Structural Style, Evolution and Hydrocarbon Prospects of the Bhittani Range, Northwest Himalayas, Pakistan*

M. Irfan Khan[1], Sajjad Ahmad[2], and Amjad Ali Khan[3]

Search and Discovery Article #10274 (2010)
Posted November 5, 2010

*Adapted from extended abstract prepared for a presentation at AAPG Annual Convention and Exhibition, New Orleans, Louisiana, April 11-14, 2010

[1]MOL Pakistan Oil & Gas Pakistan B.V. Co,
[2]Department of Geology, University of Peshawar, Pakistan
[3]Saif Energy Limited, Islamabad, Pakistan

Abstract

The Bhittani Range (Trans-Indus Salt Ranges) of north Pakistan is located in the northwestern indenter of the Himalayan Fold-Thrust Belt where east-west structural trend switches to north south. Its main topographic expression is credited to the Bhittani anticline, divisible into a couple of near orthogonal segments oriented west-northwest and north-northeast. Both these segments are bounded by a frontal fault called as Pezu-Khirgi fault that is on trend with the arcuate nature of the Bhittani anticline. The structural genesis of the Bhittani Range is mainly related to a transfer fault system located along the southwestern flank of the Bannu Basin located in the northeast. During the influence of the southward movement of the thrust slab underneath the Bannu Basin, the northwest-oriented transfer fault system experienced dextral wrenching along with a secondary southwest-directed contraction which started shaping of the Bhittani Range. Due to the continued movement along the transfer fault system and synchronous east-west compression transmitted from the left lateral convergent Kurram fault in the west, the Bhittani Range took its present-day arcuate shape. The structural style and genesis of the Bhittani Range is well constrained by the available seismic data across the Bhittani anticline. The proposed geo-seismic models depicts that the Pezu-Khirgi fault in the west-northwest segment is a steeply northeast-dipping, reverse fault that switches to west-dipping reverse fault in the north-northeastern segment of the Bhittani anticline. Current investigations reveal that underneath the northwestern apex of the Bhittani anticline a potential closure at the level of Cretaceous and Jurassic reservoirs which might be filled with hydrocarbons; live gas seeps are present all along the surface trace of the Pezu-Khirgi fault, confirming the active petroleum system in the area.

Introduction

The Bhittani Range constitutes the westernmost strike continuation of the Trans-Indus Ranges in the northwest Himalayas (Figure 1). Bhittani Range follows northwest structural trend flanking the southern margin of the Bannu Basin and switches to northeast trend along the western flank of Tank Reentrant (Figures 2 and 2-A). The Bhittani anticline is the major structural element of this range (Figure 3). The

Bhittani anticline, along its northwest segment, is disrupted along its axial trace by a thrust fault, with right-lateral transpressional deformation. Siwalik sediments are exposed all along the map trace of Bhittani anticline, whereas older rocks ranging in age from Permian to Pleistocene are exposed in the Sheikh Buddin Hills in the southeast (Figure 3). The surface geology clearly indicates that this area has undergone complex deformation, consisting of fold-thrust assemblages where the structural style is characterized by decollement-related thrusting associated with concurrent fault-bend/propagation folding (Figure 3). All the ingredients of a working hydrocarbon system exist underneath the Bhittani Range as the maturity of the source rocks in terms of hydrocarbon generation is established by burning gas seepage, found along the Pezu-Khirgi fault near Bain village (Ansari et. al., 2002). An exploratory well, Pezu-1 was drilled by PPL in 1968-69 in northwest segment of Bhittani anticline without any seismic acquisition. It penetrated over 600 meters of Siwalik sediments before entering Tertiary-Mesozoic successions (Table 1). This well was abandoned as a dry hole at 2222 meters depth in sandstone of Datta Formation of Jurassic age after drill-stem testing of both Cretaceous and Jurassic reservoir rocks. Although water-bearing, Datta sandstone was found to be of reservoir quality.

Structural Model

Geo-seismic cross section along line K-L (Figure 4) has been constructed to illustrate the structural style, kinematics as well as structural geometry of the Bhittani Range, NW Himalayas, Pakistan by utilizing the following database:-

a) Surface geological map,
b) Three 2D seismic lines with a total length of about 41.5 km,
c) Well data of Pezu-1.

The two seismic dip lines, O-784-BU-5 and O-784-BU-5A, were acquired by OGDC in 1978, covering the southwestern and northeastern parts of Bannu Basin and Tank Depression, respectively. These lines partially cover flank area of the Bhittani Range. These 62-fold data, using vibroseis as a source, data display good quality in shallow as well as in the deeper horizons. Line PPL02-PEZ-8 was acquired as dip line crossing the Bhittani Range in 2002 by Pakistan Petroleum Ltd. (PPL) as 80-fold data, using dynamite as a source (Figure 5). Wide line seismic technique (Ansari et. al., 2002) was applied for the acquisition of this line in order to obtain the better quality image in the crestal part of the Bhittani Range, which was not imaged properly by previous surveys due to the scattering effects of the faults associated with steep dips. This line is about 2 km to the southeast of Pezu-1 well drilled in the Bhittani Range (Figure 3).

The geo-seismic cross-section constructed along line KL (Figure 4) incorporates subsurface data (seismic line O-784-BU-5, O-784-BU-5A, PPL02-PEZ-8) and Pezu-1 well. The surface geological section has been integrated with the interpreted seismic and well data in order to work out an inclusive structural model for the Bhittani Range. The structural model along line K-L (Figure 4) is oriented from northeast to southwest in the central part of the Bhittani Range. It is roughly parallel to the northeast-southwest-oriented tectonic transport direction, as inferred from the trends of different structures exposed in the range and almost co-axial with all the three seismic lines used in its construction. The northeastern portion of the section located in the Bannu Basin is characterized by almost flat stratigraphic geometry in the sectional view, validated by seismic line 784-BU-5.This line is approximately 12 km long, covering the northeastern part of the model. A

couple of small normal faults have been identified on this seismic line in the southwestern margin of the Bannu Basin where it merges with the Bhittani Range.

Farther to the southwest, the Bhittani Range is fully covered by seismic line PPL02-PEZ-8-1, which is about 15 km long (Figure 5). This part of the model is depicting the Pezu-Khirgi fault to be steeply northeast-dipping, originating from the basal decollement. It brings the rocks of Chinji Formation in its hanging wall against the same rocks in the footwall to the southwest with less vertical uplift. This fault is cross-cutting through the stratigraphy on the backlimb of the Bhittani anticline. The backlimb of the anticline is dipping towards the Bannu Basin in the northeast at moderate to steep angle (45°~68°), whereas its forelimb dips towards the Tank Basin in the southwest with moderate dip angles (28°~56°) near the surface and steeper dips in the subsurface, giving it slight asymmetry in sectional view. The Bhittani anticline shows moderate uplift as compared to the surrounding lowlands. A blind, northeast-dipping thrust fault within the Triassic and underlying older rocks extends underneath the forelimb of the Bhittani anticline. At the extreme southwest, lies the Tank Basin, where the forelimb of the Bhittani anticline dips to the southwest, with lower dips below the fault. This has been established on seismic line O-784-BU-5A , which is about 14.5 km long, partially covering forelimb of the Bhittani anticline and extending towards the Tank Basin in the southwest.

Hydrocarbon Potential of the Bhittani Range

Fold and thrust belts, although they have been globally explored for hydrocarbons for more than a century, are still challenging frontiers for hydrocarbon search. The Himalayan foreland fold-thrust belt of Pakistan includes Kohat foreland fold and thrust belt along with its associated frontal ranges that include Surghar-Shinghar, Marwat-Khisor, Bhittani, and Manzai Range (Trans-Indus Ranges) and the D.I. Khan Plain in the south (Figure 1). To date, this domain has experienced several significant discoveries of oil and gas within Kohat fold-thrust belt to the north, but despite the fact that the ingredients of a petroleum system are well established in the south, it is still a challenging frontier for hydrocarbon exploration (Table 2). One such frontier is the Bhittani Range, which is characterized by a large-scale surface lead known as Bhittani anticline, and there should be little doubt in the existence of its subsurface counterpart. The presence and maturity of the source rocks in terms of hydrocarbon generation is established by burning gas seepage, found along the Pezu-Khirgi fault near Bain village (Ansari et al., 2002). Potential candidates for seal and reservoir are present in the Mesozoic sequence that is well exposed in the Sheikh Buddin hills. An exploratory well, Pezu-1 was drilled by PPL in 1968-69 in the Bhittani Range without seismic control (Table 1). Pezu-1 penetrated over 600 meters of Siwalik sediments before entering Tertiary-Mesozoic successions. This well was abandoned as a dry hole at the depth of 2222 meters in the sandstone of Datta Formation of Jurassic age after drill-stem testing of both Cretaceous and Jurassic reservoir rocks. Although water-bearing, sandstone of Datta Formation was found to be of reservoir quality. Critical review of the available literature and geological field work in the region depicts that all the ingredients of a working “hydrocarbon machine” (source, reservoir, trap/seal, timing and migration) exist in the area. The petroleum system of the area is characterized by multiple reservoirs and sealing horizons that are likely to be charged by multiple source rocks. Surface structural style shows that en echelon anticlinal closures, developed within the hanging walls of major faults, could provide primary traps for hydrocarbons. In addition, sub-thrust plays as well as stratigraphic traps (formed as a result of eastward truncation of various horizons) may provide potential drillable prospects. The presence of

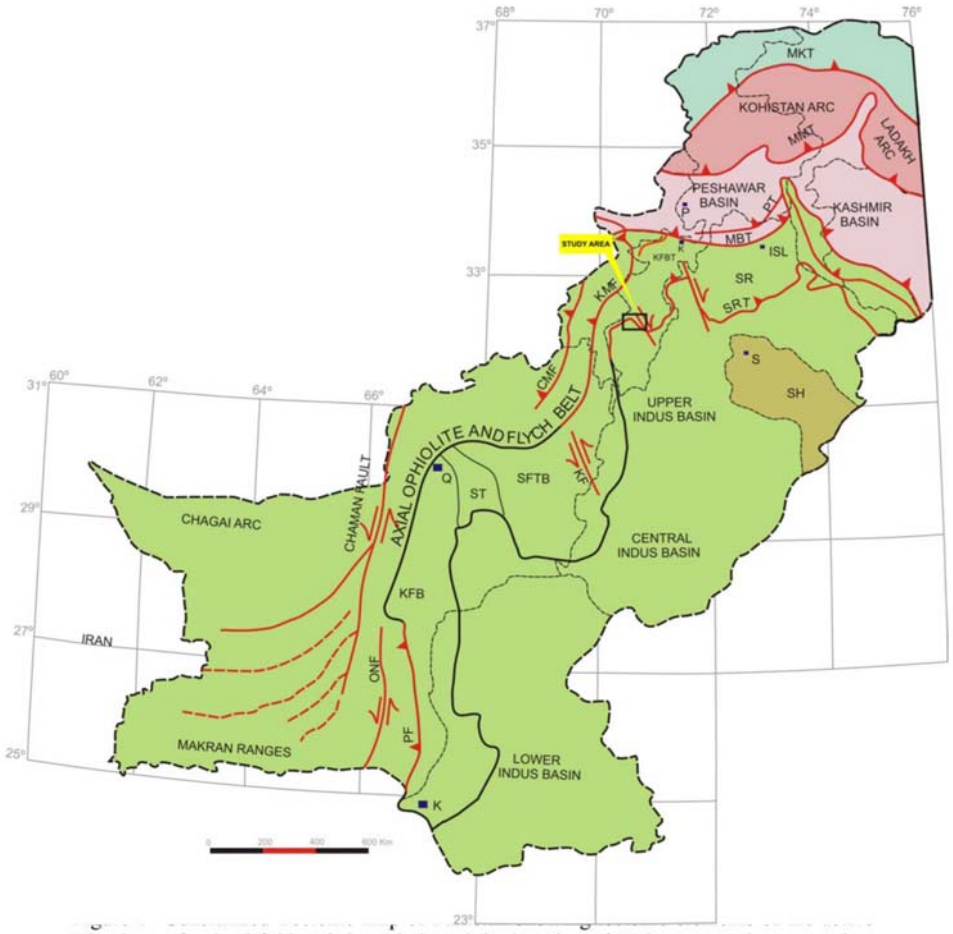
a regional hydrocarbon kitchen is well supported by the stratigraphic record of the area, whereas the oil and gas discoveries along with oil/gas seepages in the surrounding area provide clear indication of the optimum timing of hydrocarbons generation, migration and entrapment in the Bhittani Range of the Trans-Indus Ranges.

Conclusions

- The Bhittani Range is shaped by a northwest-trending anticline which is subdivided into several compartments by the Pezu-Khirgi fault.
- The Pezu-Khirgi fault is interpreted to be a dextral wrench with alternate northeast-southwest-directed compression.
- The northwestern compartment of the Bhittani anticline forms a four way closure at the level of Jurassic-Paleocene reservoirs.
- Sub-thrust plays as well as stratigraphic traps (formed by eastward truncation of various horizons) may provide potential drillable prospects.

Reference

Ansai, A.W., and Siddiqui N.K., 2002, Wideline seismic technique for imaging structurally complex areas- A case study: Conference proceedings, PAPG, Annual Technical Conference, Pakistan-2002, p. 37-45.



Himalayan foreland fold and thrust belt and the location of Makran accretionary wedge. **MKT:** Main Karakoram Thrust, **MMT:** Main Mantle Thrust, **PT:** Panjal Thrust, **MBT:** Main Boundary Thrust, **CMF:** Chukhan Manda Fault, ISL: Islamabad, **K**: Karachi, **K:** Kohat, **KFTB:** Kohat Fold and Thrust Belt, **KTB:** Kirthar Fold Belt, **KMF:** Kurram Fault, **ONF**: Omach Nal Fault, **P**, Peshawar, **PF**: Pab Fault, **Q**: Quetta, **S**: Sargodha, **SH**: Sargodha Basement High, **SRT**: Salt range Thrust, **SR/PP**: Salt Range/Potwar Plateau, **ST**: Sibi Trough

Figure 1. Generalized tectonic map of Pakistan showing tectonic elements of the active Himalayan Foreland Fold and Thrust Belt and the location of Makran Accretionary Wedge, in addition to the study area.

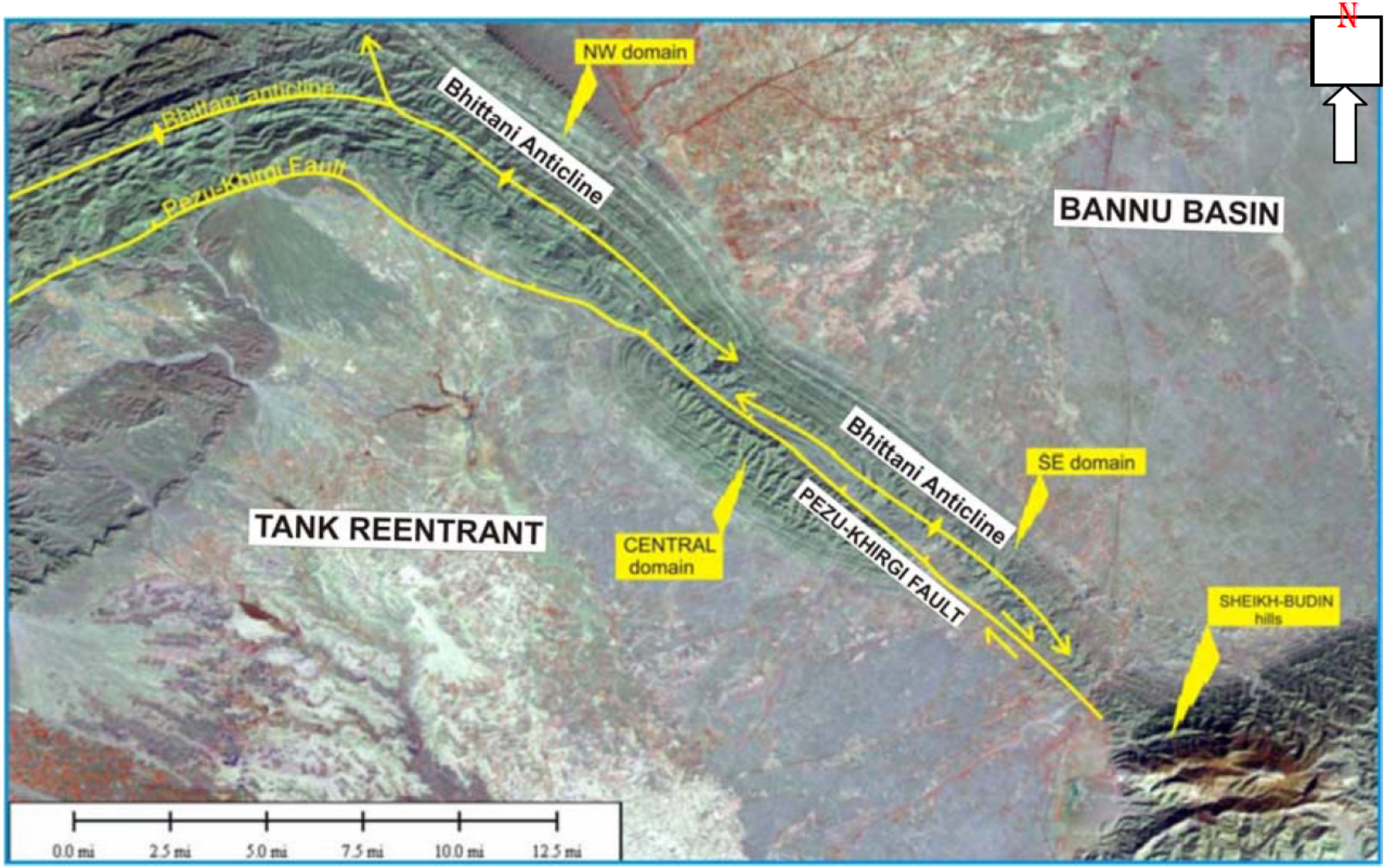


Figure 2. Satellite image showing the NW-SE-trending segment of the Bhittani anticlinal trend, NW Himalayas, Pakistan.

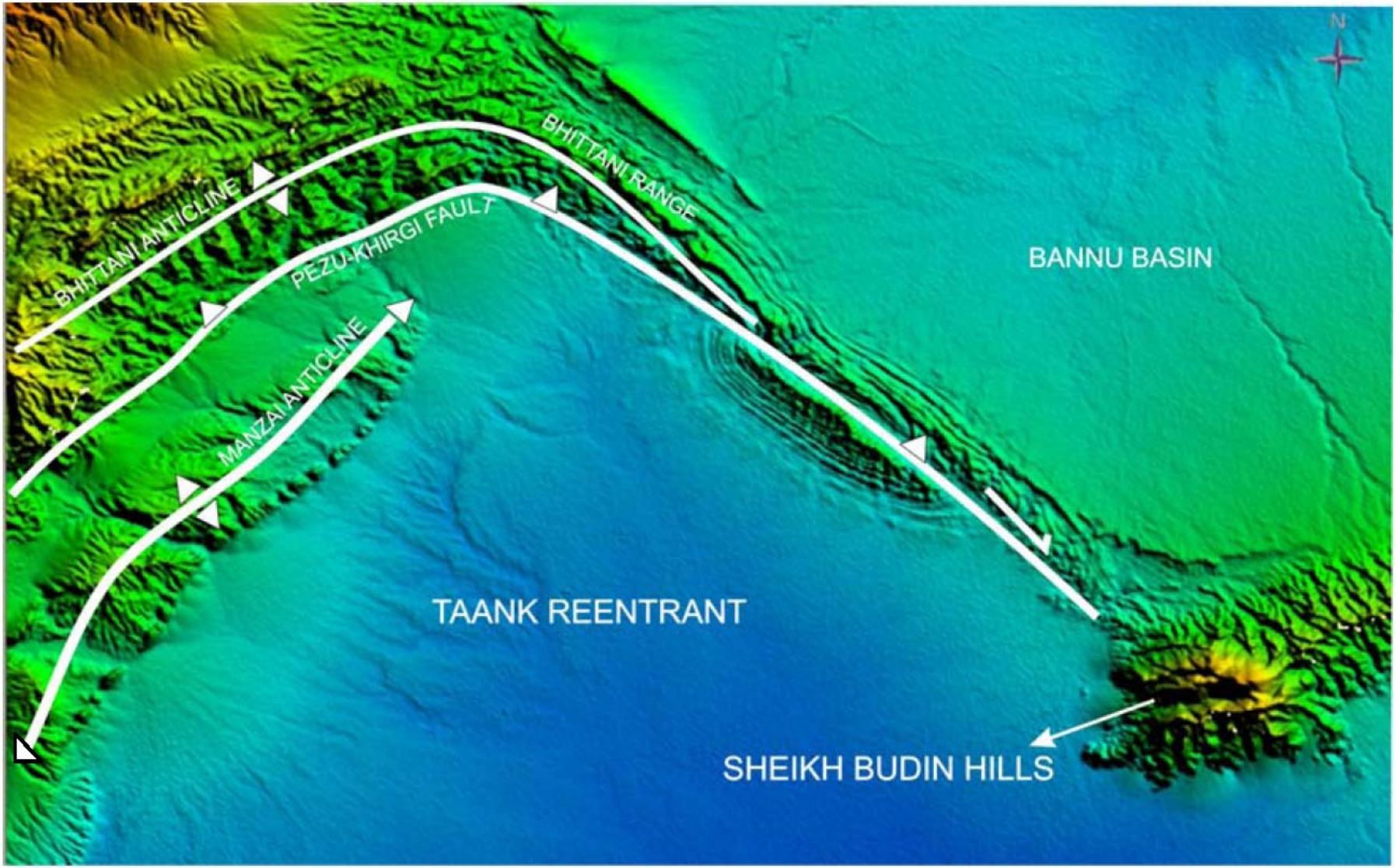


Figure 2a. DEM showing NE-trending segment of the Pezu-Khirgi thrust and associated doubly plunging Manzai anticline.

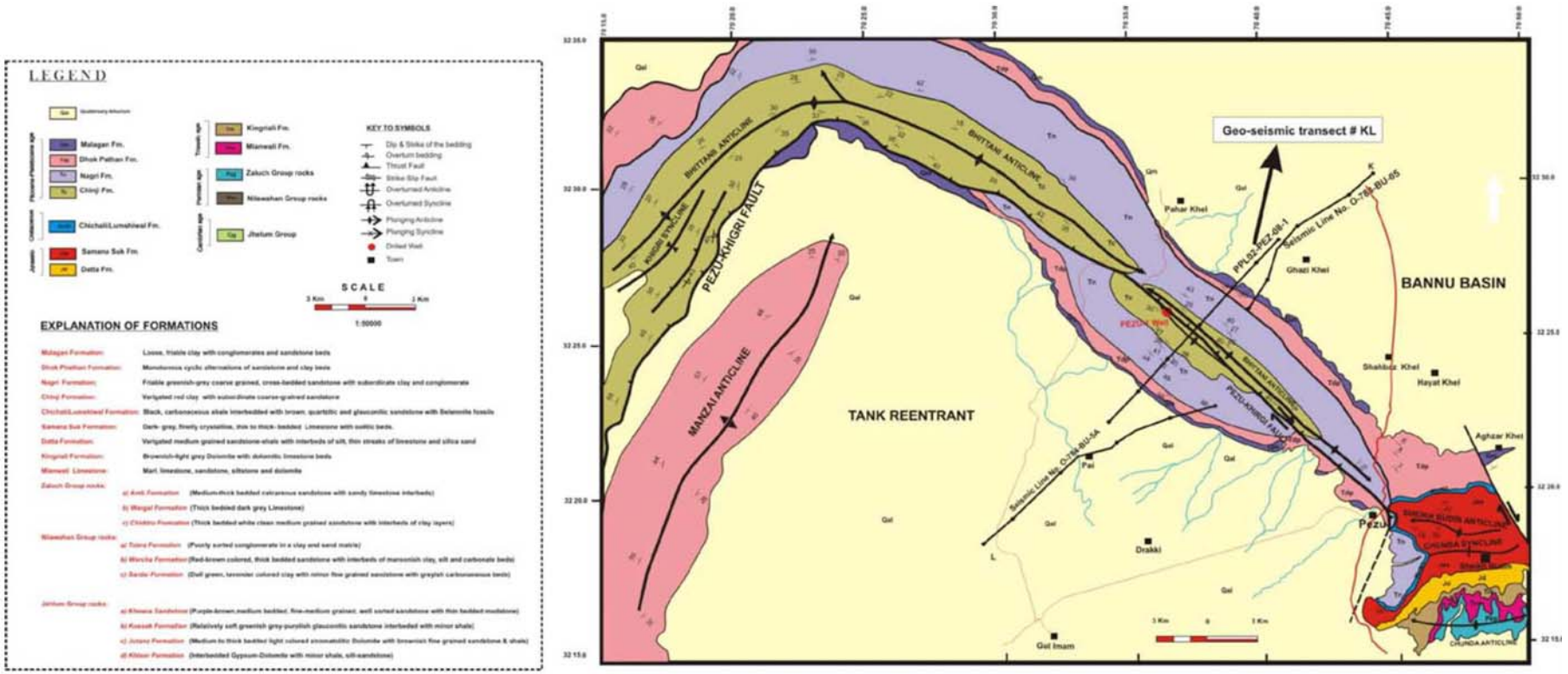


Figure 3. Geological map of Bhittani Range, showing the location of seismic line and geoseismic transect.

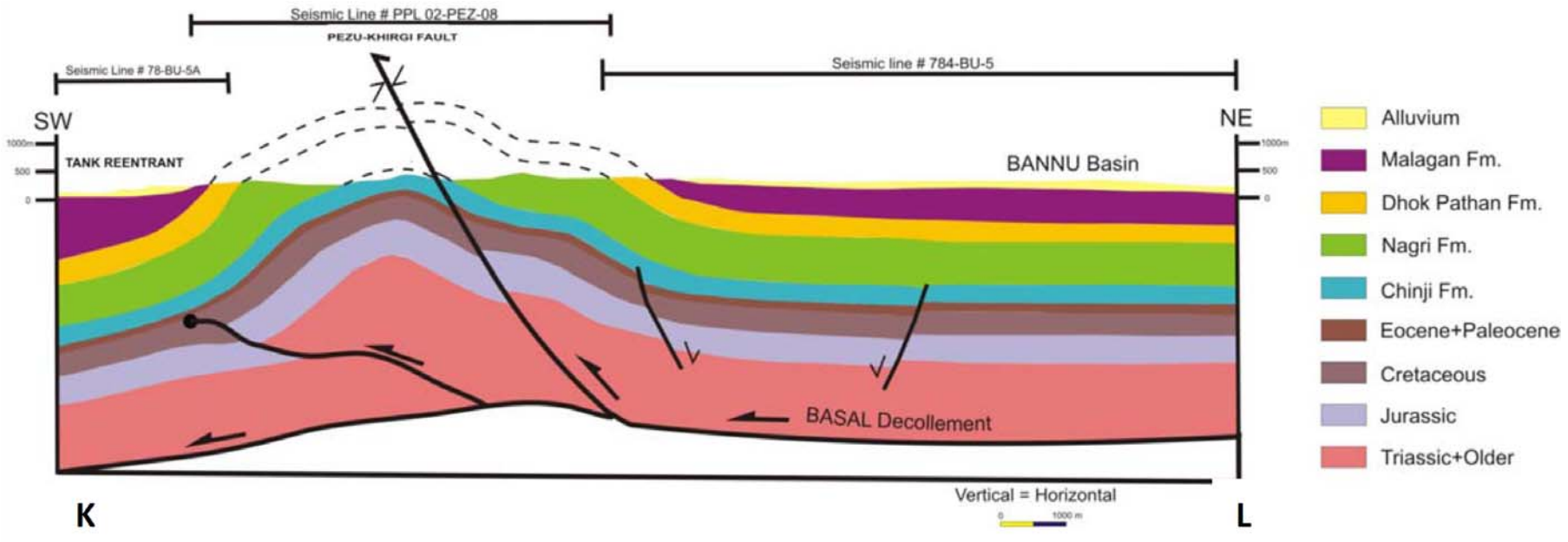


Figure 4. Geo-seismic cross section along seismic line 784-BU-5 & 5A, PPL02-PEZ-08-1.

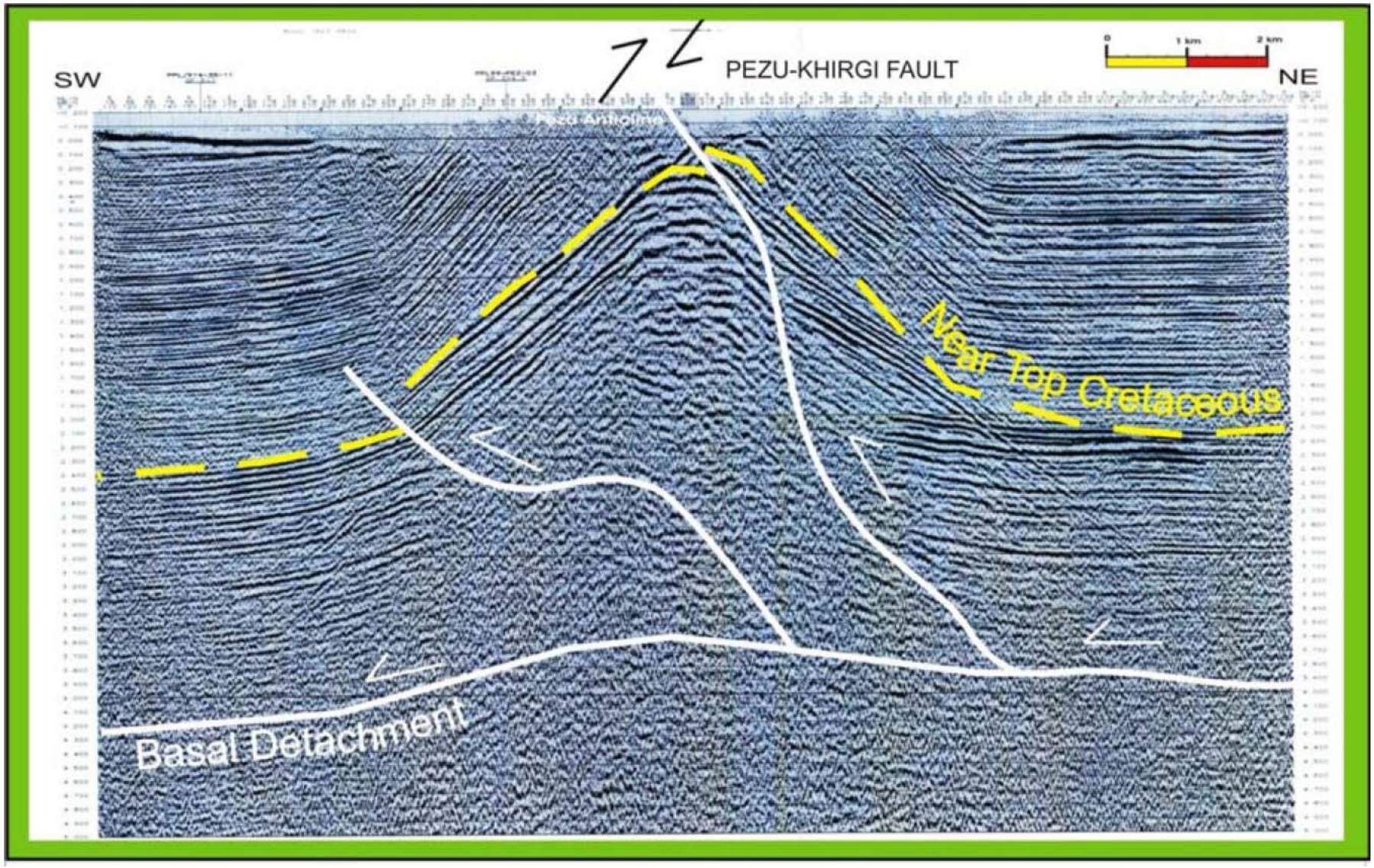


Figure 5. Interpreted seismic line PPL02-PEZ-08-01.

WELL NAME: PEZU-01	OPERATOR: PPL	DEPTH: 2222.5 METERS
LATITUDE: 32 26 04.50	LONGTITUDE: 70 36 25.50	WELL TYPE: EXPLORATORY
STATUS: ABANDONED	PROVINCE: NWFP	DRILLING YEAR: 1968-69

SR. NO.	FORMATIONS	FORMATION AGE	TOP (METERS)	THICKNESS (METERS)
1	SIWALIKS	MIOCENE-PLIOCENE-PLEISTOCENE	5	623
2	SAKESAR-LOKHART-	EOCENE-PALEOCENE	623	155
8	MUGHALKOT	CRETCAEOUS	783	209
9	LUMSHIWAL	EALRY CRETCAEOUS	992	420
11	SAMANA SUK	MIDDLE JURASSIC	1412	306
12	SHINAWARI	MIDDLE JURASSIC	1718	339
13	DATTA	EARLY JURASSIC	2057	165.5

Table 1. Drilled stratigraphy of the Pezu-1 well.

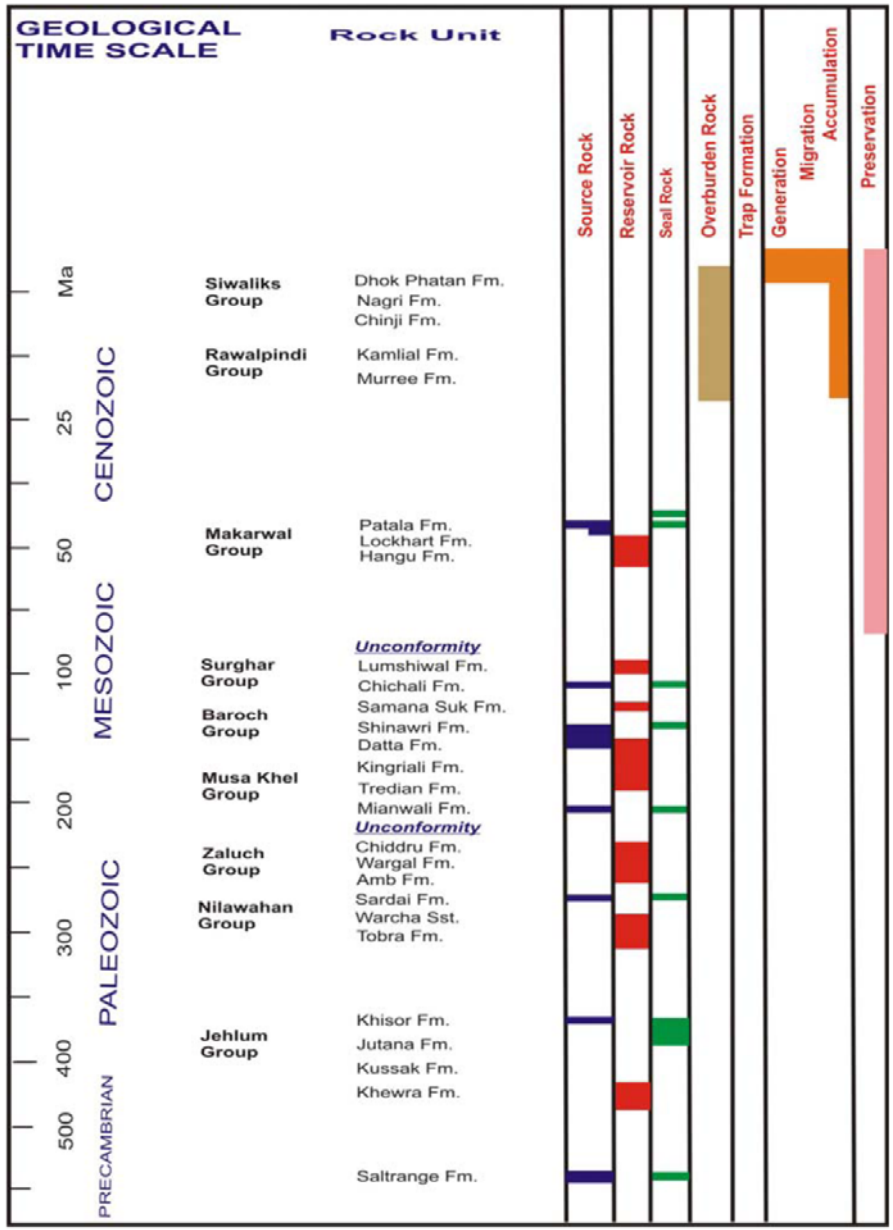


Table 2. Petroleum system of the Bhittani Range, NW Himalaya, Pakistan.