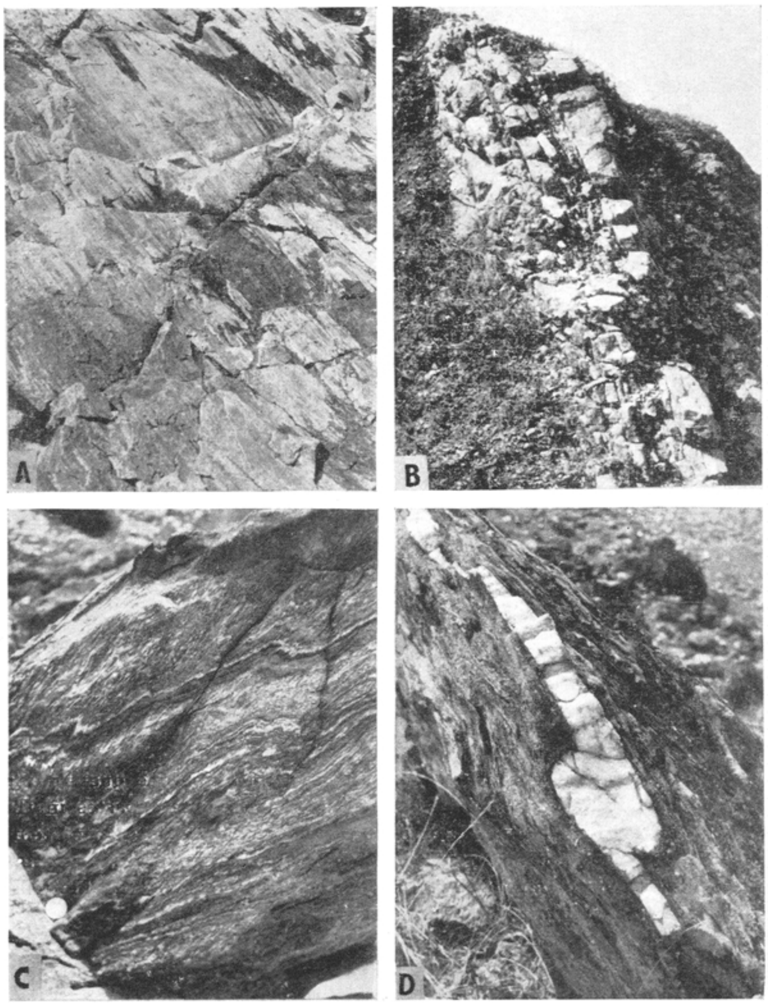

Fig. 4. (A) Slickensided surface in quartzite with cross and diagonal joints. From near Sundarnagar, not included in the map. (B) Quartz vein sheared to thinner sheets. North of Kuku Dungri. (C) Finely crenulated relict stratification laminae cut by shear planes. Kuku Dungri. (D) A quartz vein in mica schist shows bulbous growth due to folding normal to the direction of movement. Kuku Dungri.

The basic rocks, which have also responded to shearing, have often formed a crude banding due to milling and flowage of the finely granulated feldspathic paste around cataclastic relics of hornblende and epidote.

The zone of shearing in central Singhbhum extends over a belt 6 km wide. The southern limit of the recognizable mylonitic rocks lies north of the line joining Narainpur and Sindhukopa. The pelitic rocks lying south of this line are shales and very fine-grained phyllites. It seems very difficult to recognize any deformation in them due to the fineness of their texture. The quartzites also do not show any cataclasis excepting slight mortaring of the quartz grains. The primary sedimentary structures are well preserved in these quartzites, while they have been totally erased out in the mylonitic quartzites to the north.

Structures in the Thrust-belt and their Significance

(A) *Structural Elements*

Planar structures—The planar structures within the shear-zone comprise foliation (including relict stratification), slickensides and joints.

The foliation plane is the most pervasive planar structure in the shear-zone. It is defined by the parallelism of platy minerals like mica and chlorite in the pelitic schists, and hornblende in the basic schists. The studies in hand specimens as well as in thin sections confirmed the presence of a single set of foliation in the rocks of this belt. In rare instances, however, an early *S*-plane (possibly an earlier foliation) has been detected in the less sheared rocks.

The relict stratification planes are scarce in the zone of mylonites. In slightly less sheared rocks primary stratification can be recognized in the quartzites by contrasted composition of the layers (Fig. 4C). There are distinct traces of stratification in the quartzites of Kuku Dungri, where uniformly thick quartzose bands alternate with more micaceous layers. Some of the bands are very rich in tourmaline, which produce a sharp colour contrast in the rock.

The foliation planes have a general east-west strike and low to moderate northerly dip (20° to 50°, Fig. 2). A few stratification planes, measured in the shear-zone, also have a similar attitude. The dip of foliation is higher to the north, gradually becoming shallower southward. Excepting some small-scale folds and puckers, the foliation is commonly planar in hand specimens and in individual exposures. The studies on regional scale also failed to prove the presence of any large-scale folding on foliation.

Two sets of joints are almost ubiquitously present in the rocks of the shear-zone. The most persistently occurring joints are the cross-joints nearly perpendicular to the dominant lineation in the rocks (Fig. 4A). The other set, which occurs less frequently, intersects the linear structures obliquely. The longitudinal joints are comparatively rare.

Linear structures—In the belt of schists north of the shear-zone (i.e. within the anticlinorium, *see* Dunn and Dey 1942), the dominant linear structures are puckers, small folds and traces of intersection of bedding and axial plane foliation. These are *B*-lineations corresponding to the regional folds on stratification (Roy 1964, 1966*a*). Southwards from this belt appears a set of lineations nearly normal to these *B*-structures. These linear structures include mineral lineation and streaking, grooving and striae, elongated pebbles, small-scale folds and puckers.

The commonest of all the linear structures is the mineral lineation due to the parallelism of prismatic minerals in the pelitic and basic schists. In mylonites the elongate quartz grains often form a linear pattern. In a similar way the 'augen' of feldspar and quartz in migmatites form lineations. The

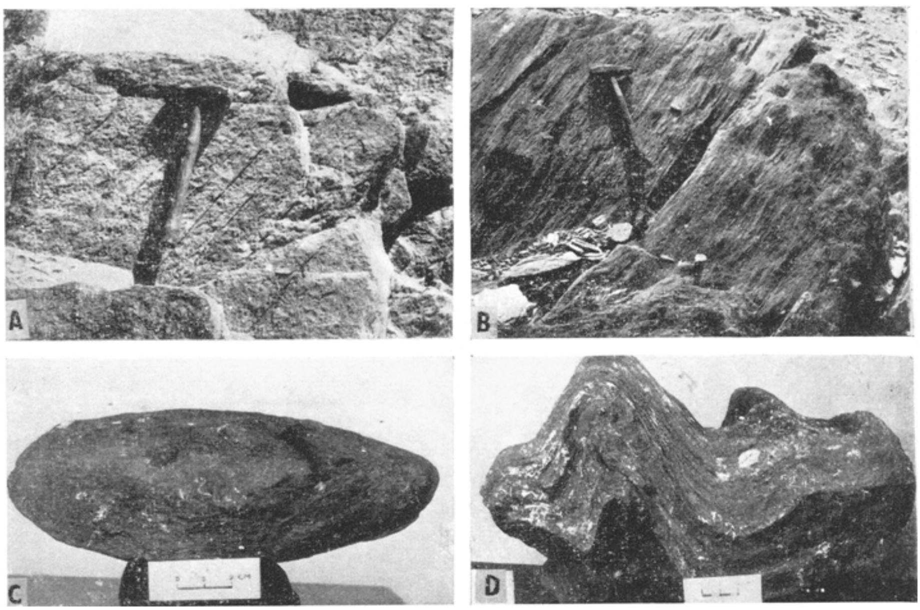

Fig. 5. (A) Mica schist with strong mineral lineation. 1·5 km south of Kuku Dungri. (B) Shear plane in quartzose mica schist with groovings and striations. South of Kolabira. (C) Stretched pebble measures along its principal axes 15 cm × 6 cm × 3·5 cm. Rangamatia. (D) Folded mylonite; axes of folds are non-cylindrical. South of Kolabira.

mineral lineation pitches 50° to 60° northeasterly on the foliation planes and becomes more and more orthogonal to the sub-horizontal puckers (*B*-lineations) northwards (Fig. 5).

The striae, groovings and streakings are also common in the shear-zone. They occur on the foliation planes of quartzites, quartzose schists and migmatites. In mylonites the striae are restricted to slickensided surfaces.

The lineation formed by the major axis of elongated pebbles is another important linear structure in Singhbhum thrust-belt. The conglomerates with elongated pebbles occur as a thin band of about 25 metres width running for about 250 metres near the village Rangamatia (22° 45′ 20″; 86° 02′ 30″). Besides this, smaller exposures occur sporadically.

The pebbles in the conglomerates form an important linear structure. They are characterized by smooth edges with one end being more flattened than the other. The typical deformed pebbles have the shape of triaxial ellipsoids with major and intermediate axes lying on the foliation planes. They usually bear striations in the direction of pebble elongation. The pebbles in all the exposures and the individuals in a single exposure display a high degree of uniformity in their orientation.

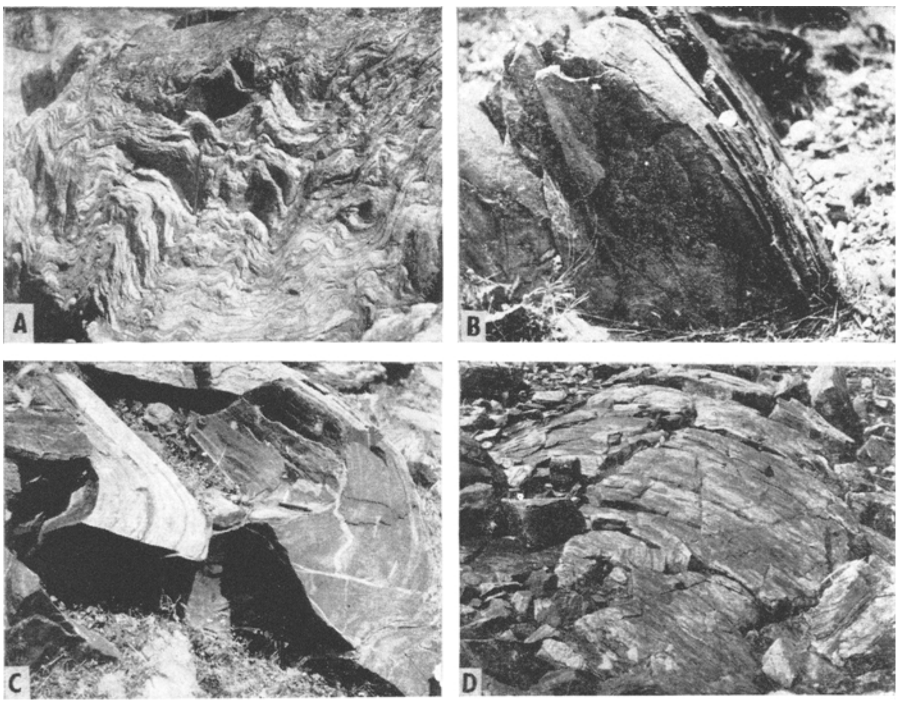

Fig. 6. (A) Folds in banded gneiss (Arkasani granite gneiss). Fold axes are down-dip and are parallel to a-lineations. About 2 km north of Rangamatia. (B) A fold in quartzite plunging in the direction of a-lineation. East of Kuku Dungri. (C) Folded quartzite-mylonite. Fold axis is at small angle to the direction of striation. Kuku Dungri. (D) Broadly warped slickensided surface in quartzite. Fold axis sub-normal to the direction of striae. Near Sundarnagar, east of the present area.

The small-scale folds and puckers are frequent in the shear-zone. The folds are usually open with broad symmetrical limbs. A few of them are slightly overturned. The folds and puckers in the shear-zone are either parallel (Figs. 6A and 6B) or normal to the mineral lineation and striae (Figs. 4D and 6D). In addition to these, there are folds which run askew to the most consistent lineations in the shear-zone (Fig. 6C).

(B) *Kinematic Analysis*

The foliation planes in the schists are the only dominant planar structures in the shear-zone. The characters of the folds and puckers defining lineation on these planes lend a monoclinic symmetry to the rocks with only one plane of symmetry normal to the direction of lineation (Weiss 1954). Based on symmetry principle, therefore, the lineation may be regarded as b-lineation (i.e. $B = (b)$-lineation of Sander 1930).

The interpretation of the down-dip lineations in the shear-zone as b-structures would, however, necessitate involving an unusual fold geometry, for which evidences are totally lacking. The outcrop pattern of the rocks in the shear-zone and the orientations of planar structures do not suggest the

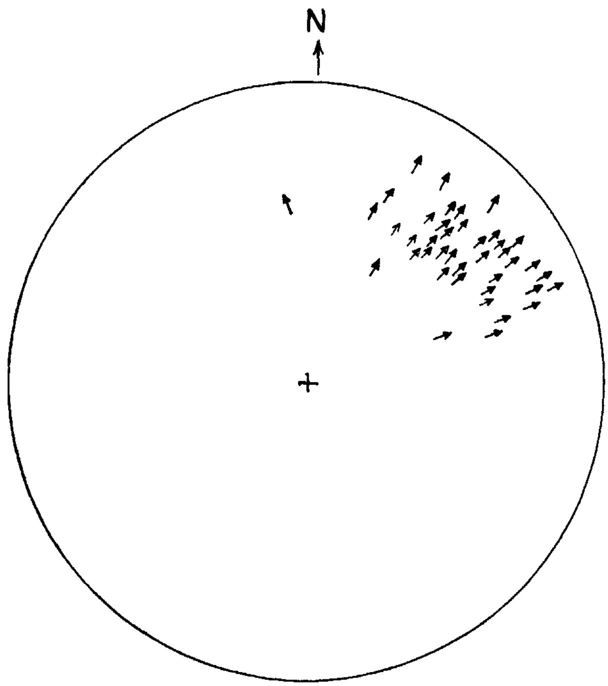

FIG. 7. Poles of striae on slickensides.

presence of any large-scale folding with axis in the direction of down-dip lineations. On the other hand, the restriction of these linear structures to the shear-zone suggests a causal connection between these structures and the shearing movement.

The single set of foliation which is present in the shear-zone shows strict parallelism with the slickensides as developed in the quartzite-mylonites. This proves that the foliation planes are ab-planes (i.e. the plane of movement). The principal direction of tectonic transport in the shear-zone has been determined in the field from a number of observations of striae on slickensides

(Fig. 7). The dominant linear structures—mineral lineation, streaking, grooving, some of the small-scale folds and puckers, and elongated pebbles—are parallel to that direction and, therefore, strongly suggest that they are *a*-lineations* (Kvale 1953, p. 55).

The formation of mineral lineation parallel to the direction of movement is a subject of disagreement among the structural geologists. Yet, the strict parallelism between the mineral lineation and the direction of tectonic transport is so common in the recognized thrust-belts of the world (Cloos 1946; Fellows 1943; Strand 1944; Kvale 1946-47, 1953; Oftedahl 1950; Balk 1952) that it appears to be a rule with few exceptions.

Of considerable interest are the folds and puckers with axes parallel to the direction of transport (Fig. 8). The folds with axes parallel to mineral lineation are not found outside the shear-zone. The occurrence of folds with axes parallel to the *a*-direction is a familiar feature in many thrust-belts all over the world (Balk 1936, 1952; Kvale 1946-47; Strand 1944; Cloos 1946; Oftedahl 1950). Such folds are also common in the Singhbhum thrust-belt (*see also* De 1954, 1957; Banerji 1959; Naha 1959, 1965; Sarkar 1964). The actual nature of movement producing folds parallel to the direction of transport is, however, not well understood, and there is a considerable disagreement among geologists about the exact mechanism. Relying on fabric diagrams (girdle normal to mineral lineation), Phillips (1937) and Turner (1957) held that these folds are the result of movement normal to the direction of thrusting as deduced from megascopic fabric. Such an explanation might be justified in certain cases, but seems to be too ideal a condition prevailing in all the thrust-belts.

The mechanism of formation of folds in the direction of tectonic transport has been elucidated by Balk (1936), Cloos (1946) and Hollingworth (*see* Kvale 1953). While Hollingworth suggested the possibility of tensional drag or flowage during unrestricted transport, Balk and Cloos stressed the importance of convergent movement in forming the folds in the direction of tectonic transport (*a*). For the folds of the present area, a stereogram was prepared showing poles of all lineations which are locally parallel to the striae on slickensides. The diagram showed a strong maximum of 21 per cent, but with considerable scatter for over 40° (Fig. 9). This clearly demonstrates that the movement was not strictly collinear in all parts of the region. The required lateral shortening might result from these non-collinear movements (De 1957; Naha 1959, 1965).

Another important linear structure that parallels the striae on slickensides is the major axis of the deformed pebbles in conglomerate. If the pebbles were spherical before deformation, then their present shape will indicate a

* The term *a*-lineation, as used here, does not refer to fabric axes defined by symmetry alone (Turner and Weiss 1963, p. 103).

considerable stretching in the direction of mineral lineation, far exceeding that perpendicular to the lineation.

The mode of stretching of pebbles is still a rather puzzling problem. The principal difficulty, of course, is because flattened pebbles lie on the shear planes. In the present area, the pebbles are strongly striated through and through—the striations being parallel to the pebble elongation, which proves beyond doubt that shear direction in this case could not have been at

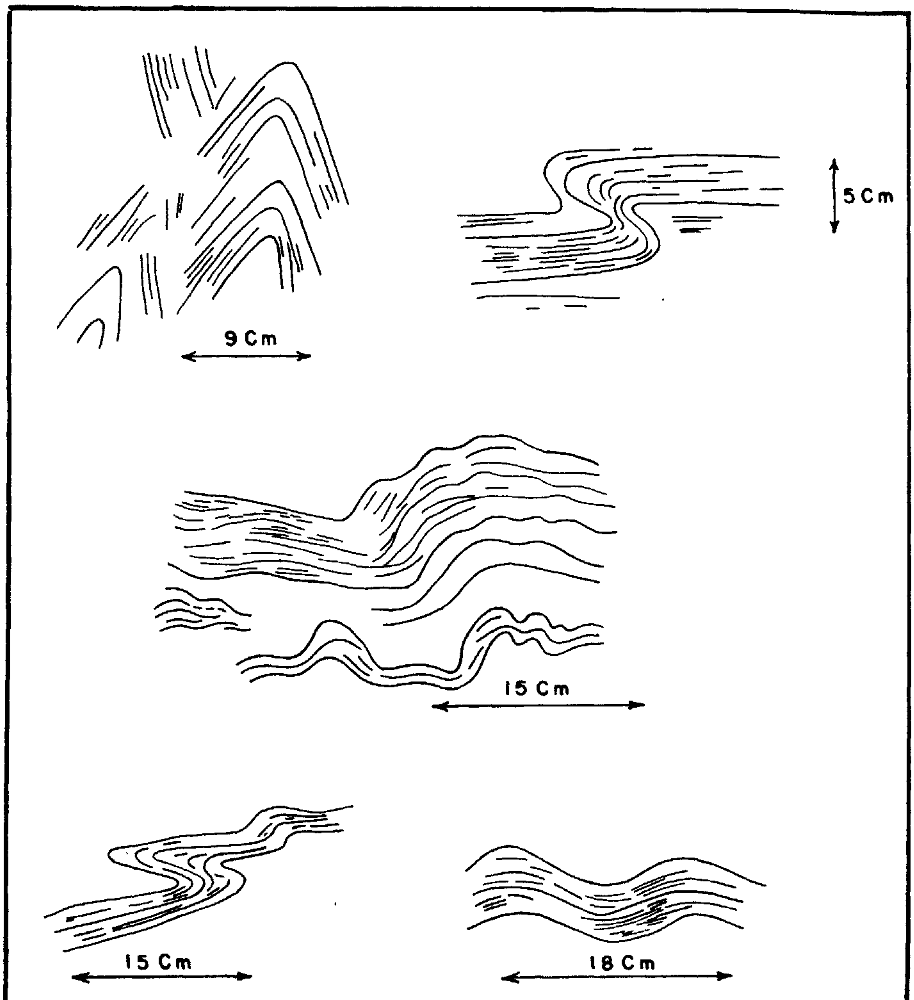

FIG. 8. Profiles showing styles of folds with axes parallel to *a*-lineations.

an angle to the pebble elongation as required by Oftedahl (1948). Although the exact mechanism is not clear, the field evidences strongly suggest that the pebbles were flattened and sheared on the same surface.

Several microfabric diagrams showing orientation of quartz *c*-axis in quartzites from different parts of the shear-zone were prepared to check the movement picture deduced from structures in the field and hand specimens. Due to extreme fineness of the grain sizes, fabric analysis was not possible for ultramylonites and mylonites. The fabric diagrams prepared for three types of quartzites, e.g. mylonitic quartzites, blastomylonites and strongly lineated non-mylonitic quartzites, exhibited a high degree of lattice orientation. The most salient feature of these diagrams is the presence of girdles of *c*-axis, either partial or nearly complete, around the megascopic *a*-lineation (Figs. 10A and B). Only one diagram showed orthorhombic symmetry of orientation of the *c*-axis, while all the other diagrams revealed monoclinic symmetry of orientation with *bc* as their only symmetry plane. A number of maxima are arranged in a girdle in these diagrams.

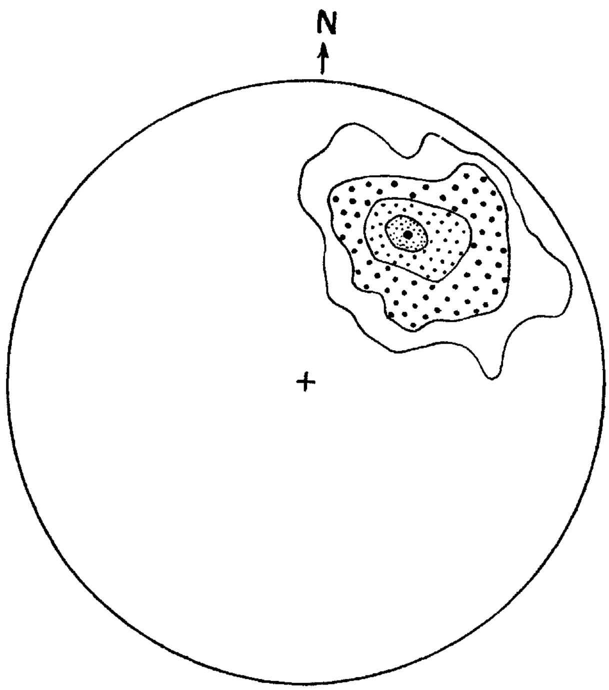

FIG. 9. Poles of 200 *a*-lineations. Contours: 1–5–13–17 per cent. Maximum 21 per cent.

Microfabric diagrams showing *bc*-girdles have been reported by almost all the workers who have made structural studies in the Singhbhum thrust-belt (De 1957; Naha 1958, 1959, 1965; Banerji 1959; Roy 1964, 1966*a*; Sarkar 1964). And the Singhbhum thrust-belt is not an exceptional case. Similar '*bc*-girdles' have been recorded by other workers from thrust-belts in other parts of the world (Strand 1944; Kvale 1945; Cloos 1947; Balk 1958).

The most significant feature of the fabric diagrams from the present area is that '*bc*-girdles' are restricted only to the rocks of the 'thrust-belt'. The diagrams prepared from the quartzites south of the thrust-belt do not show any definite girdle pattern or maxima (Fig. 10D). Although microfabric

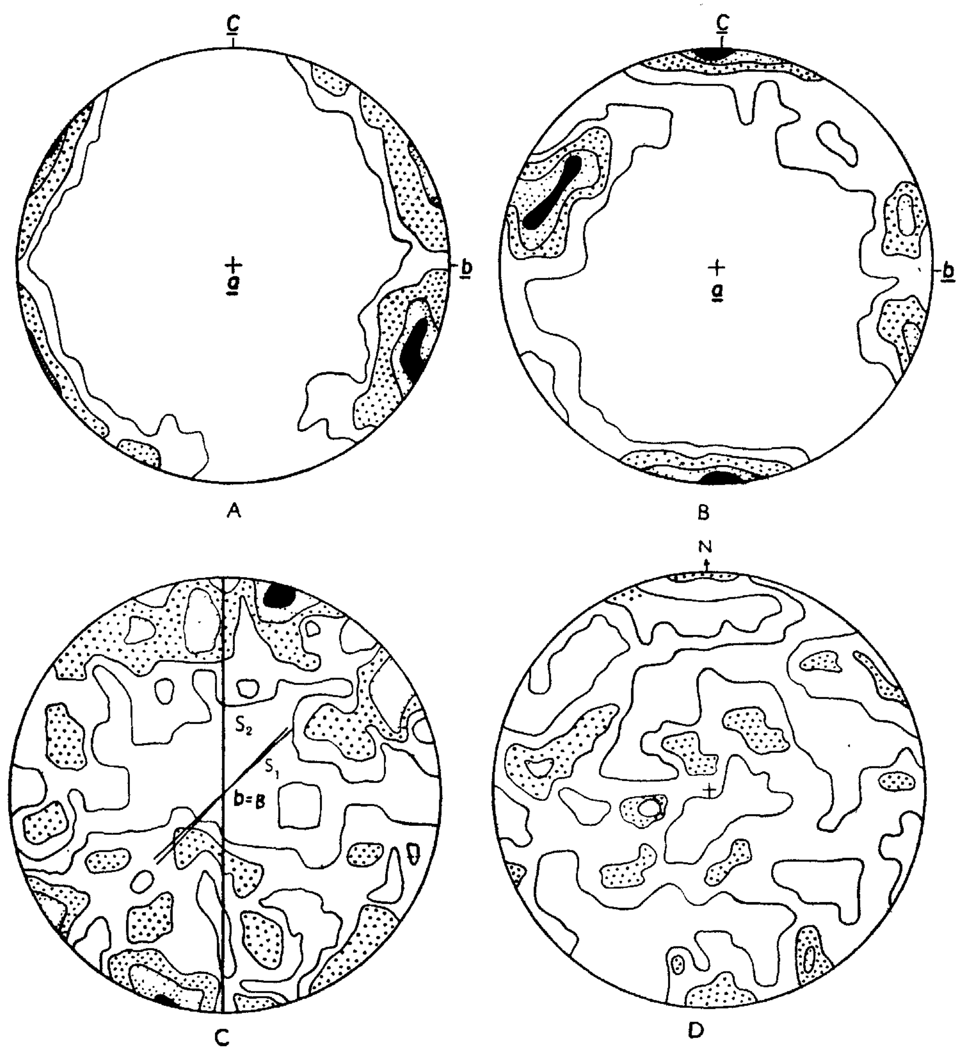

FIG. 10. Orientation diagrams of *c*-axes of quartz. Equal area lower hemisphere projection. (A) Poles of 200 *c*-axes from *bc*-section. Contours: 1–3–7–11 per cent. Quartzite, about 3 km SE of Kuku Dungri. (B) Poles of 200 *c*-axes from *bc*-section. Contours: 1–3–5–7 per cent. Quartzite from Kuku Dungri. (C) Poles of 100 *c*-axes from *ac*-section. *b*-lineation is defined by the intersection of stratification laminae (S_1) and axial plane foliation (S_2). Contours: 0·5–1·5–3·5–6·5 per cent. Quartzose mica schist from Bankati, about 11 km north of the main shear-zone. (After Naha 1959). (D) Poles of 200 *c*-axes measured from a horizontal section. No linear structure is present in the rock. Contours: 1–2–3 per cent. Quartzite from near about Baliposi, about 1 km south of the thrust.

data are lacking for a major part of Singhbhum, it is evident from available literatures that, away from the thrust-belt, *bc*-girdles are not prominent. The microfabrics obtained by Naha (1959) from Ghatsila area immediately north of the thrust-belt show girdles normal to large-scale regional fold axis (*ac*-girdles, Fig. 10C). Thus, it appears certain that the '*bc*-girdles' are present only in the thrust-belt and must be related to the movement during thrusting.

Conclusions

The structural study in the thrust-belt leads one to the following conclusions:

(1) Mineral lineation, streaking, major axis of deformed pebbles present in the shear-zone are *a*-lineations with respect to the movements in this zone.
(2) Folds and puckers with axes parallel to *a*-lineations have formed during the shear movement.
(3) The elongated pebbles, with major axes parallel to *a*-lineations, were stretched and flattened on the same surface on which they are now oriented.
(4) The axes of the fabric girdles are parallel to the direction of tectonic transport (determined from the megascopic fabric).

The thrust, though drawn as a line between Narainpur and Sindhukopa in central Singhbhum, is not clean-cut in nature, but forms a zone. The major strain must have been released through shear planes distributed over an wide area. The presence of a single set of shear foliation in this terrain supports the theory of deformation by shearing on one set of *s*-planes.

The sense of the movement direction has been determined from the attitude of small-scale folds on the shear foliation (*ab*-planes). These folds have axial planes sub-parallel to their limbs. These are overturned folds, and the direction of overturning indicates up-dip movement during shearing (Balk 1952). The movement was not, however, strictly up-dip as the *a*-lineations in most cases pitch between 50° and 60° on the foliation planes.

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