ASHIT BARAN ROY *Department of Geology, University of Rajasthan, Udaipur, India*

# Significance of Variable Plunge and Trend of Small-Scale Upright Folds in the Type Aravalli Rocks around Udaipur, Rajasthan (Western India)


## ABSTRACT

The variable axial trend and plunge in the folds of the Aravalli rocks of early Precambrian age (2,500 to 2,000 m.y.) around Udaipur (lat 24° 35′ N.; long 73° 41′ E.) in southern Rajasthan, has been interpreted as being the result of interference of two periods of folding. The later folds with approximately north-south, steep axial planes are thought to have developed over an early set of overturned folds.


## INTRODUCTION

The different rock types exposed around Udaipur (lat 24° 35′ N.; long 73° 41′ E.) in southern Rajasthan, western India (Fig. 1) belong to a number of stratigraphic horizons, starting from the Banded Gneissic Complex—a supposed basement of primordial nature, with the Aravalli Formation and Delhi System of rocks forming the successive metasedimentary covers (Heron, 1953). The Aravalli rocks here comprise a thick pile of graywacke-slate-phyllite (Poddar and Mathur, 1965), calcarenite-orthoquartzite, and carbonaceous phyllite. Crawford (1970) puts the age of these rocks (Aravallis) between 2,500 m.y. and 2,000 m.y. old.

The most obvious structure in the Aravalli rocks around Udaipur is a set of upright to steeply inclined folds with approximately north-south axial trend in almost all scales of study. The trend of these folds conforms with the "Aravalli Strike" described by Krishnan (1953). According to Heron (1953), the phyllite beds around Udaipur form a simple "anticline or anticlinorium," while limestone forms the flanks of a syncline. More recently, Poddar (1966) suggested that the dominant planar structure of the area is of the "flow cleavage of axial plane type which maintains a regional homogeneity and is of subvertical attitude." Studies made around Udaipur by the present writer have brought to light many interesting facts having relevance to the tectonic history of the area. This paper deals with the variations noted in the plunge and trend of the upright folds and traces out their significance.

## GEOMETRY AND ATTITUDINAL VARIATIONS OF THE UPRIGHT FOLDS

The upright, north-south–trending folds vary considerably in their shapes, but their geometrical characteristics closely approximate those of concentric or parallel folds. The folds are on bedding surfaces, while the most pervasive schistosity present in the rocks appears to be bedding foliation type. Most of these folds are open with large interlimb angles, although some folds are tight or even isoclinal. A set of widely

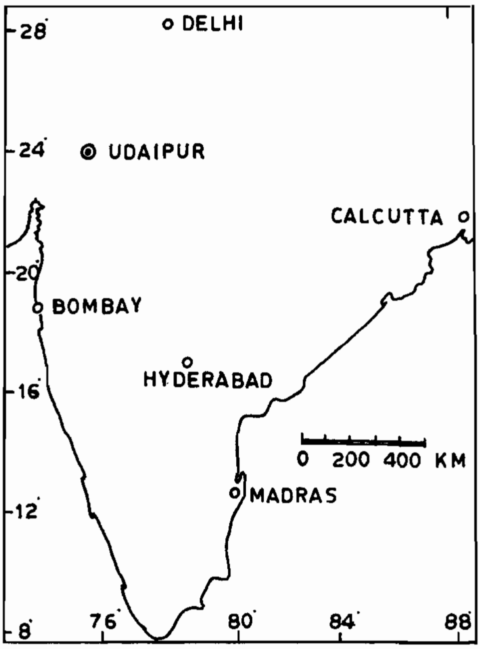


**Figure 1. Map of India, showing location of Udaipur area.**

Geological Society of America Bulletin, v. 83, p. 1553–1556, 6 figs., May 1972

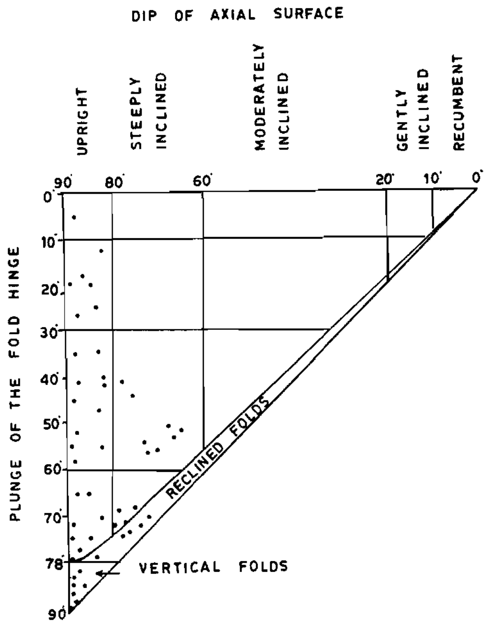


**Figure 2. Graphical representation of fold attitudes of Udaipur area (*after* Fleuty, 1964; and Ramsay, 1967).**

spaced crenulation cleavages has developed sporadically, subparallel to the axial surfaces of these folds.

The folds are grouped as upright, although the dip of their axial surfaces varies from vertical to about 65°. Thus the folds pass from upright (*sensu stricto*) to steeply inclined type. An even greater variation has been noted in the amount of plunge of the fold hinges. In Figure 2, the plunges of the fold hinges have been plotted against the dip of the axial surfaces to show the attitudinal variations of the folds (*after* Fleuty, 1964; and Ramsay, 1967). The figure brings out the following facts very clearly: (1) Most of the folds are upright with variable axial plunge from quasi-horizontal to vertical. (2) At least a few of the folds are reclined, having steep plunges with axial planes dipping at variable angles.

The swinging of the fold hinges in the north-south direction is not however absolutely unsystematic. When plotted on a stereonet (Fig. 3), the poles of the fold hinges scatter along a zone bounded by vertical to steep, approximately north-south axial surfaces. This feature is not definitely reconcilable to a cylindrical fold model having a unique axis over large areas. The domain of cylindrical folding must have been restricted to very small areas where the form surfaces (bedding foliation) were planar prior to folding. The gross noncylindri-

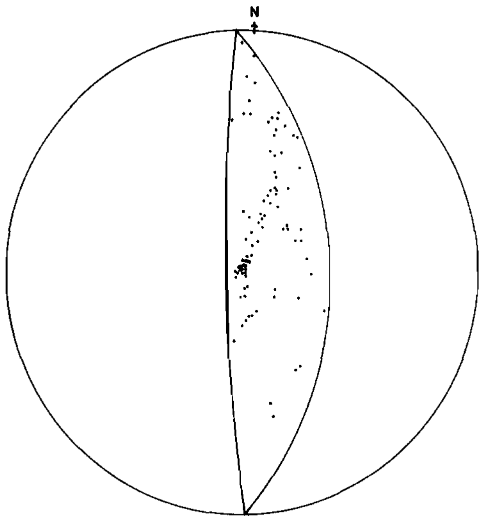


**Figure 3. Lower hemisphere projection of orientations of the "upright" fold axes (hinges).**

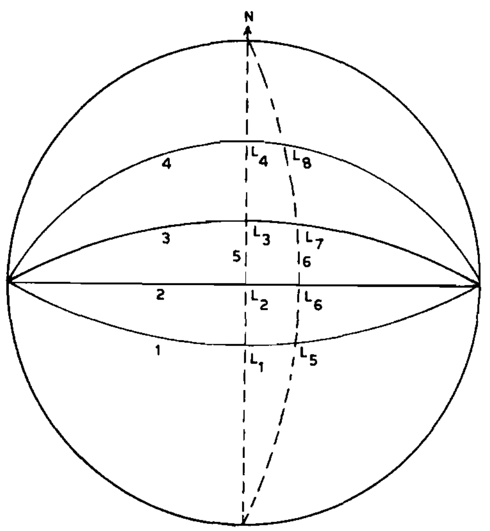


**Figure 4. Generalized stereogram showing the relations of second fold axes ($L_1$ to $L_8$) to the geometry of early form surfaces (planes 1 to 4) and the orientation of the axial surfaces of the second folds (planes 5 and 6).**

cal nature of the folds, as shown on Figure 3, suggests that these folds have developed on differently oriented surfaces. The argument is based on the principle that the attitude of any fold axis is given by the intersection of the axial surfaces of a given fold with the form surface (Weiss and McIntyre, 1957; Weiss, 1959). Thus if folds with subparallel axial surfaces develop on differently oriented bedding surfaces, the plunge of the fold axes (hinge surfaces) will vary depending upon the initial attitude of the

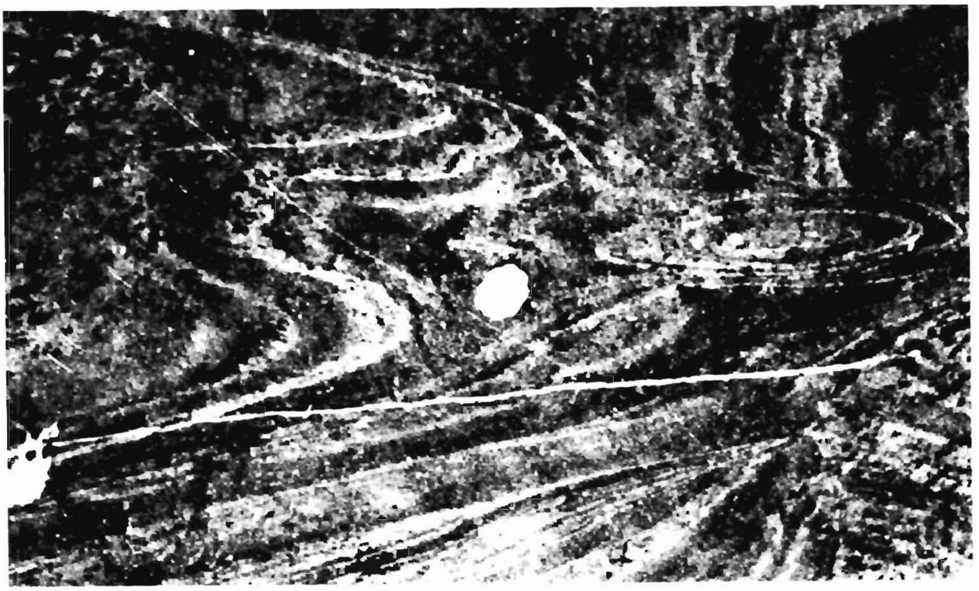

**Figure 5. "Eyed fold" formed by interference of two systems of folding in calcarenite. Diameter of the coin, 2.3 cm.**

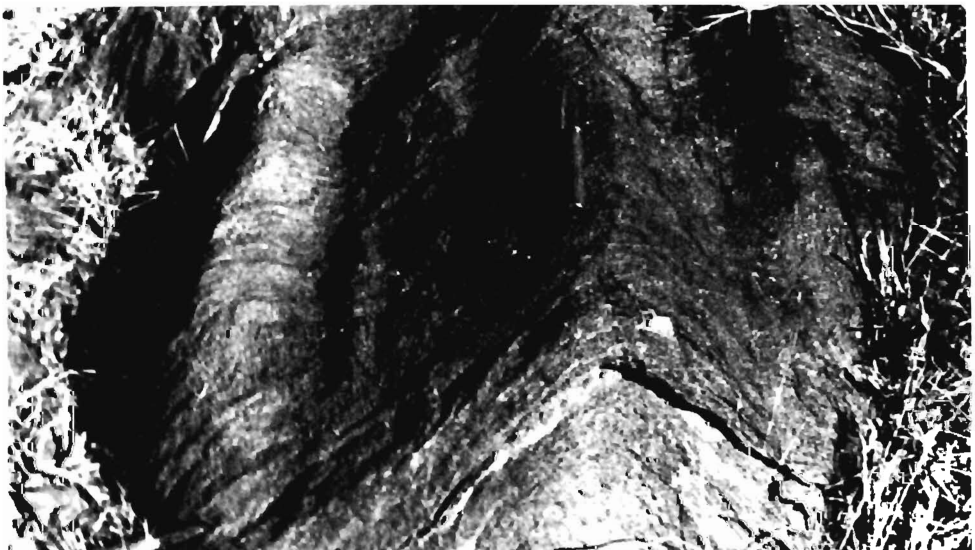

**Figure 6. Deformed early lineations over the hinges of late upright folds. The late folds show noticeable plunge variations.**

bedding surfaces. The systematic variations of the plunge of the upright folds (*sensu lato*) from low to vertical, through moderate and steep, would therefore indicate their development over overturned folds. The vertical folds would locate the positions of hinges, while the upright folds with low to moderate plunge would locate the limb regions of early folds (*compare* Naha and others, 1966; Naha and others, 1969).

Although many of the folds are oriented

north-south, a considerable variation in trend has been noted in quite a few others. This variation in the trend constitutes another significant feature in the Aravalli rocks of this region. With the axial planes striking north-south, the trend of the fold hinges swings between north and south through northeast, east, and southeast. Such a variation in the trend of the folds, however, occurs only when their axial planes fan out between 80° to 65° east. But the fanning of the axial plane of these folds alone cannot explain their diverse trend. Here again the presence of differently oriented planes is to be presumed prior to the formation of these folds, to explain the apparent anomaly in their trend. The geometric basis of this argument is shown diagrammatically in Figure 4, in which planes 1 to 4 represent differently oriented planes folded on vertical (plane 5) and easterly dipping (plane 6) axial planes. $L_1$, $L_2$, $L_3$, and $L_4$ are the resultant lineations (fold axes) when the axial plane is vertical, whereas $L_5$, $L_6$, $L_7$, and $L_8$ are the lineations when the axial plane dips easterly at a moderately steep angle. The diverse trends indicated by the latter set of lineations explain the similar feature observed in the folds of this region.

## CONCLUSION

The geometry of the fold structures of the Aravalli rocks around Udaipur, is suggestive of the presence of differently oriented bedding planes prior to the formation of these folds. This suggests at least two periods of folding in this region. The direct evidence of superposed folding is furnished by the presence of a few refolded folds in which upright folds have refolded an earlier set of folds at both small and intermediate scales. The early folds are usually extremely compressed with extended hinges (flattened parallel type of Ramsay, 1967). Even when the limbs of the upright folds extend for long distances, the details sometimes show the presence of compressed isoclines with very sharp hinges. These early folds are intraformational for the most part and are commonly misinterpreted as being bands that have pinched out due to sedimentary facies change. Small-scale "eyed folds" (Fig. 5) also suggest superimposition of two fold systems.

Further evidence of superposed folding is provided by universally present, deformed lineations over the hinges of the upright folds (Fig. 6). These lineations (usually fold mullions occurring as very fine cylindrically curved surfaces) are subparallel to the hinges of compressed isoclinal folds. A few measurements have shown that the angle between the deformed lineations and the hinge of upright folds bears a constant angular relation. This would suggest that the lineations are early and have been deformed by flexural folding of the surfaces on which they lie (Ramsay, 1960).

## REFERENCES CITED


Crawford, A. R., 1970, The Precambrian geochronology of Rajasthan and Bundelkhand, northern India: Canadian Jour. Earth Sci., v. 7, p. 91–110.

Fleuty, M. J., 1964, Description of folds: Geol. Assoc. Canada Proc., v. 75, p. 461–492.

Heron, A. M., 1953, Geology of central Rajputana: India Geol. Survey Mem. 79, 389 p.

Krishnan, M. S., 1953, The structural and tectonic history of India: India Geol. Survey Mem. 81, 109 p.

Naha, K., Chaudhuri, A., and Bhattacharyya, A. C., 1966, Superposed folding in the older Precambrian rocks around Sangat, central Rajasthan, India: Neues Jahrb. Geologie u. Paläontologie Abh., v. 129, p. 205–231.

Naha, K., Venkitasubramanyan, C. S., and Singh, R. P., 1969, Upright folding of varying intensity on isoclinal folds of diverse orientation: a study from the early precambrians of western India: Geol. Rundshau, Bd. 58, p. 929–950.

Poddar, B. C., 1966, An example of contrasted tectonic regimes from the Precambrians of Udaipur District, Rajasthan: Indian Minerals, v. 20, p. 192–194.

Poddar, B. C., and Mathur, R. K., 1965, A note on the repetitious sequence of graywacke-slate-phyllite in the Aravalli System around Udaipur, Rajasthan: Geol. Soc. India Bull., v. 2, p. 83–87.

Ramsay, J. G., 1960, Deformation of early linear structures in areas of repeated folding: Jour. Geology, v. 68, p. 75–93.

——— 1967, Folding and fracturing of rocks: New York, McGraw-Hill Book Co., 568 p.

Weiss, L. E., 1959, Geometry of superimposed folding: Geol. Soc. America Bull., v. 70, p. 91–106.

Weiss, L. E., and McIntyre, D. B., 1957, Structural geometry of Dalradian rocks of Loch Leven, Scottish Highlands: Jour. Geology, v. 65, p. 575–602.


Manuscript Received by the Society November 1, 1971

PRINTED IN U.S.A.