Geol. Bull. Univ. Peshawar, 1983, Vol. 16, pp. 1–10

OBSERVATIONS ON THE STRUCTURE OF THE MAIN MANTLE THRUST AT JIJAL, KOHISTAN, PAKISTAN

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ABSTRACT

Structures in the lower plate of the MMT at Jijal include a blastomylonite zone, Z-folds in the blastomylonite, and abundant slickensides in a breccia block. Blastomylonite foliation is cross-cut by intermediate granitic intrusive. A multi-stage history of the MMT involving (1) SE thrust motion on a deep shear zone, (2) uplift and granitic intrusion, (3) renewed thrust faulting and breccia formation at a shallow crustal level, and (4) folding of the MMT and cessation of thrust motion is suggested.

INTRODUCTION

The Main Mantle Thrust has been identified as one of a pair of suture zones that cross northern Pakistan (Tahirkheli *et al.*, 1979). It is very well exposed near Jijal (Fig. 1) where peridotite and garnet granulite are thrust over metasedimentary rocks of the Indo-Pakistan plate. The rocks of the overthrust block have been discussed in some detail (Jan, 1980; Jan & Howie, 1981), but little attention has been devoted to the rocks of the lower plate. These contain a substantial mylonite layer with dramatic fold structures that are clearly exposed along the Karakoram highway. We had the opportunity to make a study of significant field observations here.

A diagrammatic cross-section from Duber Nala to the MMT is shown as Figure 2. The large body of peridotite rests on a thin zone of breccia with serpentinite matrix (Khan & Tahirkheli, 1983). This breccia zone is separated from blastomylonite zone of similar thickness by the principal fault strand of this area. The measured attitude of this fault is N38°W 34°NE. Below this fault are rocks of the Indo-Pakistan plate, including psammitic paragneisses and cross-cutting intermediate granitic intrusions. The paragneisses are fine to medium grained, well foliated granitic gneisses with migmatitic lenses, pods and veins of pegmatite. Lo-

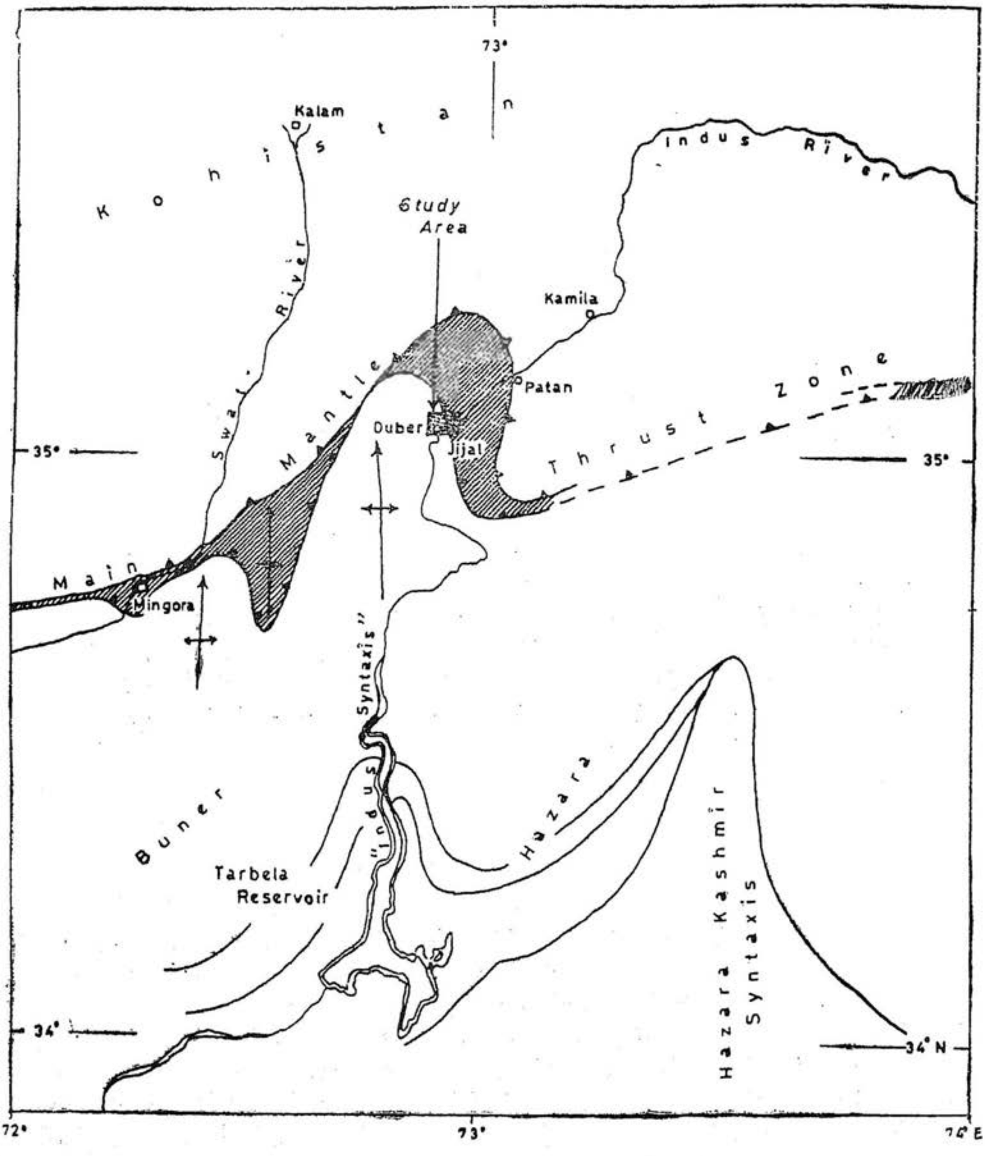


Figure 1. Location of study area along the Main Mantle Thrust Zone in northern Pakistan. Fold structures deforming the MMT are shown and related to the "Indus Syntaxis" of Calkins *et al.,* 1975.

cally layers of biotite, garnet and/or graphite schist confirm their metasedimentary origin. The blastomylonite zone beneath the main fault is developed in these paragneisses. They are intruded by several units of granitic rocks. The oldest of these is a foliated, fine to medium grained hornblende diorite which occurs as pods and dikes intruded parallel to the foliation of the paragneisses. A leucocratic grano-

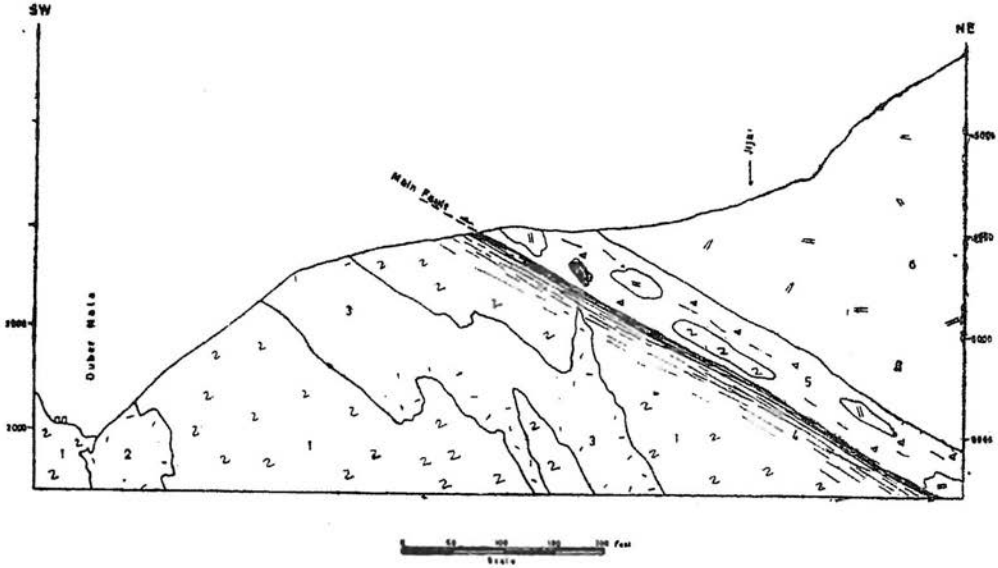


Figure 2. Cross-section northeast from Duber Nala through the MMT. Projected position of Jijal shown. Geology projected from Indus valley and Duber Nala to section line. Units are (1) Psammitic paragneisses (Salkhala ?), (2) Biotite granodiorite, (3) Leucogranodiorite, (4) Blastomylonite derived from paragneisses (5) Breccia with serpentinite matrix, and (6) Peridotite of Jijal complex.

diorite cross-cuts both the hornblende diorite and the blastomylonite layers. It does not cut the MMT, however. Near Duber, there is a coarser grained intrusion of biotite granodiorite. These intrusive granitic rocks must correlate to at least part of the Lahor granite (Ashraf *et al.,* 1980). Since they cross-cut the mylonite, they must be of Himalayan age and so cannot be related to the coarse grained augen gneisses of Mansehra and Swat.

These structural relations clearly define at least a two stage history on the MMT. Recrystallization of the peridotite and development of the blastomylonite layer would have taken place at great depth where the MMT was essentially a ductile shear zone and strain was distributed through a large volume of rock. A later stage of brittle faulting, localized serpentinization, and brecciation occurred at much higher crustal levels. Between these stages the granitic rocks were intruded and regional uplift occurred. The regional uplift may or may not have accompanied continuous activity on the MMT. Indeed, it seems probable that the second stage involved reactivation of the MMT originally developed during initial collision of the Kohistan arc with the Indo-Pakistan sub-continent.

MINOR STRUCTURES

We studied two sets of minor stuctures in the MMT zone that contribute valuable additional insight into the motion history of the fault. Minor folds are related to the development of the blastomylonite. Abundant slickensided joint planes in the breccia zone developed very late in the history of the MMT.

Large Z-folds in the blastomylonite are seen along the Karakoram highway just below Jijal (Fig. 3). The overall foliation of the blastomylonite is subparallel

Figure 3. Z-fold as seen along Karakoram highway below MMT main fault. Sketch drawn from photograph.

to the main fault of the MMT (fault = N38°W34°NE, average foliation = N 45° W 25°NE). The Z-folds developed in the blastomylonite foliation and have axial planes, S_2 subparallel to S_1. The axes of the Z-folds trend about 25°N30°E, that is, the fold axes are aligned almost directly down the dip of the fault (Fig. 4). Thus the vergence of these folds suggests strike-slip motion parallel to the strike of this low dipping fault. Such motion seems improbable and we suggest that these folds have been reoriented by subsequent folding of the MMT.

Calkins *et al.* (1975) have already inferred an antiformal structure along the Indus River near Tarbela Reservoir that they called the "Indus Syntaxis". The northward bend in the MMT west of Jijal (Fig. 1) can be interpreted as a gently plunging antiformal bend that prolongs this structure. Similarly oriented folds have been mapped in the Mingora area by Martin *et al.* (1962). If the Jijal area rocks are on the east limb of such an anticline and the anticline is unfolded to produce a smooth northeast striking, northwest dipping fault plane (Fig. 5), we find that the rotated position of the Z-folds axes is approximately horizontal. The restored vergence on these folds indicates thrust motion directly up the blastomylo-

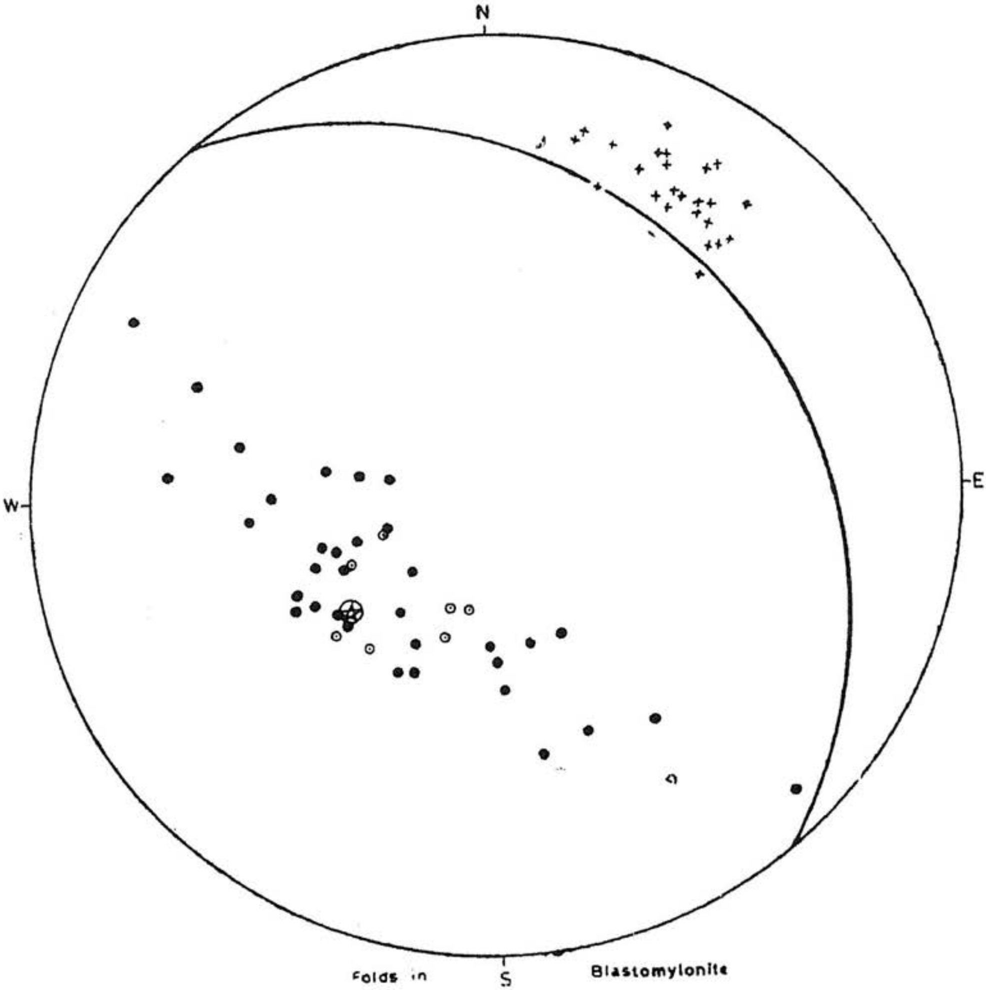


Figure 4. Equal area stereonet diagram showing measured structural features of Z-folds near Jijal. Solid circles are poles to S_1, blastomylonite foliation. Open circles are poles to S_2, axial planes of Z-folds. Crosses are axes of Z-folds. Large star is pole to main fault of MMT. Great circle is plane of main fault.

nite foliation. In Fig. 6, we have made a diagrammatic sketch of the current position of the Z-folds on the limb of the proposed post-faulting anticline.

Information on the most recent deformation of a brittlely deformed rock body can sometimes be determined from measurement of slickensided planes. Such data may often be interpreted in terms of faulting according to Coulomb's law such that slip occurs preferentially on the planes oriented at about 30° to the maximum principal stress (Regan, 1973). Less recognized is the possibility that slickensides may record motion between planes deformed during flexural-slip folding. We have

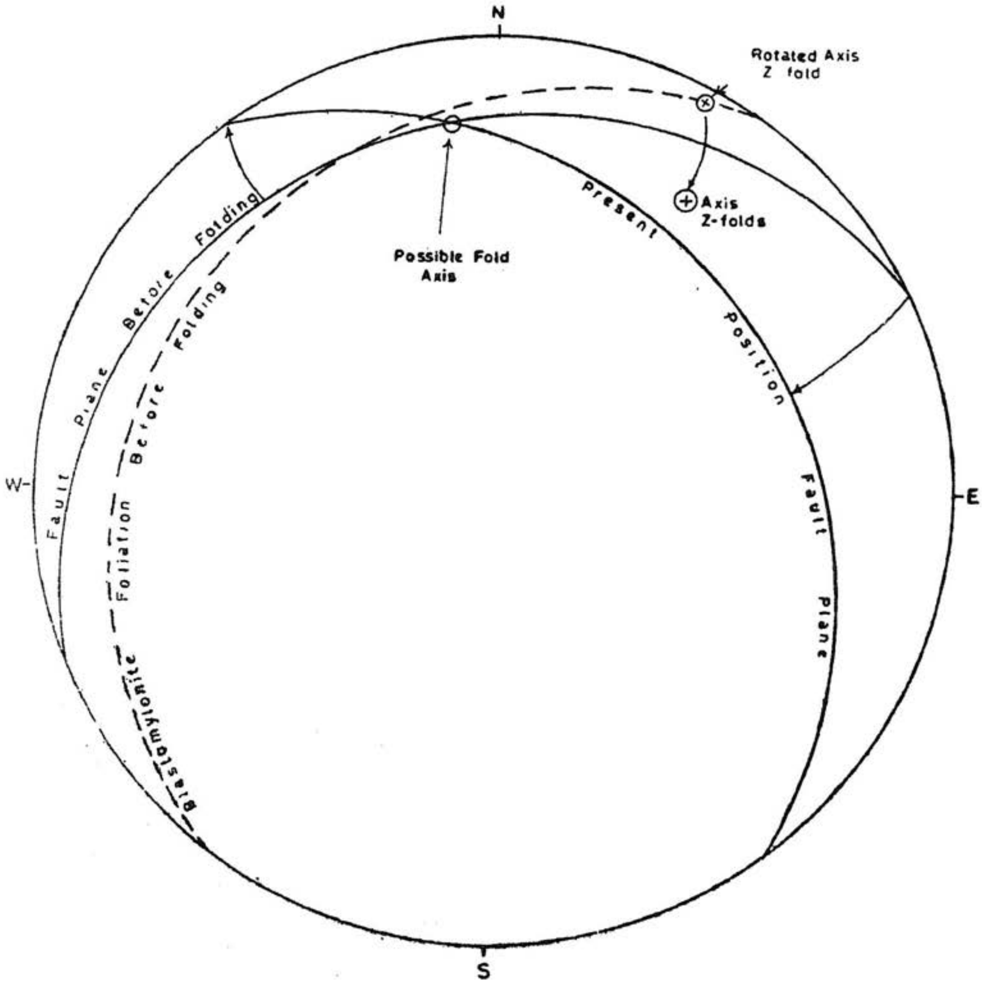


Figure 5. Equal area stereonet diagram showing effort to restore position of structures before folding of MMT on "Indus Syntaxis". Fold axis is estimated from regional geology and may contain significant error, even if hypothesis is correct. Unfolding of structures restores S_1 to position of about N 35°E 20°NW with Z-fold axes horizontal and vergence to the southeast.

recorded data (Fig. 7A and 7B) on 40 slickensided planes measured in a block of serpentinized pyroxenite about 20 meters across in the breccia zone just above the main fault of the MMT. Similar slickensides and minor faults were observed in the blastomylonites just beneath the main fault, but not in sufficient number to record. We interpret these slickensides as the result of flexural-slip folding during development of the "Indus Syntaxis" anticline. They do not show the kind of pattern expected in simple fault-related slickensides. Thus we consider these structures to support our interpretation of a large fold in the MMT as shown on Fig. 1.

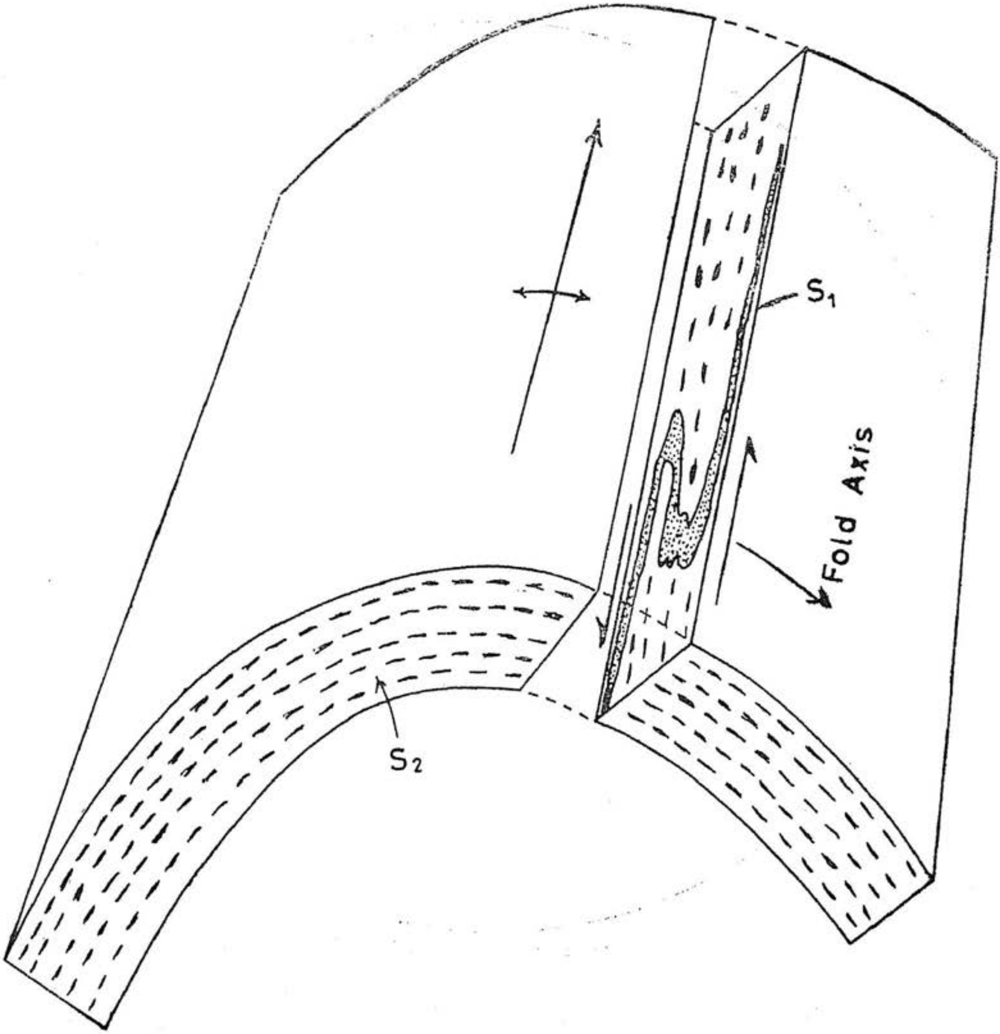


Figure 6. Block diagram illustrating the present position of the Z-folds in hypothesized "Indus Syntaxis" anticline. Shaded pattern shows folded S_1 and lines show S_2, both in blastomylonite.

IMPLICATIONS FOR THE HISTORY OF THE MMT

The observations reported above are incomplete and future field work will confirm or deny the interpretation that we have suggested. Our best account of the sequence of events recorded by the Jijal portion of the MMT is as follows.

1. Development of the Jijal ultramafic and garnet granulite complex at the base of the Kohistan Island Arc. Emplacement of the complex against the Indo-Pakistan continental crust upon collision in the early Tertiary.

Fig. 7A

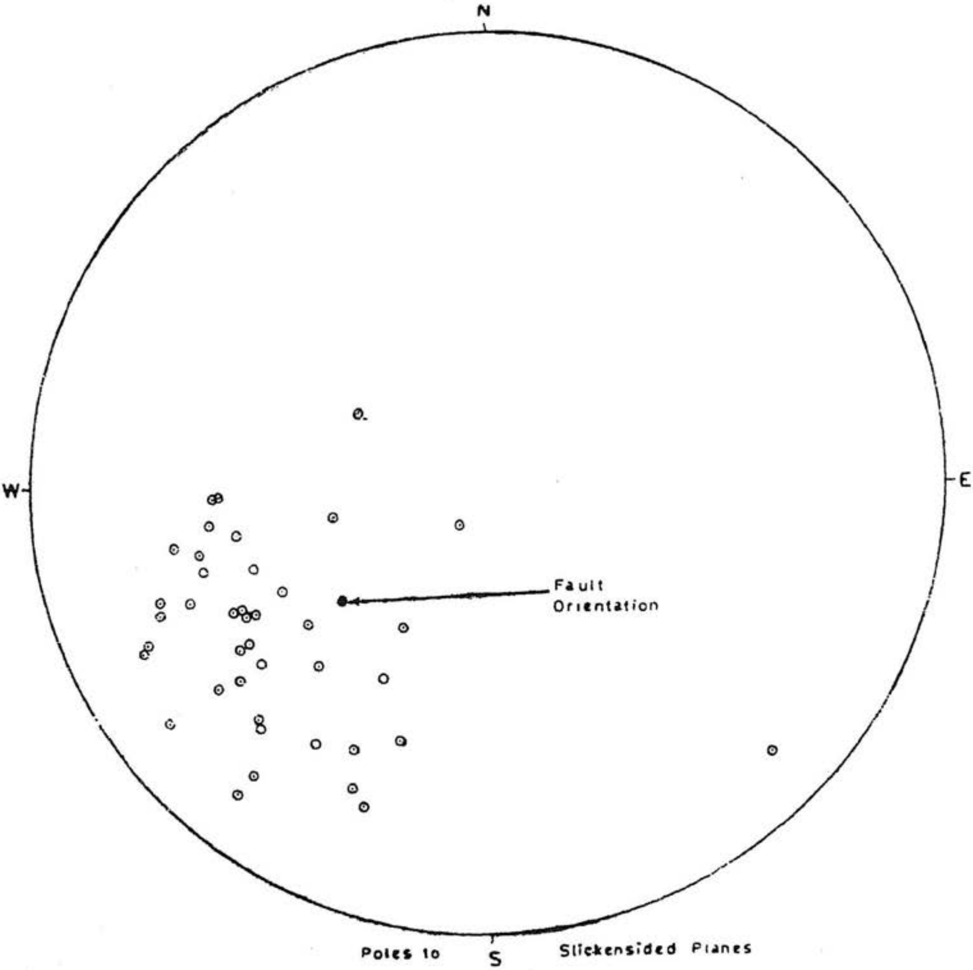


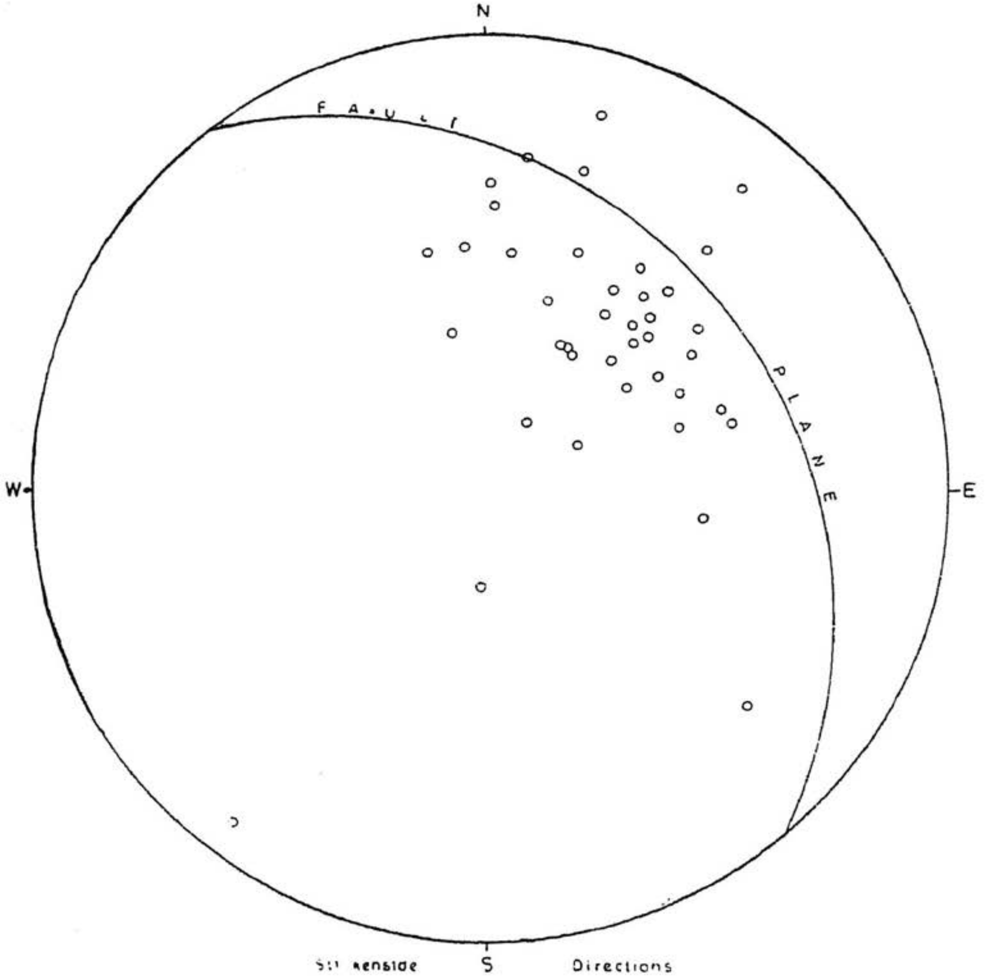
Figure 7. Orientation of slickensides in serpentinized pyroxenite block in breccia zone above main fault at Jijal; A: Poles to slickensided planes, B: Slickenside directions. Slickensides considered to develop during flexural-slip folding of the limb of the "Indus Syntaxis" anticline.

2. Thrusting of the Jijal complex over the Indo-Pakistan metasediments along a major deep shear zone; a substantial blastomylonite zone was created in the metasediments at this time. Folds in the foliation of the blastomylonite record the thrust motion.

3. Intrusion of intermediate granitic plutons and regional uplift. The MMT was probably inactive at this time.

4. Renewed thrust faulting along the MMT creates a thick serpentinite breccia at the base of the Jijal complex.

Fig. 7B



5. Folding of the MMT into an anticline along the line of the "Indus Syntaxis". No further thrust faulting occurs along the MMT.

Acknowledgements. Partial support for this study was provided by NSF USA grant INT–13158 and NASA grant NAG 9–2. Logistic assistance was provided by the University of Peshawar. Lawrence was supported as Fulbright professor at the University of Peshawar during this study. We thank R.A.K. Tahirkheli and M.Q. Jan for fruitful discussions of the geology and for field guidance. Our students A. G. Khan and T.K. Tahirkheli provided field assistance. The hospitality and interest of M. Awais of Mining International Ltd. is greatly appreciated.

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