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## Shale Gas Potential of the Ranikot Group, Lower Indus Basin, Pakistan

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### Abstract

Natural gas production from tight and impermeable shale formations can be recognized as shale gas and has developed into a significant source of natural gas globally. With the development of modern technology, natural gas prices are likely to rise rapidly in response to substantial supply and demand pressures. The gross thickness of the Ranikot Group in the Lower Indus Basin ranges from 100 m to 400 m. The Ranikot Group is nearly 300 meters thick in the studied area having a depth of more than 1000 m to 2000 m. Geochemical studies indicate that the TOC content analyzed in specimens varies in range from 0.69-8.5 wt. % and the average value is about 2.30 wt%. Hydrogen Index ranges from 40-250 mg HC/g, hence, exhibiting the type III kerogen, which is also corroborated by the Van Krevelen diagram and shows a tendency to generate the gaseous hydrocarbons. The studied samples' Production Index (PI) is between 0.02-26.2, averaging 2.41 mg HC/g rock.  $T_{max}$  varies from 420 to 444 °C, and Vitrinite Reflectance ( $R_v$ ) is between 0.4-0.8%, indicating that the organic matter in the shales of Ranikot Group is immature to early mature. In the studied shale intervals of the Ranikot Group, the clay (ductile mineral) content ranges from 20-30%, while brittle mineral content (quartz) ranges from 70-80%. High Brittleness Index, value (0.6 -Average), lesser values of Poison Ratio, and higher values of Young's Modulus reveal that Ranikot Group's shales are within the brittle region. Studied samples of Ranikot Group were mostly brittle. Therefore, it is suggested that the formation is suitable for hydraulic fracturing.

**Keywords:** Ranikot, Kerogen, Shale gas, Vitrinite, Brittleness, Properties, Wireline.

### 1. Introduction:

Shale gas is a form of hydrocarbon gas found in organically rich sedimentary rocks, i.e., shale and related lithofacies. The Natural Gas is generated and deposited in shales in the form of adsorption, and free gas exists in fractures or pores. Both the shale gas and conventional gas are similar in

composition, but shale gas is present in a very less permeable reservoir and is confined in much smaller pouches all over shale formation. Shale gas is not recoverable by using routine practices because it is locked tightly within the pores. Shale is (fine-grained, layered rock comprising of clay and silt size clasts. It is the most plentiful of sedimentary rocks, which constitutes about Sixty

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(60) percent (%) of the earth's crust. Shale deposits in the deep sea in submarine basins and river floodplains. Shales are primarily composed of about 30% clay minerals and predominantly of quartz. The less quantity of iron-oxides, feldspars, carbonates, and remains of ancient life and carbon-based materials are also present in these shales. These shale sections are regarded as the source of oil & gas and as a seal or cap rock for confining petroleum in the reservoir. The term unconventional reservoirs cover an extensive range, of formation containing hydrocarbons and a type of reservoir; that commonly do not provide commercial production of hydrocarbons without simulation. The term "unconventional" petroleum reservoirs comprise gas in gas hydrates, tight sandstones, oil-shale formation, sandstones with heavy oil, and gas shales [1]. Shale gas has come to be substantial; the mean of the natural gas all over the world due to scientific advancement and rapid rise in natural gas prices because of a large amount of supply and demand burdens. Pakistan is fronting giant problems in fulfilling; its ever-increasing energy requirements due to increasing population and industrial progress. So, it is inevitable to discover unconventional energy assets in addition to the traditional resources to fulfill; our energy requirements.)The global energy scenario has changed due to the shale gas revolution in North America. (America and Canada come to be the chief producers of the commercially; feasible gas from Shale'reservoirs.

Pakistan has an almost 827,365 Km<sup>2</sup> sedimentary basin area out of the total area of 796,096 km<sup>2</sup>. Various Shale formations having good thickness exist in this sedimentary region. These shale formations are performing as source rocks and are confirmed petroleum; systems. A significant quantity of gas has been trapped inside these unconventional reservoirs. In Pakistan, the conventional gas formations have been exploited and established; however, very minute work has been done exploring and discovering the unconventional or shale gas reservoirs until now. The latest (assessments by EIA (2013) have

revealed that in Pakistan, total reserves of shale gas are around "586" Tcf (Trillion cubic feet). Nevertheless, technically recoverable shale gas assets range from 100 Tcf to 105 Tcf. In addition to these reserves, Pakistan also reported 227 billion barrels of shale oil reserves, while Pakistan's technically recoverable shale oil reserves are about 9.1 billion barrels [2]. As Pakistan is passing through the era of energy crisis these days, it must import oil and gas from neighboring countries. Although the country is producing a small percentage of petroleum resources from conventional sources, it is not sufficient for our needs. In addition to conventional energy sources, unconventional energy sources must be developed; to meet the country's energy needs. Following are the objectives of this research

1. To determine the geochemical properties of the Ranikot Group
2. To estimate the generation potential of shale gas in the Ranikot Group
3. To determine the elastic properties of the Ranikot Group

## **2. Materials and Methods:**

### **2.1 Geology and Tectonic:**

The Southern Indus Basin is a significant element of the Indus Basin in Pakistan. It is chiefly extending to the eastern border of Pakistan between 23° N and 28°31 'N and 66°E coordinates. It is a large sedimentary basin covering an area of 550 × 250 km extending offshore (Quadri and Shuaib, 1986; Zaigham and Mallick, 2000). The basin is bounded by eastern India, the thrust mountains to the west, Murray Owen Fracture Zone to the Southwest, Jacobabad arch to the north, and Thar slope to the north and south [3]. The basin was formed by strong tectonic activity and sedimentary deposition in the surrounding area since the Late Paleozoic (Kingston et al., 1983). Zaigham and Mallick (2000) described a structural model for basement development in the basin. It is an extensional basin, and the basement structure began to develop almost in the Paleozoic due to Gondwanaland rifting. As a result of rifting, the

lithosphere became stretched and thin. This phase ended in the late Paleozoic to early Mesozoic, thus causing in Indus Basin Failed rift. Afterward, the boundaries of the rift cooled down, resulting in subsidence. The depositional sequence of Mesozoic is followed by Triassic Wulgai Formation and Jurassic Shirinab Group in the subsided zone. The counterclockwise rotation and northward movement of the Indian Plate led to the deformation of the basin and the development of the western mountain ranges (Zaigham and Mallick, 2000). African and Australian plates separated from Indian Plate later in late Jurassic time as a result of rifting. The erosion of the Sulaiman limestone group and the Lower Cretaceous Sembar resulted in the deposition of the Goru Formation on the western shelf (Iqbal and Shah, 1980). The traps were formed during Late Cretaceous to Middle Paleocene. Wrench faults formed by sloping convergence of Indian plates with Afghan block and other plates, resulting in the formation of Jacobabad and Sargodha highs. The northward and counterclockwise motion of the Indian Plate remained constant until it collided with the Eurasian Plate. To the northern and eastern parts of the Eurasian Plate, continuous orogeny caused sediments from the Eurasian Plate to be deposited on the Indian Plate. After that, the Indian Plate deposited carbonate rocks during the Eocene to Miocene and began to sink into the Eurasian Plate, forming trenches along the subduction zone. This led to extensive sedimentation within the trench and to the uplift of mountain ranges such as the Suleiman-Kilta and Himalayas. Later, the counterclockwise rotation and northward movement of the Indian Plate caused the basin to deform and form the western mountain range (Powell, 1979). The Southern Basin is located on the southern side of the Sukkur Rift and marks the boundary between the central and the southern Indus Basin. The Indian Shield bounds it to the eastward and the Indian Plate to the western side. The Triassic-aged rocks are the oldest rocks in this area. The tectonic setting of Pakistan is shown in Figure 1.

## 2.2 Stratigraphy of the Area:

The Southern Indus Basin contained Triassic to Quaternary sedimentary deposits. The older formation is the Wulgai Formation which is made up of dark-colored grey shales interbedded with calcareous mudstone, sandstone, and limestones. Moreover, the sedimentary deposition of the Jurassic sequence is composed of Datta, Shinwari, Shirinab, Chiltan, and Mazar Drik Formations. These formations are mainly comprised of shales and limestones, which may be dominant at higher depths. The Chiltan Formation has thick, pisolitic, and black-colored limestone beds and has no contact with the upper Mazr Drik Formation in most of the areas. But it has conformable contact with Sembar Formation. The Mzr Drik Formation mainly consists of grey limestone and lacks dark shales in the Southern Indus Basin. The formation is restricted to northwards, where its thickness is 30 m [4], [5]. In the Southern Indus Basin, the cretaceous succession is widely exposed and comprised of shale, sandstone, and carbonate rocks. This depositional sequence starts with Sembar Formation, which contained mainly shales interbedded sandstone with some limestone. Shales and siltstones are chiefly found in the western segment of the Southern Indus Basin and slightly disappear to the eastern side, while sandstone is present towards the eastern and northeast of India [5]. The Cretaceous Goru Formation directly overlies the Sembar Formation and is categorized into two parts. The Upper Goru and Lower Goru are mainly dark, grey, and marron shales and mudstone deep marine settings. The Lower Goru Formation predominantly has sandstones and shales, showing the local distinctions in shale deposits [6]. The Upper Goru is organically rich and has oil-prone with high H.I. values but has an immature state to generate hydrocarbons. Its thickness decreases in almost all directions from the south to the central part of the Southern Indus Basin. The organically rich Lower Goru Formation is described as moderate and can produce oil or condensates [3]. Parh limestone consisted of thin layers of argillaceous carbonate rocks showing light

grey, creamy to white color, present in all the parts of the Basin [5].

The Cretaceous Moghal Kot Formation comprises mudstones, limestones, and sandy limestones. The basin shows the heterogenic lithology. Generally, the clastic lithology has a thick deposition, whereas carbonate rocks mixed with clay have thinner depositions. The Pab sandstone is light, grey, and brown in nature and shows fine coarse grains with interbedded clay or shale, from hard to soft. It was deposited nearshore settings and showed the regression phase (Zaigham and Mallick, 2000). The Paleocene Ranikot Group comprises three formations, Khadro, Bara, and Lakhra formations, which mainly consist of yellow, brown sandstone with shale. The Eocene Laki Formation is made up of limestone, interbedded shales deposited under

shallow -marine-estuarine settings, and solely estuarine shale present in the western side of the Basin (Quadri and Shuaib, 1986). Kirthar Formation is comprised of interbedded shales and limestone and sandy beds in some areas. Kirthar Formations overlies by shales and sandstones of Nari Formation (Oligocene) and Gaj Formation shale of Miocene age, deposited in the nearshore environment (Kazmi and Jan 1997). The Siwalik group consists of Chinji, Nagri, Dhok Pathan, and Soan Formation. This group of formations is formed via cyclic sandstone and clay deposition. Most of them are rich in fossils of invertebrates, such as mammals, reptiles, birds, and fish. These successions vary by several kilometers in thickness. There is an unconformable contact with the upper conglomerate and a conformable contact with the

**Table 1:** Stratigraphic column of the southern Indus Basin.

Age		Stratigraphy	Lithology	Petroleum System		
Era	Period				Epoch	
Cenozoic	Quaternary	Recent	Siwaliks	Red clays, sandstones, and Conglomerates	Trap/Seal	
		Tertiary	Eocene	Kirthar, Laki, Ghazij	Interbedded limestone, shale, and minor marl	Source
	Palaeocene		Raikot Group	Dungan	Nodular-massive limestone and subordinate shale	
				Lakhra	Interbeds of limestone, sandstone, and shale	
		Bara				
Mesozoic	Cretaceous	Late	Pab	White quartzose sandstone	Reservoir	
			Mughalkot	Calcareous mudstone and shale		
			Parh	Platy Limestone		
		Middle	Goru	Sandstone with interbedded shale limestone	Reservoir/Seal	
	Early	Sembar	Nodular limestone and black silty shale	Source/Seal		
	Jurassic	Middle	Chiltan	Limestone	Source	
		Early	Shrinnab	Limestone and shale		
Triassic		Wulgai	Shale, Marl and Limestone			



Figure 1: Sedimentary Basin, Tectonic Framework of Pakistan, and studied well locations [6].

### 2.3 Methodology:

In this research, the LECO CS-300 carbon analyzer was used to measure Total Organic contents in the lab. About 0.2 grams of the rock specimen are treated with concentrated HCL to eradicate the carbonates. The LECO CS-300 carbon analyzer is utilized to find carbon content in coal, coke, shale, petroleum products, ores, and several other non-metallic matters. In this instrument, the specimens are burned in the presence of oxygen at about 1000° C, where the oxidation of carbon occurs to CO<sub>2</sub>. Wetness and dirt are removed, and CO<sub>2</sub> gas is determined by the solid-state infrared detector (I.D.) [7], [8].

Petroleum potentiality and the level of thermal maturation of the kerogen present in a rock are accessed by using Rock-Eval pyrolysis practice [9]. Peters et al. (1986) have described particulars of these analytical methods. Pyrolysis continues with an iso-thermal temperature scheme of 300 °C to 650 °C in the presence of nitrogen. The temperature rises at 25°C per minute. Flame ionization detector (FID) is utilized to measure the pyrolyzed hydrocarbon.

X-ray diffractometer is utilized for mineralogy determination. By utilization, mineralogical data rock brittleness can be illustrated by different methods. The quantitative proportion of brittle minerals, i.e., quartz, dolomite can be used to assess the brittleness index (B.I.) of a shale reservoir. Jarvie et al. (2007), Wang and Gale (2009) described the definitions of Brittleness Index on the basis of

#### V<sub>p</sub> from Sonic Log

V<sub>p</sub> is calculated from sonic logs by using the following equation

$$V_p = \frac{\left(\frac{1}{DT} \times 10^{-6}\right)}{3.281} \quad \text{¶}$$

VS from Vp	·Vs = (Vp - 1360)/1.16 ¶
Young's Modulus	·E = ρVs <sup>2</sup> (3Vp <sup>2</sup> - 4Vs <sup>2</sup> )/Vp <sup>2</sup> - Vs <sup>2</sup> ¶
Poisson Ratio	·ν = Vp <sup>2</sup> - 2Vs <sup>2</sup> /2(Vp <sup>2</sup> - Vs <sup>2</sup> ) ¶
Shear Modulus	·μ = ρVs <sup>2</sup> ¶
Lame 1 <sup>st</sup> Parameter Density	·λ = ρVp <sup>2</sup> - 2ρVs <sup>2</sup> (ρ) ¶
Lame 2 <sup>nd</sup> Parameter Density	·λ = μρ ¶

Where, .....

E = Young's Modulus, λ = lame Parameter, V<sub>p</sub> = P-wave Velocity, μ = Shear Modulus, V<sub>s</sub> = S-wave Velocity, ρ = Density, DT = Sonic log.

the compositional discrepancies of the minerals present in the rocks, by the calculation of the essential minerals, chiefly separating the brittle minerals in the rock specimens by taking the quartz and dolomite into account, as the more brittle minerals in the case [11].

$$BI_{Jarvie(2007)} = \frac{Qz}{Qz + Ca + Cly} \quad \text{¶}$$

and

$$BI_{Wang(2009)} = \frac{Qz + Dol}{Qz + Ca + Cly + TOC} \quad \text{¶}$$

Where; Q<sub>z</sub> = quartz, Dol = dolomite, Ca = calcite minerals, TOC = total organic contents, and clay = clay minerals in a rock by its weight.

Jarvie et al. (2007) have suggested an equation to calculate the brittleness index using the quantitative percentage of various minerals, i.e., quartz, clay, and calcite. Wang and Gale (2009) Also presented an equation to calculate the brittleness by incorporating TOC with the quantitative mineral percentage.

Wireline logs were used for rock mechanical properties determination. Acoustic logging is a generally significant and direct technique for the assessment of the mechanical properties of rock. Schlumberger DSI, the acoustic logging tool, is used for measuring compressional and shear velocity. We can compute the elastic coefficients because acoustic logging provides us V<sub>p</sub>, V<sub>s</sub> and density ρ, by using these acoustic velocities and density.

### 3. Results and Discussion:

#### 3.1 Total Organic Carbon Content (TOC):

TOC is the quantity of organic-carbon in the sediments [2], [6], [12]. The Studied samples of the Ranikot Shales were dark grey to black and indicated a high quantity of organic matter. The TOC values obtained in the laboratory ranges from 0.69 to 8.5 wt. %, averaging 2.30 wt. %. The highest value of TOC (8.5 wt.%) was found in well D. Usually, the changes in TOC contents are due to the

change in the environment of deposition, breakdown of organic matter, weathering, and thermal maturation by sediments burial. Environments with low oxygen contents or anoxic environments are the best sources for preserving organic matter. Diagenetic processes after deposition, rising temperature, and pressure due to burial depth cause thermal variations of organic matter, which cause the change in TOC values. TOC values in the wells of the study area are shown in Table 2.

**Table 2:** TOC values of the Ranikot shale in the studied wells.

S.#	Well Name	Depth (m)	Thickness (m)	TOC (wt.%)	
1	A	1750-2130	380	$\frac{1.31 - 3.74}{2.78(15)}$	
2	B	1180-1380	200	$\frac{0.87 - 4.9}{2.15(11)}$	
3	C	1170-1285	115	$\frac{0.69 - 1.87}{1.42(8)}$	
4	D	1180-1305	125	$\frac{1.2 - 8.5}{2.55(13)}$	
5	E	1100-1330	230	$\frac{0.74 - 1.76}{1.40(3)}$	

$$a \cdot \frac{\text{range}}{\text{mean}(\text{sample amount})}$$

#### 3.2 Rock-Eval Pyrolysis:

The generated Rock-Eval Pyrolysis parameters are (free hydrocarbons), (Hydrocarbon that can be generated),  $S_3$  ( $CO_2$ ) and  $T_{max}$  while the calculated parameters are oxygen index (O.I.), hydrogen index (H.I.), production index (P.I.), genetic potential (G.P.), and vitrinite reflectance based on  $T_{max}$ , etc. The mean values of significant parameters acquired by the pyrolysis of Ranikot shales in various wells are furnished in Table 3. Production Index (P.I.) is calculated by using the relationship  $S_1 / (S_1 + S_2)$ . The typical production index values in studied wells vary between 0.16-5.35(mg H.C./ g TOC) (Table 3) and show in place generated petroleum [13]. The post-depositional processes like weathering or

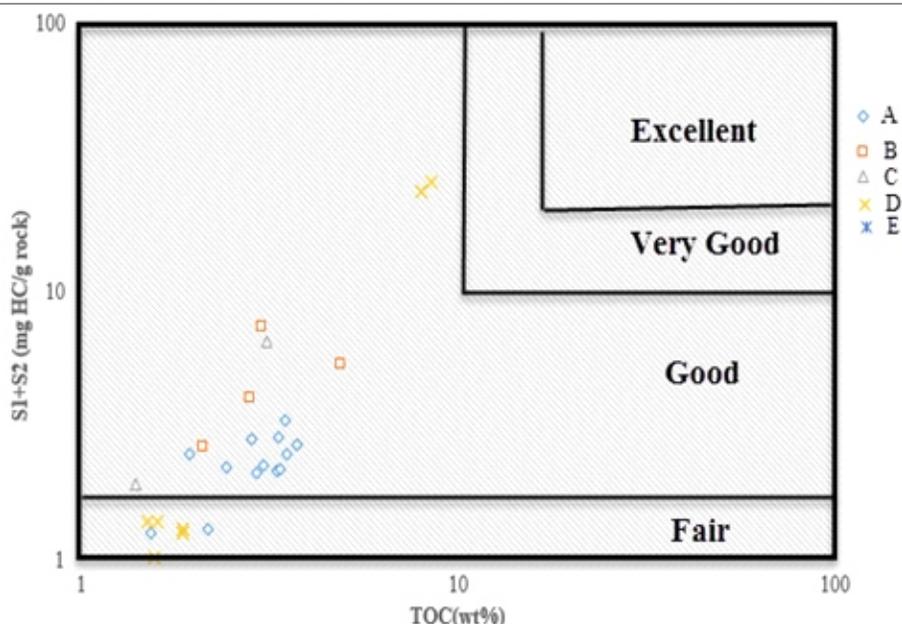
oxidation reduce hydrogen and increase oxygen to the kerogen that can gradually alter the original P.I. value. Commonly, the shale gas yielding sections indicate "P.I." values in the range of 0.6 to 1.5, but shale units with more than 0.1 PI can produce an outstanding degree of hydrocarbons. The richness of Organic matter or G.P. is calculated by the mathematical relationship  $GP = (S_1 + S_2)$  [14]. Evaluation of source rock that is dependent on the G.P. values is shown in Figure 2, where fair to good genetic potential is found in most of the rock samples that have been studied. The average genetic potential in the considered wells ranges from 0.68 to 4.65 mg HC/g rock. The maximum quantity of G.P. is 26.08 mg HC/g rock, as indicated

by the sample from the depth of 1190 m in well D (Table 3). Samples of the Ranikot Shale show good generation potential. Hydrogen Index  $HI = S_2 / TOC \times 100$  [9]. The average hydrogen index observed from the samples of Ranikot Group in the studied

well ranges from 41.7 to 87.09. Lower the Hydrogen Index, i.e.,  $<125.34$  mg HC/g TOC, higher will be the potential to produce gaseous hydrocarbons. The mean oxygen index value range from 27.67 to 42.35 mg  $CO_2/g$  TOC in the area.

**Table 3:** Rock-Eval Pyrolysis average quantities in the studied wells

Sr.#	Well-Name	S1 (mg-HC/g-rock)	S2 (mg-HC/g-rock)	S3 (CO <sub>2</sub> /g-rock)	GP (mg-HC/g-rock)	T <sub>max</sub> (°C)	HI (mg-HC/g-TOC)	OI (mg-CO <sub>2</sub> /g-TOC)	PI
1	A	0.42	1.69	0.85	2.1	437	60	31.34	0.2
2	B	0.1	1.95	0.85	2.05	424	69.1	42.35	0.16
3	C	0.11	1.39	0.36	1.5	430	72.28	27.67	0.18
4	D	0.3	4.3	0.89	4.65	428	87.09	40.42	5.35
5	E	0.15	0.52	0.49	0.68	429	41.7	38.4	0.23

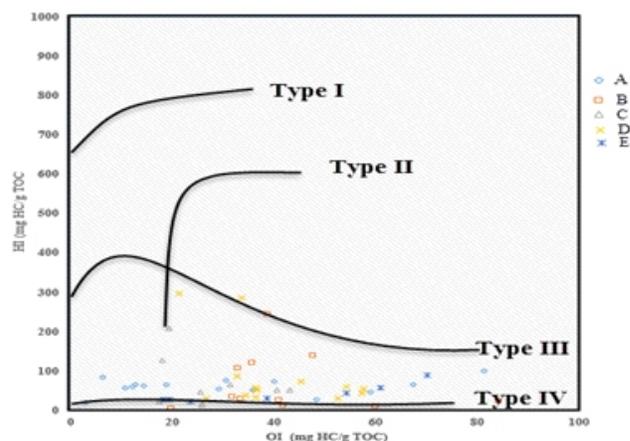


**Figure 2:** The relationship of TOC with G.P. in the studied wells (Modified after Akinlua et al., 2005)

### 3.3 Kerogen Type:

The investigated specimens show the presence of type II and III kerogen as identified from the Van-Krevelen diagram cross plot between H.I. and O.I. (hydrogen index and oxygen index) Figure 3. With the increase in the burial depth, O.I. decreases, whereas the Production Index (P.I.) rises with burial depth (Espitalie, J., Marquis, 1986). Kerogen type is also determined by the cross plot of the Hydrogen Index and T<sub>max</sub> [17], which also deciphered type III kerogen Figure 4. Another relationship between S<sub>2</sub> and TOC also confirms the presence of Type III kerogens Figure 5. The studied samples are identified, having gas-producing matter organic matter in Ranikot shales, proficient in generating mostly gas, which might be from

humic substances and continental higher plants [18].



**Figure 3:** Modified Van Krevelen diagram of studied samples.

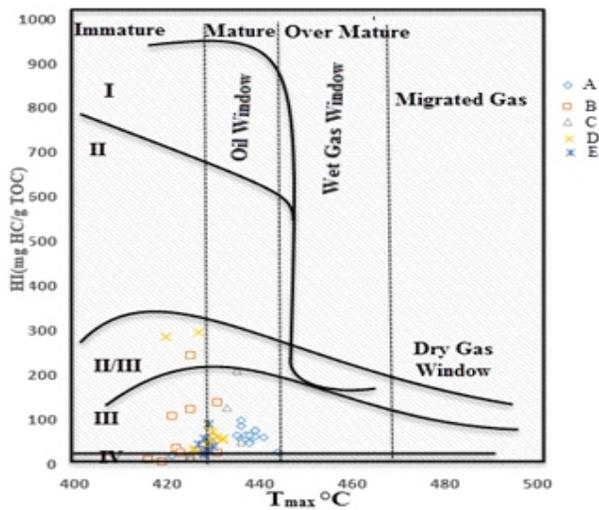


Figure 4: The Cross plot amongst  $T_{max}$  and Hydrogen Index (H.I.).

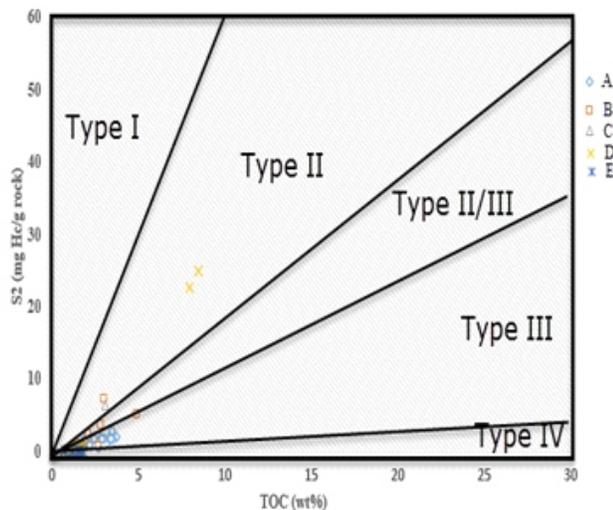


Figure 5: The cross plot between TOC and revealing kerogen typing.

### 3.4 Thermal Maturity:

The rock-eval pyrolysis data is utilized to calculate thermal maturation and the type of the kerogen.  $T_{max}$  range can be incorporated to estimate the maturity of the O.M., i.e., by the cross plot of  $T_{max}$  and H.I. (Figure 4) or calculation of maturity by numerical approaches. The thermally immature and thermally mature boundary is the  $T_{max}$  value of 434 °C, while the  $T_{max}$  value of 465 °C is the limit between mature and the over mature organic matter (Espitalie, J., Marquis, 1986). The peak or highest temperature ( $T_{max}$ ) of 444 °C was observed from the shale samples of well A at the depth interval of 1948 to 1952 m. The optical technique for computing thermal maturity is vitrinite reflectance [19], [20]. The value of vitrinite reflectance (Ro) boosts with an increase in the maturity of kerogen. Since the Tmax can indicate the thermal maturity from rock eval pyrolysis, so  $T_{max}$  can be converted into the vitrinite reflectance (Ro) with the help of a mathematical relationship, i.e., [9]. So after using this relationship, the Ranikot shales samples indicate that the average Ro values of the studied wells are shown in Table 4. The maximum average quantities of Ro (0.7%) are recorded in well A. Depth vs. Ro cross plot is displayed in Figure 6, which shows Ranikot shale is in the mature stage. Moreover, the cross plot TOC and  $S_1$  were constructed to distinguish between indigenous and non-indigenous (migrated) hydrocarbons (Figure 7). Studied samples from the Ranikot shales indicate that organic matter is indigenous

Table 4: Average Ro calculated from  $T_{max}$

Sr.#	Well Name	Depth (m)	Ro From $T_{max}$
1	A	1750-2124	0.7
2	B	1180-1300	0.48
3	C	1170-1285	0.59
4	D	1180-1305	0.55
5	E	1260-1330	0.55

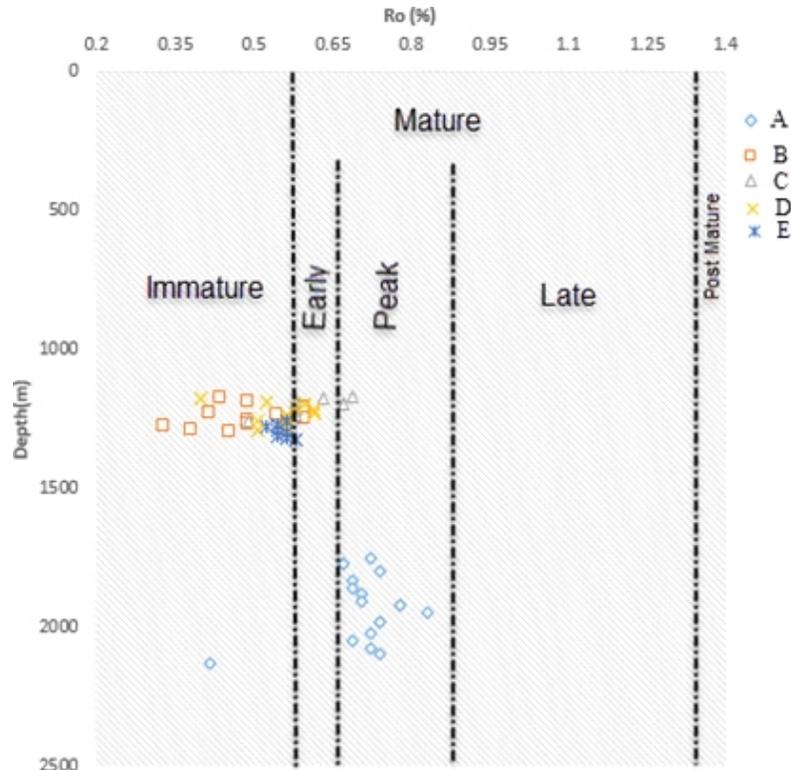


Figure 6: Depth versus Calculated Ro (%)

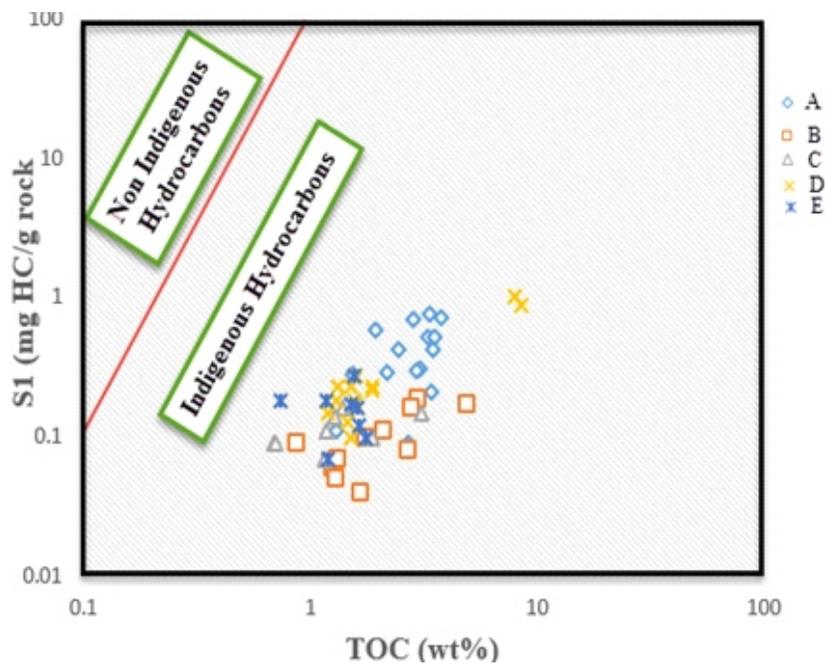


Figure 7: Cross plot between TOC and  $S_1$ .

**3.5 Brittleness Based on Mineralogy:**

Brittleness associated with mineralogy is a vital factor in gas production from tight/concentrated shale gas reservoirs that need stimulation [9]. During the process of stimulation, a network of

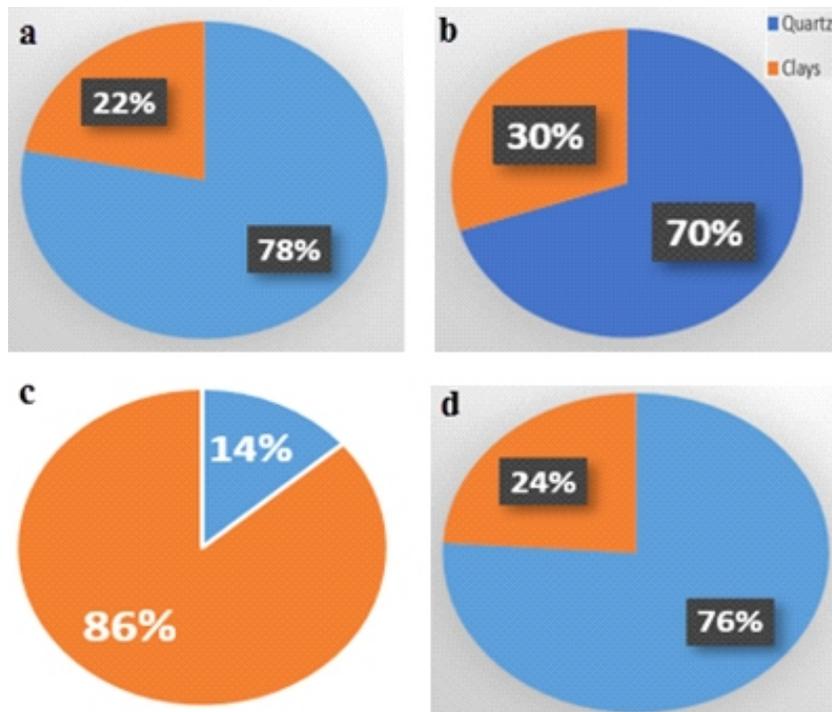
fractures is generated. The porosity of the shale is significantly increased by providing the connection between the borehole and the micro-pores. Percentages of quartz, clay, and carbonates can influence the gradient of fractures in the shales. X-ray diffraction of shale samples from Ranikot

Group shows that the rock unit comprises silty shale that contains dispersed quartz particles of silt size and is surrounded by a continuous depositional matrix. To evaluate the mineralogy of Ranikot shale of the Lower Indus Basin, the volume portions of various minerals, e.g., clay, quartz, and carbonate contents, are calculated. The mineral contents of the Ranikot shales were accessed by the X-Ray Diffraction technique and then was used to calculate the brittleness indices (B.I.) with the help

of mathematical equations proposed by Wang and Gale (2009); and Jarvie et al. (2007) [9], [11]. Average brittleness index (B.I.) of the studied wells is in the range of 0.17 to 0.78, shown in Table 5. So, from these results, it is clear Ranikot shale has brittle behavior in the wells. Because the shales with a Brittleness Index greater than 0.48 are brittle in nature. The quantitative analysis results of XRD data are shown in Figure 8.

**Table 5:** Brittleness Index of Ranikot shales in the studied wells

Sr.#	Well Name	Depth (m)	BI (Jarvie)	BI (Wang)
1	A	1750-2124	0.78	0.64
2	B	1180-1300	0.7	0.65
4	D	1180-1305	0.18	0.17
5	E	1260-1330	0.76	0.74



**Figure 8:** Quantitate (XRD) Results of Ranikot formation (a,b,c, and d, are the samples from Well A, B, D and E respectively) showing the quantitative percentages of minerals.

**3.6 Elastic Properties via Wireline Logs:**

Brittleness index is defined by the geomechanical features like Young's modulus (E) and Poisson's ratio ( ). The greater values of Young's modulus and lower values of Poisson's ratio in the shales are the clear signs that the shales are more brittle [21]. [22] had applied the term "Brittleness Average" for

Poisson's ratio and Young's modulus, which has a practical relationship to differentiate brittle horizons from ductile zones. According to Grieser and Bray (2007) hypothesis, the ductile rocks have low Young's modulus and high Poisson's ratio values and high Young's modulus and low Poisson's ratio are the indicators of the brittle

rocks. They proposed the standardization of "E" and "ν" by using their ranges, resulting in scaled elastic parameters [22].

This research employed the elastic logs corresponding to each well to approximate "Poisson's ratio and Young's modulus. μ lithology models suggested by [23] are very useful for the classification of reservoirs and for discovering the relationship between brittleness and properties of rock. and μ logs matching to each well and cross plot the μ template are also

computed, and projected brittle/ductile categorization for the three main general minerals, clay, carbonate and quartz as presented by Perez and Marfurt (2013) are overplotted. By narrating Figures 9 & 10, we perceive that shale with higher clay minerals lies in less ductile to ductile zone. The incompressibility and rigidity of rocks correspondingly measured by the parameters of and μ'. As greater the clay content μ decreases, but may symbolize reverse trends have been detected. A fair and proven pointer for lithology and brittleness index is .

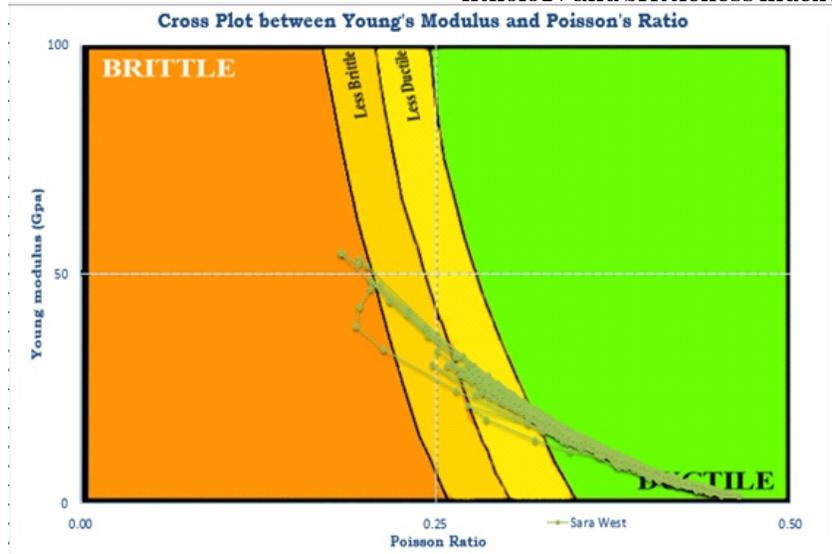


Figure 9: Cross plot between Young's modulus and Poisson's ratio, demonstrating empirically demarcated ductile & brittle regions in the Ranikot Group in the well E, overplotted after Grieser and Bray, (2007), green color is showing Ductile, and red color is for brittle regions.

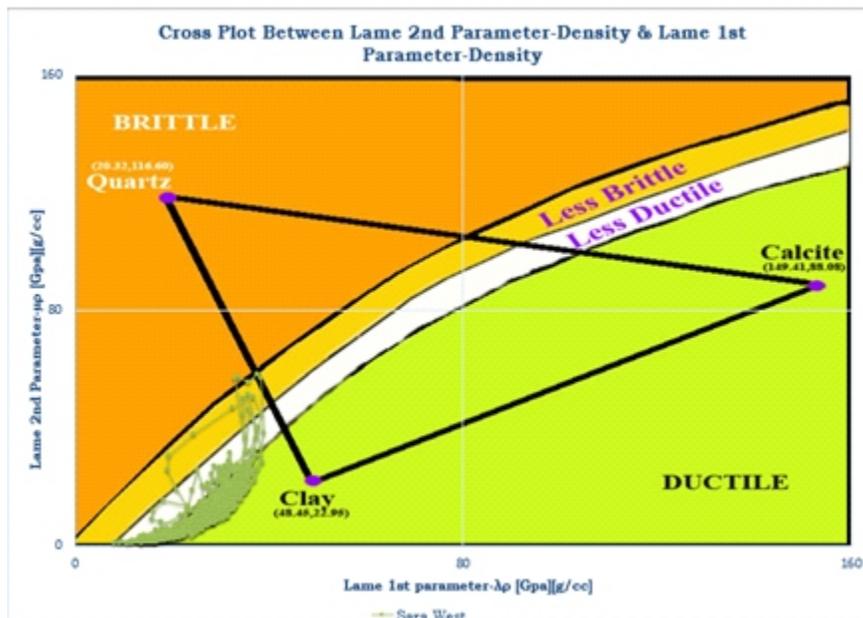


Figure 10: Cross plot between λ and μ corresponding to Ranikot Group in well E (Modified after Perez and Marfurt, 2013).

#### 4. Conclusion and Recommendation:

The shale unit of Ranikot Group is investigated to assess its potential as a shale gas reservoir in the Lower Indus Basins, Pakistan. Geochemical, mineralogical, and brittleness parameters and shale properties were evaluated that control the hydrocarbons generation, production/expulsion, storage, and access to these gas reserves. The thickness of the Ranikot Group in the study area ranges from 100 m to 400m. The subsurface depth of the Ranikot Group is identified as more than 1000 meters and up to 2000 meters in the research area. It is organically rich with mixed organic matter of type III, II/III. The average value of TOC is 2.2 wt. % with generation potential of 2.41 mg HC/g rock and the average Hydrogen Index is about 67.32 mg HC/g TOC. Based on calculated vitrinite reflectance and  $T_{max}$  data, the Ranikot Shale is immature to early mature at the studied intervals. Ranikot Shales has a good prospect to produce gaseous hydrocarbon, as indicated by the low hydrogen index. Mineralogically, the Ranikot shale is composed of an average of 65% quartz and 35% clays. Ranikot Shale has a tendency of hydraulic fracking or fracturing as indicated by more brittle mineral (quartz) content and high brittleness index value (> 0.6). Moreover, the elastic properties are consistent with the brittleness of the Ranikot group. As the Ranikot Group has good shale gas potential. For complete understanding and exploitation of this potential in the future, the following are some recommendations.

- 1) Detailed work needs to be carried out like Petrophysical analysis, Biomarker studies, and Geomechanical modeling.
- 2) The quality of the results of this study can be further improved by using the latest and highly sophisticated instruments.

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