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Imprints of Transtensional Deformation along Kalabagh Fault in the Vicinity of Kalabagh Hills, Pakistan

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ABSTRACT

Kalabagh Hills are the Trans-Indus extension of Western Salt Range, underlain by Precambrian to Cenozoic Platform and Plio-Pleistocene fluvial sediments. Being in close proximity to the Kalabagh Fault Zone these sediments have well preserved imprints of deformation. The structural data in the area suggests two suites of structures that are compressional and extensional in nature. The main compressional structures include a north-northwest trending Kalabagh Anticlinorium, cored by Paleozoic rocks. The western limb of the Kalabagh Anticlinorium is uplifted along a high angle reverse fault named as Kuch Fault which juxtaposes Jurassic rocks against the Quaternary Kalabagh Conglomerates. The extensional structure includes a couple of local and regional scale normal fault that bound the Kalabagh Anticlinorium in the east and west. The eastern most and major fault bordering the Kalabagh Hills is the Kalabagh Fault that is a high angle, east dipping normal fault characterized by transtentional deformation. Outcrops of Precambrian Salt Range characterize this fault. Though both of the structural suits exhibit similar north-northwest trend, however their kinematics are attributed to different mechanisms. The compressional structures are interpreted to be the result of southwestward translation of the Precambrian to Eocene platform and overlying molasses sediments along a basal decollement. Whereas the extensional structures are the result of salt flowage along the compressional structures giving rise to salt diapers that uplifted the flanks of the Kalabagh Anticlinorium which finally collapsed along gravity faults. The extensional structures are interpreted to be the youngest as they cross cut the earlier compressional structures.

INTRODUCTION

The Kalabagh Hills represent the Trans-Indus extension of the Western Salt Range, lying north of Kalabagh City, Mianwali District (McDougal & Khan, 1990) (Figure 1). These hills occupy important structural transect between the Western Salt Range and Surghar Range, and can serve to unravel the structural relationship between these two important tectonic orogens of northern Pakistan. It is also important to understand the nature of deformation associated with the Kalabagh Fault Zone that extends 120 Km from the southwestern corner of the Salt Range near Khushab to the Southern Kohat Plateau, bordering the northern flank of Kalabagh Hills (Figure 1). The Kalabagh Fault Zone is characterized by right lateral transpressional deformation McDougal & Khan, 1990), trending N150W. This fault zone terminates the west-southwest trending Salt Range Thrust front on the west, extending up to north of the Surghar Range into the southern margin of the Kohat Plateau (McDougal & Khan, 1990). A thick succession of Precambrian to Mesozoic platform and Pleistocene molasse sediments characterize the Kalabagh Hills and have well preserved imprints of deformation associated with the Kalabagh Fault Zone.

The Kalabagh Fault Zone was initially recognized by (Gee, 1980) in his geological maps extending from the Eastern Salt Range to the Kalabagh area in the west. The Kalabagh Fault is present in a map of the active faults of Pakistan (Kazmi, 1979). Yeats et al (1984) described Quaternary deformation along the Kalabagh Fault. According to McDougal & Khan (1990) the Kalabagh Fault Zone is formed by transpressive right lateral strike-slip movement along the Western Salt Range allochthon in northern Pakistan. Lateral ramping from a decollement thrust along an Eocambrian evaporite layer produced north-north west to north west trending folds and north east to north dipping thrust faults in a topographically emergent zone up to 10 Km wide. Along the Kalabagh Fault 12-14 Km right lateral offset has been interpreted (McDougal & Khan, 1990).

REGIONAL AND STRATIGRAPHIC SETTING

The India-Eurasia collisional event of South Asia begun in middle to late Eocene producing the world spectacular Himalayan ranges (Stocklin, 1974 & Stonely, 1974). The northward under thrusting of the Indian Plate underneath the Eurasian Plate have resulted in the formation of a south-directed thrust system that constitutes the major tectonic fabric of Pakistan (Figure 2) (Powel, 1979). The Salt Range Thrust along with the Trans-Indus Ranges Thrust is the southern most of the Himalayan thrust system of the north Pakistan and places Paleozoic to Eocene platform sequence over the undeformed alluvium covered Punjab Foreland in the south. Right lateral Kalabagh Fault offset the Western Salt Ranges from its western analogue that is the Trans-Indus Ranges (Figure 3) and is characterized by Quaternary deformation displacing recent terrace deposits, course of Indus River and is considered as active in nature (McDougal and Khan, 1990).

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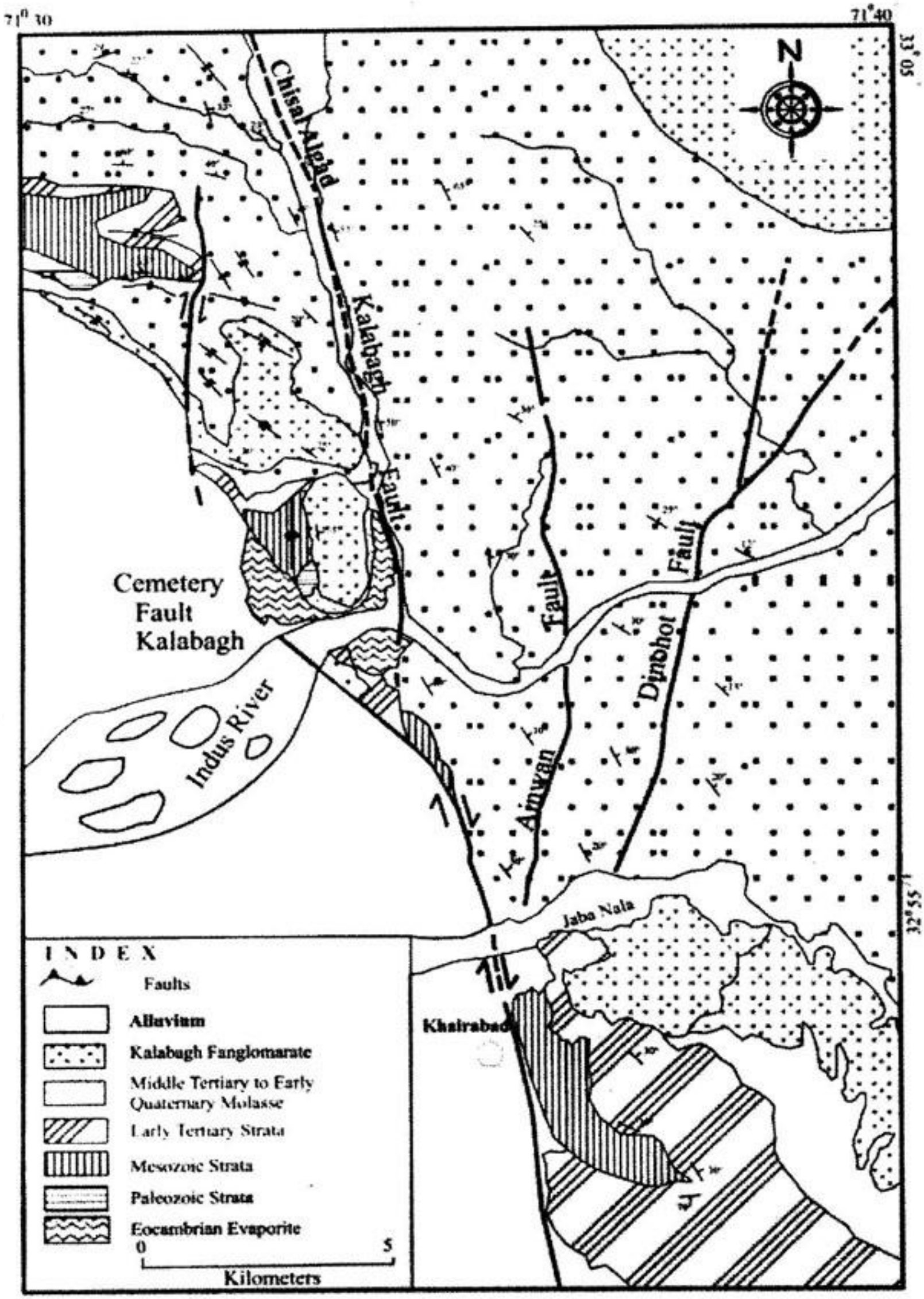

Figure 1- Geological map of the Western Salt Range and Kalabagh Hills showing major tectonic features in the region (Modified after McDougal and Khan, 1990).

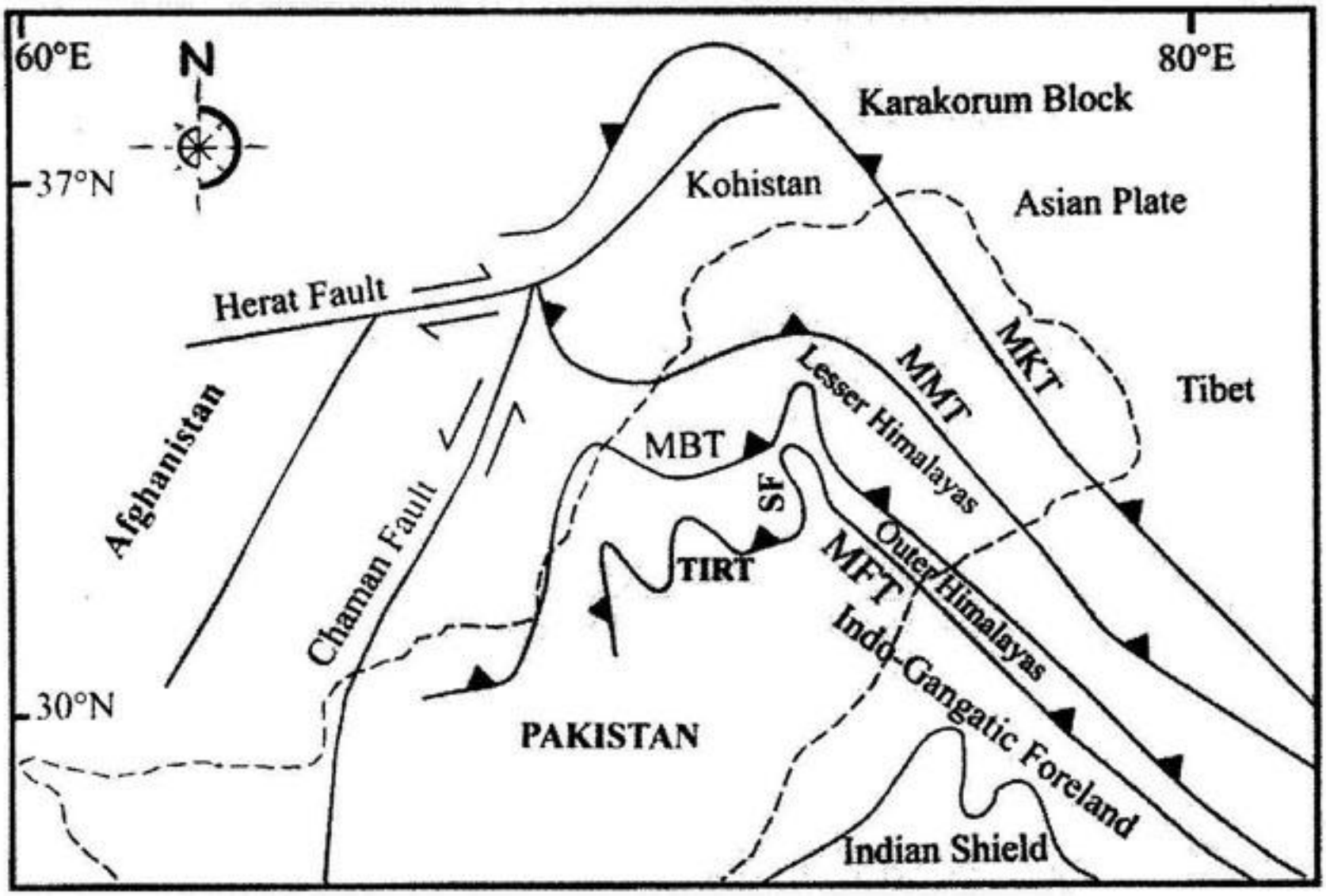

Figure 2- Tectonic map of the north west Pakistan (Modified after Powel, 1979).
MKT = Main Karakorum Thrust; MMT = Main Mantle Thrust;
MBT = Main Boundary Thrust; MFT = Main Frontal Thrust;
SF = Surghar Fault; TIRT = Trans Indus Ranges Thrust

The oldest rock units outcropping in the Kalabagh Hills belongs to the Precambrian Salt Range Formation and appear in fault contact with the younger platform and molasses sediments (Figure 4). The stratigraphic succession of the area falls under Zaluch Group at the base overlain by Mianwali, Tredian and Kingriali formations of Triassic age (Table.1) (Gee, 1980). Datta, Shinawari and Samana Suk formations of Jurassic age overlie this sequence. The Cretaceous sequence is represented Chichali and Lumshiwal Formation whereas the overlying Paleocene age sequence consists of Lockhart Limestone and Patala Formation. The Eocene rocks of the area belong to Nammal and Sakesser formations with a hiatus at the top, separating marine strata from the fluvial molasse sediments of Siwalik Group up to Nagri stage.

STRUCTURAL ANALYSIS

Figure 4 illustrates the distribution of structural geometries within the Kalabagh Hills. A north-northwest trend with slight deviation at places characterizes the outcropping rocks within the Kalabagh Hills. On map the Kalabagh Hills appears as a fault bounded block with normal sense of slip as indicated by the stratigraphic relationship observed along these faults. Two faults designated as Kalabagh Fault and Indus Fault mark the eastern flank of the Kalabagh Hills (Figure 4). The eastern one that is the Kalabagh Fault is oriented north-northwest and follows the trace of Chisel Algad (Figure 4). It is the most prominent fault of the mapped area and has been referred as Kalabagh Fault by the previous workers as well (McDougal & Khan, 1990 & Gee, 1980). The stratigraphic relationship along the Kalabagh Fault is well exposed immediately north of the Indus River bank and juxtaposes the Precambrian Salt Range Formation against the eastward dipping Siwalik Group of Pliocene age. Along the map trace of Kalabagh Fault the Precambrian Salt Range Formation disappears northward and the fault runs within the Siwaliks on both sides of the fault (Figure 4). The dip data and stratigraphic relationship along the fault trace suggest that the eastern block of the Kalabagh Fault has been down thrown towards east and the salt diaperically intrudes the surface along the fault trace. Immediately west of Kalabagh Fault, Indus Fault has been mapped. On the

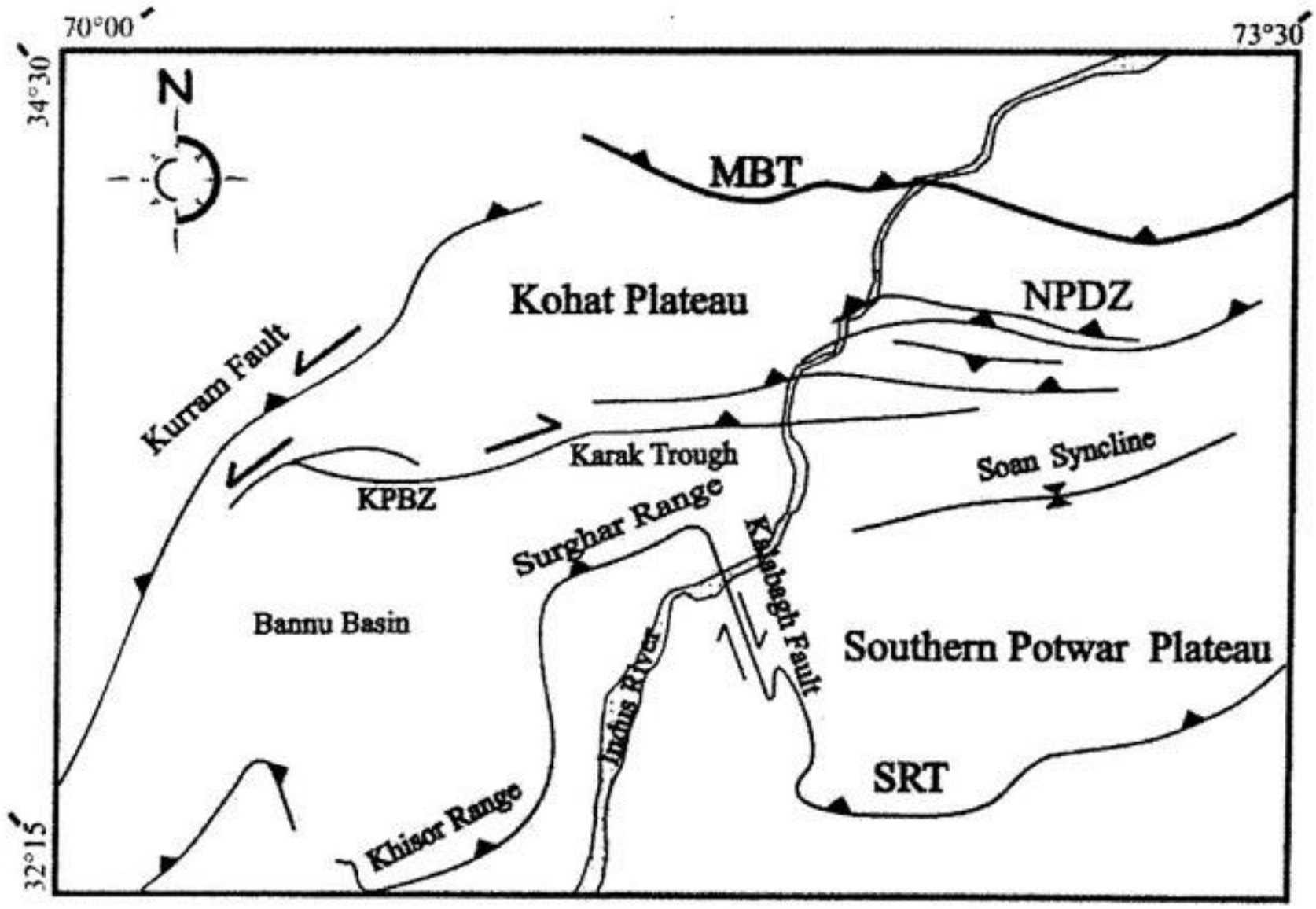

Figure 3- Structural map of the Kohat and Potwar Plateau.
KPBZ = Kohat Plateau Boundary Zone;
NPDZ = Northern Potwar Deformation Zone; SRT = Salt Range Thrust

map, Indus Fault appears as a splay of the Kalabagh Fault and along this fault the western flank of the Kalabagh Hills is downthrown to the west. West of Indus Fault the Kalabagh Conglomerates form the skyline of the Kalabagh Hills. Underneath the Kalabagh Conglomerates the rocks as old as Permian crop out in the core of a regional anticlinal structure that comprises several shallow anticlinal and synclinal folds. This major structure is named as Kalabagh Anticlinorium. The Kalabagh Anticlinorium along with its associated folds is characterized by north-northwest trend and is detached at the level of Permian rocks.

The western flank of the Kalabagh Anticlinorium is faulted out along a steeply dipping fault named as Kuch Fault hat brings the Permian-Eocene strata against the Quaternary Kalabagh Conglomerate in the west. Along its entire map trace it appears as a high angle reverse fault with its eastern block up thrown towards west. West of Kuch Fault, an east dipping normal fault namely Chighlan Fault is mapped. Stratigraphic relationship along this fault suggests that its eastern side is down thrown towards east. Further west of the Chighlan Fault, Kuch Tendar Fault appears as the western most bounding fault of the Kalabagh Hills. It is north-northwest oriented and brings Jurassic rocks in faulted contact with Salt Range Formation. Chighlan, Kuch Tendar and Kuch Fault merge to form a single fault zone north of Kalabagh Town (Figure 4).

Cross section along line A-A$'$ of figure 4 is drawn perpendicular to the major structural trend of the Kalabagh Hills and display the most spectacular example of large-scale collapse of crustal blocks associated with salt flowage and migration along faults (Figure 5). On a northeast to southwest traverse along the cross section A-A/, the Kalabagh Fault appears as a steeply southwest dipping normal fault along which the northeastern flank of the Kalabagh Hills is downthrown to the southwest. Beneath the Kalabagh Fault, a salt plug, migrating upward has been interpreted based on the map relationship of the fault (Figure 4).The Kalabagh Hills southward of Kalabagh Fault is characterized by an upright to southwest overturned folds that seem to be related to the shortening of detachment above the Salt Range Formation related to motion along Kuch Fault. On the cross-section Kuch Fault is steeply northeast dipping and seems to have deformed rocks as young as Kalabagh Conglomerates in its footwall.

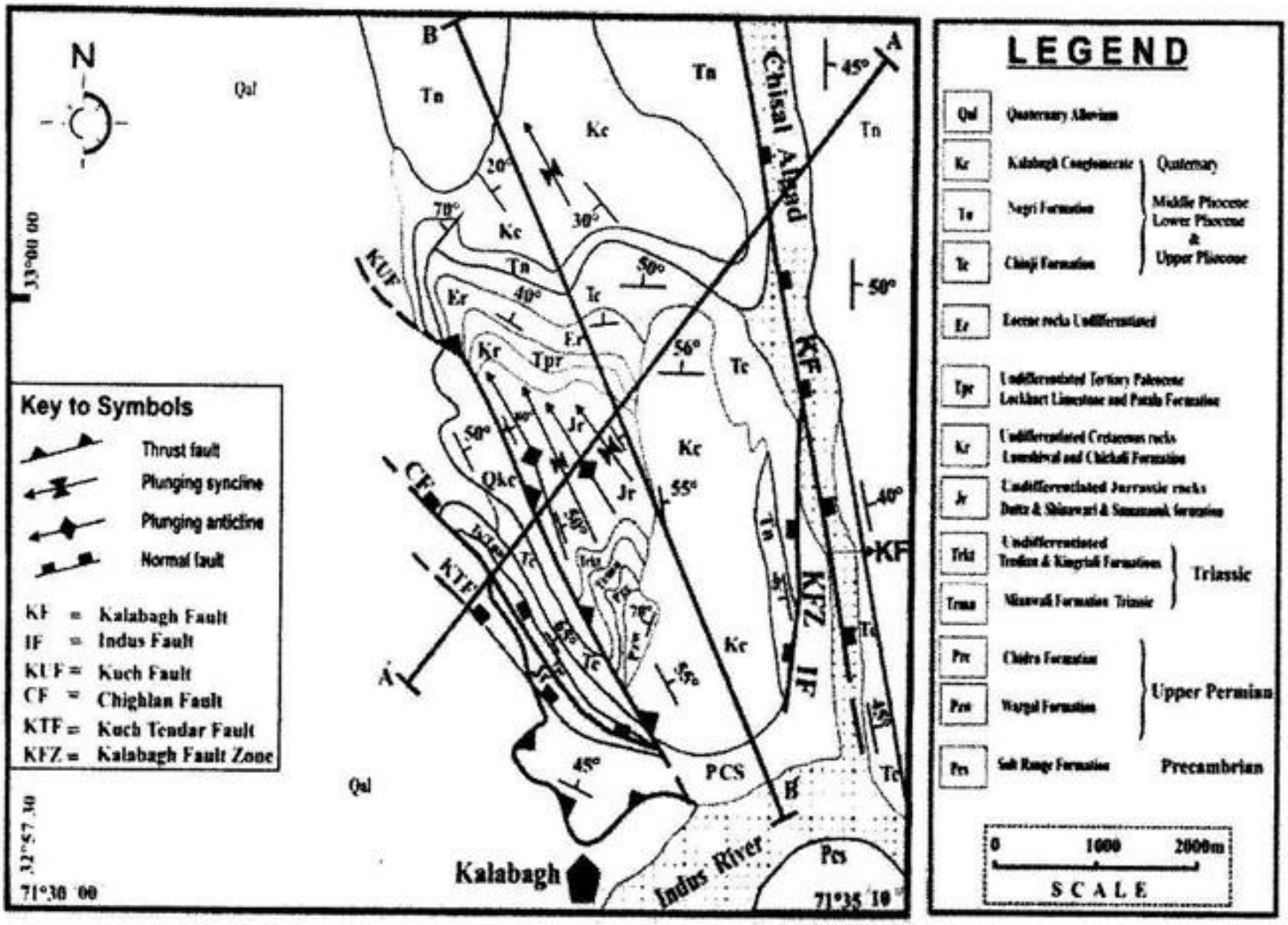

Figure 4- Geological map of the Kalabagh Hills, Mianwali District, Punjab, Pakistan.

Southwest of Kuch Fault, a couple of normal faults are present, along which the hanging wall rocks are down thrown toward northeast.

The role of salt diapirism in the structural evolution of Kalabagh Hills is well demonstrated on the cross section (Figure 6) along line B-B/ of figure 4. Cross-section B-B/ is drawn parallel to the strike of the Kalabagh Hills and clearly demonstrates that the topographic expression of the Kalabagh Anticlinorium is mainly the result of salt migration into the anticlinal core. A regional basal decollement at the crystalline basement and salt Range Formation is inferred translating westward in addition to a component of south translation as well (Figure 6). The southward translation is well supported by the fold geometry of Kalabagh Anticlinorium.

DISCUSSION AND CONCLUSION

Previous account of the Kalabagh Fault in the vicinity of Kalabagh Hills suggests that it truncates folds and thrust faults developed in the Eocambrian and Quaternary sediments cropping out near Kalabagh Town (McDougal & Khan, 1990). According to this interpretation the structure of Kalabagh Hills is regarded as a doubly plunging anticline cored by Paleozoic limestone that is overlain by deformed Kalabagh Conglomerate on its north limb. This anticline is believed to have offset by 12-14 km in a right lateral sense along the Kalabagh Fault.

In contrast to this interpretation the present account of structural data depicts an entirely different scenario for the structural evolution of Kalabagh Hills. Two contrasting suits of structures are preserved within Kalabagh Hills that are compressional and extensional in nature. The main topographic expression of the Kalabagh Hills is attributed to a north-northwest oriented Kalabagh Anticlinorium cored by Precambrian rocks and its western limb is uplifted along a high angle reverse fault named as Kuch Fault. This compression related Kalabagh Hill structure is bounded by a couple of north-northwest trending normal faults in the east and west. All the structures mapped in the area whether contractile or extensional share similar trend that is north-northwest. This structural trend is almost the same as that of the Kalabagh Fault that trends N15OW along the eastern flank of Kalabagh Hills. If the previous interpretation were regarded true then one would expect northwest oriented folds in the vicinity of the major fault zone (Harland,

Table 1. Stratigraphic framework of Kalabagh Hills (After Gee, 1980).

System	Series	Group		Formation
Quaternary	Pleistocene	Siwalik Group		Nagri Formation
	Miocene-Pliocene			Chinji Formation
				Unconformity
TERTIARY	Eocene			Sakesar Formation
				Nammal Formation
	Paleocene			Patala Formation
				Lockhart Limestone
MESOZOIC	Cretaceous		Upper	Lumshiwal Formation
			Lower	Chichali Formation
	Jurassic		Upper	Sama Suk Formation
			Middle	Shinawari Formation
			Lower	Datta Formation
	Triassic			Kingriali Dolomite
				Tredian Formation
				Mianwali Formation
PALEOZOIC	Permian	Late	Zaluch Group	Chhidru Formation
				Wargal Formation
PRECAMBRIAN				Salt Range Formation

1975), which is not found in this case. The structural trend east of the Kalabagh Fault is more or less north-northwest and does not show any sort of rotation associated with the Kalabagh Fault. In fact the Kalabagh Fault is characterized by normal sense of slip with its eastern side down thrown to the east and the Precambrian Salt Range Formation diapirically extrudes to the surface along the fault trace.

Based on these observations it is considered that the Kalabagh Hills have deformed as a result of east to west directed tectonic transport and is probably related to the deformation associated with an oblique ramp on the main Salt Range decollement. The previously established 12-14 km displacement along the Kalabagh Fault is not clear as well. The Kalabagh Conglomerate does not come in contact with the Kalabagh Fault within the Kalabagh Hills area.

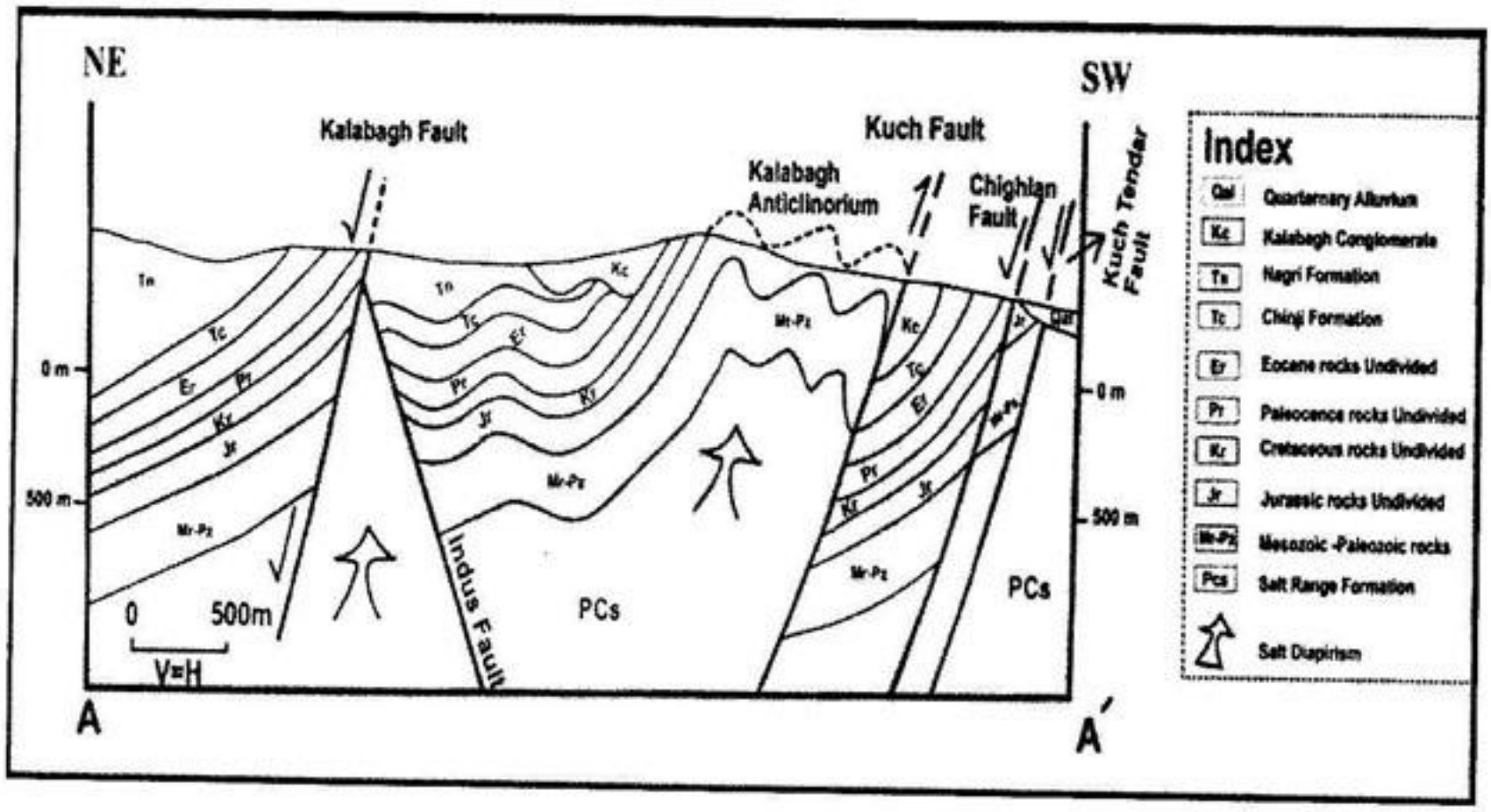

Figure 5- Geological cross-section along line A-A′ of figure 4.

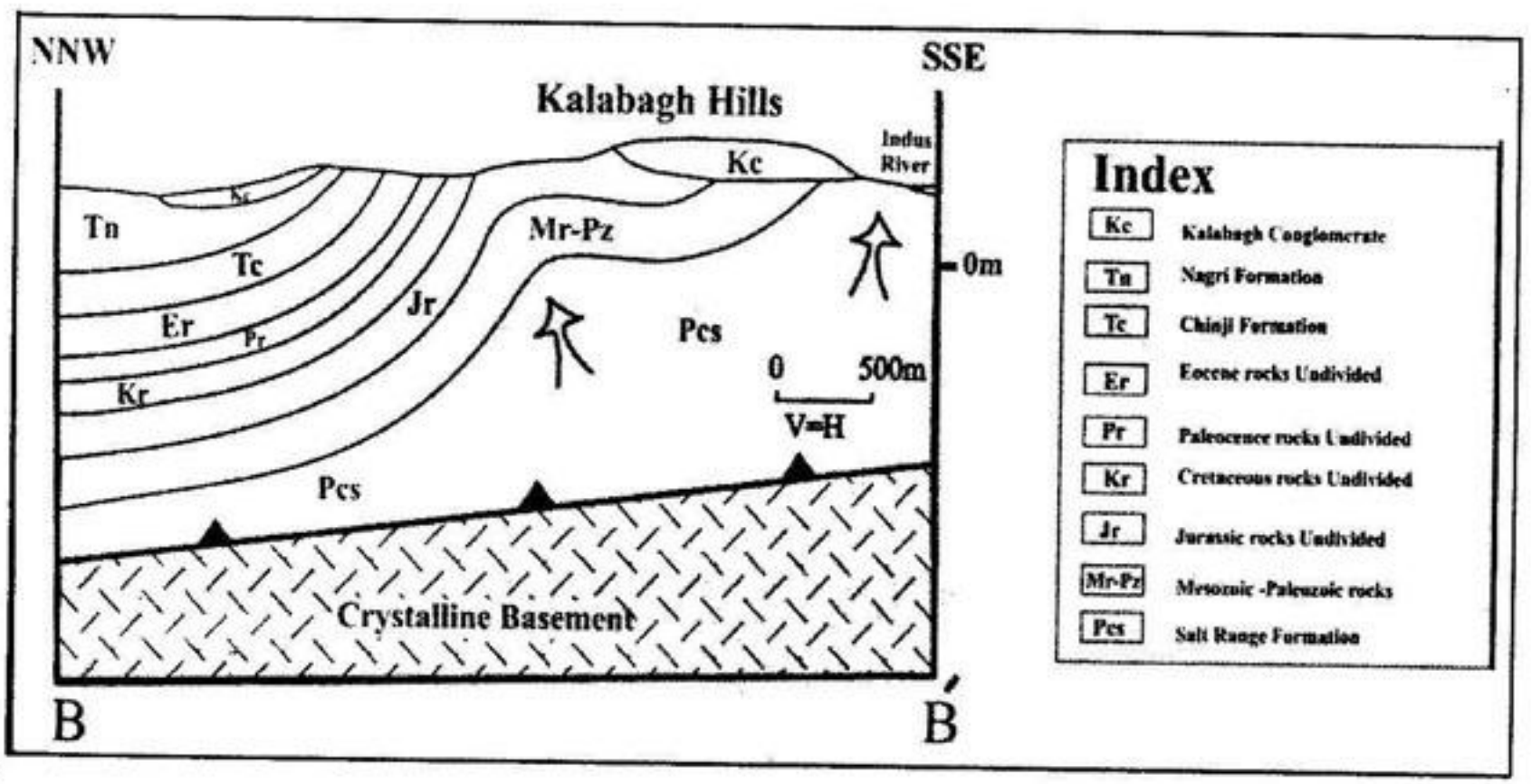

Figure 6- Geological cross-section along line B-B′ of figure 4.

Furthermore, the compressional structures of the Kalabagh Hills are bounded by extensional faults that contribute a lot to the complexity of structural style as well. The extensional structures are believed to be the youngest as it cross cut the earlier compressional structures. The development of these structures are largely due to the salt migration along the compressional structures, followed by salt plugs extruding to the surface and finally large scale crustal collapse of the Kalabagh Hills along the normal faults mapped on its flanks.

As for as the hydrocarbon prospectivity of the region is concerned the role of salt diapirism should not be overlooked as the salt extrusions can lead to the development of viable potential structural traps.

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