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Deformation of Rocks of the Mahakaushal Super Group around Barman, the Narmada Valley, Narsinghpur District, M. P.

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Abstract: ***The rocks of Mahakaushal Super group exposed around Barman along the Narmada Valley has suffered the two phases of the deformation in the early proterozoic period, phase one accounts for shearing movement (E1), followed by phase two (E2 and E3) which caused folding episodes (F1 and F2) in the rocks. The first fold structures (F1, related to E2) caused by a combination of tangential longitudinal strain and oblique flexural slip, suggesting initial unsymmetrical disposition of rocks layers in relation to principal stresses which produced numerous slicken sided fibres which are unrelated to any recognisable faulting activity in the rocks. Cleavage contemporaneous with F1 folds shows slight transection in a few minor folds. In submacroscopic fold chains, the geometry of single or paired folds suggests their initiations in the north and gradual propagation to the south along the layering, newer folds probably appearing with the advancing stress front. The youngest structures (F2, related to E2) are broad flexural slip warps, lying at high angle to early folds. The shearing movement (E1) also caused intrusion of basic dikes and quartz veins. Intrusion of a second set of basic dikes was the youngest event in the area which is unrelated to any deformation or metamorphism.***

Keywords: tectonic, deformation, longitudinal strain, proetozoic, contemporaneous, shearing movement, stress front

1. Introduction

The field area lies 1 km ESE of Barman (23°02'N: 79°01'E) in the Narsinghpur district of Madhya Pradesh It consist of rocks of Mahakaushal Super group (Proterozoic age), exposed along about 1.5 - 2km long course of the Narmada river, on sides of the bridge on N. H 26. The geology on the banks comprises alluvial cover, the nearest exposures of similar rocks are found in few villages on the northern bank and along the river course.

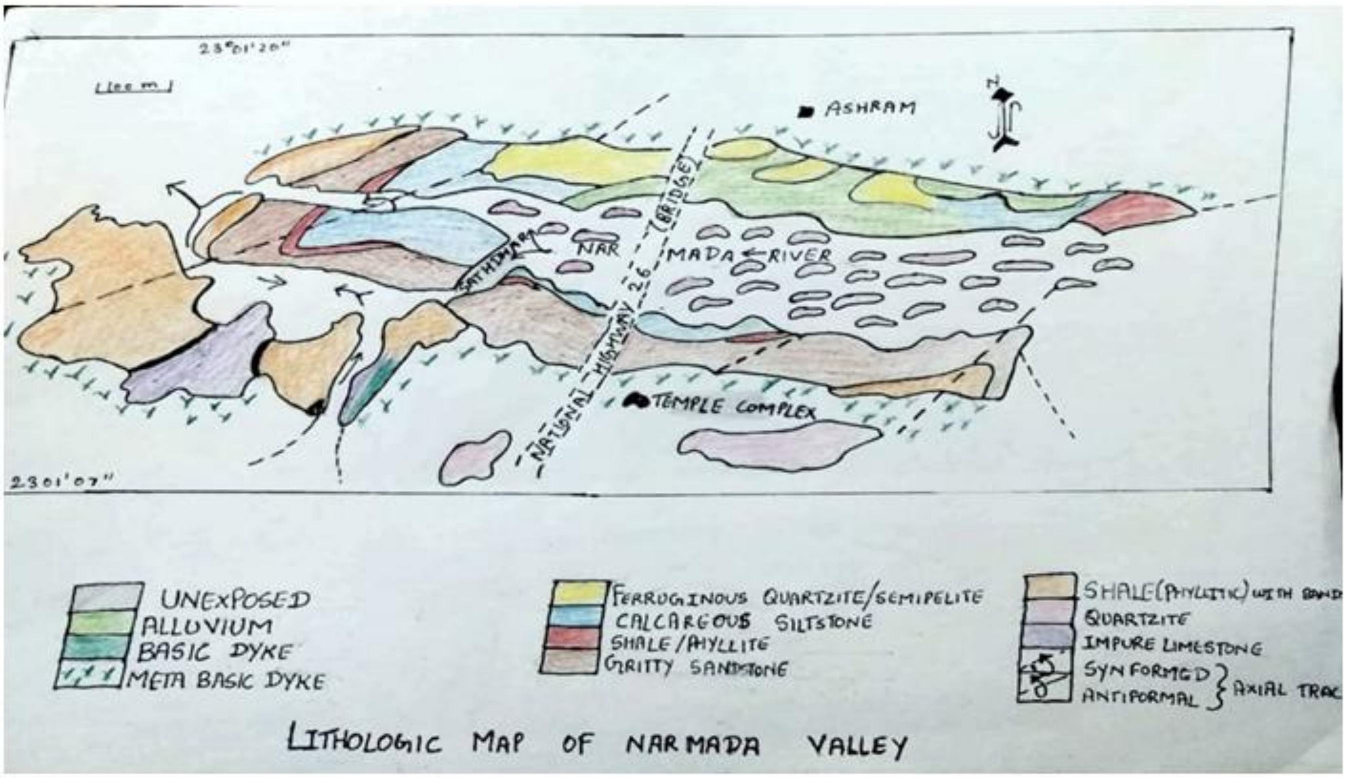
Das et al., (1975) and Roday mapped a small area near Hiranpur village (about 7 km NNE of the bridge) and correlated these lithostratigraphic units with Bijawar rocks in the Chhatarpur district of Madhya Pradesh. these rocks are supposed to be affected by conjugate shear zone.

Lithology: The general lithology of the area comprises the rocks from early proterozoic to recent time. Rocks of early proterozoic include Limestones, Shales, Phyllites, Sandstones, Quartzite and intrusive which are unconformably overlied by Deccan Basalts and Intertrappean Limestone of upper cretaceous. Thick cover of river alluviam forms the youngest litho unit of recent time.

Table 1

Table 1 Showing overall lithology of Mahakaushal Group of rocks in Barman area

Recent	Alluviam
Upper Cretaceous	Deccan trap Intertrappean limestone Deccan Trap basalt
	................Unconformity......................
Eaerly proterozoic	Basic and Meta Basic intrussive dyke Ferruginous Quartzite /semipelite Calcareous siltstone Ferrugenous Phyllite / shale Yellow shales Gritty sandstone Impure Limestone Brecciated Quartzite Quartzite interbedded with black chert
	-------------Base not unexposed---------------



Geology:

The older Quartzite are white to light grey in colour with few thin bands of Black Chert in it. Brecciated Quartzites are exposed near Bitli hill beside Sagar Narsinghpur highway. Impure limestone, at places dolomitic, is interbedded with the chert layers, possibly syn - jointed pink quartzite in which quartz occurs in optical continuity with siliceous - ferruginous cement. Both the units are emplaced along their bedding planes by quartz veins.

The most widespread occurrence is of gritty sandstone, at places much quartzitic , interlayered with numerous shaly or phyllitic bands in its basal 8 m, while the upper 2m are predominantly arenaceous. The latter portion is coarse grained and prominently graded bedded in the upper part whilst the lower is relatively finer and mainly cross - bedded. Burrow structures with random movement are sometimes noticeable on the gently dipping bedding planes, in contact zone with overlying phyllitic member. Graded and cross - beds show a right way - up for considerable strike length: only at the northwestern and southeastern extremities is the pronounced inversion suggested. The argillaceous bands are deep yellow to maroon in colour. Sigmoidal tension gash veins are slectively developed in this lithology especially in the upper arenaceous part. Gritty sandstone is overlain by a 1 - 5 m thick layer of phyllitic unit. Pressure solution seams and cleavage axial planer to F1 folds is well developed.

Calcareous siltstone is dark grey to black in colour and shows development of pressure solutions seams related to shearing movement. The cleavage , axial planer to F1 folds, whose excellent refraction can be noticed in a vast number of sections. This unit attains a maximum thickness of 8 to 10 m and is devoid of tensile veins. The youngest lithologic unit of proterozoic is a ferruginous quartzite, tending at places to be semi - pelitic. It is chocolate brown to red in color and is copiously intruded by basic material along and across its bedding planes.

All these rocks are unconformably overlain by Deccan basalt and intertrappean limestone of cretaceous period however their exposoures vary place to place. Younger alluviam of river Narmada is the youngest deposite in the area.

(A) Dolomite with Alluviam exposed in Chawarpatha

(B) Exposoures of Quartzite and Phyllites along the bridge

Igneous Intrusives –

Rocks of the area are intruded by 2 dykes, one possibly syn - E1 and the 2nd is post - tectonic. Younger dyke is undeformed and unmetamorphosed, being coarse and doleritic while the older dyke is slightly ambhibolitic and metadoleritic in composition containing deformed xenoliths and amygdules. Strain analysis has suggested the symmetry of deformation to be close to plane strain. The dyke was possibly emplaced in contemporaneity with the shearing movement and evolved before folding F1. contacts of dike with invaded rocks are much infiltrated with veins and stringers. The dyke is olive to pistachio green to grey in color and shows spheroidal weathering. There are also found excellent cleavage mullions related to F2 folds. The dyke intruded gently, having trend EW and is emplaced vertically. The younger dike trends N 68°, grey to black in color having no evidence of deformation and hence considered post tectonic. It is inclined steeply to the north.

(A) Metabasic Dyke & Quartz vein intrussion in Phyllite

(B) Quartz veins intruded in Metabasic Dyke

Structures - In 2 phases of deformation, this area witnessed 3 generations of structural trends designated as E1, E2and E3 here

E1 structures: The earliest deformation was caused by a dextral shearing movement along NS line. In different parts of the horizon sigmoidal veins and tension gashes were developed in arenaceous lithogies like gritty sandstone. This being a function of the composition variation in the same unit, all veins are approximately 15 to 25 cm wide and separated by similar interval tending NS. The filling of quartz in the veins is derived either by diffusion from the wall rock or by deposition from siliceous solutions, apparently supplied by the fractionation of the accompanying basic intrusion. The amount of shear computed by analysing these veins (Ramsay and Graham, 1970) varies from 0.5 ϒ suggesting the mean displacement across the entire zone to be of the order of 140 per cent. Bedding planes are the areas where the maximum sigmoidality is usually reported, which implies that the maximum displacement vector lay at a high angle to bedding. Two sets of gashes usually occur conjugate to each other (Shainin, 1950; Roering, 1968).

High angle pressure solution cleavage also accompanies the veins. The folding of cleavages is found similar to the axes of F1 fold which implies that the shear movement predates the earliest folding in the rocks. The trnd of the cleavages lies approximately NW - SE, at 45° to the directions of similar shear. The veins generally propagate in N45°. Price (1966) suggested that the veins were produced due to high pore water content in deforming sediments. Narrowing of vein spacing across pressure solution seams and variable width of mesoscopic shear zones suggest the deformation to be one of volume reduction.

(A) Sigmoidal veins plunging towards river

(B) Folded strata exposed beneath new bridge

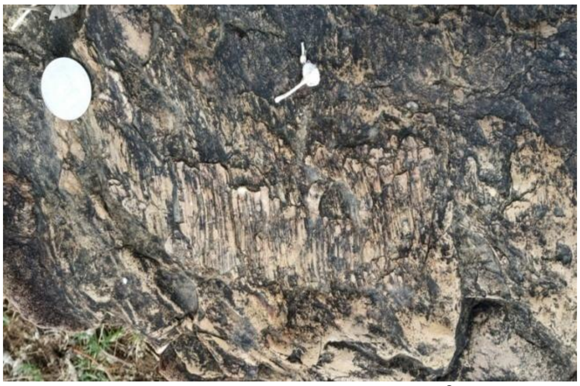
E2 Structures: This episode of deformation caused folding F1 in the rocks on both major and minor scales. These folds are symmetrical or overturn to the North and plunge roughly ENE up to 21°. While the normal limb trends approximately ESE and dips North gently, the overturned limbs trend cast or ENE and dip north or NNW moderately to subvertically. Many minor folds are, however, asymmetrical with one limb vertical and their axial surfaces inclined moderately or steeply to the North. A slaty cleavage accompanies these folds, which trends approximately EW and dips North and a few minor folds shows transaction (Powell, 1974; Borrodaile, 1978) with angular departure between fold hinge and cleavage trace up to maximum 22°, but generally less then 10°. The fold hinges generally trend N61°, but the cleavage trends roughly EW. The fold profile shows a class 1 B to 1 C geometry (Ramsay, 1967) and a marked differential flattening. These folds evolved from combination of tangential longitudinal strain (Ramsay, 1967) and flexural - slip; the former is adduced by extension fissures parallel to fold hinge, the latter by slickensided fibre growth on layer surfaces. The lineations developed are cleavage mullions and ellipsoidal axes of quartz in more psammitic units.

Slickensided fibrous growth:: Slickensided fibres of quartz are reported on bedding planes in gritty sandstone, growing principally across one plane to another through a small angle not exceeding 5°. Quartz constituting the fibres are presumably derived by diffusion from the deforming translating rock layers. These are unrelated to any fault movement. The field evidence suggested that these were produced as a result of flexural - slip between layers during the buckling process.

The slickensided fibres do not always lie exactly at right angles to the fold hinge, rather then they make an angle less than 90° with the fold hinge lines On the Overturned limbs, the fibres plunge approximately northwards . on the normal limbs however the fibre plunges vary from ENE to SE. The departure from the ideal hinge - normal trend in most cases suggested that the folds evolved by symmetrically with references to the principal stresses (This perhaps implies that the present plunge of folds evolved as plunging ones, schematically shows how the trend of slickensided fibres would vary on to the principal strains, by oblique flexural - slip The deformation considered in this case is one of plane strain).

The angle between the slickensides and strikes of bedding, shows variation. This shows that higher values are found on the overturned limbs. The fibres consist of essentially of quartz and found on the layer surfaces of predominantly arenaceous units only, e. g. gritty sandstone. The fibres occur in steps suggesting break in incremental slips on uneven surfaces of layers (Durney and Ramsay, 1973). On a single surface, the fibres are sometimes curved suggesting rotational slip of layers during buckling. In this case, the fibres away from hinge line are always disposed at a larger scale.

One more fascinating feature is the presence of algal structures in Phullitic rocks representing biological activities in the area.

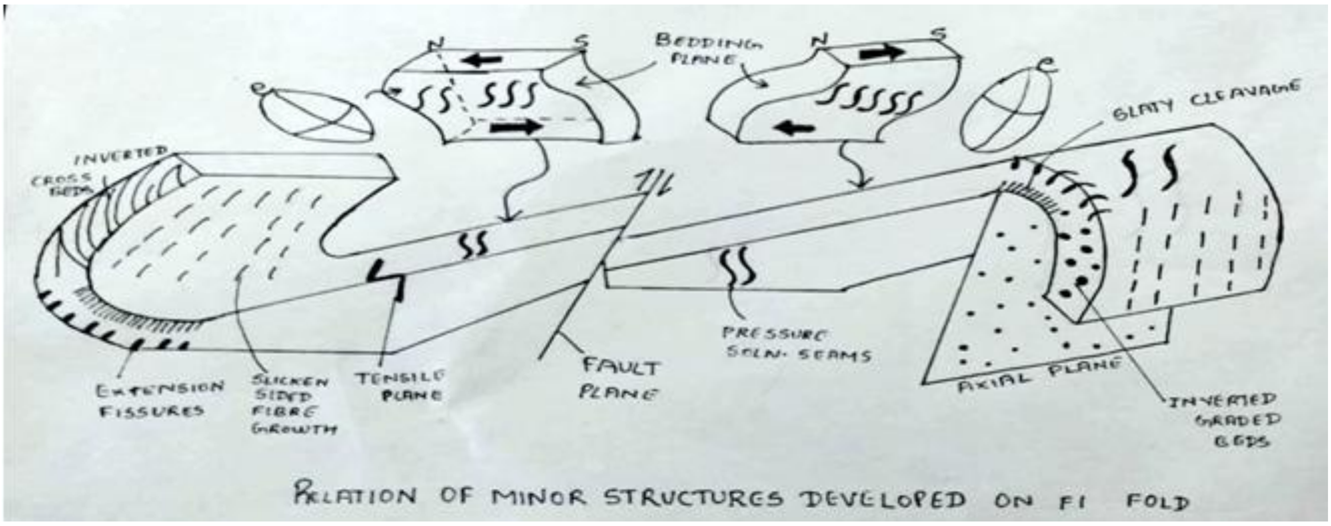


A. Slickensides striking N125°

B. Algal structures in Phyllite

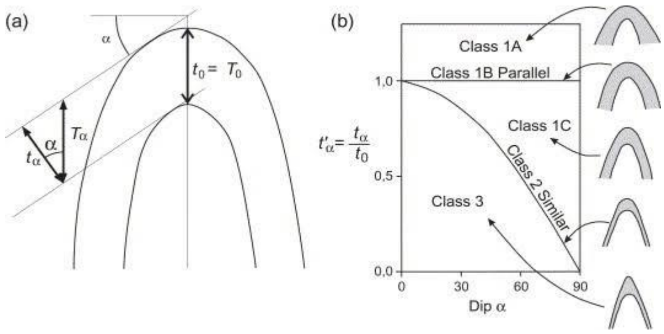
Cleavage /fold relation: transected folds evolve owing to time lag between inception of folding and development of cleavage in case of non - coaxial (Hobbs, et al., 1976) strain history (powell, 1974) and rarely in case of a coaxial strain history as well (Borrodaile, 1978). Since cleavage always developed parallel to the principal plane of the ellipsoid, this is more commonly observed in case the rocks have undergone non - coaxial deformation. The delay in cleavage development may be due to the early forces bringing about only some intergranular adjustments or 'grain boundary sliding ' with actual ductile flow probably occurring rather late in the fold history (Powell 1974). Powell has described examples of transected folds from the Precambrian rocks of Tasmania and Borrodaile (1978) has described many examples from Canada and Scotland. The latter has also described two limiting geometrical parameters between which they encompass all kinds of transected folds.

Number of minor structures is developed on the folded strata and their origin and orientation can be understood through the schematic diagram that how these structures are related to folding, faulting and bedding planes in both the limbs. Extension fissures, slickensided fibers, slaty cleavages, pressure solution seams and inverted cross beds are developed in both sides of the fault plane that can be seen clearly in the diagram.



Folds of the area can be divided into three categories:

a) Type 1: Folds in cleavage is apparently axial planer in their profiles but the trend of cleavage is different from that of the fold hinge In case of an upright fold plunging north.
b) Type2: Fold in which cleavage is not axial planner in fold profile but its trnd is the same as that of the fold hinge. In case of an upright non - plunging fold trending north.
c) Type 3: Combination of type 1 and type2, i. e. folds in which cleavage is neither axial planner nor is it trend parallel to fold hinge. In case of an upright non - plunging fold trending north.



Refraction of cleavage: In well - laminated rock types such as calcareous siltstone / shale/slate, refraction of cleavage converges towards the axial planes of minor folds while passing from a competent to relatively less competent band. In graded beds cleavage takes an arcuate form owing to rather slow change in competence from coarser to finer medium.

Fold formation and geometry: Folds are formed by a combination of tangential longitudinal strain (Ramsay, 1967) and flexural - slip. The former is supported by numerous extension fissures parallel to fold hinge in outer arcs of folded layers. A cleavage is noticed at the inner arcs. The position of surface of no finite longitudinal strain varies in minor folds and in fact it is hard to exactly place it in naturally developed folded layers. The flexural - slip appears to have been more dominant, especially in the initial stages. It must have had a negative value (de Sitter, 1964) at the time of fold inception but the later development of folds must have occurred by increasing layer - parallel slip and accompanied in more mature stages by internal deformation in layers thus producing finite geometry that suggest the play of both the processes. Folds do not appear to have suffered any layer - parallel strain. Slight thickening of hinge areas and corresponding thinning of limbs, especially in less competent layers is particularly noteworthy. Also, stretching of layers parallel to axial surfaces is adduced by boudinage structures

Fold propagation: The tightness of folds in a single chain is variable together with other fold parameters. In any fold train, greater with other fold parameters. In any train, greater tightness and amplitude are observed at the northern end of the train suggesting that the first folds initiated at the northern end and newer folds formed by their serial propagation along the layering to the south (Cobbold, 1976). This probably implies that stress front migrated from north to south.

Apparent class 3 geometry: Folds exposed on subhorizontal river bed depict apparent class 3 geometry since these sections are at low angle to fold hinge. Dubey and Cobbold (1977) have studied fold propagation along their axes in experiment and have substandtiated their studies by natural examples from Bude and Cornwall in Southwest England. Their work has shown that a fold arising at a point of deflection has greater amplitude and tightness with a near chevron style at the point of origin but that it opens up progressively away the point of origin in either direction along the hinge line. A hinge at low angle to fold hinge would therefore cut layers of different curvature more often with outer layer having greater curvature than the inner
E3 structures: Folds related to this deformation (F2) are broad flexural - slip wraps, with large wavelength, small amplitude and slight asymmetrically Fracture cleavage related to these folds has produced mullion structures in more competent varieties. Mullions show variable plunge amounts and low directional stability due to superposition of earlier cleavage of variable attitude, a result of fanning. Besides, the fractures cleavage related to this deformation also shows considerable fanning.

Joints: There are well developed in gritty sandstone. Their trend shows greater frequency in the ENE region suggesting that these are probably extension joints formed by tangential in folded layers during the E2 episode. Another frequency in the WNW region is seen perhaps two sets shear fractures formed during E3 owing to EW compression which bisects the dihedral angle of shearing.

In the field area different sets of joints can be seen in the Phyllite, Quartzite and Sandstone

(A) Joint sets in Phyllite

(B) Joints in Quartzite

2. Conclusion

The rocks examined present evidence of three deformations. The first deformation was essentially shearing of partly consolidated rocks, accompanied by intrusion of basic dike and quartz veins. This resulted in several thousand tension gash veins whose sigmoidality suggests considerable displacement. Pressure solution seams accompany the tensile veins and the narrowing of veins across the seams is suggestive of the deformation but some volume reduction (Flinn, 1978; Ramsay and Wood, 1973; Powell, 1972; Knipe and White, 1979).

The first folds related to a second deformation and appear to have evolved by a combination of tangential longitudinal strain and oblique flexural - slip. Slickensided fibres were produced as a result of flexural - slip on bedding planes and appear to be unrelated to any fault movements in the area. Cleavage contemporaneous to folds shows slight transection, such folds have been divided into to three categories depending upon whether cleavage bears angular relation to the (A) fold hinge, (B) folds axial surface or to (C) both. Any strong departure from axial planner deposition is considered for the geometrical classification presented.

The youngest event in the tectonic history of the area is the intrusion of a second basic dike which shows no traces of metamorphism or deformation. As no younger rocks are seen in the area, its exact age relations cannot be known, but it postdates all the structures found in the Mahakaushal Group of rocks. Its trend is parallel to the F1 axes and it appears that the dyke was intruded along the pre - existing shear zones in rocks.

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