Journal of Mountain Area Research
Vol. 6, 2021
https://doi.org/10.53874/jmar. v6i0.121

*Full length article*

# FRACTURE ANALYSIS AND RESERVOIR POTENTIAL OF EXPOSED EOCENE SUCCESSIONS ALONG KOHAT-ORAKZAI TRANSACT KHYBER PAKHTUNKHWA, NW PAKISTAN

*Muhammad Yaseen[1,3]*, Shahid Ali Shah[1], Junaid Khan[2], Adnan Samiullah[1], Adil Jan[1], Muhammad Sheeraz Khan[1], Saad Sair[1]*

1. Department of Geology, Abdul Wali Khan University Mardan, Khyber Pakhtunkhwa, Pakistan
2. Department of Earth Science, University of Haripur, Khyber Pakhtunkhwa, Pakistan
3. Department of Earth Sciences, Quaid-i-Azam University, Islamabad

## ABSTRACT
The present research work is primarily focusing on fracture analysis of exposed Eocene limestone to estimate the reservoir potential by Monte Carlo Techniques. The methodology implemented is the scanline method which were used for fracture data collections during field work. Three stations were selected for fracture data which consists of 30 scanlines for comprehensive petrophysical properties i.e., fracture density, porosity, and permeability. The computer software was used for interpretation of fracture orientation data. The interpretation demonstrates two prevailing fracture sets existing in the study area which have average NE and NW strike. However, the correlation between their properties is documented based on charts. The consequence specifies that the correlation between density and porosity is variable although the density and permeability is linear. The qualitative classification was based on NFR system analyzed for the reservoir potential which shows very defective correlation whereas fractures provide flexible assistance and does not offer significant additional porosity and permeability. Thus, it occurs from type 4 to type 3 NFR system of classification.

**KEYWORDS:** Reservoir Characterization, Eocene Rocks, Kohat-Orakzai, KP, Pakistan

*Corresponding author: (Email: yaseengeo@awkum.edu.pk, Phone: +92-336-963233-6).

## 1. INTRODUCTION

The study area lies between geodetic coordinates of station (01) is 33 40 11.15 N 71 12 07.42 E, station (02) is 33 40 10.9N 71 12 04.5E and station (03) is 33 34 09.3N 71 23 32.2E. The study area comprises of limestone which is part of Kohat foreland basin located in northwestern Pakistan (Fig. 1). The Kohat foreland basin itself is the western most portion of the east west trending foreland basin that is connected with the Himalayan orogenic belt. In the North, the Kohat basin surrounded by Main Boundary Thrust (MBT). The Mesozoic to Cenozoic sediments of Margalla, Kalachitta, and Kohat-Kotal ranges carried by MBT to the surface, tectonically overlying sediments that are deposited in the adjacent foreland basin including Potwar and Kohat [1]. The Kurram fault in the west which considered as the north south trending transgressional zone mark. The tectonic boundary of the Kurram fault is associated with the Kurram-Waziristan ranges. The Bannu depression lies in the southern portion of the Kohat foreland basin. The sedimentary rocks sequence is exposed in the Kohat basin which is consists of Paleocene-Eocene i.e., limestone, shale, evaporites, sandstone and conglomerates which are succeeded by an unconformity overlain by Miocene.

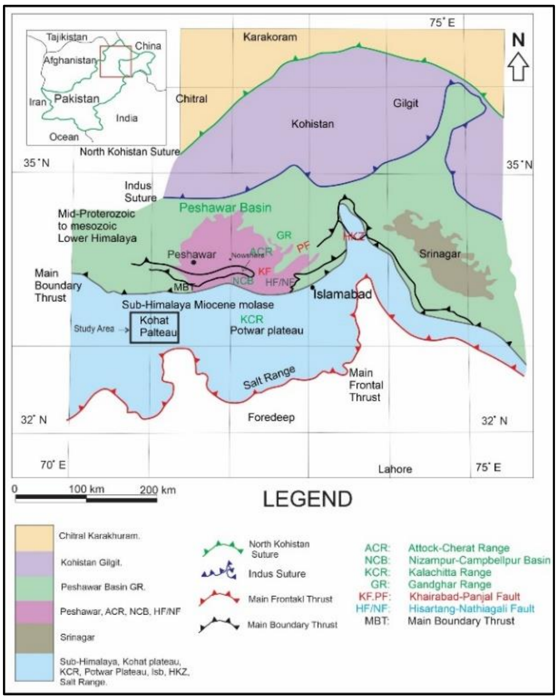


**Fig. 1:** Show the tectonic map of northern Pakistan showing the structural boundaries (modified after [30].

Conventionally the Kohat plateau name is used in the existing literature, but it does not correctly fulfill the definition of a plateau. The Kohat plateau geographic borders is marked by Kohat Range in the northeast, river Indus in the east, in the southeast Surghar Range, Bannu basin in the south and Samana Range in the northwest [2].

The Kohat foreland early studies was focused on establishing its stratigraphic framework, referred to as by many geoscientists from geological survey of India mainly by [3], [4], [5], [6]. The stratigraphic relationship between Salt Range and Kohat salt deposited is offered by [7], this relationship was just a regional overview of the area. An innovative report on Gypsum deposits of the Kohat area was published by [8] from Geological survey of Pakistan (GSP). [9] established the lithostratigraphic units of Kohat region. [10] carried out the detailed investigation of the Kohat foreland basin including a comprehensive geological map at scale of 1:250,000. Detailed sedimentological studies of the region owe to [11] who performed an extensive work on the depositional environment of the Cenozoic rocks.

The first systematic approach to the structural understanding of the Kohat foreland basin attributed to [12]. In this approach they organized a well-adjusted cross section through eastern Kohat foreland basin and Surghar Range which describing the fold and thrust propagation underneath the Kohat basin. Structural model for Kohat foreland basin was delineated by exploiting the low angle, north-dipping imbricate thrusts fault under a passive roof thrust [13]. The structural explanation of the Kohat basin exhibits that it a complex, hybrid terrain comprising of wrench and compression related to structural sorts [14]. The latest structural account of the Kohat foreland basin is attributed to [2] highlighting structural mismatch between the surface and subsurface structures. Moreover, the tectonic evolution of the study area was presented along the Akhurwal-Kohat area showing the major stresses along the MBT producing deformations parallels to the major structures [15].

## 2. GEOLOGY AND STRATIGRAPHY OF THE STUDY AREA

### 2.1. Regional geologic setting

The earth has been contracted periodically since its formation, and a consequence of its contraction new oceans and continents are formed and interchange their position throughout geologic time. In late Paleozoic, the continents joined to produce a single landmass called Pangea and the ocean around it is called Panthalassa [16]. Later, the tectonic forces drive the Pangea to divides into two supercontinents called Laurasia in the north and Gondwanaland towards south [17]. The North American and Eurasia plate was part of Laurasia while the Gondwanaland was comprising of South America, Antarctica, India, Africa, and Australia. The Indo-Pakistan plate lies in the Gondwanaland [18]. Due to the splits of Gondwanaland the India becomes isolated continent. About 120 million years ago the India started breaking and drifting gently at a rate 5cm per year towards the north. The Indian plate then started moving towards Eurasian plate [19].

Approximately 50 million years ago the Indian and Eurasian plate strikes which results into the uplifting and formation Himalayas [20]. The current research area is situated in the lesser Himalayas and Karakorum orogenic belt which is established due the collision of Indian and Eurasian plates [21]. This part of Himalayan foreland basin is mostly deformed which is covering approximately 10,000 square meter area of anticlinal hills and the tectonic history of these belt recorded from Precambrian to the recent rock unit in the region. The Himalayan thrust belt in Pakistan from North to south is comprise of Main Karakorum Thrust (MKT), Main Mantle Thrust (MMT), Main Boundary Thrust (MBT) and Salt Range Thrust (SRT) [22]. The study area represents Kohat foreland basin which is surrounded in the north by Main Boundary Thrust (MBT) (Fig. 1), to the south by Surghar, Khisor, Marwat Ranges separated by strike slip Kalabagh fault from salt range thrust (SRT). In the east Kohat is separated from Potwar basin marked by the Indus River and the NNE-SSW oriented Kurram fault restricted to the west.

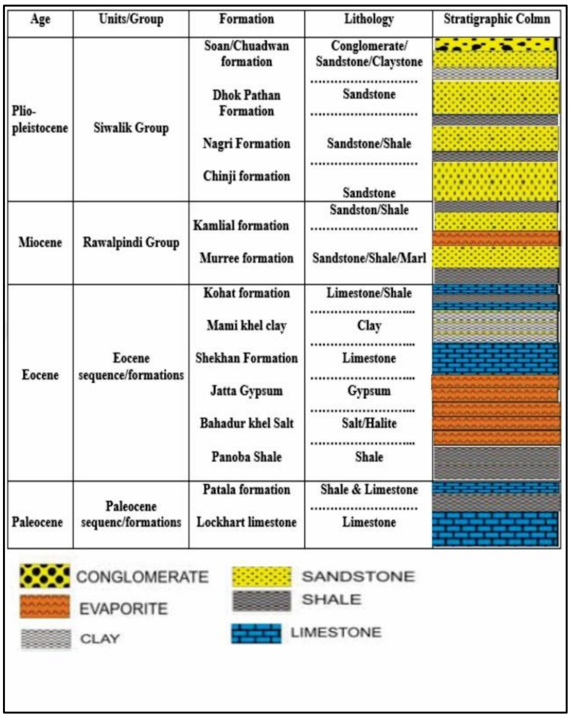


**Fig. 2:** Show the stratigraphic column of the study area.

### 2.2. Stratigraphy

The stratigraphic sequence of the research area is from Paleocene to Plio-Pleistocene (Fig.

2). Kohat formation have been selected for research work. The lithology of Kohat formation is composed of dominantly brownish limestone with the interbedded shale at the base.

## 2.3. Kohat formation

Kohat formation was named as Kohat shales by [23]. The lithology of Kohat formation is comprises of predominantly dense highly jointed massive thin bedded foraminiferal limestone and yellow green shale at the base which is interbedded with the greenish grey or various colored shale [2]. Kohat formation have three members which includes (1) Habib Rahi Limestone: which consist of tan to light-grey, pink, fine to medium-crystalline and thick bedded limestone. (2) Sadkal Member: it comprises of green, greenish-grey shale. This unit is recognized only in the northeast part of the region. (3) Kaladhand Member: the lithology of this member is composed of grey, fine to medium-crystalline thin-bedded limestone with interbedded shale (Meissner et al., 1974). The Kohat formation have highly fossiliferous limestone (Fig. 3), with having conformable lower contact with the underlying Mami Khel Clay and upper unconformable contact with overlain Miocene series [2].


**Fig. 3:** Fossiliferous appearance in Kohat formation.

## 2.4. Murree formation

Murree formation exposed in the Kohat area consist of a higher percentage of brown, greenish grey sandstone with medium to coarse grained sandstone and shale with white marl at places. (Fig. 4). The fossil record of the formation is extremely poor (poorly fossiliferous).

**Fig. 4:** Murree sandstone with medium to coarse grained and shale.

## 3. MATERIAL AND METHODS

Detailed Geological field work was conducted to study area to collect the surface stratigraphy and the fracture orientations data. The strike and dip have been measured for each fracture and the data was gathered with the help of Burton compass. Scanline method was presumed for fracture analysis. In this method, particular rectangle was marked in the study area which have different fracture orientations. A line of one-meter was drawn on the face of the selected outcrop and the length and the orientation of each fracture which cut across the 1m line was collected with the help of Burton Compass and Field-Move Clino application.

Subsequently, the data correlation, interpretation, and illustration has been succeeded with several application, which contain Google Earth used for observing and interpretation of field data, Global Mapper was used for generating the coordinate projection and collect the digital elevation model (DEM) (Fig. 5). The application Corel draw suit was utilized for sketching and mapping of model. (Fig. 6), the utilization of Corel draw suit was to mark various fracture on images that were acquired throughout the geological field (Fig. 7 A-H). The orientation and projection of the fractures on Stereonet was illustrated through Geo rose application (Fig.8A).

### 3.1. Fracture density

Fracture density is the cumulative length of all the fractures divided by area of that rectangle [24]. Fracture abundance of a rock is described by fracture density [25]. The fracture density has direct relation with fracture connectivity thus, the fracture connectivity increases with increase of fracture density presenting a trendline (Fig. 9) [26]. The fracture density can be calculated by particular equation [25]:

$$\text{Fracture density: } FD = \Sigma L / A$$

$$FD = \Sigma L / L \times W$$

### 3.2. Fracture porosity

The Monte Carlo equation finds out the fracture porosity which depends upon the length of the fracture, width of the fracture and area of the fracture. Thus, fracture porosity and density are dependent on each other showing in a trendline (Fig. 10). The following equation used to determine the fracture porosity [24].

$$\text{Fracture Porosity} = (1/A) \sum_{i=1}^{N} (L_i \times W_i) \times 100$$

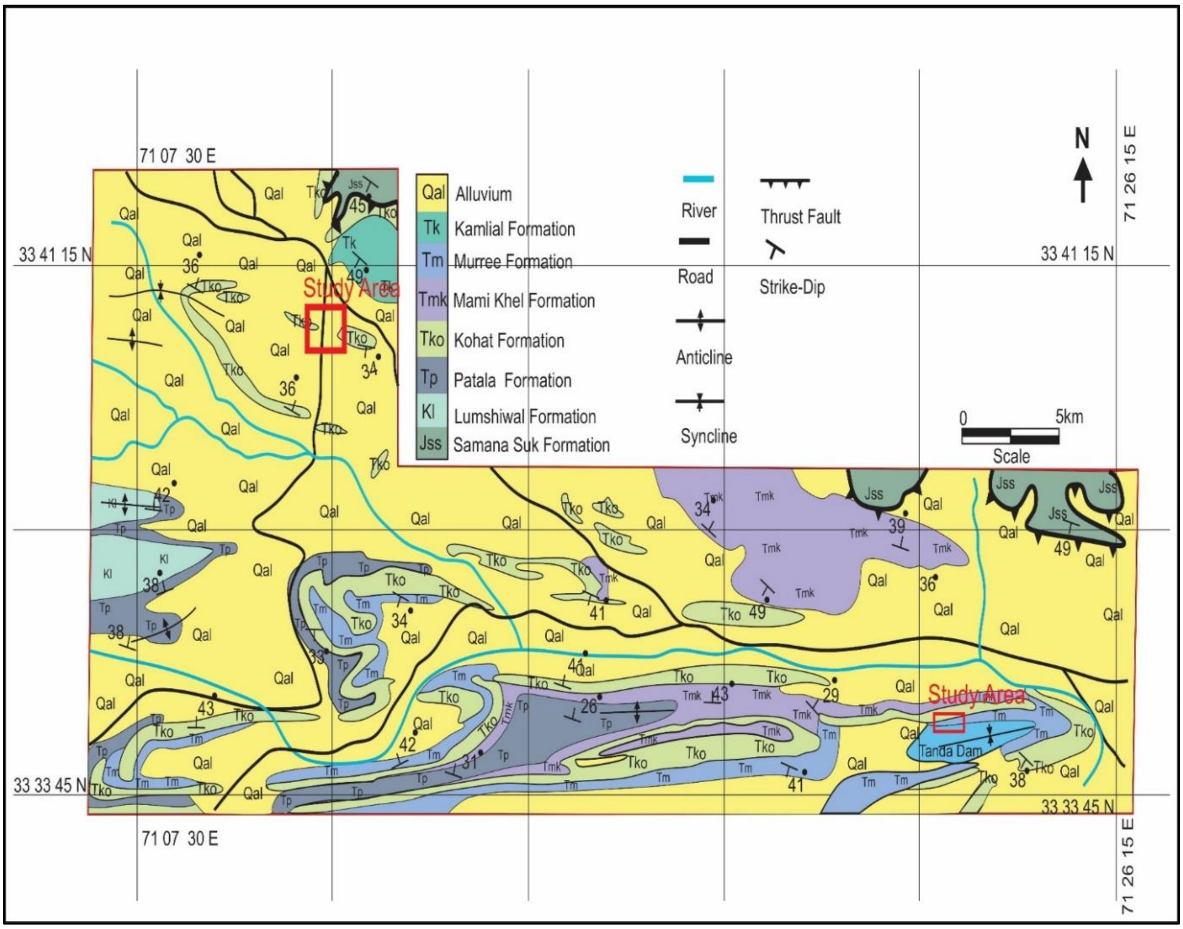


**Fig. 5:** Show the digital elevation model (DEM) of the study area.

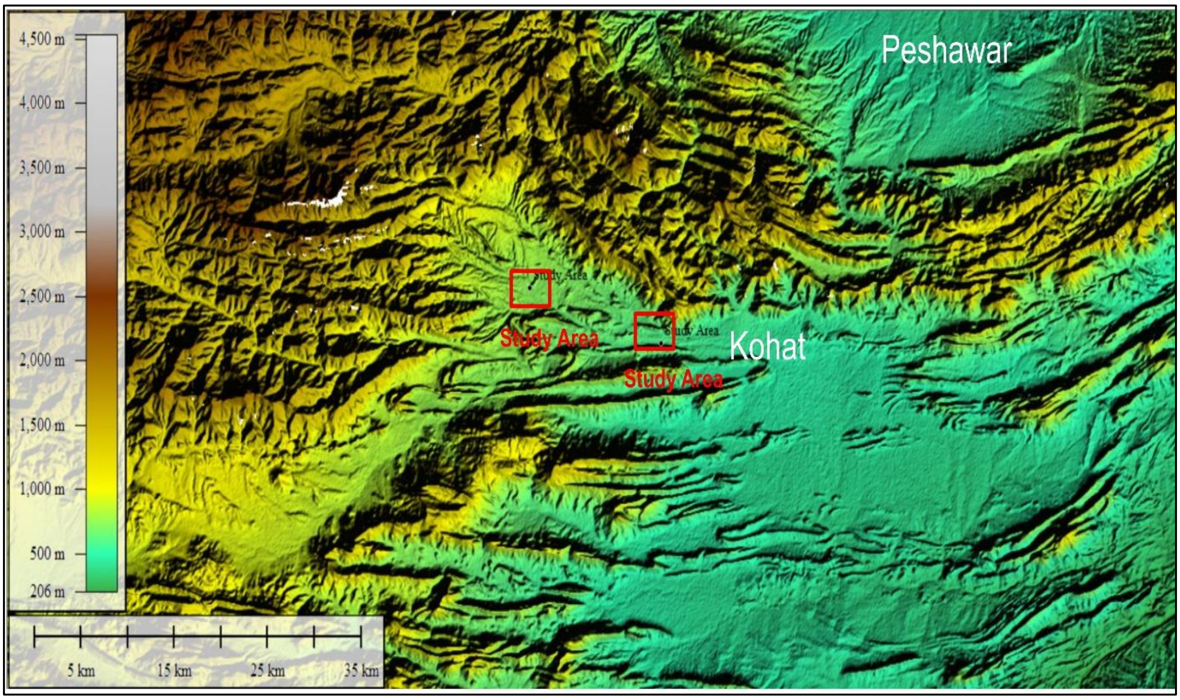


**Fig. 6:** presenting a geological map of study area showing the box indicating the formations encountered for fractured data collection.

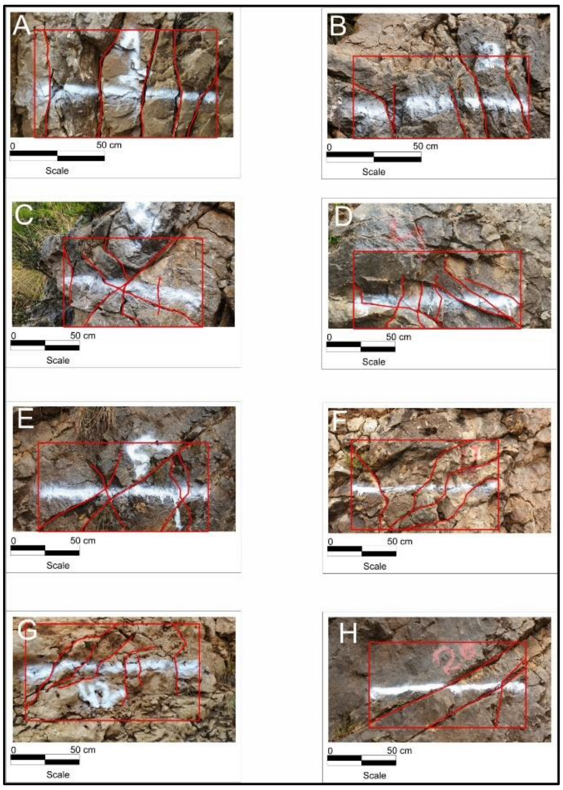


**Fig. 7:** (A-H) show a field image of the scanline method for fracture analysis.

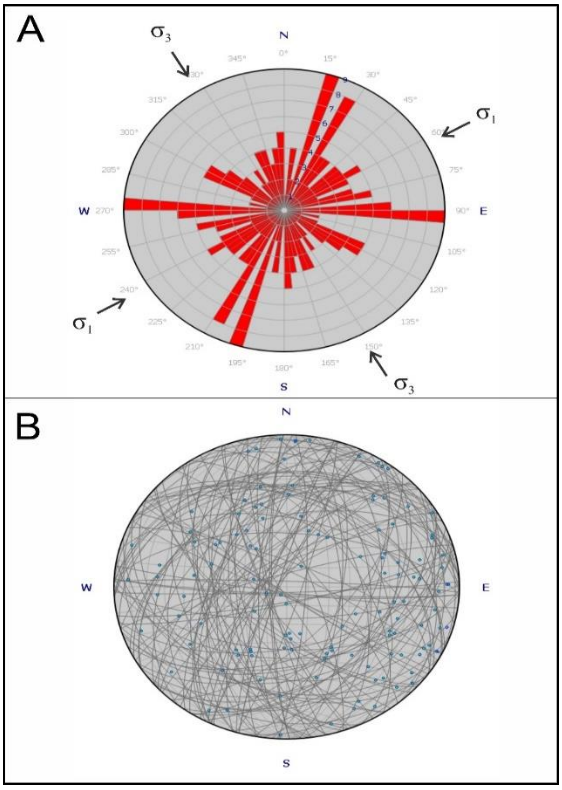


**Fig. 8:** (A) show the cumulative fracture orientation along 30 stations and (B) shows the projection of fracture data on Stereonet diagram along 30 stations.

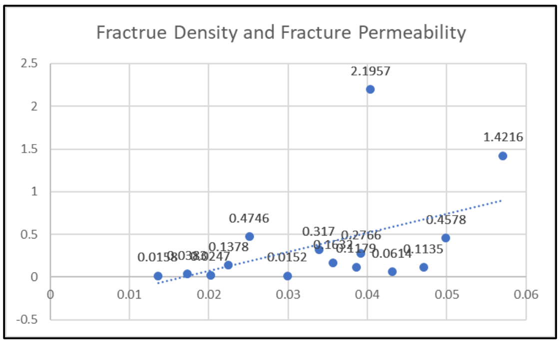


**Fig. 9:** show the relationship between fracture density and permeability

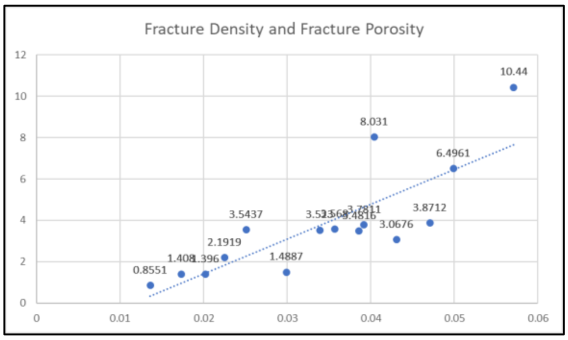


**Fig. 10:** show the relationship between fracture density and porosity.

## 3.3. Fracture Permeability

The competency of a rock or rock fracture to transmit fluid through it. Permeability is one of the significant petrophysical property which impact the quality and behavior of reservoir [27]. The fracture permeability is obtained by the following equation [28]:

$$\text{Fracture Permeability } (K) = (3.5 \times 108)\ (1/A)\ \Sigma_{i=1}^{N} (Li \times Wi^3)$$

## 3.4. Results

The method adopted for the fracture analysis is scanline method for the particular research area. In this method, the fracture analysis has been used for the orientation and spacing of the fractures. The characterization of reservoir properties has been resulted by the estimation of fracture porosity and permeability.

### 3.5. Fracture orientation analysis

The Georose (Yong Technology Inc.) application had been used for the interpretation of fracture orientation data. The oriented data interpreted on Georose application which analyzed the stresses directions. There are three types of stresses directions, (1) maximum stress (δ1) which is compressional stresses, (2) Minimum stress (δ3) which is extensional stresses (Fig. 8A).

## 4. SCANLINE METHOD FOR EVALUATING FRACTURE DENSITY, POROSITY AND PERMEABILITY

### 4.1. Kohat formation

The fracture data was gathered along 30 stations of the Kohat Eocene formation. The dominant lithology of this formation is consisted of foraminiferal Limestone with interbedded green shale at the base. The observation of fracture data has been made on Georose application which shows the fracture presents in the study area are frequently Compressional in nature because the plotted data on Rose diagram shows maximum stresses direction on North-East direction (Fig. 8A) (Table 1).

1 **Table 1:** The calculated parameters of Kohat Formation along 30 stations in the study area.

| Substation No. | Formation Name | Total no. of Fractures | Calculated Stress Direction | Fracture Density in $cm^{-1}$ | Fracture Porosity in % | Fracture Permeability in MD |
|---|---|---|---|---|---|---|
| 1 | Kohat Formation | 6 | N 10° E | 0.0571 | 10.44 | 1.4216 |
| 2 | Kohat Formation | 5 | N 50° E | 0.0499 | 6.4961 | 0.4578 |
| 3 | Kohat Formation | 5 | N 60° E | 0.0431 | 3.0676 | 0.0614 |
| 4 | Kohat Formation | 9 | N 55° E | 0.0471 | 3.8712 | 0.1135 |
| 5 | Kohat Formation | 5 | N 30° E | 0.0357 | 3.568 | 0.1632 |
| 6 | Kohat Formation | 7 | N 30° E | 0.0339 | 3.523 | 0.317 |
| 7 | Kohat Formation | 9 | N 85° W | 0.0386 | 3.4816 | 0.1179 |
| 8 | Kohat Formation | 9 | N 75° E | 0.0225 | 2.1919 | 0.1378 |
| 9 | Kohat Formation | 5 | N 75° E | 0.0136 | 0.8551 | 0.0158 |
| 10 | Kohat Formation | 5 | N 40° E | 0.0202 | 1.396 | 0.0247 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 11 | Kohat Formation | 7 | N 75° E | 0.0392 | 3.7811 | 0.2766 |
| 12 | Kohat Formation | 5 | N 75° E | 0.0173 | 1.408 | 0.0383 |
| 13 | Kohat Formation | 9 | N 70° E | 0.0251 | 3.5437 | 0.4746 |
| 14 | Kohat Formation | 9 | N 15° W | 0.0404 | 8.031 | 2.1957 |
| 15 | Kohat Formation | 4 | N 75° E | 0.0299 | 1.4887 | 0.0152 |
| 16 | Kohat Formation | 8 | N 15° W | 0.0571 | 10.44 | 1.4216 |
| 17 | Kohat Formation | 6 | N 30° E | 0.0431 | 3.0676 | 0.0614 |
| 18 | Kohat Formation | 6 | N 60° W | 0.0357 | 3.568 | 0.1632 |
| 19 | Kohat Formation | 7 | N 75° E | 0.0386 | 3.4816 | 0.1179 |
| 20 | Kohat Formation | 4 | N 75° W | 0.0136 | 0.8551 | 0.0158 |
| 21 | Kohat Formation | 10 | N 45° W | 0.0392 | 3.7811 | 0.2766 |
| 22 | Kohat Formation | 6 | N 70° W | 0.0251 | 3.5437 | 0.4746 |
| 23 | Kohat Formation | 5 | N 60° E | 0.0299 | 1.4887 | 0.0152 |
| 24 | Kohat Formation | 6 | N 60° W | 0.0499 | 6.4961 | 0.4578 |
| 25 | Kohat Formation | 7 | N 30° E | 0.0471 | 3.8712 | 0.1135 |
| 26 | Kohat Formation | 6 | N 45° E | 0.0339 | 3.523 | 0.317 |
| 27 | Kohat Formation | 6 | N 4° E | 0.0225 | 2.1919 | 0.1378 |
| 28 | Kohat Formation | 12 | N 10° W | 0.0202 | 1.396 | 0.0247 |
| 29 | Kohat Formation | 4 | N 15° W | 0.0173 | 1.408 | 0.0383 |
| 30 | Kohat Formation | 7 | N 10° W | 0.0404 | 8.031 | 2.1957 |

2

The permeability range of the total 30 station is 0.0158 - 1.4216 MD in which only three station shows the maximum permeability (Table 1). These three stations represent in the research area maximum fluid flow through its fracture because of extremely opened and predominantly interconnected.

## 4.2. Reservoir potential

Kohat Eocene formation have been arbitrated for reservoir potential by examine the surface fracture data and mathematically calculations of different parameters. According to the method of [29], Kohat formation were classified quantitatively. According to this arrangement, the permeability value of <1 MD (108) were placed in type 4 class and 1-99 MD were placed in type 3 class (Table 2).

**Table 2:** The naturally fracture reservoir (NFR) values of fracture density, porosity, and permeability

| Fracture Density in Cm-1 | Fracture Porosity in % | Fracture Permeability (108) in MD | NFR Type | Maximum Stress Direction |
|---|---|---|---|---|
| 0.0136 - 0.571 | 0.8551 - 10.44 | 0.0158 - 1.4216 | Type-4 to Type-3 Type-2) Fracture provide essential permeability Only Types 3) Fractures provide a permeability assistance | NE & NW |

## 4.3. Stress analysis

From the results of fracture data plotted on Rose diagram, the fractures are showing the northeast-southwest orientations. The stress analysis is used to calculate the stress direction which have a genomic association with the formation of folds. For the maximum stress's direction, the documented fracture data from the field have been plotted on the Rose diagram and interrelated with the geological map (Fig. 11), showing the formation and geological features. The maximum compressional stresses are sketched and allocated to the geological map (Fig. 12). The extreme compressional stresses are categorized into two classes in the study area.

According to (Table No 1) the northeast-southwest stresses orientation is calculated in 20/30 rectangles. The stresses direction of these stresses is collaborated with the station No. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 15, 17, 19, 23, 25, 26, 27 and 28. These station stresses are the maximum stresses on the study area (Kohat Formation). Furthermore, in the (Table No. 1) northwest-southeast orientation of stresses is associated in 10/30 rectangles. The direction of these stresses is on station 12, 14, 16, 18, 20, 21, 22, 24, 29 and 30.

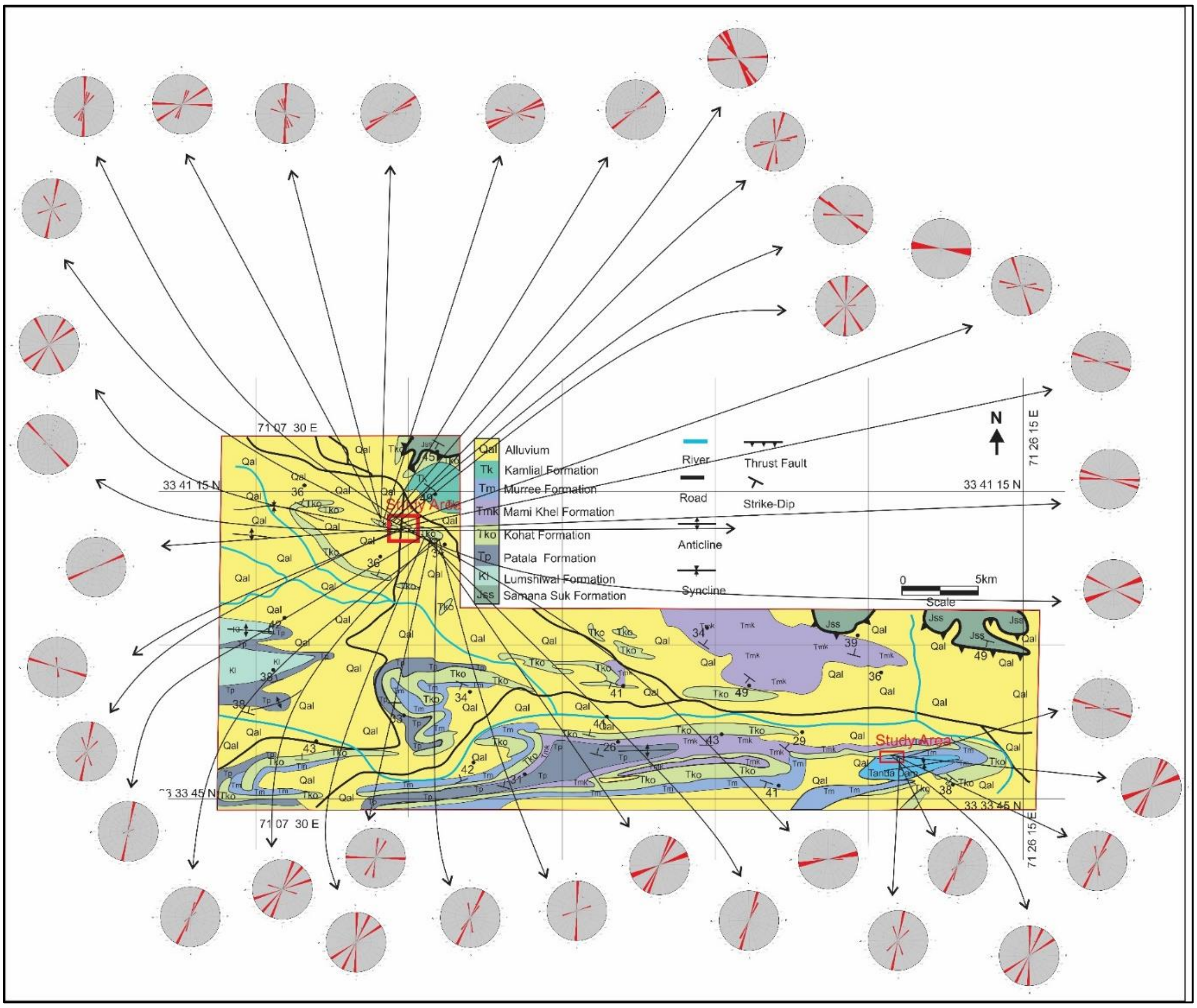


**Fig. 11:** show the fractures data plotted in the study area (red box).

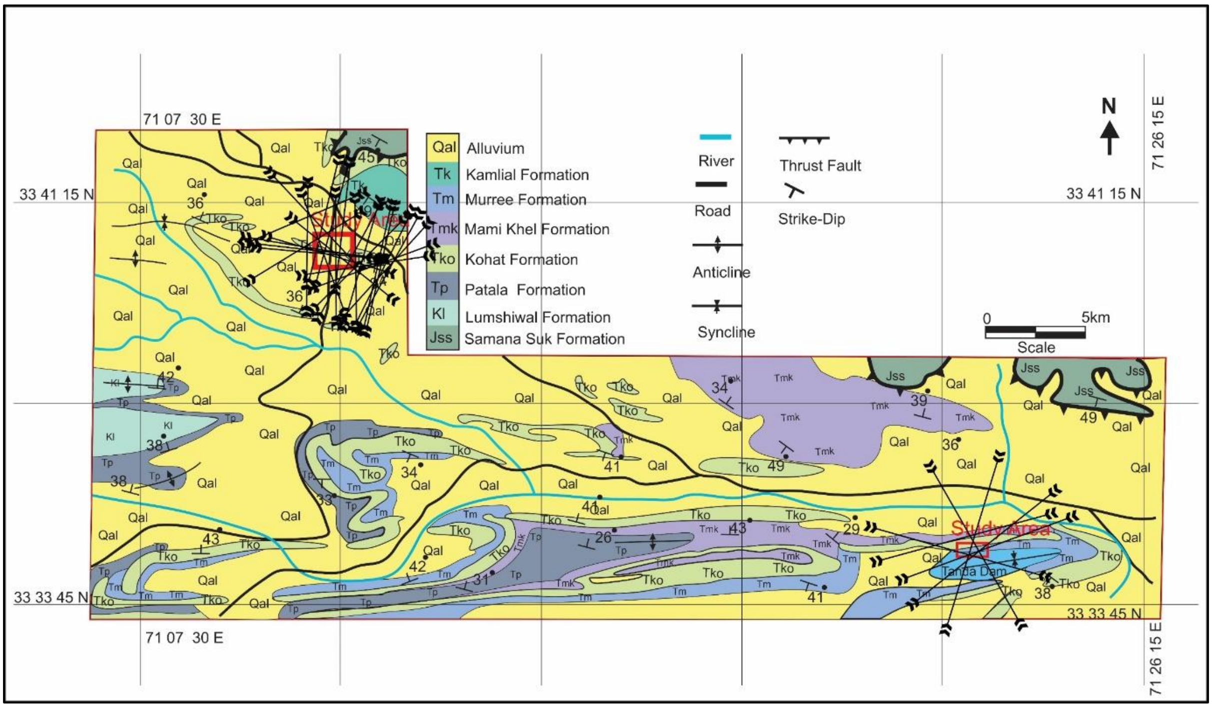


**Fig. 12:** Show a calculated stress of each station on study area map based on the surface fractures data.

## 5. DISCUSSION AND CONCLUSION

During this research work the analysis was carry out on 30 distinctive stations to find the fracture orientations data and its parameters. These parameters includes Density, fractures length and width on every single station. The mathematical computation on the obtained field data evaluated the fracture density, porosity, and permeability of each station. The field data from the study area plotted on Stereonet diagram that demonstrated the stresses orientation i.e., compressional, and extensional. The end result of the research concluded the Density, porosity, and permeability, which illustrated comparatively weak to strong association. In typical case the permeability and density have direct relation, but some stations are having less density and high permeability because of dissolution and vuggy porosity due to which it indicates weak relationship. The connection between porosity and permeability is notable that specifies independent relation on each other. Relationships was prepared density ranging from 0.0136-0.571 cm-1, porosity ranging from 0.8551-10.44 % and permeability ranging from 0.0158-1.4216x108 MD by fracture analysis with NFR (Naturally Fracture Reservoir). For reservoir potential the qualitative classification was estimated which determines very defective correlation whereas fractures provide flexible succor and does not offer significant additional porosity and permeability. Thus, it occurs from type 4 to type 3 NFR system of classification.

## ACKNOWLEDGMENT

The authors are grateful to the Chairman, Dean and particularly the administration staff of Department of Geology, AWKUM for facilitating the field work to the study area. We are obliged to Professor Dr Sajjad Ahmad (DG, GSP) for their conceptualization in the field data interpretation.

## DECLARATIONS

**Funding:** The authors are thankful to Department of Geology, AWKUM for providing financial assistance in field work.

**Conflicts of interest/Competing interests:** The authors declare no any conflict of interest/competing interests.

**Data availability:** Not applicable.

**Code availability:** Not applicable.

**CRediT Authors' contributions:**

**Muhammad Yaseen**: Conceptualization, Methodology and Software. **Shahid Ali Shah**: Data interpretation, Writing- Original draft preparation, **Junaid Khan**: Visualization, Investigation. Adnan Sami & **Muhammad Sheraz**: Field data Supervision **Adil Jan & Saad Siar**: Software, Validation, Writing- Reviewing and Editing.

## REFERENCES

[1] Khan M, Ahmed R, Raza HA, Kemal A., Geology of petroleum in Kohat-Potwar depression, Pakistan. AAPG Bull, (1986), 70(4):396–414

[2] Ahmad, s., a comparative study of structural styles in the Kohat plateau, NW Himalayas, NWFP, Pakistan, (2003).

[3] Fleming, A., On the Salt Range in the Punjab. Quarterly Journal Geological Society of London, 1853, 9(1):189-200.

[4] Oldham, R.D., Report on the geology of Thal-Chotiali and p a rt of the Mari country. Records Geological Survey of India, 1892, 25(1) s18-29.

[5] Wynne, A.B., A geological reconnaissance from the Indus Khushalgarh to the Kurram a t Thai on the Afghan frontier. at Records Geological Survey of India, 1879, 12 (2):1 0 0-11 4.

[6] Davies L., The fossil fauna of the Samana Range and someneighboring areas. Part I: An Introductory Note, Geol. Survey India, Mem. Palaeont., 1930, NS, 15, 15.

[7] Gee E., The age of the Saline Series of the Punjab and of Kohat: National Academy of Science Proceedings, 1945, v. 14.

[8] Raza, S. Q., & Khattak, A. K., Gypsum deposits of Kohat District NWFP. West Pakistan, 1972.

[9] Fatmi, A.N., Lithostratigraphic units of the Kohat-Potwar province, Indus basin, Pakistan. Memoirs Geological Survey of India, 1973, 10:1-80.

[10] Meissner, F. F., Woodward, J., & Clayton, J. L., Stratigraphic relationships and distribution of source rocks in the greater Rocky Mountain region, 1984.

[11] Wells, N. A., Marine and continental sedimentation in the early Cenozoic Kohat Basin and adjacent northwestern Indo-Pakistan (Doctoral dissertation, University of Michigan): 1984, p. 22-28.

[12] Ghani, H., Ahmad, I., Ahmad Sr, S., & Ali, F., Structural evolution of southern Kohat fold and thrust belt, a case study from Karak area, Pakistan. Journal of Himalayan Earth Sciences, 2015, 48(2), 1.

[13] Abbasi, I. A., & McElroy, R., Thrust kinematics in the Kohat plateau, trans Indus range, Pakistan. Journal of structural Geology, 13(3), 1991, 319-327.

[14] Ahmad, S., Ali, F., Khan, M. I., & Khan, A. A., Structural Transect of the Western Kohat Fold and Thrust Belt between Hangu and Basia Khel, NWFP, Pakistan. Pakistan Journal of Hydrocarbon Research, 2006, 16, 22-35.

[15] Yaseen, M., Wahid, S., Ahmad, S., Rehman, G., Ahmad, J., Anjum, M. N., & Mehmood, M., Tectonic evolution, prospectivity and structural studies of the hanging wall of Main Boundary Thrust along Akhurwal-Kohat transect, Khyber Pakhtunkhwa: implications for future exploration. Arabian Journal of Geosciences, 2021, 14(4), 1-17.

[16] Kearey, P., Klepeis, K. A., & Vine, F. J., Global tectonics. John Wiley & Sons, 2009.

[17] Adie, R. J., The position of the Falkland Islands in a reconstruction of Gondwanaland. Geological Magazine, 1952, 89(6), 401-410.

[18] Datta, D. K., & Subramanian, V., Texture and mineralogy of sediments from the Ganges-Brahmaputra-Meghna River system in the Bengal Basin, Bangladesh, and their environmental implications. Environmental Geology, 1997, 30 (3), 181-188.

[19] Boutelier, D., Chemenda, A., & Burg, J. P., Subduction versus accretion of intra-oceanic volcanic arcs: insight from thermo-mechanical analogue experiments. Earth and

Planetary Science Letters, 2003, 212(1-2), 31-45.

[20] Turner, R., Geoscape: Lessons learned from 15 years of geoscience utreach. Geoscience Canada: Journal of the Geological Association of Canada/Geoscience Canada: journal de l'Association éologique du Canada, 2013, 40(4), 371-381.

[21] Hussain, H., & Zhang, S., Structural evolution of the Kohat Fold and thrust Belt in the shakardarra area (south-eastern Kohat, Pakistan). Geosciences, 2018, 8(9), 311.

[22] Awais, M., Ishaq, M., Akhtar, N., Haroon, M., & Khan, S., Mesoscopic Structures can give Insights to the Regional Ones–An Example of Pumpelly's Rule from a part of Kala-Chitta Range near Kahi Village, Nizampur, Khyber Pakhtunkhwa, Pakistan: An Insight into Economic Geology. International Journal of Economic and Environmental Geology, 2019, 80-84.

[23] Eames, F. E., A contribution to the study of the Eocene in western Pakistan and western India C. The description of the Scaphopoda and Gastropoda from Standard sections in the Rakhi Nala and Zinda Pir areas of the western Punjab and in the Kohat district. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 1952, 1-168.

[24] Jadoon, W. A., Shami, B. A., & Abbasi, I. A., Fracture analysis of Khaur anticline and its implications on subsurface fracture system. In PAPG-SPE Annual Technical Conference and Oil Show, 2003, pp. 3-5.

[25] Davis, G. H., Reynolds, S. J., & Kluth, C. F., Structural geology of rocks and regions. John Wiley & Sons, 2011, Ch.5, p. 216-218.

[26] Maillot, J., Davy, P., Le Goc, R., Darcel, C., & De Dreuzy, J. R. (2016). Connectivity, permeability, and channeling in randomly distributed and kinematically defined discrete fracture network models. Water Resources Research, 52(11), 8526-8545.

[27] Lewis, M. A., Cheney, C. S., & O Dochartaigh, B. E., Guide to permeability indices, 2006.

[28] Muskat, M., Calculation of initial fluid distributions in oil reservoirs. Transactions of the AIME, 1949, 179(01), 119-127.

[29] Nelson, R., Geologic analysis of naturally fractured reservoirs. Elsevier, 2001, p: 109.

[30] Burg, Jean-Pierre, Bernard Célérier, Nawaz M. Chaudhry, Munir Ghazanfar, Felix Gnehm, and Michael Schnellmann. "Fault analysis and paleostress evolution in large strain regions: methodological and geological discussion of the southeastern Himalayan fold-and-thrust belt in Pakistan." Journal of Asian Earth Sciences 24, no. 4 (2005): 445-467

Received: 04 Sep. 2021. Revised/Accepted: 13 Dec. 2021.