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A preliminary account of the Middle Jurassic plays in Najafpur Village, southeastern Hazara, Khyber Pakhtunkhwa, Pakistan

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Abstract

The southeast Hazara forms a part of Himalayan fold and thrust belt of Pakistan. The study area is covered by Mesozoic-Cenozoic age rocks that have undergone severe deformation and is characterized by the formation of complex fold and thrust assemblages. The structures include northwest and southeast verging thrust systems with associated folds. Two deformational events separate the structures in the area. The structures in the northwestern quadrant display southeast facing direction whereas the southeastern quadrant is dominated by structures that dip towards southeast. The general trend of the structures is northeast-southwest and that attributes to the northwest-southeast contractile deformation. The trend of the structures depicts that stresses were directed from northwest. The folds are found to be tight to overturned and the cores of the folds are usually occupied by competent Samana Suk Formation. The organic rich horizons were observedin the field within the Formation, the TOC of which was calculated as 0.28%. Microfacies analysis reveals well sorted and well-rounded ooidal-peloidal grainstones and packstones as well as dolomitized and fractured wackestones and mudstones. The diagenetic signatures include fracturing and dolomitization depicting its source and reservoir quality for a hydrocarbon prospect.

Keywords: Jurassic; Grainstones; Samana Suk; Hazara; Hydrocarbon prospects.

1. Introduction

The Hazara Hill Ranges represent passive margin sediments of Mesozoic-Cenozoic ageof the Indian Plate that have been shortened and uplifted along the Main Boundary Thrust (Izzat, 1993). The area has undergone severe deformation, evident from overturned folds and thrust faults. The exposed strata verge towards the southeast indicating south directed stresses during the continent-continent collision. The study area, Najafpur, is a part of Hazara Fold and Thrust belt, western Himalaya and is bounded at north by the Panjal Fault and to the south by the Main Boundary Thrust (MBT; Fig. 1).

The work of Wynne (1873 and 1875), Waagen (1872), Middlemiss (1896) and Cotter (1933) is considered as the pioneer of geological investigations in the Hazara area. The first ever detailed report on the geology of the Hazara area was published by Wynne (1875) and followed by others. Middlemiss (1896) conducted detailed work on the geology of the Hazara for the first time to make a preliminary geological map of a major part of the said area to give an account of stratigraphy and major structures. Latif (1970) gave a brief account of the stratigraphy of southeastern Hazara, supported by a detailed geologic map. The Stratigraphic Committee of Pakistan, later on, accepted his stratigraphic nomenclature. The southeastern Hazara shows a stratigraphic succession from Pre-Cambrian to Miocene with notable unconformities (Ghazanfar et al., 1990; Fig. 2). The rocks exposed in the study area range from Jurassic to Eocene age. Different researchers (Masood, 1989; Qureshi et. al., 1997; Sheikh et. al., 2001 and Hussain et. al., 2013) have worked on the Samana Suk Formation revealing its fabric and depositional environments in the area. However these authors did not focus on the petroleum potential of the Formation.

It is obvious that the stratigraphy of the area has been established by the past geologists but none of them gave significant focus on the structural geometry and hydrocarbon prospects. This paper attempts to concentrate on reconnaissance structural mapping, deformational style of the study area, analysis of organic rich horizons and the reservoir quality of the middle Jurassic, Samana Suk Formation.

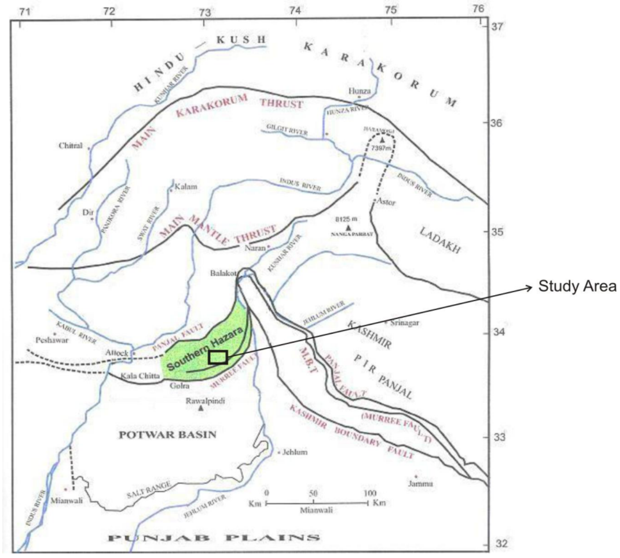

Fig. 1. Tectonic Map of North Pakistan, showing the study area (after Kazmi and Rana, 1982).

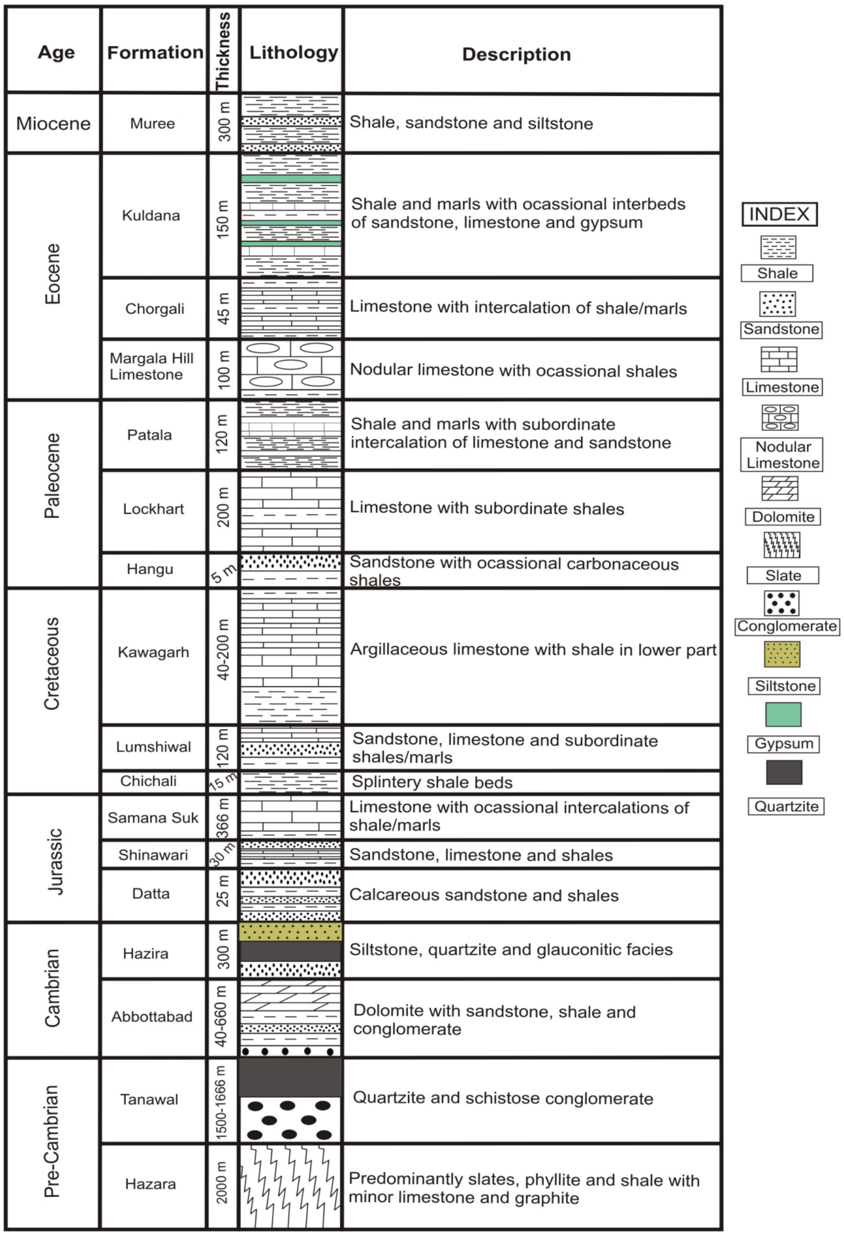

Fig. 2. General stratigraphy of southeastern Hazara, Khyber Pakhtunkhwa, Pakistan. Thicknesses are not to scale (after Latif, 1970).

2. Materials and methods

A detailed field work was conducted in order to acquire the field data to get structural insights and prepare a geological map of the area. Geological map of Latif (1968) and Google Earth imagery were used as base maps in the field. The field data was then used in Google Earth to laterally trace the stratigraphic contacts between various formations. The line work of Google Earth was then finally drafted into geological map in Arc GIS 9.3. For cross sections drafting Corel Draw X7 was used.

The Samana Suk Formation was sampled randomly for their facies analysis, thin sections were prepared and petrographic study was conducted by using digital camera fitted Nikon Polarizing microscope at the Department of Geology, University of Peshawar. The constituents of rocks were identified, classed according to Dunham (1962) scheme of classification and interpretated according to Flügel (2004). Total organic carbon of the organic rich interval in the formation was measured with Perkin Elmer-Clarus 600 Series GC-MS at the National Center of Excellence in Geology, University of Peshawar.

3. Results

3.1. Main structural elements

The study area is an integral part of the Lesser Himalayas and has undergone considerable shortening, evident from mesoscopic and macroscopic folds and thrust faults. The general trend of the structures northeast-southwest (Fig. 3). The major folds and faults of the study area are discussed as under:

3.1.1. Folds

The major folds include Dhartian Anticline, Dhabula overturned Syncline, Bagran overturned Anticline, and Bharle overturned Syncline (Fig. 3, 4, 5).

Dhartian Anticline occurs in the northwestern part of the study area, near village Dhartian. The core of the fold is occupied by the Samana Suk Formation while Kawagarh Formation covers its flanks. The fold axis is northeast-southwest oriented following the general trend of the region. The Dhabula overturned Syncline runs in the middle of the area and has Margalla Hill Limestone in its core. Adjacent to this syncline, an overturned anticline "Bagran overturned Anticline" occurs and its core is occupied by the Samana Suk Formation. The Bharle overturned Syncline is a southwest-northeast trending syncline and is located in southern part of the area with its southern limb overturned.

3.1.2. Faults

The study area is characterized by various reverse faults that include the Najafpur Thrust, Shah Kabul, & Sarbaroot fore-thrusts and Bagran & Kangrian back-thrusts.

The northeast-southwest oriented Najafpur Fault is dipping at about 60° towards northwest. This fault is detached within the Cretaceous sequence and has brought the Lumshiwal Formation over the Lockhart Formation of Paleocene age (Fig. 3).

The Shah Kabul and Sarbaroot faults have same orientation as that of the Najafpur Fault. Along the Shah Kabul Fault the Cretaceous Lumshiwal Formation is thrusted over Chorgali Formation while the Sarbaroot Fault brings the Lumshiwal Formation over the younger Patala Formation. All these three faults are southeast verging.

The Bagran Back-thrust thrusts the Lumshiwal Formation over the Lockhart Formation in the southwestern portion of the mapped area. The Kangrian Back-thrust is present in the southeastern corner of the mapped area and is dipping at 60-65° towards northwest. Lumshiwal Formation is thrusted over Kawagarh Formation along Kangrian Back-thrust.

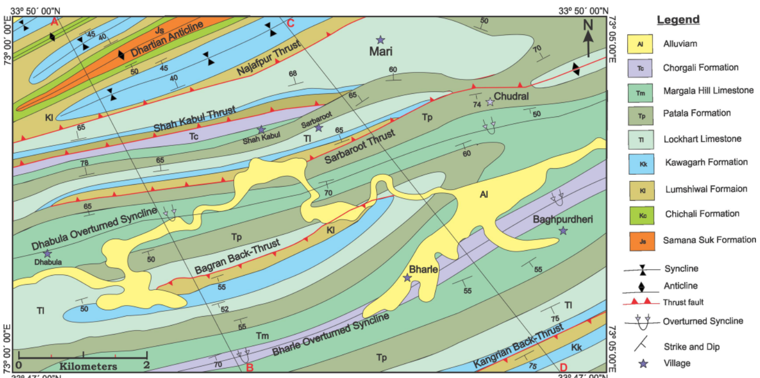

Fig. 3. Geological map of the study area.

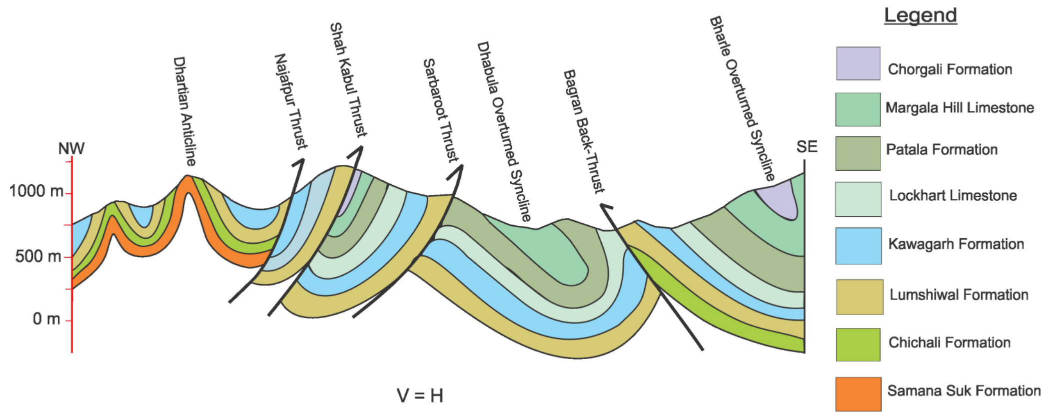

Fig. 4. Cross section along line AB of the map in Fig. 3.

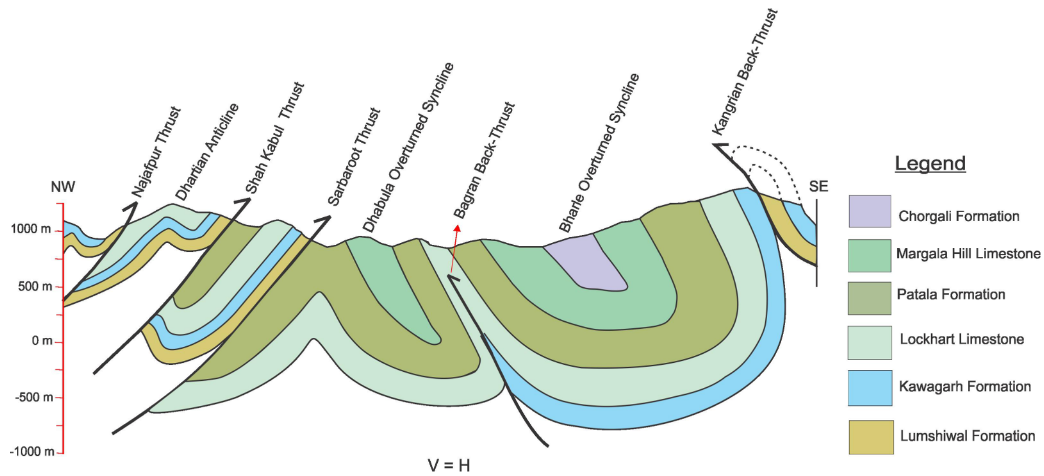

Fig. 5. Cross section along line CD of the map in Fig. 3.

3.1. *Structural transects*

In order to understand the subsurface geometries of the exposed structural features, two geological cross sections have been constructed along line AB and CD (Figs. 4 and 5) of the map in Fig. 3 and are described as under.

Cross sections AB and CD

The structural transect along the section line AB is perpendicular to the general structural trend of the study area (Fig. 3). Majority of the formations dip steeply towards northwest. In the northwest, an alternate series of tight synclines and anticlines occur in the hanging wall of Najafpur Thrust (Plate 1A). Next to the folds the thrust system is present which includes the Najafpur, Shah Kabul and Sarbaroot Fore-thrust (Plate 1B) and Bagran Back-thrust (Plate 1C). The fore-thrusts are steeply dipping towards northwest with southeast facing and opposite are the dipping and facing direction for the Bagran Back-thrust. Further southeast a train of overturned fold is present including Dhabula overturned Syncline, Bagran overturned Anticline and Bharle overturned Syncline (Plate 1D).

The section line CD deciphers the northeast wards extension of the structures present in section line AB. The Bagran Back-Thrust is concealed in this part of the mapped area. In the southeastern portion of this section the Kangrian Back-Thrust is present, which has brought the Lumshiwal Formation over the Kawagarh Formation.

3.2. *Facies analysis: source and reservoir potential of Samana Suk Formation*

Facies analysis of Middle Jurassic Samana Suk Formation for hydrocarbon source and reservoir characteristics was carried out. A two meter organic rich horizon (Plate 2A) is obvious on the outcrop in Bagnotar area. Two samples (approximately 300 grams each) were analyzed to find out the TOC. The determined average TOC value for both the samples was 0.28% (Table 1).

The study reveals presence of grain supported peloidal-oolitic grainstones, packstones and mud supported bioclastic wackestones and mudstones.

The percentage of each facies is shown in figure 6. The peloidal-oolitic grainstones and packstones constitute 35% and 25%, respectively, making them the dominant facies (Fig. 6). Both these facies are well sorted and well-rounded and are cemented by sparry calcite (Plate 2B) and admixtures of lime mud and spar (in packstones). Often but not commonly they are cross cut by void fractures (Plate 2C). The mudstones (Plate 2D) and wackestones (Plate 2E) comprise 30% and 10% of the facies. The lime mudstones are frequently fractured and have acquired both selective and pervasive dolomitization. The dolomite crystals (Plate 2F) are euhedral, ferroan in some cases, and are fine sand in size. The selective dolomitization is common in lime mudstones but is also found replacing grains and filling fractures. Most of the peloids are fecal pellets; however micritized and mud peloids are not uncommon. The ooids have peloids, bioclasts and quartz grains as nuclei and are represented by concentric, radial and radial-concentric microfabrics. Diverse skeletal grains are present, some of which are broken whereas others are preserved as whole skeletons. The intraclasts are more than 2 mm in size and dominated by mud supported facies. The terrigenous grains are in the form of fine sand to silt size angular siliciclasts. The overall abundance of the allochemical constituents in the microfacies is given in the Figure 7.

Plate 1

Fig. A: Field photograph showing northwest looking view of the Najafpur Thrust.

Fig. B: Field photograph showing northeast looking view of the Sarbaroot Thrust.

Fig. C: A view of the Bagran Back-Thrust. The black lines show the prevalent dip direction of the structures.

Fig. D: A view of the Bharle overturned Syncline.

Table 1. The TOC analysis of the organic rich horizon within Samana Suk Formation in Bagnotar area.

Sample	Carbon	Water	Weight	TOC	TIC
B-01	10.3128	1.35521	305.8	0.269593	10.03583
B-02	8.958069	1.644426	300.8	0.300115	8.652276

Plate 2

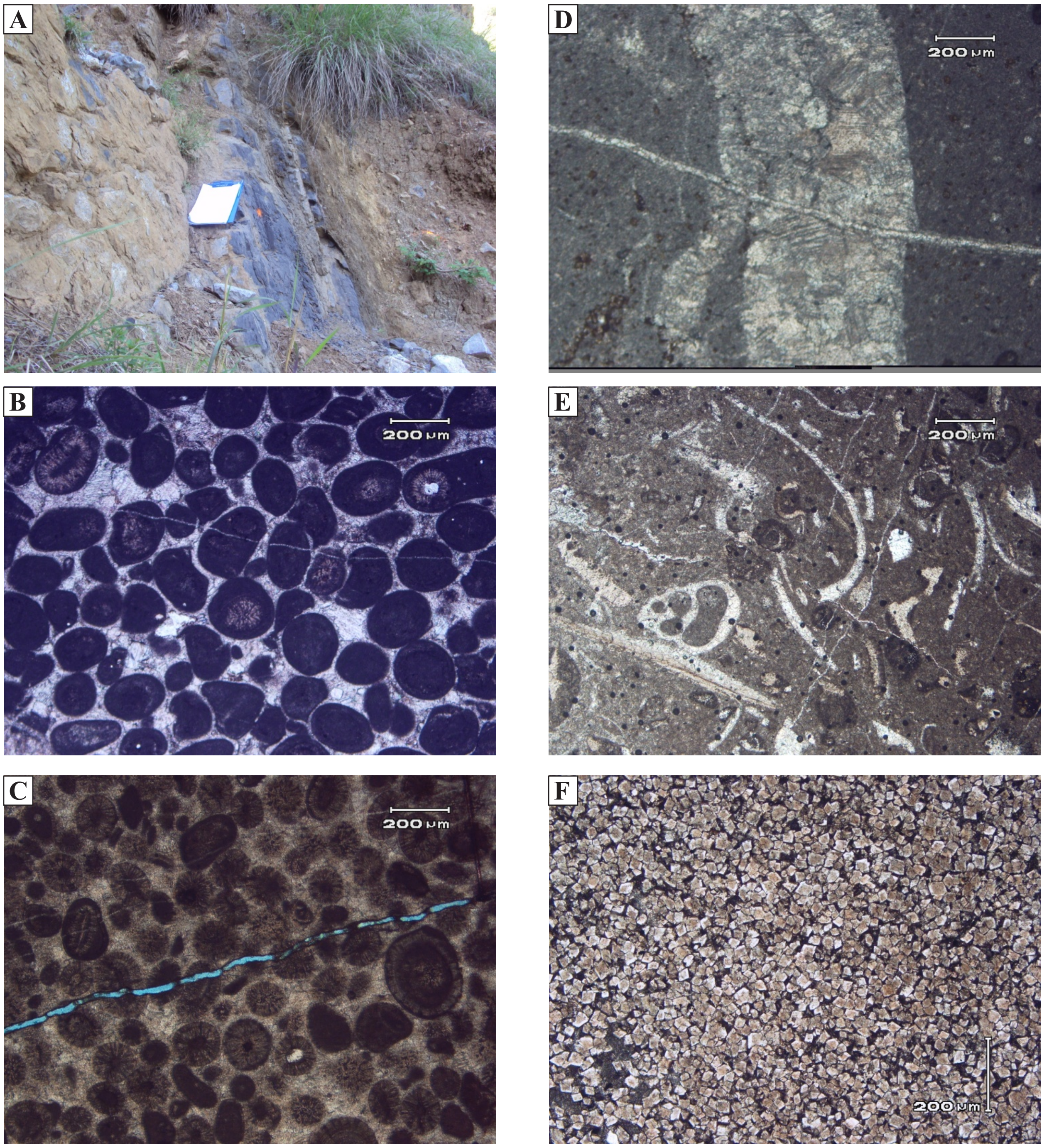

Fig. A. Field photograph showing organic rich horizon within the Samana Suk Formation in the Bagnotar Section.

Fig. B. Photomicrograph showing peloids embedded in sparry calcite cement in the grainstone facies within the Samana Suk Formation in Bagnotar Section.

Fig. C. Photomicrograph displaying ooidal grainstone having a void fracture in the Samana Suk Formation in Bagnotar Section.

Fig. D. Photomicrograph showing fractures cross cutting each other in the lime mudstone facies in the Samana Suk Formation in Bagnotar Section.

Fig. E. Photomicrograph showing bioclastic wackestone facies in the Samana Suk Formation in Bagnotar Section.

Fig. F. Photomicrograph displaying euhedral crystals in the dolostone facies in Samana Suk Formation in Bagnotar Section.

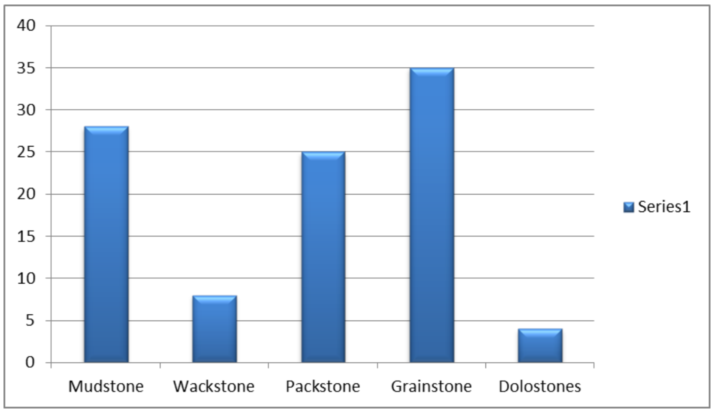

Fig. 6. Abundances (in percentage) and distribution of microfacies within Samana Suk Formation.

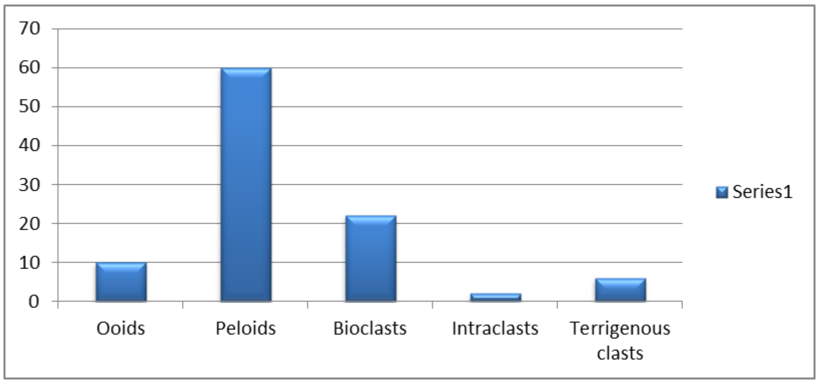

Fig. 7. Abundances (in percentage) and distribution of the grains within Samana Suk Formation.

4. Discussions

4.1. *Structure style and deformation*

The current investigation reveals the mapped orientations of the structures in the area are in coincidence with the changing trend of the MBT. This northeast-southwest orientation of the folds and faults are in coincidence with Kazmi and Rana (1982). The structural synthesis implies that the area has been subjected to northwest-southeast contractile deformation that produced northeast-southwest oriented structures. The initial phase of deformation is characterized by northwest directed translation as envisaged by the back-thrust and northwest facing overturned folds (Fig. 4, 5). These north vergent folds and south-dipping back-thrusts in the hanging wall of the MBT may have been associated with the episode of back folding that followed Late Miocene south-directed thrusting along the MBT (Pogue, 1994). The northwest facing overturned folds are cross cut by relatively younger southeast verging fore-thrusts (Fig. 4). During this younger structural event the general translation of deformation is southeastwards. All the mapped thrusts are out of sequence thrusts as are developed in the deformed thrust sheet of MBT and may be associated with the increase in the decollement dip above the basement (McDougall and Hussain, 1991).

The thrusts are usually detached within the Cretaceous sequence and have brought the competent lithology (sandy limestone/calcareous sandstones) of Lumshiwal Formation on top of younger strata. These back-thrusts bear the same general trend as that of the other structures but with an opposite vergence. The Dhabula, Bharle and Bagran folds are overturned in northwest direction and are likely to be associated with the backthrusting episode. The anticlinal folds in the hanging wall of Sarbaroot Thrust found within the subsurface in Samana Suk Formation in structural transect CD can be the probable trapping structures for the hydrocarbons if further evaluated.

4.2. *Facies analysis: source and reservoir potential of Samana Suk Formation*

The Samana Suk Formation, being a proven reservoir in Manzalai Oil Field, Kohat Plateau, was assessed for source and reservoir potential in the Hazara area. The results of the present work are satisfying regarding the hydrocarbon holding potential. The grainstones and packstones dominated microfacies divulge that deposition of the Samana Suk Formation was on a high energy carbonate platform which is in accordance with tethyan shelf of Nizami and Sheikh (2009) and tethyan carbonate ramp of Hussain et. al (2013). The carbonaceous mudstone, an organic rich horizon, lies just below a mud cracked fine grained unit and is believed to have been deposited in the restricted, marshy parts of supratidal environments. The determined TOC of the horizon makes it a potential source for generation of hydrocarbons. In addition to source rock perspective, 60% of the facies are the grain supported in the form of grainstones and packstones that are composed of well rounded and well sorted sediments. The well rounded shape and well sorted nature of the sediments result in an overall increase in porosity and permeability (Fraser, 1935; Krumbein and Monk, 1942 Rogers and Head, 1961; Pryor, 1973; Beard and Weyl, 1973). The mud supported facies, owing to its fine grained nature, are not barren of the reservoir capability. The facies is either dolomitized, partially or completely, or contain some void fractures both of which add to the reservoir potential of the formation. The dolomitization results in an overall increase in porosity by 13% (Chilingar and Terry, 1964). The overall assessment of the formation, as a result of facies analysis, signifies that the formation bears excellent reservoir potential and can serve as a considerable target in quest of the hydrocarbons. The presence of organic rich horizons makes the formation a future hydrocarbon prospect of the area.

5. Conclusions

The area depicts Jurassic to Eocene strata that is faulted and contains tight to overturned anticlines and synclines. The thrust faults are detached within the Cretaceous strata and have emplaced the rock units over younger Cretaceous rock unit as well as Cenozoic strata. The carbonaceous mudstones present within the Jurassic Samana Suk Formation can serve as a source rock horizon. The presence of subsurface folds related traps within the Samana Suk Formation makes this area a probable region for future hydrocarbon exploration. This formation is a grain supported carbonate unit and contains a variety of facies including well sorted, well rounded grainstones, packstones to fractured and dolomitized mudstones and dolomites all of which are capable of holding significant amounts of hydrocarbons.

6. Recommendations

The strata have been extended in the subsurface based on the surface dips. Detailed seismic survey is required to have a significant insight into the subsurface geology of the study area. In order to understand the maturity of the organic content and locate more organic rich horizons an extensive fieldwork is recommended.

Acknowledgement

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