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Thrusting and Strike-slip Faulting along the Western Boundary of Indo-Pakistan Plate

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ABSTRACT

Along western boundary of the Indo-Pakistan plate a system of Riedel R and R' shears is expected to develop due to a dominant component of simple shear. The majority of strike-slip faults trend between N-S and NNW-SSE, close to the expected orientation of R shears. A few strike almost parallel to the expected orientation of R' shears Faults close to R shears show dextral sense of displacement. Both the orientation and sense of displacement suggest that majority of these strike-slip faults are secondary Riedel shears, developed in response to a plate scale sinistral simple shear, along the Chaman transform fault.

With the exception of Sulaiman Lobe, thrusts along the western boundary of Indo-Pakistan plate generally trend N-S. Palaeomagnetic studies suggest that E-W oriented thrusts of Sulaiman Lobe may be result of a later clock-wise rotation. The general N-S trend of these thrusts is almost parallel to the orientation of plate boundary and suggests that they may be part of a positive flower structure developed in response to regional sinistral transpression along the transform plate boundary.

INTRODUCTION

The western boundary of the Indo-Pakistan plate running through western Pakistan and eastern Afghanistan is generally considered to be a transform boundary marked by major strike-slip faults (Lawrence and Yeats, 1979; Lawrence et al, 1981). The most famous of these strike-slip faults is the Chaman fault, first recognized by Griesbach in 1893. This fault connects the Himalayan collision zone to the north, and the Makran convergence zone to the south (Farah et al, 1984). Lawrence and Khan (1991) suggest a sinistral displacement of about 450±10 km along the Chaman fault. Recently several studies (Yeats and Lawrence, 1984; Coward and Butler, 1985; Baig and Lawrence, 1987; Lillie et al, 1987; Abbasi and McElroy, 1990; Jadoon, 1991a; Jadoon et al, 1992) evaluated the thrust systems of Pakistan. Awan et al (1991) discussed the evolution of strike-slip faults. According to Sarwar and Dejong (1979), and Lawrence et al (1981) close to western boundary of the Indo-Pakistan plate, collision was oblique . Recently Ahmed and Ali (1991) discussed the transpression related structures along the Kirthar Range of Pakistan. However, the evolution of transpression related structures, along the western boundary of the Indo-Pakistan plate, has not been discussed so far in detail.

This preliminary study is an attempt to evaluate the evolution of both strike-slip faulting and thrusting in relation to transpression along the western boundary of the Indo-Pakistan plate (Figure 1A).

SECONDARY STRUCTURES ASSOCIATED WITH A TRANSFORM PLATE BOUNDARY

Because of regional scale strike-slip the mechanism of deformation along a transform plate boundary should have a dominant component of simple shear. A number of secondary structures have been recognized within such domains of simple shear (Sylvester, 1988). However, in this paper we will discuss the evolution of only secondary strike-slip faults and thrusts.

Strike-Slip Faults

Two sets of secondary strike-slip faults or shear zones, associated with a major strike-slip or transform fault, have been observed both in laboratory (Cloos, 1928; Riedel, 1929; Tchalenko, 1970; Wilcox et al, 1973) and in field (Keller et al, 1982; Erdlac and Anderson, 1982; Woodcock, 1988). These shear zones are collectively called as Riedel shears, (Ramsay and Huber, 1987), and individually designated as synthetic (R) and antithetic (R') shears (Figure 1B). The en-echelon R shears generally develop first followed by R' shears and other structures (Sylvester, 1988). The R shears form at an angle of 15-20° and R' shears at an angle of 60-75° to the principal displacement zone (Tchalenko and Ambraseys, 1970).

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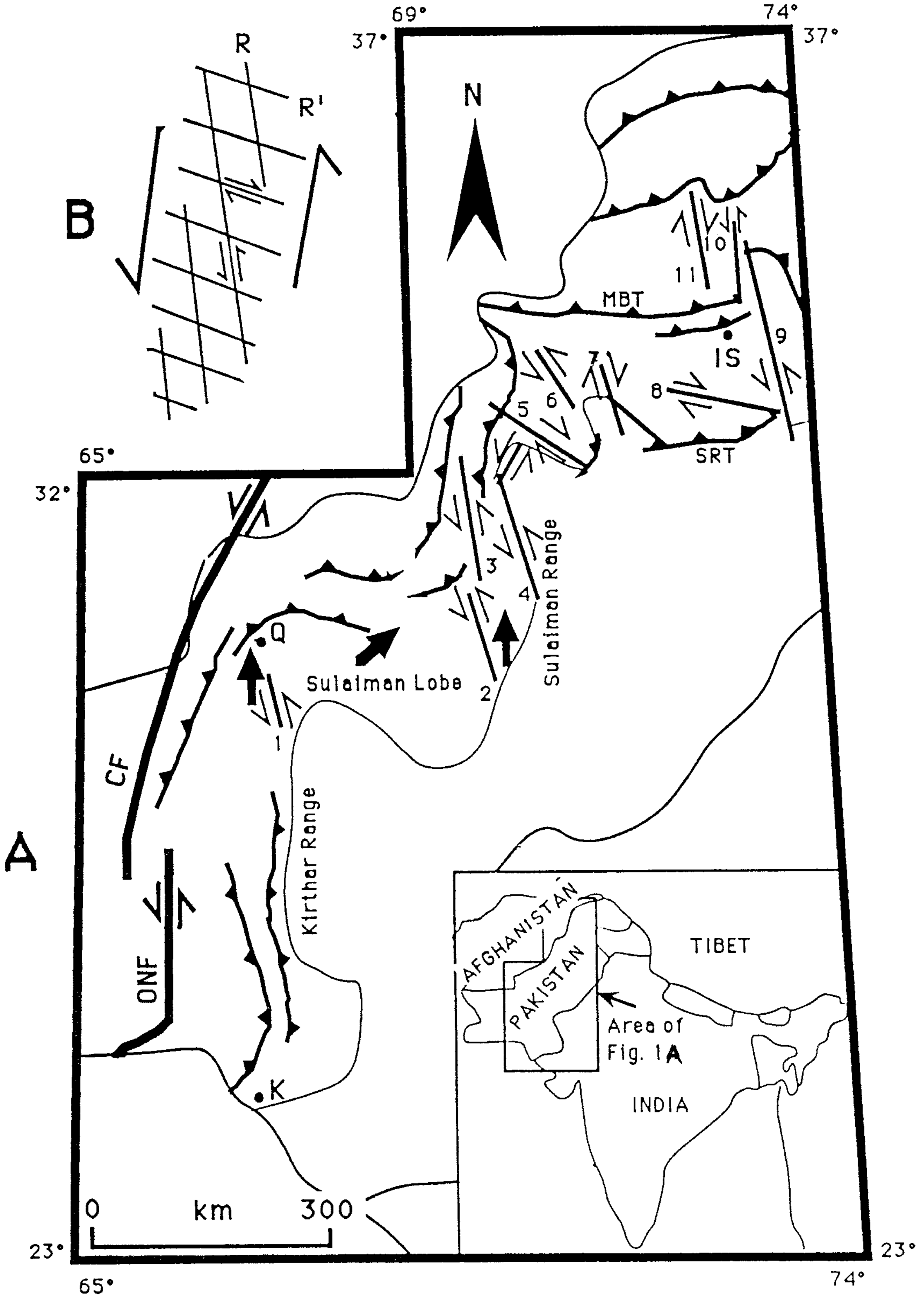

Figure 1- (A) Tectonic map of Pakistan (modified after Kazmi and Rana, 1982). Lines with teeth represent thrust faults, lines with half arrows represent strike-slip faults. Arrows indicate palaeomagnetic rotation vectors after Klootwijk et al (1986). MBT= Main Boundary Thrust, SRT = Salt Range Thrust, CF = Chaman Fault, ONF = Ornach Nal Fault, Q = Quetta, IS = Islamabad. 1 = Mach fault, 2 = Kingri fault 3&4 = Sulaiman range fault zone, 5 = South Bannu fault, 6 = North Bannu fault, 7 = Kalabagh fault zone, 8 = Kallar Kahar fault, 9 = Jhelum fault, 10, = Shinkiari fault zone, 11 = Thakot fault. (B) Model orientation of conjugate Riedel sheas along a major sinistral strike-slip fault or transform plate boundary.

Thrust Faults

Both laboratory studies (Lowell, 1972; Wilcox et al, 1973; Bartlett et al, 1981; Naylor et al, 1986) and field mapping (Wellman, 1955; Sylvester and Smith, 1976; Burke, 1979; Davis and Duebendorfer, 1982) demonstrate that uplift along oblique convergence zones, in response to a component of horizontal shortening associated with strike-slip, generally leads to the development of an upward branching arrangement of faults termed as positive flower structure by Wilcox et al (1973). Within such structures fault blocks rise upward and outward like a stack of imbricate thrusts (Figure 2). Individual thrusts of this stack strike almost parallel to the principal displacement zone, while the displacement vector along these thrusts has components of both strike-slip and dip-slip parallel and perpendicular to the principal displacement zone respectively (Figure 2).

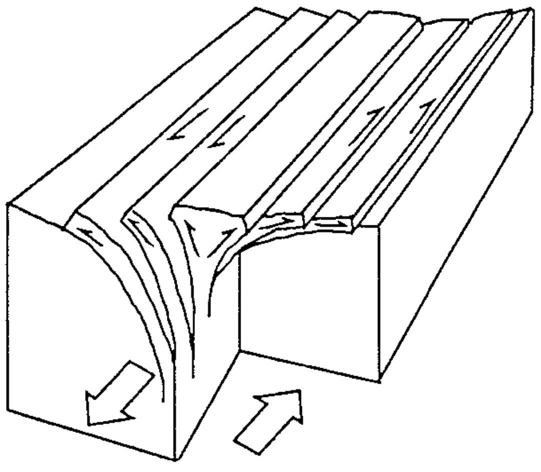

Figure 2– A model of positive flower structure associated with sinistral transpression.

PATTERN OF THRUSTING ALONG WESTERN BOUNDARY OF THE INDO-PAKISTAN PLATE

Tectonic map of Pakistan (Figure 1A) shows that thrusts in northern Pakistan generally trend between E-W and ENE-WSW e.g., Salt Range Thrust and Main Boundary Thrust on the western side of Hazara Kashmir Syntaxis etc. In the Sulaiman and Kirthar ranges, along western boundary of the Indo-Pakistan plate thrusts trend between N-S and NNE-SSW, however, there are major structural arcuations e.g., the Sulaiman Lobe, where, thrusts have an almost E-W orientation.

Palaeomagnetic rotation vector for Sulaiman / Kirthar Ranges and Loralai area in the Sulaiman Lobe (Klootwijk et al, 1981) suggests 50° clockwise rotation for rocks in the Loralai Valley and almost no rotation for N-S trending Kirthar Range. Results from the Sulaiman Range show a complex pattern of rotation. As samples were collected from sites close to a major strike-slip fault i.e. the Kingri fault, observed complexity may be a result of local shearing. Klootwijk et al (1986) considered no rotation for the Sulaiman Range. Jadoon (1991b) and Kemal et al (1991) suggest a NNE-SSW orientation for the Mesozoic passive margin underneath the Sulaiman thrust lobe of Pakistan. Given a plate convergence vector of N5°W (Minster et al, 1974), the E-W trend of thrust system in the Sulaiman Lobe is consistent with proposed 50° clockwise rotation. The absence of rotation in the N-S trending Sulaiman/Kirthar Ranges suggests that thrust system in these ranges originally developed as N-S oriented structure with an eastward transport direction. Such N-S original orientation for the thrust system parallel to the principal displacement zone or transform plate boundary indicates that it may have evolved as part of a positive flower structure.

PATTERN OF STRIKE-SLIP FAULTING ALONG WESTERN BOUNDARY OF THE INDO-PAKISTAN PLATE

Along the western boundary of the Indo-Pakistan plate a large number of recognized active faults (Kazmi, 1979) are strike-slip faults. These strike-slip faults are of different orientations (Figure 1A). A careful observation indicates that the orientation and sense of displacement of majority of these strike-slip faults fairly correspond to a system of Riedel shears developed after sinistral strike-slip along the Chaman fault. A very significant number of these faults strike between N-S and NNW-SSE close to the expected orientation of secondary R shears of the Chaman fault (Figure 1). The sense of displacement for these faults is generally sinistral.

The dextral South Bannu fault and the Kallar Khar fault (Figure 1A) trend parallel to the expected orientation of secondary R' shears of the Chaman fault. The less common occurrence of faults of this orientation correspond with the earlier field observations of Keller et al (1982), who suggested that R' shears rarely develop in nature.

DISCUSSION

Close to the western boundary of the Indo-Pakistan plate, the mechanism of deformation should have a strong component of simple shear due to plate scale sinistral strike-slip displacement along the Chaman fault zone. The orientation of strike-slip faults in Pakistan, east of the Chaman fault may be controlled by: (a) the orientation of pre-existing basement fractures or weak zones (Swaminath et al, 1964), and (b) transpression along the Chaman fault (Sarwar and DeJong, 1979; Lawrence et al, 1981). Presently, there is not much evidence for an array of pre-existing basement fractures, corresponding to the observed orientation of strike-slip faults. Alternatively, we propose that these strike-slip faults represent a set of Riedel shears related to a major sinistral simple shear along the western transform boundary of the Indo-Pakistan plate. This is based on a consistent relationship present between these secondary strike-slip faults and the major Chaman fault (Figure 1A). For these secondary faults, minor deviations from the orientation observed in laboratory experiments are possible due to local geological changes. Average trend of faults close to R shears is a few degrees anti-clockwise from that observed in experimental models. Such anti-clockwise rotation is expected because of continuous sinistral displacement along plate boundary rather than the nearly instantaneous development of R shears in laboratory. At present, mapping of these faults shows little continuity up to the transform plate boundary. This may be due to the lack of detailed mapping in areas close to the Chaman fault or because of the fact that this system is still in its early stages of development. Other reason of this discontinuity may be the local dominance of thrusting over strike-slip faulting due to transpression along this transform plate boundary. Few faults having an orientation similar to R shears but opposite sense of displacement have been interpreted as lateral ramps to thrust sheets e.g., Kalabagh fault (McDougal and Khan, 1990) (Figure 1A).

The palaeomagnetic evidence of clock-wise rotation of E-W trending thrusts in the Sulaiman Lobe and the N-S trend of thrusts in the Sulaiman/Kirthar Ranges close to the orientation of transform plate boundary suggest that thrusting here developed as part of a positive flower structure. The idea of flower structure is consistent with the recently reported extensional and compressional jogs from Kirthar Range (Ahmed and Ali, 1991). However, complex palaeomagnetic results from the Sulaiman Range suggest that still more investigations are required to test this hypothesis.

CONCLUSIONS

1) Along the western boundary of the Indo-Pakistan plate, N-S and NNW-SSE oriented strike-slip faults with sinistral sense of displacement may correspond to the R shears of the Chaman fault.

2) The WNW-ESE trending South Bannu fault and the Kallar Kahar fault may correspond to R' shears of the Chaman fault.

3) Most of thrusts along this plate boundary may have originated as N-S trending structures being part of a positive flower structure.

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