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Structural Geometry and the Time-Relation of Metamorphic Recrystallization to Deformation in the Precambrian Rocks near Simulpal, Eastern India: Discussion

Mukhopadhyay and Sengupta (1971), who studied an area of about 15 sq mi in the Midnapur district of West Bengal, have inferred the presence of structures of three generations and consider the structural sequence to be representative of about 2,000 sq mi of the Singhbhum anticlinorium. They have observed cross-bedding in one point among discontinuous exposures in this zone of supposedly refolded isoclinal folds, and think the structure to be a synclinorium, complementary to the Singhbhum anticlinorium, more than 100 mi long and 15 to 20 mi wide. On the strength of cursory examination of the Galudih area to the west, they suggest regional isoclinal folding earlier than the mappable upright folds reported from that area up until this date. This interpretation has prompted them to relate the posttectonic metamorphism inferred in their area with the metamorphism supposedly postdating the early isoclinal folding in the Galudih–Ghatsila area, leading finally to a comparison with the metamorphic history of the Alps and the Scottish Highlands. Thus there is a discrepancy between the scale of observations and the scale of inferences.

From near Simulpal in the area described by Mukhopadhyay and Sengupta (1971), I reported what was at that time considered to be a rather unusual structure–a steeply plunging reclined fold–with northeasterly trend and a curving axial surface (Naha, 1959). That interpretation has been confirmed by Mukhopadhyay and Sengupta. From my experience with structures of the Galudih–Ghatsila area to the west (Mukhopadhyay and Sengupta, 1971, Fig. 2) I suggested that the Simulpal fold might be due to coaxial folding of the axial surface in a zone of northeast-trending folds overturned westward. Mukhopadhyay and Sengupta take the folds with east-southeast–striking axial planes to be earlier and the folds with north-northeast–striking axial planes to be later. In the Galudih area, from mapping of continuous quartzite beds with cross-bedding at hundreds of exposures, from lineations due to the intersection of bedding and well-developed schistosity, and from β axes of bedding poles, I worked out a series of nearly upright folds with fanning of axial planes and fairly uniform, gentle axial plunge toward east-southeast (Naha, 1956, 1962, 1965) (confirmed subsequently by Gaal, 1964). Three stages of deformations were reported, the first of which caused the large folds and axial-plane schistosity to develop. Isograds of progressive regional metamorphism were drawn, and the progressive metamorphism from the chlorite to the staurolite–kyanite zones were considered to be broadly contemporaneous with the folding movement. From experience in the Simulpal area, and from detection of local "earlier schistosity parallel to bedding in very thin micaceous bands within the quartzite" in the Galudih area (1971, p. 2260), Mukhopadhyay and Sengupta suggest a regional isoclinal folding prior to the development of the axial-plane schistosity and the upright folds in the Galudih area. Numerous cross-bedding data from this area indicate that the dip directions of the limbs and the plunge directions of the fold-hinges are invariably the directions of younger beds. Suggestion of regional isoclinal folding before the upright folding in the Galudih area does not, therefore, warrant any serious attention. One is, however, intrigued by the methods of analysis that can lead to such gross error in the deduction of fold geometry in an area where

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the evidence from top and bottom features is incontrovertibly against any isoclinal early folding. And the correctness of the structural interpretation of the authors in their own area becomes suspect.

Inferences by Mukhopadhyay and Sengupta, about the metamorphic history of the Simulpal rocks and the regional structural–metamorphic corelation, lean heavily on their interpretation of bedding-plane schistosity in thin micaceous zones within mica-poor layers. This schistosity has been taken by the authors as the first-phase schistosity parallel to the axial planes of the isoclinal early folds, whereas the dominant schistosity is the axial-plane schistosity of the second generation. In the only places where both of these schistosities are found in the Simulpal area, mainly bedding-plane schistosity is reported to be present in the thin micaceous layers, whereas in the thicker, more quartzose layers schistosity is of the axial-plane type of the second generation (Mukhopadhyay and Sengupta, 1971, p. 2253). It is well known that in mica schist and quartz-mica schist, the mica-rich layers invariably behave as incompetent materials as compared to the more quartzose layers. During folding the incompetent micaceous layers are more deformed than the associated competent layers. This explains the common observation that schistosity is better developed in incompetent micaceous layers than in more competent mica-poor layers. The same principle is applicable in cases of superposed deformation, where the new schistosity should be better developed in an incompetent micaceous layer than in a more competent mica-poor layer. Therefore, the inference of the authors, that the axial-plane schistosity in the mica-poor competent layers is of the second generation (without any trace of the earlier schistosity), whereas the dominant schistosity in the mica-rich laminae is of the first generation, is untenable. It may be pointed out that near-parallelism of schistosity and bedding, especially in thin incompetent laminae within much thicker competent beds, is expected wherever schistosity is associated with well-developed buckling or flexural-slip folds. Both theoretical arguments and experimental studies (Ghosh, 1966; Ramberg and Ghosh, 1968; Dieterich, 1969[1]) show that the AB planes of the strain ellipsoids are differently oriented in competent and incompetent layers, chiefly because of unlike amounts of layer-parallel shear strain in layers of different competence. The layer-parallel shear is larger in the less competent layers; hence the AB planes of strain ellipsoids make lower angles with bedding than in more competent layers. In particular, the amount of shear strain or flexural slip will be extremely high in *thin* incompetent laminae occurring in thicker, more competent layers as described by Mukhopadhyay and Sengupta, and as are present in the Galudih–Ghatsila area, resulting in near-parallelism of bedding and schistosity in the mica-rich laminae. Such an explanation seems more logical than a speculation of isoclinal early folding, particularly in a terrain like Galudih–Ghatsila where the evidence from top and bottom features makes any hypothesis of isoclinal early folding untenable.

Mukhopadhyay and Sengupta begin their thesis with the statement "The dominant schistosity throughout the area is parallel to the axial plane of the second-phase folds and cuts across the first-phase folds both on major . . . and minor scales" (1971, p. 2252). Neglecting for the time being the question of folds of different generations, this statement implies that on the scale of the map the dominant schistosity is parallel to the axial plane of some large folds, whereas it is oblique to the axial planes of some other mappable folds. Since this schistosity is the only dominant schistosity throughout the area, it must represent large deformation. Yet, it is surprising that the large-scale folds of the first generation are totally unaffected and are still cylindrical, as indicated by five of the six bedding-pole diagrams (Figs. 6a–6e). Again, in the small scale, no convincing evidence for concluding that the dominant schistosity is parallel to the axial planes of folds of a later generation has been presented by the authors. In none of the sketches of their Figure 4 are the folds on bedding affected at all by a later folding. Since the dominant schistosity shows a considerable variation in attitude throughout the area, the claim by the authors of crosscutting relation between the schistosity and the large-scale folds is also questionable on the following grounds: (1) Where competent and incompetent layers are present, the attitude of schistosity is expected to vary from layer to layer (cleavage refraction) and in different portions of a fold in the same layer. (2) Laboratory experiments on development of folds of different orders by

[1] The authors can profitably examine Figure 5 of Dieterich (1969), which shows near-parallelism of bedding and schistosity, and crenulation cleavage in the micaceous layers in folded quartzite–phyllite.

Ghosh (1968, Fig. 18) have shown that both the general style and the axial planes of folds of different orders may vary considerably, the axial planes of the small folds making a significant angle with those of the larger folds. Experiments on flexural-slip folding of foliated layers enclosing nonfoliated material by Weiss (1969, Pls. 15F and 16N) have also shown that the axial planes of folds of even the same order and of the same generation may vary considerably in attitude. It therefore follows that schistosity parallel to the axial plane of a small fold may develop oblique to the axial plane of a larger fold of the same generation.

Any elaborate discussion on the interpretation of structure and metamorphism in the Simulpal area is pointless as assumptions, assertions, and data are intermingled in the text, and data and interpretation are inseparable in the map.[2] Only a few points are mentioned here:

1. As has been briefly alluded to, five out of the six domains within three subareas show cylindrical folding in spite of the supposedly large-scale second folding. In domains where both hinges and limbs of early folds are involved in a later folding, the early fold axis would be distorted and the second fold axes would vary from point to point; any unique β is geometrically impossible. The only bedding-pole diagram which is supposed to show large-scale folding of the second generation is their Figure 6h. This diagram is ambiguous as no unique π-circle like the one shown by the authors can be drawn. Incidentally, it is unfortunate that the authors have divided the subareas further without giving any reason and without showing the demarcations in the map, so that reading of the map together with the projection diagrams becomes impossible.

2. The deductions on metamorphic history hinge on the interpretation of schistosities of different generations within and outside the porphyroblasts. Where the identification of the first-phase schistosity is debatable and its significance ill-understood, deductions on recrystallization–deformation relation on the basis of *si-se* fabric are entirely speculative. Furthermore, unpublished data collected by me indicate that the spatial variation of metamorphism in the Simulpal area is rather erratic. Until the authors present an isogradic map (similar to the maps presented by me from the Galudih–Ghatsila area and by Roy, 1966, from central Singhbhum), their contention that the "isogradic lines are quite regular" and "cut across the trends of the first and second generation major folds" (p. 2257) is unacceptable; I submit that it is difficult to draw a faithful isogradic map in this 15-sq mi area. Besides, even if the recrystallization–deformation relation in the Simulpal area is what the authors believe it to be, there is no reason to assume that the metamorphism here is coeval with that in eastern and central Singhbhum, where the interrelation of structure and metamorphism is much better documented. Therefore, the authors' correlation of the metamorphism at Simulpal with the metamorphism in the Singhbhum terrain is of dubious value, and their further intercontinental correlation of the Simulpal metamorphic history with that in the Alps and the Scottish Highlands is unfortunate.

Finally, there may be a case for the thesis of Sarkar and Saha (1962) that the northeast-trending structures east of Ghatsila have been superposed on the west-trending folds of the Galudih–Ghatsila area to the west. But there is no case for the assumption of Mukhopadhyay and Sengupta that the west-trending folds in the Galudih–Ghatsila area are preceded by isoclinal folding; their suggestion on metamorphic history of that area based on this assumption is therefore untenable. Beside being internally inconsistent, the thesis of Mukhopadhyay and Sengupta is disconcerting in its extrapolation of interpretations of doubtful validity from a very small area to a much larger region where the structural–metamorphic relations are much clearer.

[2] As bedding is not shown in the structural map (the bedding-plane trend map is very much generalized) it is difficult to check the bedding-schistosity relations. The linear structures are grouped as belonging to different generations; it is not clear how many of these are intersections, fold axes, and puckers. Strangely enough, the linear structures of the first and second generations are not differentiated in Figure 5, and no first-phase linear structure is plotted in the projection diagrams (Fig. 6).

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