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Tectonics and hydrocarbon prospects of Potwar area

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DEDICATED TO...

Our loving Parents and respectable Teachers

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ABSTRACT

The tectonic depression of Potwar sub-basin is formed as result of continent- to - continent collision at the northwestern margin of Indian plate. Presently two-fold division is envisaged for the Potwar sub- basin on the basis of deformation style, that is Northern Potwar Deformed Zone (NPDZ) and the Plate Form Zone. The NPDZ is laying in the south of Kalachitta Margalla hills. It is structurally complex zone.

The Potwar sub-basin is one of the major hydrocarbon-producing provinces of the country. The geochemical results and other co- relations studies indicate that the oil being produced from Potwar basin is mainly sourced by Patala Formation.There are other potential source rocks of Precambrian and Mesozoic age. The Potwar region is profilic area with multiple structural and stratigraphic leads, such as simple anticlines, popup structures, hanging wall anticline, sub thrust and unconformities. Attempt has been made to relate hydrocarbon entrapment in various areas of Potwar basin with distinctive structural domain, which defines orientation, styles and geographic distribution of structures and migration form the source rock to reservior Multiple reservoir of clastic and carbonates from Cambrian to Eocene age exist in different parts of sub- basin.

For the carbonate reservoirs of Eocene age there exist a relationship between the lineament and oil discoveries

INTRODUCTION

The Potwar sub- basin is part of the foreland fold and thrust belt located at the northern rim of the Indian plate in the fort links of Western Himalays in Pakistan and lie within the Indus basin

Structurally, Potwar sub- basin is very complex and mostly features do not conform to the sub surface geometry due the presence of the deformation at different levels

It is bounded in the north by thrust Kala Chitta – Margalla Fault Zone. In the east by left lateral strike slip- Muree Jhelum fault system and in the south by Salt Range thrust. Whereas in the west it is bounded by the right- lateral Kalabagh strike- slip fault and merge in to Kohat pleateu in the north west (Iqbal & Ali. 2001)

The Potwar region was one of the first area explored for petroleum in the world. The first oil was drilled in 1866 near an oil seep at Kundal west of study area. The Attock Oil Company drilled the Khaur anticline mapped by the geological survey of India in 1870 in 1914.

The well proved to be the first commercial oil discovery in this region as well as in the South Asian Sub Continent.

REGIONAL TECTONIC SETTING

The development of thick shelf margin reefal limestones in the Permo-Triassic time (Searl etal; 1983) suggest the first rifting event of the Gondwanaland and development of the Atlantic type passive continental margin. The early rifting of micro-continents away from the northern margin of the Gondwanaland with the development of Pale-Neotethys with a spreading ridge in between these micro plates gradually drifted towards north and welded to the Eurasian plate during Cretaceous to Paleocene times. The rifting of India from Africa and Madagascar probably started in the Cretaceous, which initiated regressive deposition of Early Cretaceous deltaic and associated deep sea fan lobes which propagated across south east and Central Pakistan. The initial northward drift of the Indian Plate from Early Cretaceous to Middle Eocene was rapid at a rate of 130-150 mm/y (Klootwijk and Peirce, 1979 Duncan, 1990). The counter clockwise rotation of the Indian Plate relative to Eurasia around a close pole during Early Eocene was coincident with reduction of is velocity to 40-60 mm/y which finally settled down to 2 mm /yr from Early Oligocene to the present Finally collision between the Indian and Eurasian continental crust occurred in the Late Eocene. The continued under thrusting of the Indian Plate since Cretaceous produced the spectacular mountain ranges of the Himalayas and a chain of foreland fold and thrust belts as thick sheets sediments trusted over the Indian craton. (Fig 1)

In the present plate tectonic setting Pakistan lies on the north western corner of the Indian lithospheric plate, which represents part of the Tertiary convergence between the Indian and Eurasian plates. The deformation style and structure on the edges of these plates mimic their past and present inter-relationships. In the Indian Himalayas, northern collision zone has been identified as Indus-tsangpo suture (TS), Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Main Frontal Thrust (MFT) (fig 1). The collision zone in the northern Pakistan has been subdivided as the Main Karakoram Thrust (MKT), Main Mantle Thrust (MMT), Main Boundary thrust (MBT) and Salt Range Thrust (SRT)(Fig 2). Pre-Cambrian basement rocks are exposed along the Sargodha High about 80km south of the SRT. Its east-southeast trend parallel to the main

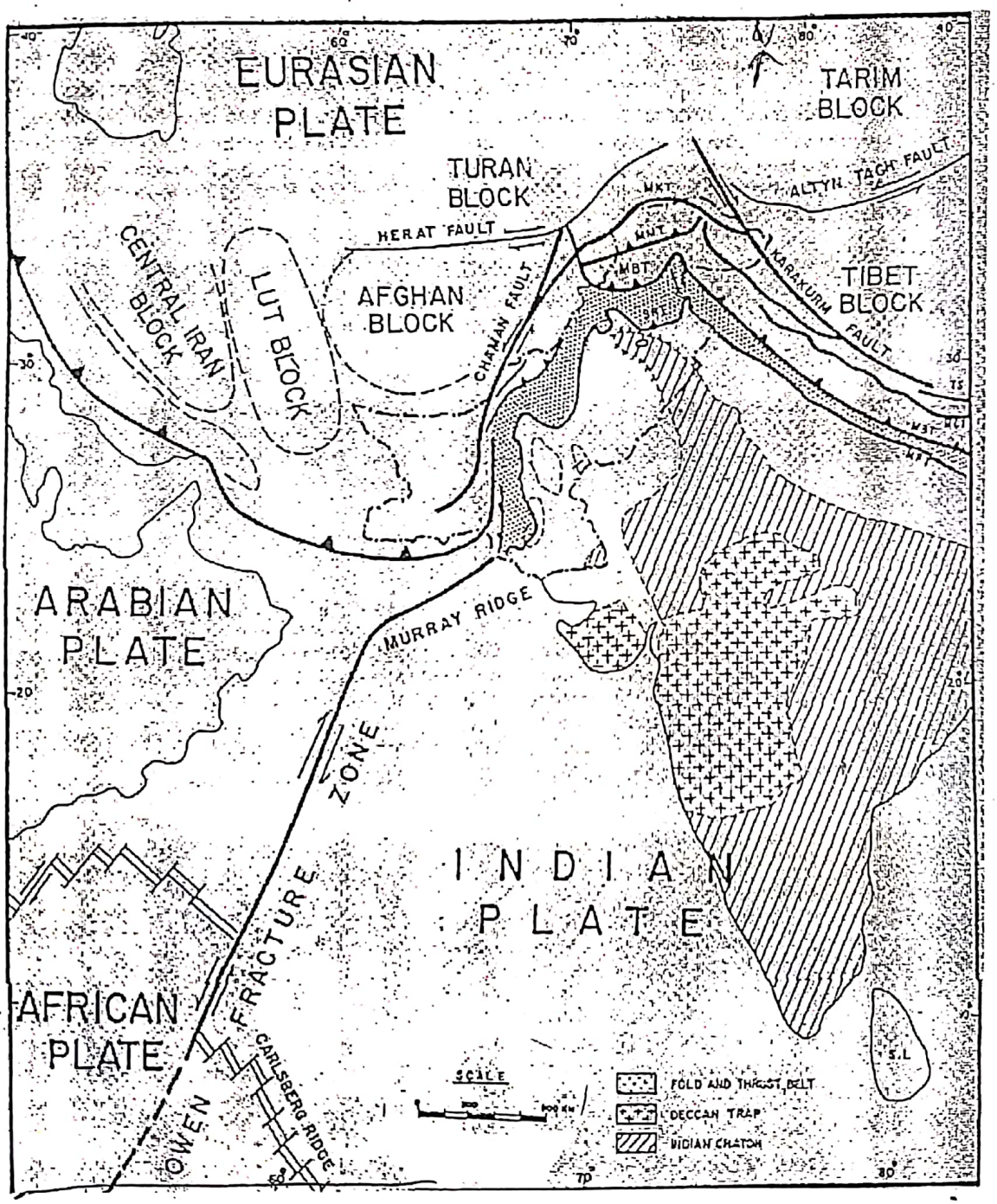

Figure-1
Regional tectonic map, showing the location of Pakistan on the northwestern corner of the Indian plate and regional tectonic features in the area. MBT=Main Boundary thrust,

Himalayas corresponds to the lithospheric flexural bulge developed due to northward under thrusting of the Indian plate and loading of south verging thrust sheets.

The collision in the west is oblique along a transgressional fault zone. The discontinuous belt of ophiolites, which runs through the Bela and Zhob valleys, represents the suture. Presently the Chaman/Oranch-Nal Transform Fault Zone (COTFZ) marks the western plate boundary. The triple junction located northwest of Karachi, which is the eastern limit of the Makran Subduction Complex. The Indian plate is separated from the African plate along the Carlsberg Ridge while the Owen fracture zone marks the boundary between the Indian and Arabian plates.

The mid Tertiary collision zone east of the COTFZ can be subdivided into stratigraphically and tectonically distinct regions viz., northern montane area, axial belt and Indus basin. While Indus basin is further subdivided into upper, middle and lower Indus sub-basins. The area west and northwest of the axial belt represents the Balochistan basin, which includes the Makran Subduction complex and Kakar Khurasan Flysch Trough. (Fig 2)

POTWAR SUB-BASIN`

The Potwar sub- basin is the part of Indus basin and is located on the northern rim of Indian plate in the foothills of western Himalayas in Pakistan.

It is bounded in the north by thrust Kala Chitta_ Margalla fault zone. in the east by left lateral strike slip Muree Jhelum fault system and in the south by Salt Range Thrust.

Whereas in the west it is bounded by right lateral Kalabagh strike slip fault and merge in to Kohat pleateu in the northwest (Iqbal & Ali, 2001). (Fig 3)

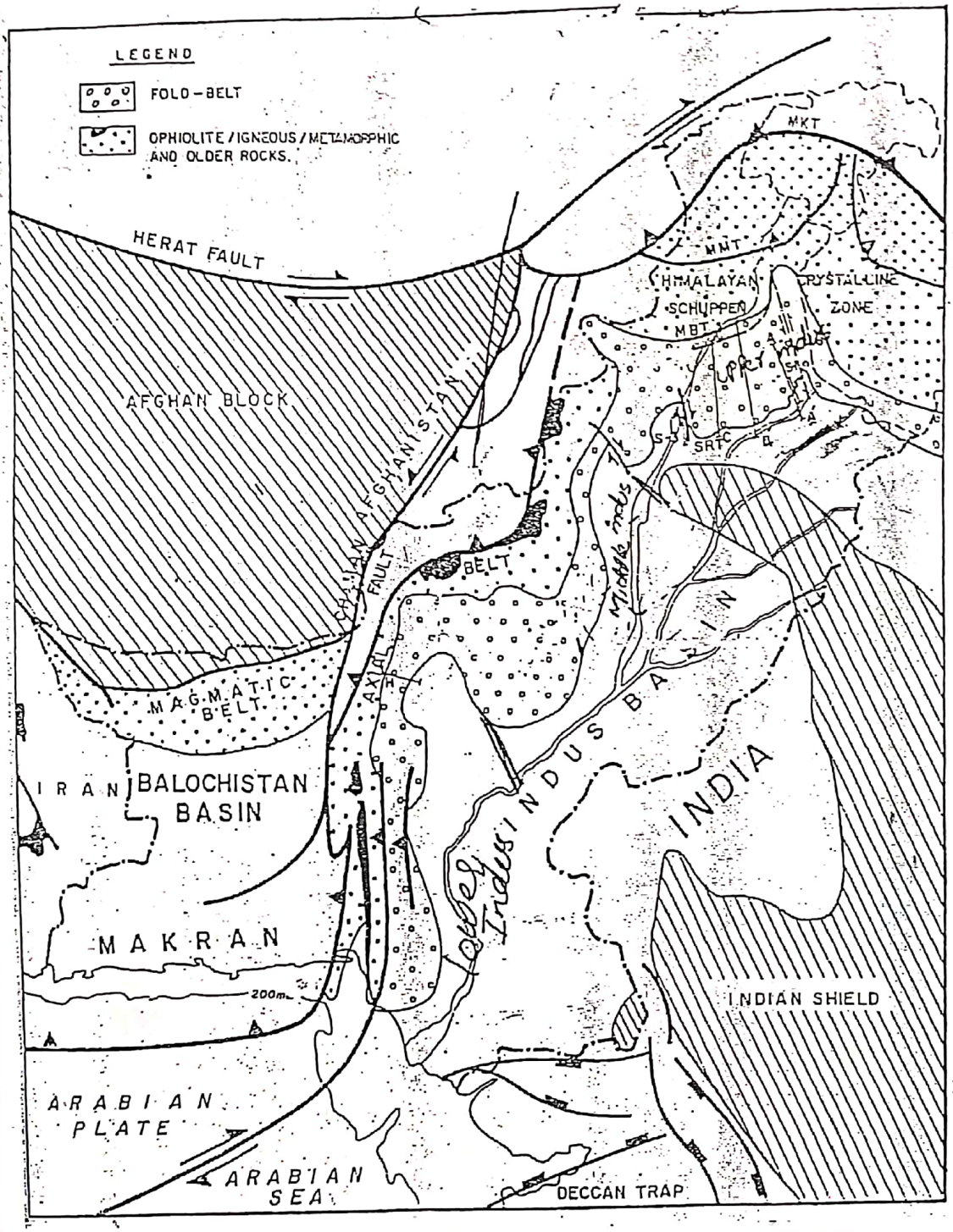

Figure – 2
Generalized Tectonic map of Pakistan, Showing the location of study area.

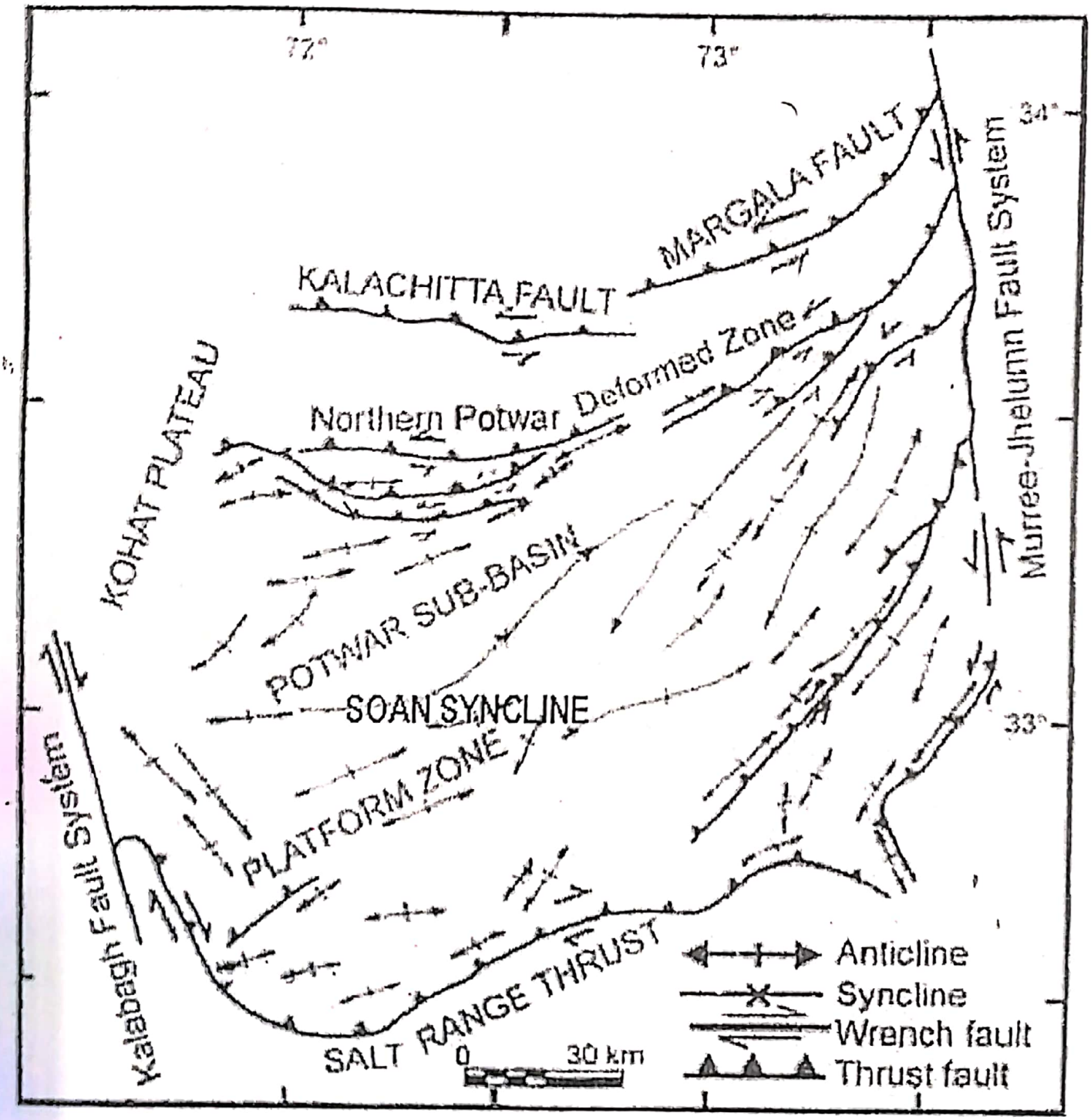

Figure – 3
Map showing structure elements in Potwar sub-basin, Pakistan (After Iqbal & Ali 2001)

GENERALIZED STRATIGRAPHY

The generalized stratigraphy of the area is given in fig 4 and is discussed as follows:

Introduction

The Eocambrian to recent rocks are present in the Potwar area. The Eocambrian to Eocene rocks lie in the sub surface whereas the Miocene to Recent rocks are exposed at the surface. These rocks are folded and thrusted southward during the Tertiary Himalayan collision. This collision initiated the Himalayan foreland basin. The Neogen mollase sediments fill the Himalayan foreland basin

The Khaur-Nakka Rian area comprises of mollase sediments of Miocene to Recent, the mollase sequence has commulative thickness of about 3000 meters. The mollase sequence includes the sediments of Rawalpindi and Siwalik Groups. The Rawalpindi group comprises of Muree and Kamlial formations, whereas the Siwalik Group includes the Chingi, Nagri and Dhok Pathan formations. The Ecocambrian Salt Range Formation to Late Eocene Kuldana Formation occurs in the subsurface.

Pre-Cambrian

Salt Range Formation

The Salt Range Formation consists of bright red and ferruginous red marl, gypsum, clay, dolomite, khewrite and salt (Wyyne, 1878, Gee, 1945, Asrullah, 1967). The underlying contact is with metamorphic basements rocks of Indian plate and the overlying contact with the Tobra Formation is unconformable. The average thickness if the Salt Range Formation is 1000 meters (Baker etal, 1987). In the subsurface the rock unit has been encountered as for as Karampur in the Punjab plains and the Khaur-Nakka Rain area in the Northern Potwar. The Salt Range Formation acts as decollement to the overlying Paleozoic-Mesozoic sequence. The seismic and gravity study (Baker etal, 1987; Pennock 1989) shows that the Salt Range Formation lies in the core of anticline. The thickness of

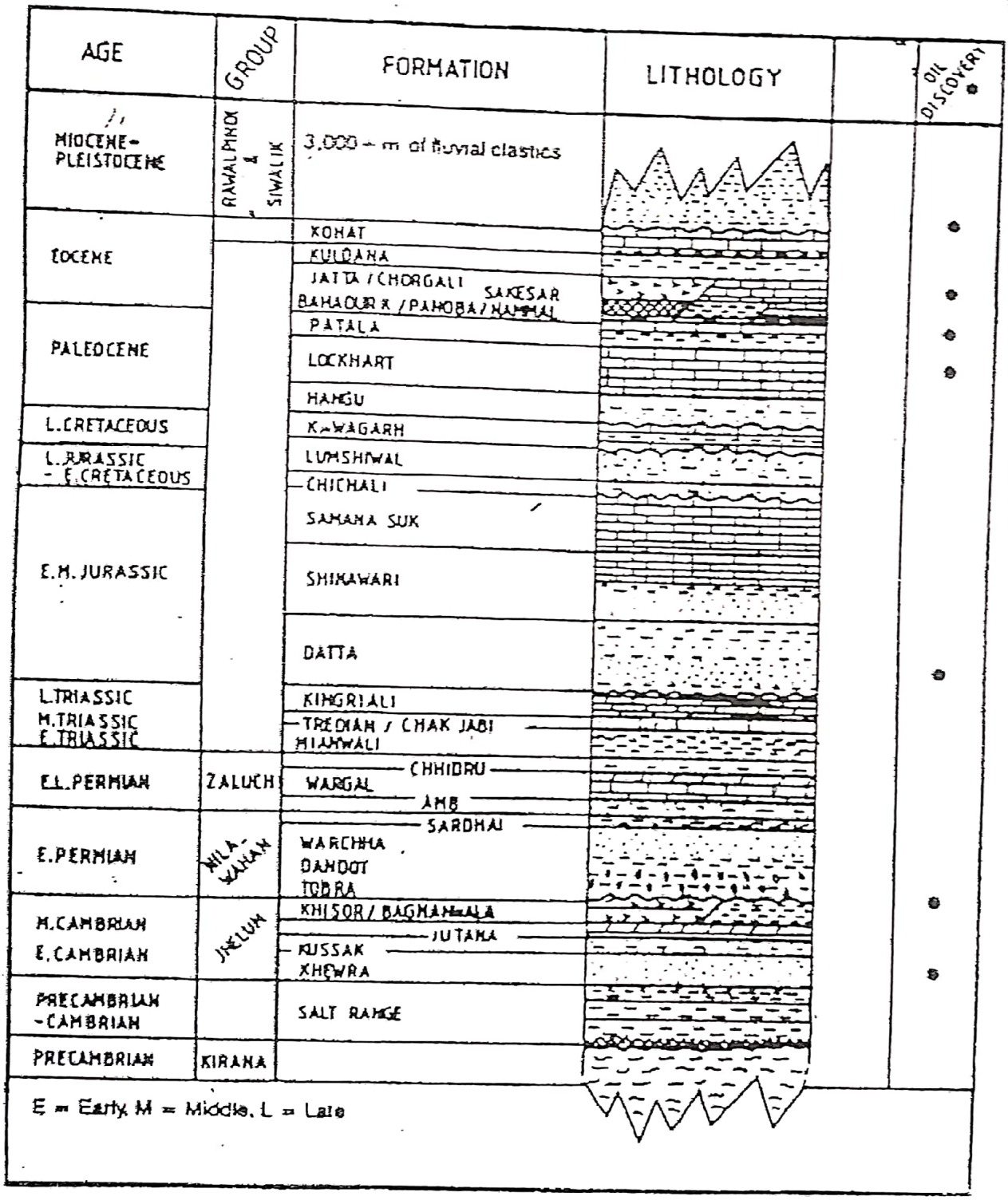

Figure – 4

Generalized lithostratigraphic coloum of Potwar Depression (After Khan et al, 1986).

Salt Range Formation varies from 2000 to 2500 meter in Potwar (Baker etal 1987). In the study area the Salt Range Formation in subsurface lies in the core of Khaur anticline. The formation represents the evaporatic sedimentation that occurred in an enclosed basin in arid condition. The age of Salt Range Formation is Ecocambrian.

Cambrian

Cambrian sediments are well-exposed in the Salt Range. In the eastern Salt Range, the Cambrian sequences consist of four formations of the *Jhelum* Group: *Khewra Sandstone, Kussak Sandstone ,Jutana Formation and Baghanwala Formation.*

Khewra Sandstone

The Khewra Sandstone (Shah 1977) overlies the Late Proterozoic Salt Range Formation without any apparent disconformity. Type locality is the Khewra Gorge in the eastern Salt Range. The Khewra Sandstone is widely exposed in the Salt Range. The Khewra Formation consists mainly of reddish brown to purple, thick-bedded to massive sandstone with few brown shale intercalations. The sandstone is characteristically cross-bedded, has abundant ripple marks and mud cracks, and, in places, exhibits convolute bedding. Thickness of the Khewra Sandstone is 150m at the type locality in the eastern Salt Range. Apart from rare trace fossils, the formation is devoid of fossils. Because of its position between the late Proterozoic Salt Range Formation and the fossiliferous early Cambrian Kussak Formation, the Khewra Sandstone is thought to represent the basal part of the Lower Cambrian.

Kussak Formation

The Kussak Formation (Shah 1977) rests disconformably upon the Khewra Sandstone, marked by a widespread thin conglomerate developed at the base of the Kussak Formation. Type locality is near Fort Kussak in the eastern Salt Range. It has also been encountered by wells drilled in the southeastern Potwar area and in the Punjab Plain. The

formation consists mainly of grey, silty and sandy glauconite shale with some sandstone intercalations and few black shale layers. The thickness of the formation is 75m at the type locality. The fossils in the Kussak Formation point to an early Cambrian (Schindewolf & Seicheler 1955) and early middle Cambrian age (Teichert 1964). The fauna together with the glauconite content indicates a marine depositional environment.

Jutana Formation

Type locality is near Jutana village in eastern Salt Range.It is composed of cliff forming, thick bedded to massive, brownish weathering, sandy dolomites and dolomitic sandstone with few shale intercalations. The formation has yielded some brachiopods, gastropods and trilobites, among them Redlichia noetling and Pseudtheca. The fossils indicate a late Early Cambrian to Early Middle Cambrian age

Baghanwala Formation

Type locality is Baghanwala village in eastern Salt Range. Thickness of formation is about100 meters in type locality, but it is commonly reduced by erosion in other parts of Salt Range. The Baghanwala Formation consists mainly of reddish brown shales and platly to flaggy sandstone characterized by an abduance of salt pseudomorphs. Ripple marks and mud cracks are common. The age of Baghanwala Formation is Middle Cambrian

Nilawan Group

Permian

It consists of four formations:

Tobra Formation

Dandot Formation

Warchha Sandstone

Sardhai Formation

Tobra Formation

It consists of brownish colour clay, silt, sand, pebble, cobble and boulder. The Tobra Formation includes three facies. It has tillitic facies of marine sandstone, freshwater facies with few boulder shale and siltstone and complex facies of sandstone and boulder. The lower contact of Tobra Formation with the Salt Range Formation is unconformable; whereas, its upper contact with Dandot Formation is gradational. The thickness of Tobra Formation is distributed in Salt Range and Potwar areas. The age of Tobra Formation is Early Permian.

Dandot Formation

It consists of light gray to olive green and yellowish Sandstone with thin pebbly beds and subordinate dark gray splintery shales (Wynne. 1878; Waagen, 1879). The formation has gradational contact with the underlying Tobra Formation and the sharp and conformable contact with the Warcha Sandstone. The thickness of the Dandot Formation is 62 meters. The formation is encountered at the subsurface in Khaur-Nakka Rian area and is widely distributed in Salt Range. The age of Dandot Formation is Early Permian.

Warcha Sandstone

The Warcha Sandstone consists of medium to coarse –grained sandstone, conglomerate and shale (Gee, 1945). The sandstone is red, purple and showing lighter shades of pink colour. The Warcha Sandstone conformable overlies the Dandot Formation. The upper contact with the Sardhi Formation is transtational. On the basis of bore hole data the thickness of this formation is 120meters in Khaur-Nakka Rian area. The age of Warcha Sandstone is Early Permian.

Sardhai Formation

The Sardhai Formation consist of bluish, greenish and lavender colour clays, minor sand and siltstone and carbonaceous shale (Wynne, 1878) the lower contact of Sardhai Formation with the Warcha Sandstone is transitional while the upper contact with Amb Formation is conformable. The thickness of the unit is 70 meters. The age of Sardhai Formation is Early Permian.

Zaluch Group

Amb Formation

The Amb Formation consists of sandstone, limestone and shale (Teichert, 1966; Waggen, 1891). The sandstone is gray. Calcareous medium – grained and medium to thick bedded. The limestone is brownish gray and richly fossiliferous with large productus. The shale is gray to dark gray. The Amb Formation has transitional contact with the underlying the Sardhai Formation while the upper contact with the Wargal limestone is conformable. The thickness of formation is 70 meter in Khaur Nakka Rian area. The formation is widely distributed in Kishore Range and Salt Range. The age of Amb Formation is Late Permian.

Wargal Limestone

The Wargal Limestone consists of limestone and dolomite of light gray, olive gray and brownish gray colour (Noetling 1901; Teichert, 1966) the contact of Wargal Limestone with the underlying Amb Formation is conformable whereas the upper contact with Chhidru Formation is transitional. The thickness of formation is 138 meters. The age of formation is Late Permian.

Chhidru Formation

The Chhidru Formation consists of shales of pale yellowish gray to medium gray calcareous sandstone and minor limestone. The colour of sandstone is white whereas the limestone is light gray to creamish gray.

The lower contact with the Wargal Limestone is transitional while the upper contact with the Mianwali Formation is para- unconformable that marks the Permo – Triassic boundary in Pakistan. The thickness of formation is 80 meters in Khaur Nakka Rian area. The age of formation is Late Permian.

Triassic

In the Potwar sub-basin, Triassic is represented by only one formation, i.e. Mianwali Formation.

Mianwali Formation

The Mianwali Formation consists of marl, limestone, sandstone, siltstone and dolomite. (Pascoe, 1959; Kummel, 1966). The colour of limestone and sandstone is gray to dark gray. The lower contact of Mianwali Formation with Chiddru Formation is para-conformable while the upper contact with the Datta Formation is conformable. The average thickness of Mianwali Formation is 65 meters. The formation is widely distributed in the Potwar area and Salt Range. The age of Mianwali Formation is Triassic.

Paleocene

Hangu Formation

The Hangu Formation consists of sandstone with gray shales (Davies 1980). The sandstone is white gray reddish brown and dark rusty brown in colour. It is fine to coarsed grained and thick to medium bedded. The formation includes some conglomeritic sandstone, nodular limestone and shale. The lower contact of the formation with the

Datta Formation is unconformable. The upper contact with the Lockhart limestone is conformable. The thickness of formation is 38 meters. The Hangu Formation is widely distributed in Salt Range and Kala Chitta areas. The age of Hangu Formation is Early Paleocene.

Lockhart Limestone

The Lockhart Limestone is gray to light gray and medium to thick bedded (Davies.1980; Latif, 1970). The colour of limestone is dark gray to bluish gray in the lower part. The limestone is flaggy it contain dark bluish gray and calcareous shales in lower part. The lower contact with the Hangu Formation is conformable while the upper contact with Patala Formation is transitional. The thickness of formation is 90 meters. The formation has rich assemblages of fossils including foraminifers, corals and mollusks. The age of formation is Early Paleocene.

Patala Formation

The Patala Formation consists of shale and marl with subordinate limestone and sandstone. The shale is dark greenish gray and at places carbonaceous and calcareous. The limestone is white to light gray. The limestone is nodular. The Patala Formation conformably overlies the Lockhart limestone. The total thickness of formation is 48 meters. The formation is widely distributed in Kohat Potwar area. The formation is richly fossiliferous. The age of formation is Late Paleocene.

Eocene

Nammal Formation

The Nammal Formation consists of shale marl and limestone. The shale is gray to olive green while the limestone and marl are light gray to bluish gray. The upper contact of Nammal Formation with Sakesar limestone is conformable and transitional while the

lower contact with the Patala Formation is conformable. The Nammal Formation is widely distributed in Salt Range and Surghar Range. The age of formation is Early Eocene.

Sakesar Limestone

The Sakesar Limestone dominantly consists of limestone with subordinate marl and chert. The colour of limestone is creamish to light gray whereas marl is cream to light gray. The lower contact of formation with Nammal Formation is transitional. The upper contact with the Chorgali Formation is conformable and transitional. The thickness of formation is 92 meters. The formation has rich assemblages of foraminifers, mollusks and echinoids. The age of formation is Early Eocene.

Chorgali Formation

The Chorgali Formation consists of shale and limestone (Pascoe, 1920, Latif, 1970). The lower unit consists of dolomitic limestone and shale. The shales are calcareous in nature. The colour of dolomitic limestone is white to light gray. It is medium bedded. The colour of shale is gray to greenish gray. The lower contact of the Chorgali Formation with the Sakesar Limestone is conformable while the upper contact with Kuldana Formation is gradational. The total thickness of formation is 72 meters. The age of formation is Early Eocene.

Kuldana Formation

The Kuldana Formation consists of shale and marl with sandstone limestone and conglomerate (Latif. 1970). The shale is purple brown, pale gray and red in colour. The marl is brown to pale gray with few beds of gypsum. The lower contact of Kuldana Formation with the Chorgali Formation is conformable while the upper contact with the Murree Formation is unconformable. The thickness of formation is 46 meters. The

formation is widely distributed in KalaChitta, Northern Potwar and Kohat areas. The age of formation is Early to Middle Eocene.

Miocene

Rawalpindi Group

The Stratigraphic Committee of Pakistan approved the term Rawalpindi Group after the Rawalpindi District for the rocks comprising Murree Formation and Kamlial Formation in Kohat –Potwar basin. The rocks of Rawalpindi group indicate the initiation of significant Himalayan uplift

The middle portion of this part consists of sandstone of light gray, reddish to maroon and dark red and clay of purple and bright red colour. The upper part of this portion consists of clay sandstone and conglomerates.

In its upper part sandstone ratio increases as compared to Middle and Lower portion of formation. The Murree Formation consists of sand stone, clay siltstone and conglomerate (Wyyne, 1874; Pilgrim, 1910). The bed thickness of sandstone varies form 2 to 7 meters. The thickness of clay layers varies from 7 to 13 meters. The colour of sandstone is reddish to maroon and dark red. The sandstone unit is interbedded with reddish to purple clays. The upper most sandstone unit grades into siltstone and clay. The gray to light gray sand stone is bedded with clay and silt. The sandstone has quartz filled, Calcite filled and opens veins. The conglomerate of Murree Formation in places is composed of pebbles of sandstone and siltstone. The size of pebbles ranges from 1mm to 3 cm. The lower contact of this unit is not exposed in Khaur-Nakka Rian area. The lower contact is unconformable with various Eocene formations while the upper contact with Kamilal Formation is gradational. The thickness of the formation is 1650 meters.

It is up to 3030 meters is Northern Potwar but thins out 90 meters at Banda Davel Shah in Western Kohat. The Murree Formation is deposited in fresh water showing continental environment. The Murree Formation is poorly fossiliferous. It has silicified wood, fish remains and mammilan bones. The age of Murree Formation on the basis of fossils is Early Miocene.

Kamlial Formation

The Kamlial Formation consists of sandstone, clay, grit and conglomerates (Pinfold, 1918; Pascoe, 1963). The sandstone of Kamlial Formation is medium to coarse grained, hard and compact. The colour of sandstone is gray, dark gray and greenish gray. The greenish gray colour of Kamlial Formation is due to presence of tourmaline and epidote mineral. The colour of clay is red, purple and brown. The conglometric bed occurs in unit, which range in thickness from 20 to 90cm. The conglomerates of the formation are clast and matrix supported. The clast of sandstone is 2mm to 7 mm. These clast are elongated to rounded. The sandstone has calcite filled and open veins. Spherodial weathering is displayed in the formation, which is the characteristic feature of formation. Spheriodal weathering is due to thinly laminated aquigranular sandstone of the formation. The formation is thin to thick bedded. The total thickness of Kamlial Formation is 260 meters. The formation is widely distributed in Potwar- Kohat area. The Kamlial formation marks the continental environment. The age of formation is Middle to Late Miocene.

Siwalik group

Medlicot (1868) used the name Siwalik for the upper part of the Himalayan mollase sediments. The Group is mainly composed of sandstone and clay. These were deposited in the rivers of the Sub-Himalayas where the mollase sediments were deposited since the Miocene Himalayan uplift. These mollase sediments are erosional products of southward migration of Himalayan thrust sheets. This shows that the erosional and uplifting history of Himalayas is recorded within the mollase filled foreland basin. The Siwalik Group is very interesting from fossils study point of view, containing best vertebrate faunal succession in the world. Stratigraphic Committee of Pakistan divided this Group into four following formations.

Chinji Formation

The Chinji Formation consists of dominantly red clay, which is mostly brick red alternating with sandstone (Pilgrim, 1913; Lewis, 1937). The colour of clay is reddish, brown to brick red and violet. The colour of sandstone is light gray, gray and ash gray. The siltstone is ash gray and chocolate in colour. The sandstone has calcite filled; quartz filled and open joints and fractures. The bedding in sandstone is medium to thin bedded. The sandstone is medium-to-coarse-grained. The thickness of sandstone beds is rarely greater than 20 meters but clay bands may be as much as 50 meters thick. The conglomerates are found at different horizons throughout the Formation. The conglomerates are polymict-having pebbles of limestone, chert and granite. The clay to sandstone ratio in the Chinji Formation is 70:30. This shows that the Formation contains the highest clay content in the Siwalik Group. The cross bedding is present in sandstone. The Chinji Formation in underlain and overlain conformably by the Kamlial and Nagri Formation respectively. The Formation is present along the northern and southern limbs of the Khaur anticline. The total thickness of Chinji Formation in Khaur-Nakka Rian area is 1050 meters. The Formation forms the gentle slopes and ridges. The Formation is widely distributed in the Kohat-Potwar basin. The Formation is richly fossiliferous and has abundance of vertebrate fauna in Potwar-Kohat area. The vertebrate fauna includes crocodiles, turtles, lizards and aquatic birds. The paleomagnetic work suggests the age of Formation is Late Miocene 14.3-10.8 Ma (Johnson et al., 1982)

Pliocene

Nagri Formation

The Nagri Formation consists of sandstone with subordinate clay (Lewis, 1937). The sandstone is greenish gray to olive gray colour. The sandstone of Nagri shows salt-pepper texture. The texture of sandstone is medium to coarse-grained. The sandstone is thick to massive bedded. The sandstone is hard and compact in its upper part. The clay is sandy and salty. In the sandstone of Nagri Formation calcite filled and open joints and fractures

are present. The colour of clay is brownish, red, brick red, pale orange and yellowish gray. Nagri Formation is mainly composed of alteration of 60% sandstone with 40% clay. The thickness of sandstone bed varies from 40 to 65 meters. Similarly the thickness of the clay bands ranges from 15 to 35 meters in the mapped area. The cross bedding is of high magnitude as compared to other Formations of the mapped area. The Nagri Formation has low magnitude of cross bedding in its lower part whereas it has high magnitude of cross bedding in its upper part. The polymict conglomerates of the Formation consist of pebbles of basic, granitic, volcanic, metamorphic and sedimentary rocks. The matrix of conglomerates is sandy and at places calcareous in nature. It gives gas bubbles when treated with 10% HCL. The size of pebbles varies from 7mm to 5cm and is elliptical to round in shape. The conglomerate levels increases from bottom to top of the Formation. In the lower part the sandstone is thin to medium bedded and medium to coarse-grained. The upper and lower contacts of the Formation with the Dhok Pathan and Chinji Formation are gradational respectively. The total thickness of the Formation in Khaur-Nakka Rian is 1100 meters.

The Nagri Formation is well exposed along the southern and northern limbs of the Khaur anticline. The Formation is exposed in Dhok Milan, Dhok Bhakwal, Makial and Ahmadal areas along the southern limb of the Khaur anticline. In Sapiala Syncline it is exposed, also the northern limb at Pind and Dhok Darial areas. The Formation is widely distributed in Potwar and Indus basin. The Formation shows continental environment. The rich assemblage of vertebrate fauna is recorded (Gill, 1952) from the Formation, which include crocodiles and rihnoceratides. The wood fossils are present in the Formation. The paleomagnetic work suggests that the age of the Formation is Early Pliocene 11.8-8.5 Ma (Johnson, 1982).

Dhok Pathan Formation

The Dhok Pathan Formation consists of cyclic deposition of sandstone, siltstone and clay (Pilgrim, 1913). The ratio of the sandstone and clay is 50:50. The sandstone is gray to light gray, brown and whitish in colour. Sandstone is medium to coarse-grained and cross-bedded. The colour of clay is yellowish, brownish and dull red. The siltstone is of

yellowish to brownish in colour. It is sandy and calcareous in nature and gives bubbles when treated with 10% Hcl. The bedding is medium to thick. Individual bed thickness of sandstone varies from 5 to 22 meters whereas the clay bands are 3 to 22 meters. The upper part shows lenticular bedding. The sandstone of the Dhok Pathan Formation is very loose, porous and friable.

The sandstone has calcite filled and open joints and fractures. The conglomeratic lenses and layer occur in the middle and upper part of the Formation. The polymict conglomerates contain pebbles of granite, limestone, and volcanic, plutonic, mafic and metamorphic rocks. The conglomerates of limestone dominate over volcanic and igneous rocks. The conglomerates range in size from 4 cm to 6 cm. The Formation has a gradational contact with the Nagri Formation whereas the upper contact with alluvium is uncomfortable in Khaur-Nakka Rian area. The total thickness of the Formation in mapped area is 400 meters. The Dhok Pathan Formation is well exposed in the core of the Sapiala Syncline along the Sapial village and Sapiala Kas. The Formation is present along the southern limb of the Khaur anticline near Kot Maliaran, Narraghi, Muthrala, Dewal, Majran, Marali and Nakka Rian areas. The Dhok Pathan Formation is deposited in continental environment. The Formation has very rich assemblage of vertebrate fossils. On the basis of the fossils and paleomagnetic study the age of
Dhok Pathan Formation is Middle Pliocene 7 Ma (Johnson, 1982).

Soan formation

Type locality is near Mujahad village; principal reference is near Urak village. This formation rests conformably on Dhok Pathan Formation with a marked coarsening of the clastic sediments and appearance of massive conglomerates beds. The formation largely consists of massive conglomerates with subordinate sandstone, siltstone and clay.

TECTONICS AND ASSOCIATED STRUCTURE STYLES

Potwar sub- basin represents a large wedge of Phanerozoic rocks, which is about 6km thick below the Kalachitta fold-belt and is tapering towards the Sargodha High (Fig 5). The Potwar sub- basin is fault-bounded basin. The basin is filed with thick syntectonic molasses sediments derived from the rising Himalayas.

The Potwar Pleateu can be sub divided on the basis of deformation style in to the Plat Form Zone and Northern Potwar Deformed Zone (NPDZ) separated by Soan Syncline (Fig 3&5)

The structural pattern of Potwar sub-basin is the result of south ward directed Principal Horizontal Stress (PHS) develops as a consequence of collision and under thrusting of Indian Plate beneath the Eurasian mass in the north and subsequent left- right lateral transpressional strike- slip movements during Late Tertiary time along Muree Jhelum and Kalabagh fault systems respectively (Ali& Iqbal, 2001).

The transpressional movement in the northern part of sub basin has created a decollement- fault in the Salt Range Formation overlying the Pre- Cambrian basement. As a result of these tectonic episodes highly deformed thrusted structures in the north, thrust faults and associated Salt Range thrust in the south, salt cored anti clines with both forward and backward thrust have been developed from east to west through the Central part of sub-basin (Fig. 5)

The plateform zone

The Eastern Potwar Platform Zone represents strong deformation as compared to central and western Potwar platform zone. The forward and backward thrusts bounded salt cored anticlines represents both foreland and hinter land verging deformation

In the central and western part of platform region only minor deformation is present with in the over thrusted Phanerozoic sedimentary section, due to effective decoupling with in Eocambrian evaporites above the basement (Fig 6 & 7)

The western Potwar platform zone is similar to Central Potwar platform zone in all respect the strong deformation in the eastern platform region maybe attributed to the terminal of left lateral strike slip movement along Muree Jhelum fault system in to thrust

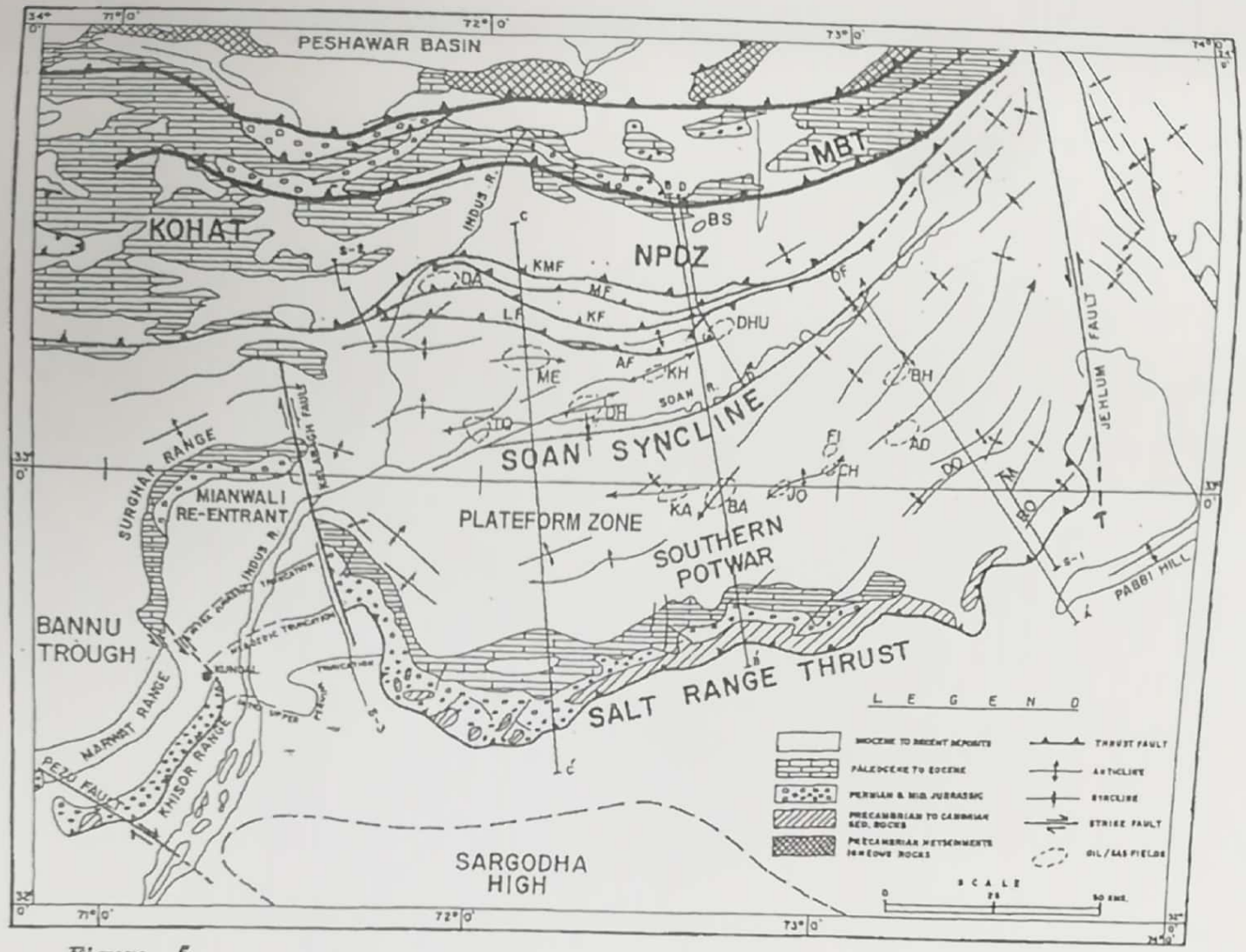

Figure – 5

The A-A: B.B: C-C: D-D: are the seismic section shown in figure 6, 16 and 15 structure are abbreviated as AD=Adbhi oil field AF=Ahmadal Fault, A=balkassar oil oil field Bh= Bhangali of field CH: Chak Naurange FI=fim Kassar oil field Dii=Dhuhan oil field

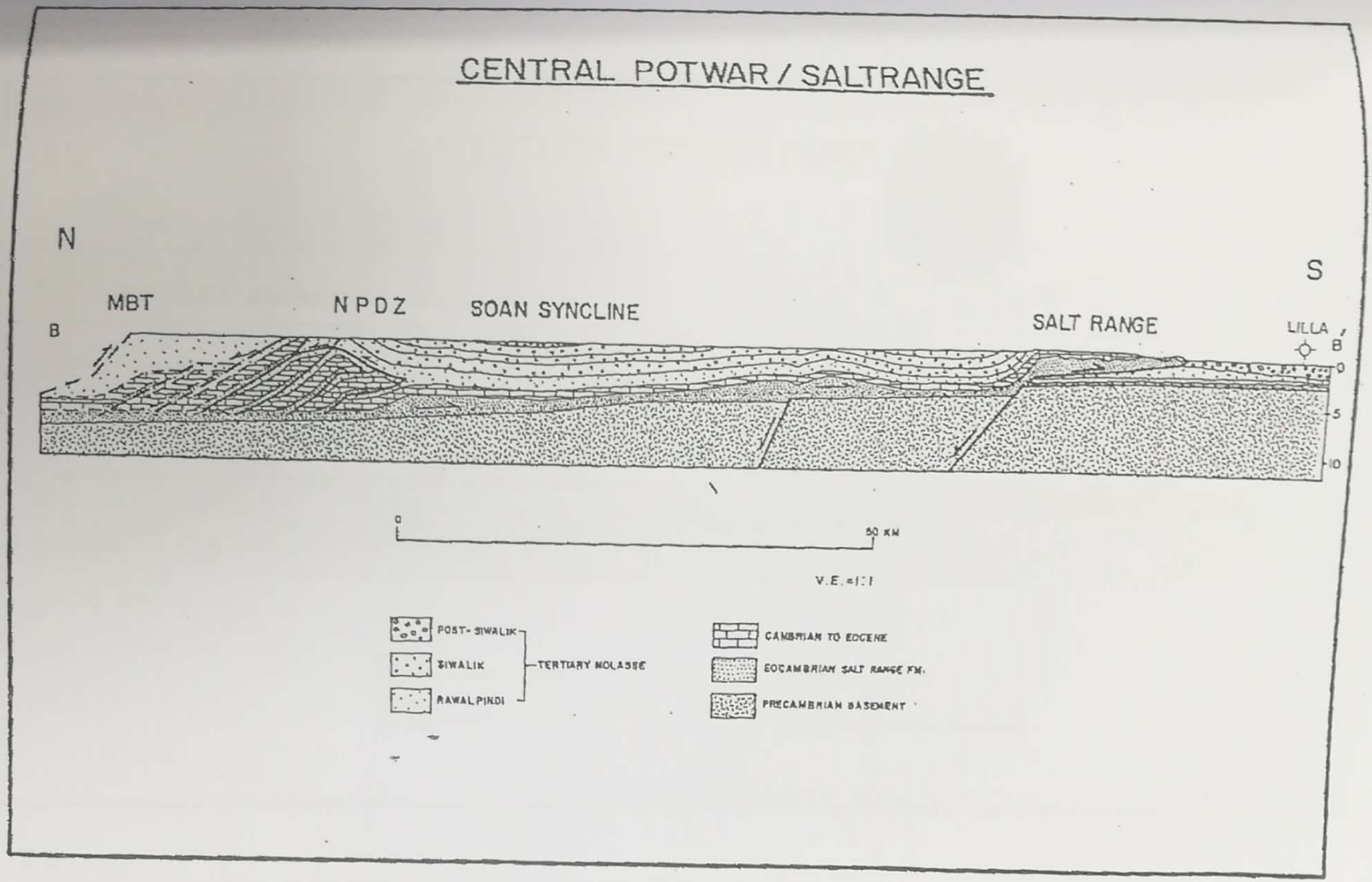

Figure – 6

Balanced cross-section along line B-B (see figure for location in the NPDZ The salt range thrust sheet up against the basement normal fault and thrusted over the Punjab plains along a basal

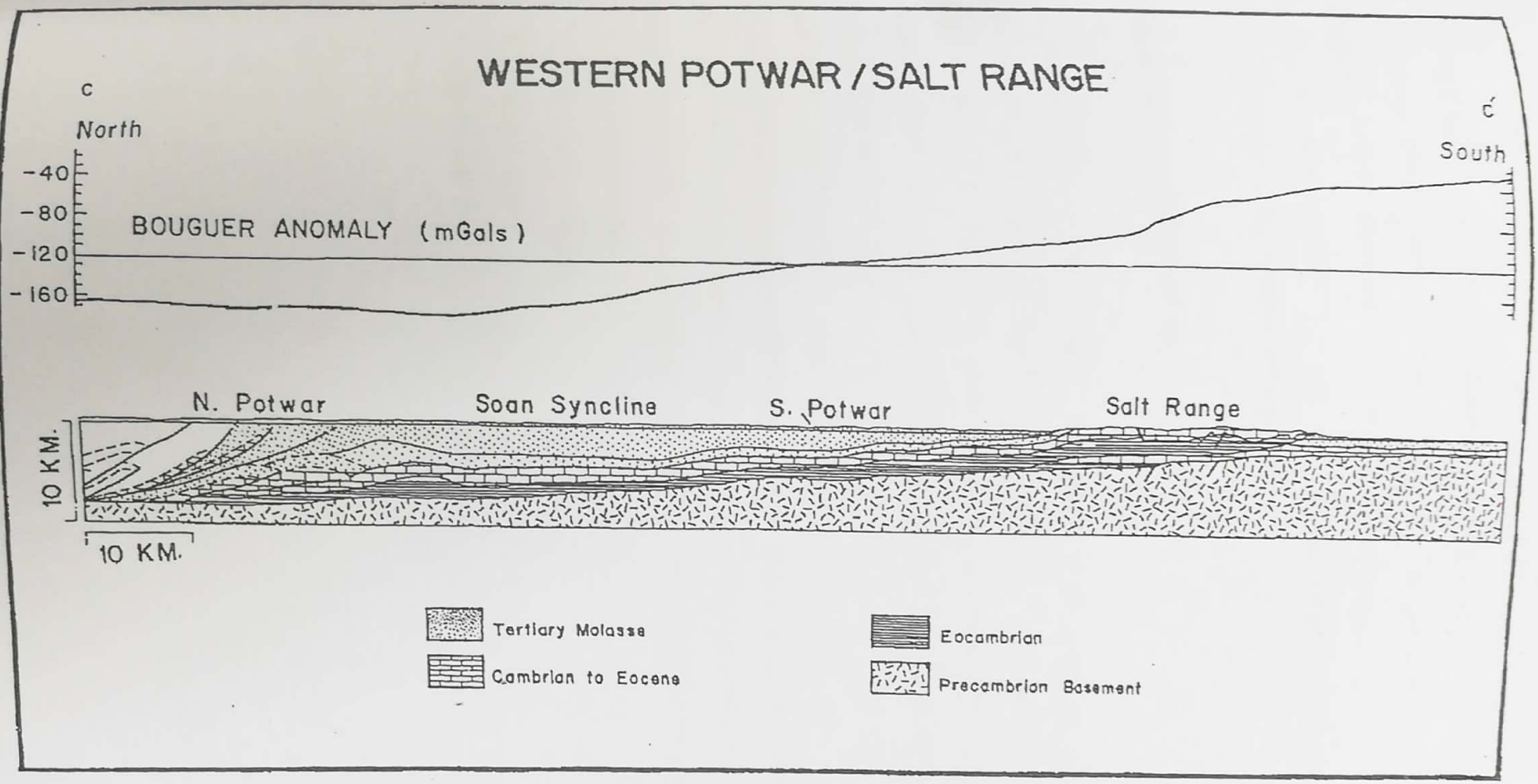

Figure – 7

Balanced cross section along line C-C (for location see Figure) Northern that the basement normal fault is missing in the western salt range little deformation in the southern Potwar and emergent thrusts in the NPDZ (Leathers, 1987).

fault (Fig.3 & 5) on surface these thrust faults do not extend in to the central and western part of the platform region. Therefore these areas are less deformed and the deformation as mentioned earlier attributed to the salt movement only.

The platform area is mainly covered with the thick fluvial sediments of Swalik Group (Chinji, Nagri and Dhok Pathan formations)

Northern potwar deformed zone

The northern Potwar Deformed Zone (NPDZ) is the northernmost part of the active foreland and thrust belt of the Potwar sub-basin in Pakistan (Fig 3&5). The highly dissected NPDZ is an area of wide synclines, compressed folds and closely spaced imbricate thrust. The deformation style of the NPDZ abruptly changes form east to west While the western NPDZ that is characterized by compressed and faulted anticlines separated by large synclines, representing the emergent thrust front.

In Central Potwar, structures are mainly fault bounded mostly by thrust and back thrust, while at some places, asymmetric anticlines are bounded by a single fault

Based on the seismic interpretation, the structures in Potwar area may be divided into:

1. Pop-up anticlines
2. Salt cored anticlines
3. Triangle zones
4. Figure (8& 9)

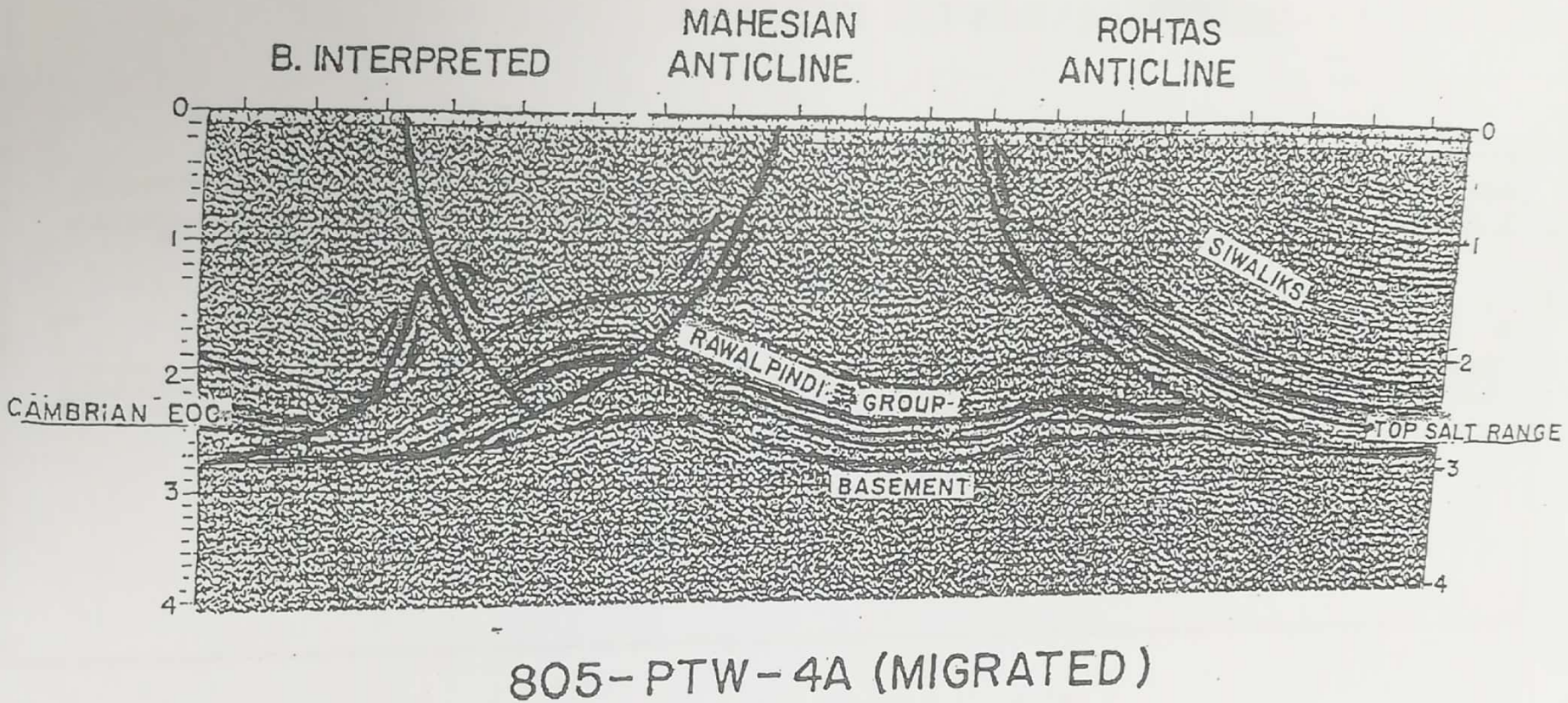

Figure - 8
Interpreted seismic time section (s-1) from the eastern salt range (for location see figure &) the line 805-PTW-A4 is migrated, 12 fold, dynamite source recorded and processed by OGDC in 1980 (After Kemal (1991).

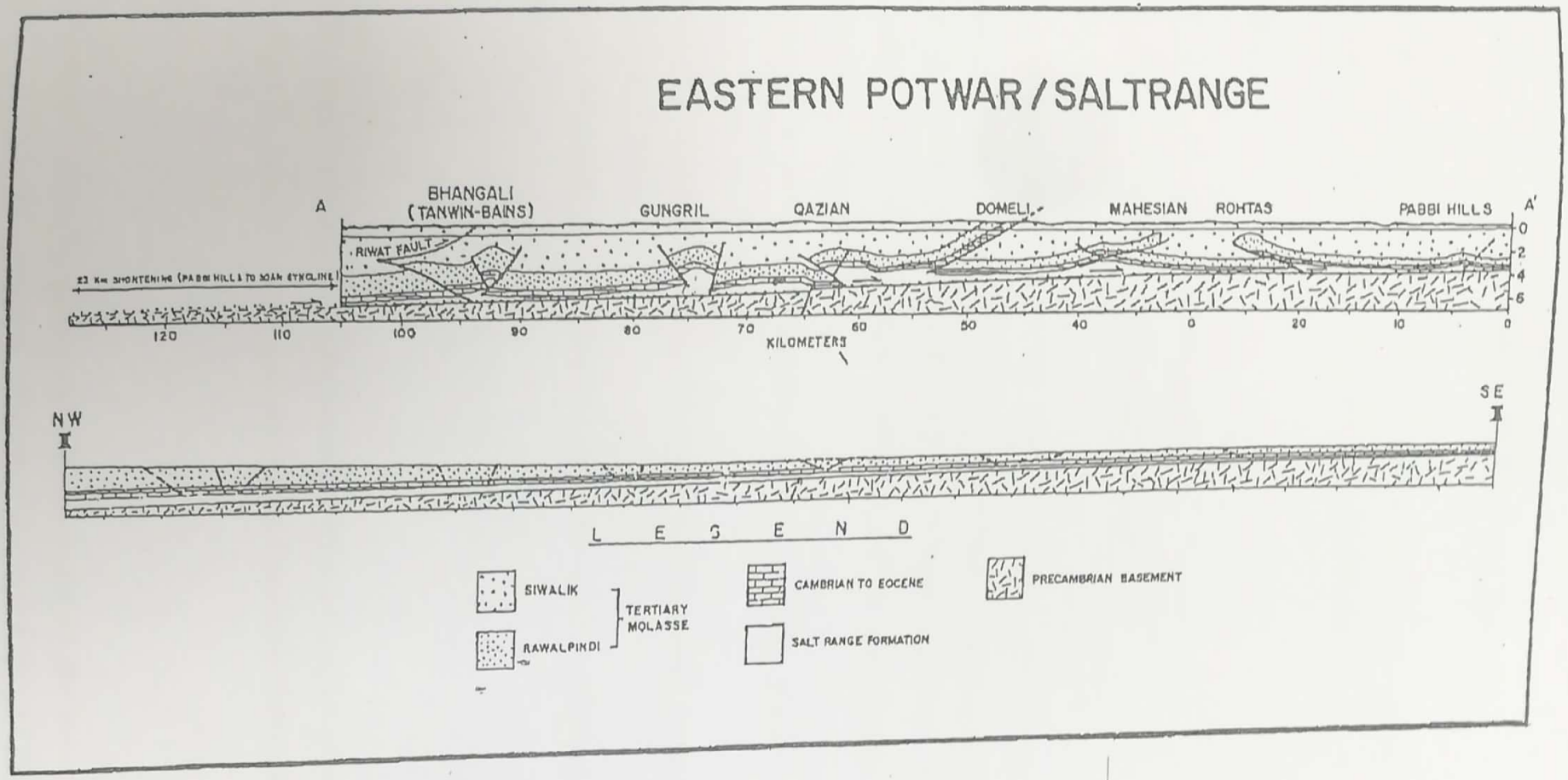

Figure – 9

Balanced and restored cross section along line A-A: location see figure 7) Notice that fault are warping to SE as well as to NW and basement is gently dipping towards north (Panneck oil 1989)

HYDROCARBON HABITAT

So far 9 oil and 5 condensate fields have been discovered in the region. The condensate fields are located in the north, northwest and southeast (Fig 10.)

Source rocks

1 Paleocene shale's of Patala Formation
2 Precambrian oil shales of Salt Range Formation.

Oil shale horizons developed within Salt Range Formation in the eastern Salt Range are known potential source rocks (Ahmed, 1998) contains a high percentage of organic matter (TOC up to 26%), oil shales also occur in Western Salt Range in the middle part of the formation where they like wise constitute good oil source rocks, though of some what lower, quality (TOC 6-8%)

These source rock horizons maybe mature due to over burden in various part of the sub-basin.

Patala Shales of Paleocene age have been proven as the main source rock in the sub-basin (TOC up to 1.57%)

These organic rich shales were deposited partly in anoxic conditions prevailing during Paleocene time

Reservoir rocks

In the Potwar region oil has been discovered in Paleocene- Eocene carbonates, Jurassic sandstone, Permian sandstones and limestones and Cambrian sandstones (kamal, 1992).

Cambrian

The sandstone of Khewra Formation is well developed in the eastern Potwar with more than 21% average porosity, and it is oil producing in the Adhi and Hissakiswal field.

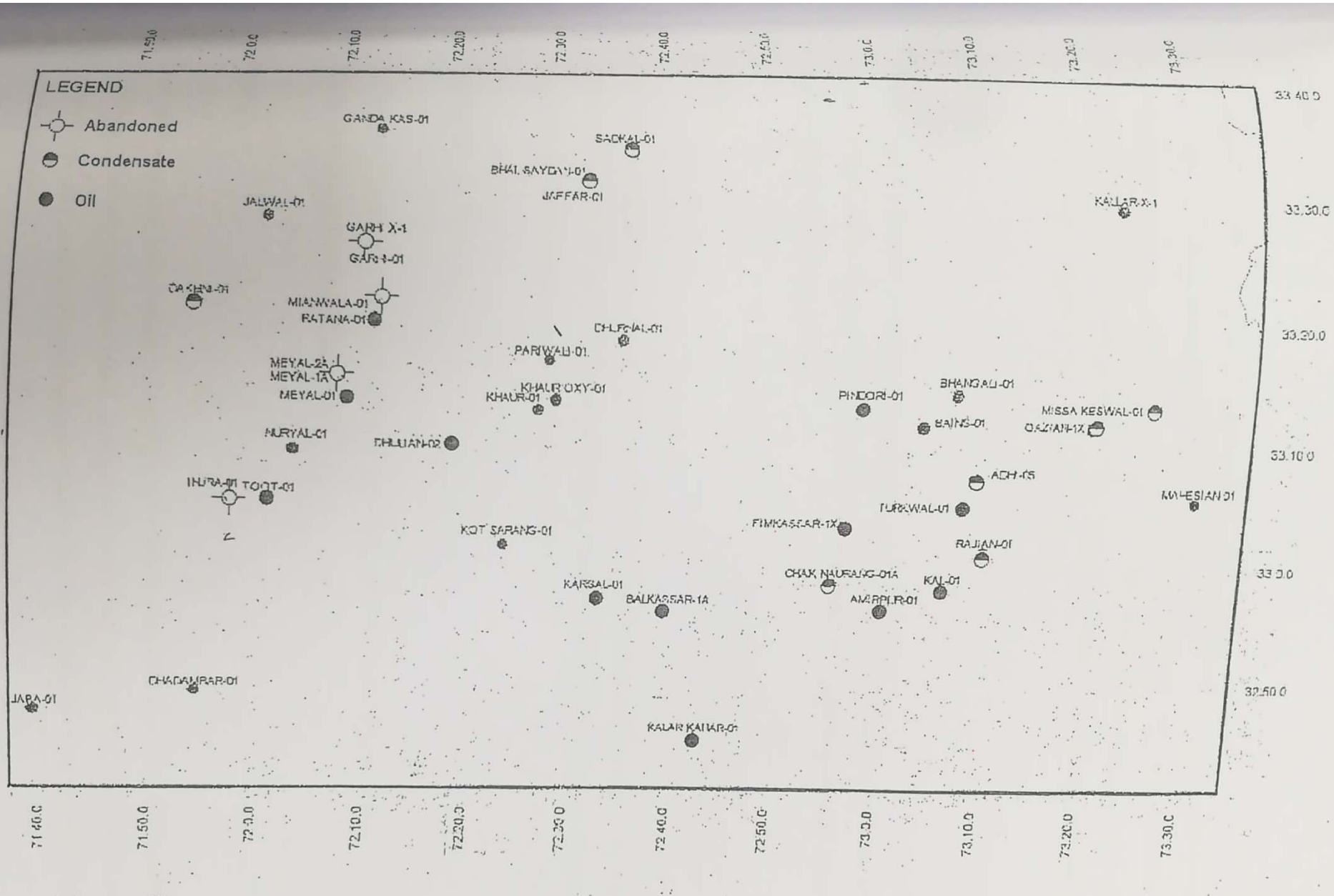

Figure – 10
Total Exploratory wells present in Potwar basin

Permian

The Tobra Formation represents tillitic, fresh water and mixed diamicite and sandstone facies in the Eastern, Central and Western Salt Range respectively. This formation has been penetrated in few wells of Potwar region. It is oil producing in the Adhi field, where it has more than 10% average porosity. The Wargal limestone is producing oil from the secondary fracture porosity in the Dhurnal oil field.

Triassic

The Tredian Formation of middle Triassic age is non-marine unit and it is well developed in the Western Salt Range. The thick sand stone intervals exhibit potential reservoir characteristics with good porosity.

Jurassic

The Datta Formation of early Jurassic age is of continental origin and it is widely developed in the Western Salt Range/Potwar Pleateu. The sand stones are producing oil/gas in Toot and Meyal oil fields in the Central Potwar.

Paleocene

The Hangu Formation consists of sandstone with intercalations of gray shales and it is widely developed in the Potwar areas.

Eocene

The carbonates of the Chorgali and Sakesar exhibit excellent reservoir characteristics. The Chorgali Formation composed of limestone and shale and is widely distributed in the Potwar area. The Chorgali and Sakesar carbonates are producers in many oil fields of Potwar pleateu.

Miocene

The sandstone beds of Murree Formation exhibit good reservoir quality in the Khaur oil field similar situation could be encountered in any other structure in the Potwar pleateu.

TRAPS

The Western Potwar pleateu has already been largely explored. In the Plateform Zone, Eocene and older potential targets were deposited mainly in shallow marine and paralic environments that provide good settings for stratigraphic traps. In the Eastern Potwar, Adhi wells have been producing oil from the Tobra Formation, which overlies an unconformity. The trap is partly stratigraphic.

The discovery of Dhurnal oil field in the triangle zone (fig 11) opened up new avenue for the future exploration in the foreland fold and thrust belt of the NPDZ.

The discovery of under thrusted Dakhani field in the Western NPDZ and later discovery of Bhal Sayedan in the hinter land dipping imbricate stack, confirmed the petroleum potential of the NPDZ

The structure style of the Central, Western and Eastern parts of Potwar sub-basin show a marked difference. In the Central and Western parts of Potwar the deformation appears to have occurred by south verging thrusting. Whereas in the Eastern part the deformation is mainly in the northeast-southwest direction with tight and occasionally over turned anticlines separated by broad synclines.

This difference maybe related to lesser amount/ thickness of salt in the Infra Cambrian in the eastern area and very low dip of basement (1"_1.5") as compared to Central Potwar (2"to 3").

Lithofacies maps show better developments of Cambrian sandstone facies in the eastern part, and of Permian limestone facies and Triassic- Jurrasic sandstone facies in the western part (Fig 12&13). The western Potwar has already been largely explored however several structures such as Makhad, Injira, Pachnad, and Tamman are still untested (Fig 14). As a result of recent seismic investigation, more prospects have been delineated. Similarly many structures are available in eastern Potwar, which after the

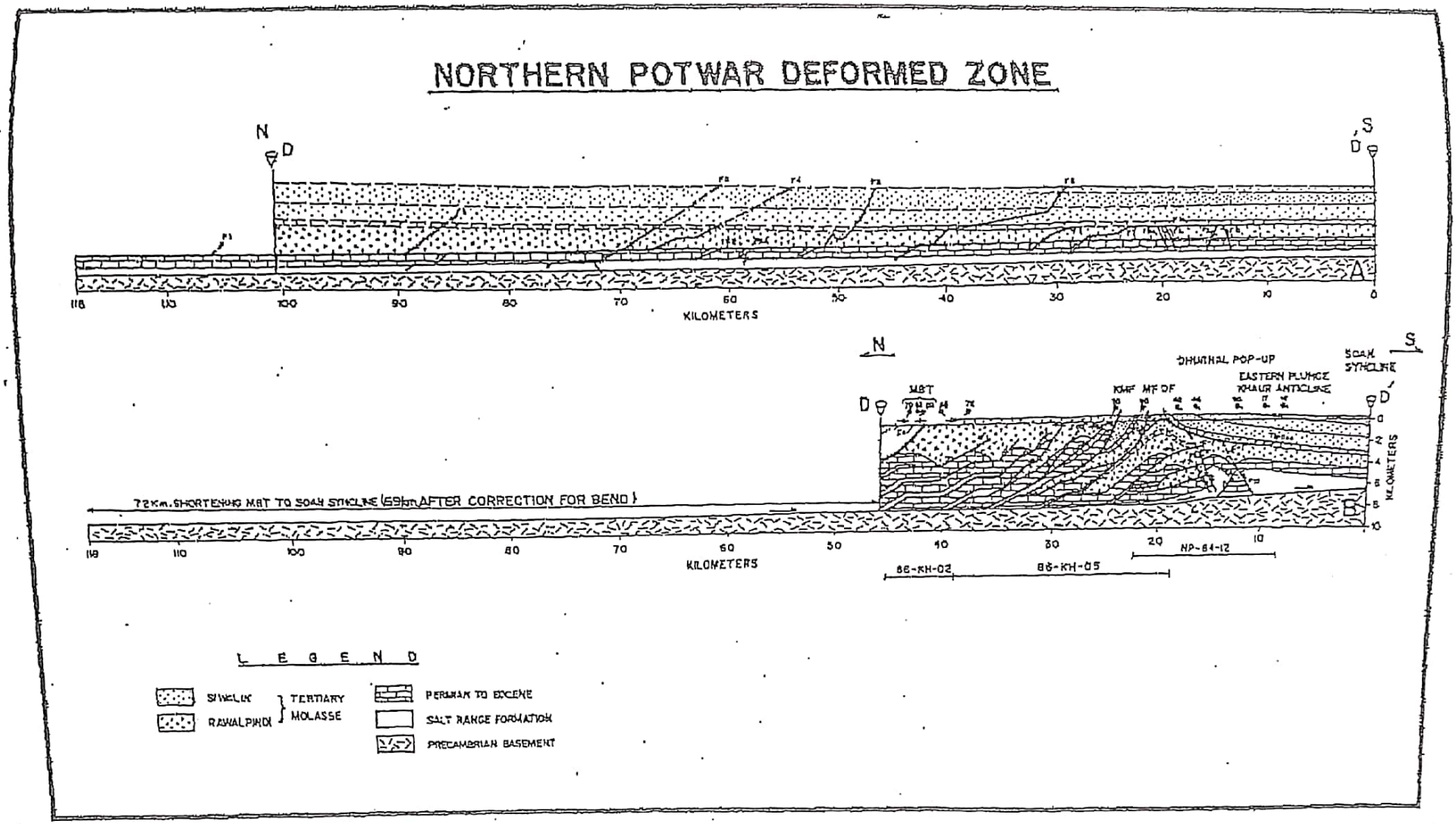

Figure – 11
Balanced and restored cross-section alone line D-D for location see figure 7 in the NPDZ

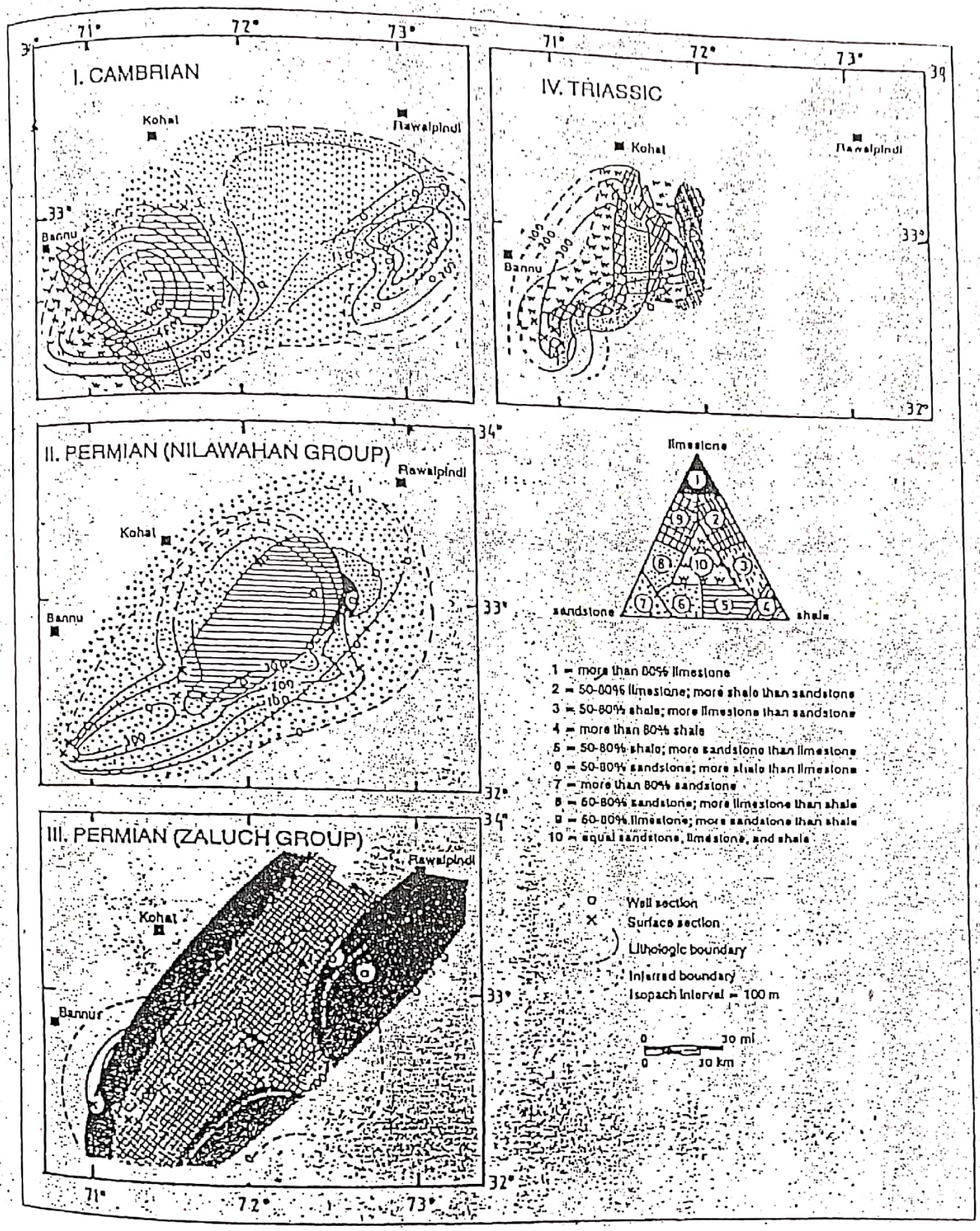

Figure- 12
Lithofacies maps of (1) Cambrian, (2) Permian (Nilawahan), (3) Permian (Zaluch), and (4) Triassic.

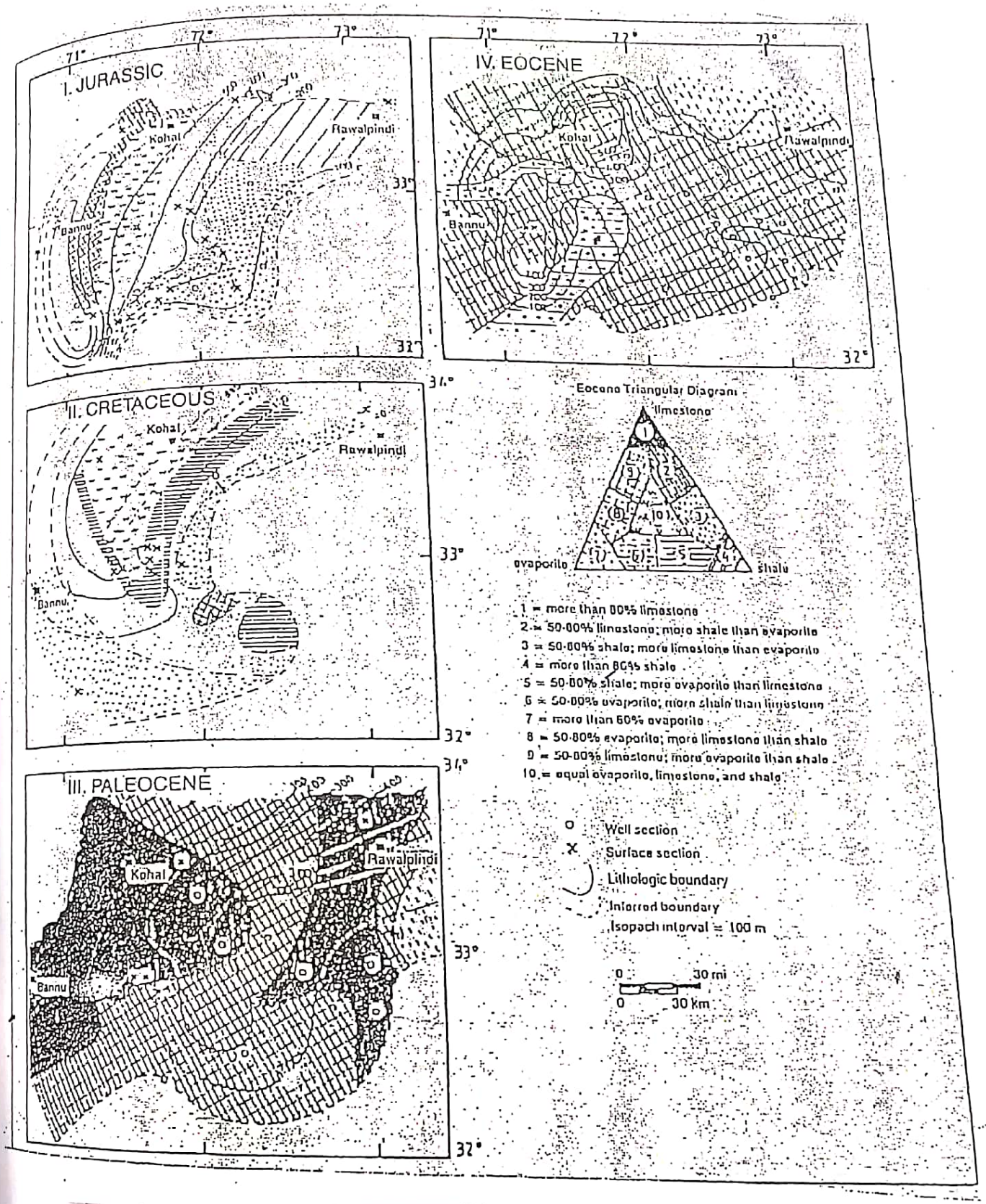

Figure- 13

Lithofacies maps of (1) Jurassic, (2) Cretaceous, (3) Paleocene, and (4) Eocene. For Jurassic, Cretaceous and Paleocene triangular diagram, see figure 12.

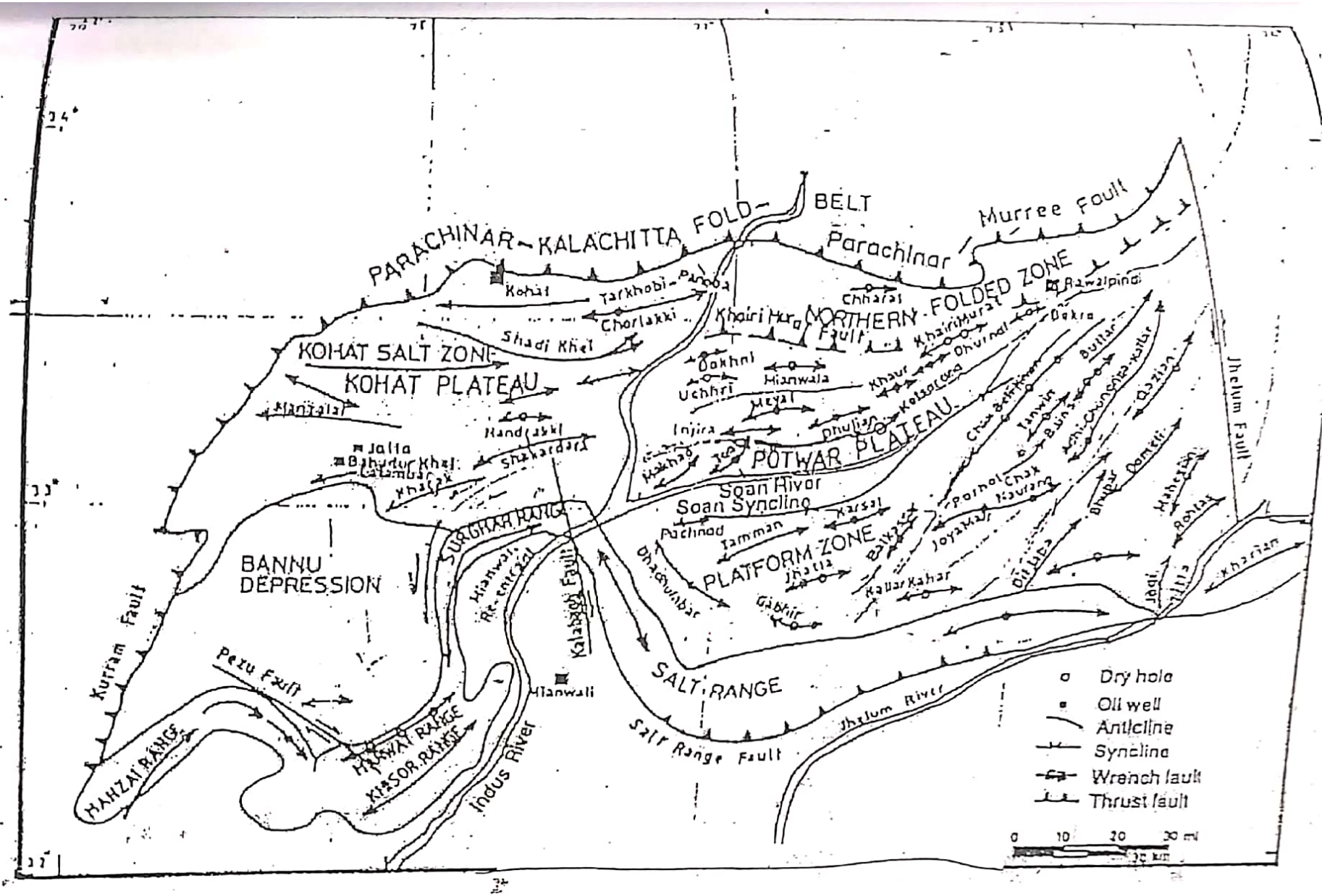

Figure - 14
Structural map of Kohat – Potwar depression

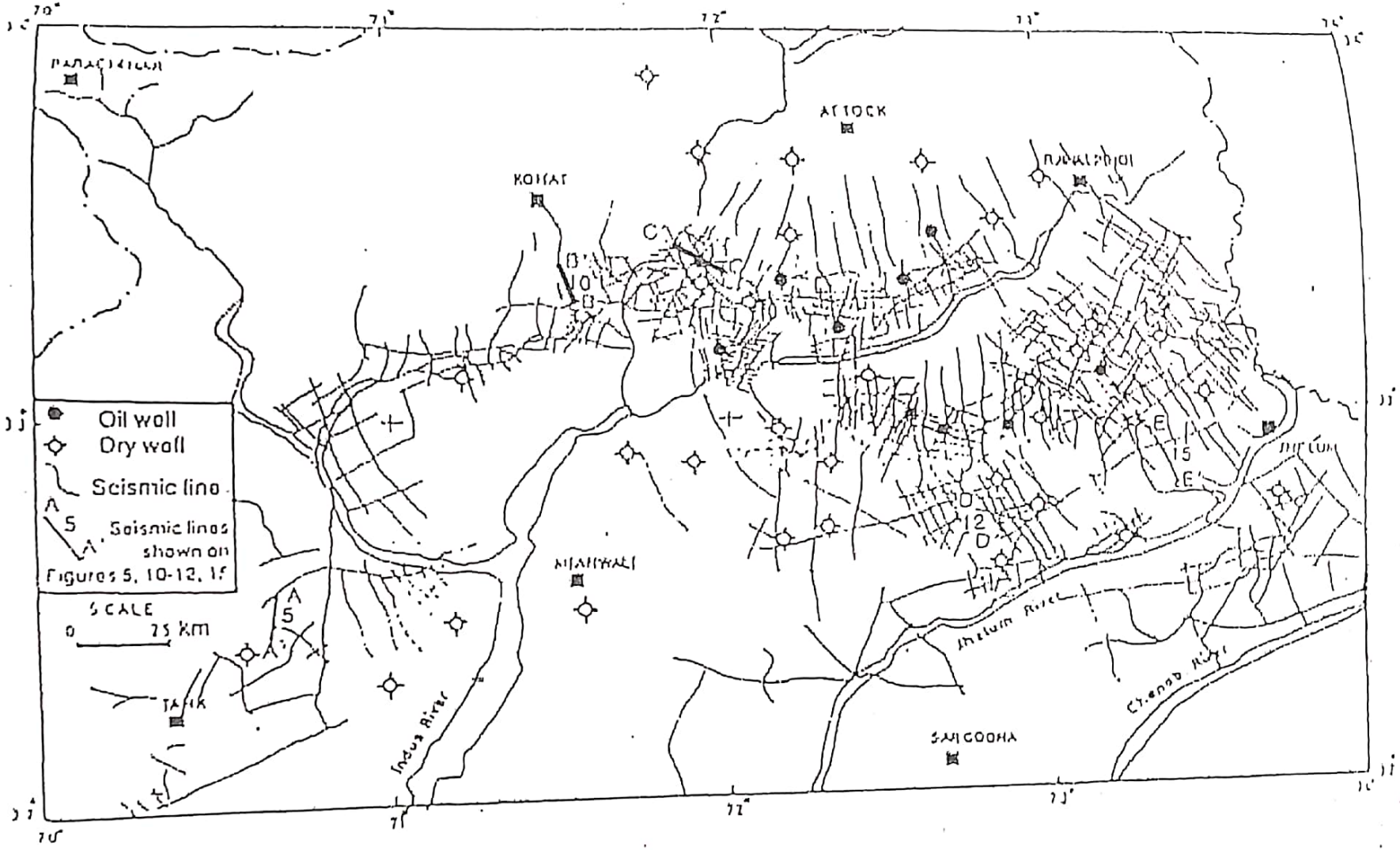

Figure-15
Multifold seismic survey and exploratory drilling in Kohat- Potwar depression

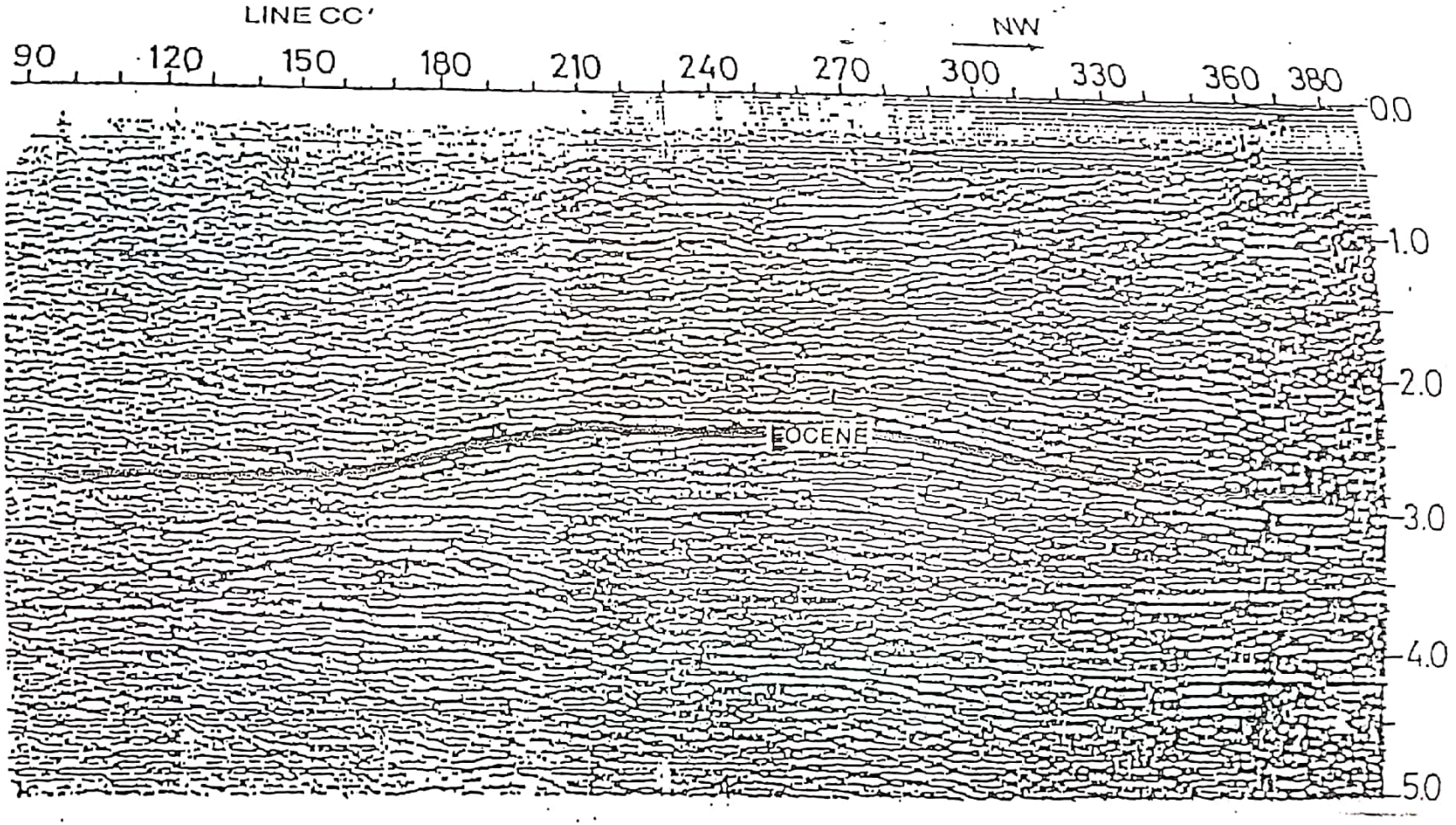

Figure –16

Profile along line CC' showing gently folded, broad anticline in Platform zone of Potwar plateau. For location see fig no 15

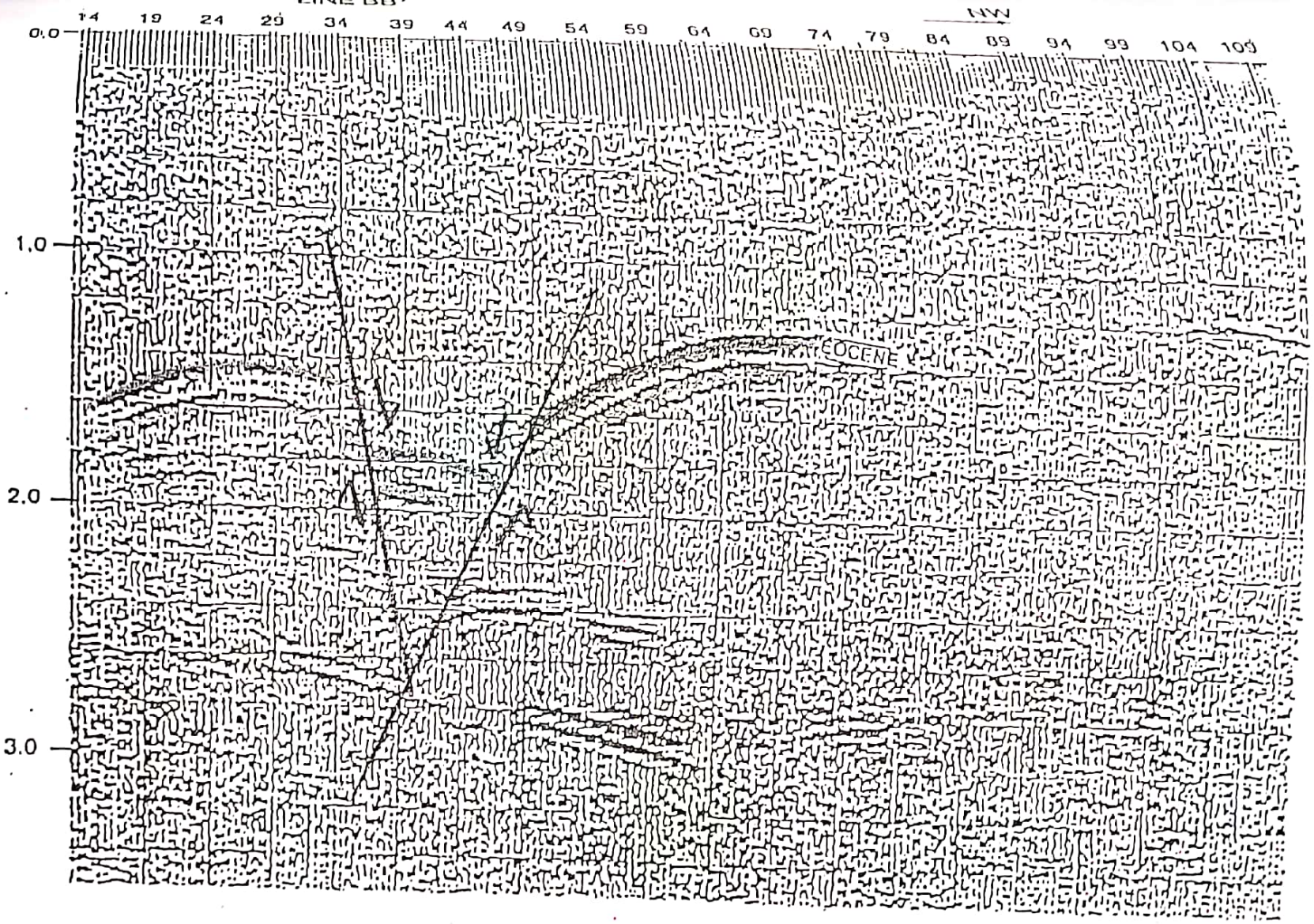

Figure- 17

Profile showing structural complexities due to tectonics in Kohat salt zone. For location

success of Adhi field, hold good prospects for Paleozoic, and Tertiarly objectives, structures such as Buttar, Kallar and Ghungrilla, which are in line with Adhi, can be reevaluated for drilling (Fig 14). Structures such as Kotsarang, Kallar Kahar, and Mahesian (Fig 14)which failed to produced due to wrong location could be reopened after conducting combine seismic and geologic research. Structures such as Chak Beli Khan, Bains, and Tanwin (Fig 14) could not be drilled to target depths due to drilling problems however these attractive plays should also be redrilled.

In the Platform zone, Eocene and older potential targets were deposited mainly in shallow marine and paralic environments that provide good settings for stratigraphic traps. Unconformities also offer goof potential for stratigraphic traps, which generally are, combine with structural traps. Six significant unconformities the sedimentary sequence of platform zone (Fig 4). In the eastern Potwar Adhi wells have been producing oil form Tobra Formation, which overlies an unconformity the trap is partly stratigraphic.

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