Influence of Tectonic Stress Regime on Fracture Porosity of Tight Carbonate Reservoirs*

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Abstract

Fracture zones are usually characterized by an increased fracture density and thus a higher secondary porosity. In the studied area (Potwar Basin, Northern Pakistan), the porosities derived from a neutron log and fracture apertures (obtained via high-resolution resistivity images) are very low, even if the resistivity images show a high fracture density cataclastic zone. This analysis refers to a tight carbonate reservoir located close to a major fault zone, with a high density of fractures that do not contribute to fluid flow due to their small apertures. The compressive, reverse faulting regime with active hanging walls led to the formation of the main hydrocarbon traps, these being laterally delimited by such faults. Borehole breakouts and drilling-induced fractures were used for tectonic stress evaluation. The dominant minimum stress direction identified in the analyzed wells is WSW - ENE, normal to the direction of drilling-induced fractures, as indicators of the maximum stress direction, which are oriented NNW - SSE. The orientation of drilling-enhanced fractures confirms the maximum stress direction as determined via drilling-induced fractures. The alignment of the major fault and the natural fractures, parallel to the minimum horizontal stress direction, suggests a compressional tectonic regime at the moment of their formation. The maximum tectonic stress, normal to the fractures direction, has contributed to apertures closure and secondary porosity reduction. This explains why in an area characterized by intense cataclasis, resulted from the fault proximity, porosity is less than 2% and fracture apertures are, generally, less than 0.5 mm. However, the simultaneous presence of breakouts and drilling-induced fractures in the same well is an indicator of a strike-slip stress regime. One may conclude that a change in the tectonic stress regime took place, from a compressive to a strike-slip one. The major fault, which initially had a compressive character (dominantly vertical movement), later became a strike-slip one, with a dominantly horizontal component. Knowledge of the fractures’ propagation direction with respect to maximum tectonic stress is extremely important for the potential design of horizontal wells. Experience has shown that production is highly correlated to fracture volume and connectivity in tight formations, implying the future successful economic development of this particular field lies in knowledge of the fracture propagation direction.
References Cited


In certain types of reservoirs, fractures provide the major storage space for hydrocarbons, as well as their main flowing pathway. When primary porosity (represented by the pore network of reservoir rocks) is very low, secondary porosity (fractures, fractures and dissolution vugs) make up the dominant part of total porosity. This situation is mostly encountered in compact rocks such as carbonates, crystalline or magmatic basement, or highly-cemented sandstones. This study refers to a carbonate reservoir located in the proximity of a fault zone, with a high density of fractures which do not contribute to fluids flow due to their small apertures. The maximum tectonic stress, normal to the fractures direction, has contributed to apertures closure and, consequently, to secondary porosity reduction.

2. Geological Setting of the Area (I)

The studied area is situated in Potwar Basin and represents a part of the frontal zone of northwestern Himalayan fold and thrust belt, located in northern Pakistan. The Potwar Basin can be divided in two zones: a deformed, northern one (North Potwar Deformed Zone – NPDZ) and a less deformed southern one – the Soan Syncline (Fig. 1). It has an elongated shape, of about 130 Km in length, developed in a N-S direction, being delimited by thrust faults at North (NBT – Main Boundary Thrust) and South (SRT – Salt Range Thrust) and strike-slip faults at East and West.

The compressive, reverse faulting regime with active hanging walls (overthrust fault) lead to the formation of the main hydrocarbon traps, these being laterally delimited by such faults. The Pre-Cambrian Salt Range Formation is overlain by the Cambrian to Eocene platform sequences (Fig. 2). In Potwar Basin, the Early to Middle Cambrian Jhelum Group is on the Eocene Salt Range Formation (Gee, 1934). The Jhelum Group includes Cambrian Khewra and Kussak Formations. These were deposited in basin to shallow marine environments. The base was uplifted during Otracozoan to Carboniferous, therefore, no sediments were deposited in Potwar Basin (Shami and Baig, 2012).

The Jhelum Group is disconformably overlain by the Permain Nishan Group. It includes the Tohra, Darbot, Warcha and Sardahi Formations. The Late Permian Zaluch Group was eroded or not deposited in the area. The Late Permian to Cretaceous interval is not very well exposed in the Potwar Basin, due to the intense erosion. The Late Cretaceous marine transgression caused thick deposition of the Paleocene to Eocene carbonate-shale sequence. It includes the Lokhart, Patala, Sakessar and Chorgali Formations. The carbonates of these formations form the principal reservoirs for the accumulation of oil in the area. Hangu Formation is not identified in this part of Potwar Basin, which was eroded after deposition and is identifiable on outcrop representing residual environments of deposition. The upper part of the stratigraphic section comprises of the Mocrene to Pleistocene non-marine molasse deposits. The molasse deposits include the Murree, Kamlial, Chinji and Nagri Formations. The transgressive molasse sediments represent the erosional products of the southward advancing Himalayan thrust sheets. Paleocene Patala shales have been proved as the principal source of hydrocarbons, being deposited in anoxic environment. The total organic carbon (TOC) content varies from 0.5 to more than 3.5%, with an average of 1.4%, the kerogen being of types II and III.
The cataclastic fractures are very frequent but show a random distribution of propagation directions (strikes). The borehole breakouts (Fig. 12-left) and drilling-induced fractures (Fig. 12-middle) have been used as means for tectonic stress evaluation. In all three wells, pre-existing fractures enlarged by the drilling process have been identified (Fig. 12-right), their orientation being parallel with the maximum tectonic stress direction.

The porosity derived from the neutron log (breaskealibrated), has very low values in the carbonate formations. This agrees with the very small fractures apertures obtained from resistivity images. Because the main hydrocarbon reservoir is located in the carbonate Sakessar Formation, the statistical analyses carried out will refer only to this reservoir. The total porosity of Sakessar Formation in zones with less than 5% shale content in wells 2 and 3 is usually less than 2%, with occasional higher values in the zones with significant secondary porosity.

The orientation of drilling enhanced fractures (Fig. 14) confirms the maximum tectonic stress direction as determined by the drilling-induced fractures. Given that the analyzed zone is highly tectonized, a change in the tectonic stress direction was observed on different depth intervals in a well (well 2). Nevertheless, a dominant breakout direction can be identified in all three wells: WSW-ENE. The drilling-induced fractures, as indicators of the maximum tectonic stress direction, are oriented WNW - SSE, normal to the breakouts direction (parallel to the minimum stress direction) (Fig. 13).

Knowledge of the fractures’ density and their apparatus is extremely important for the potential design of horizontal wells, attempting to keep the fracture apertures as open as possible.

4. CONCLUSIONS

- The alignment of the major fault and fractures, parallel to the direction of the minimum horizontal stress, suggests the existence of a compressional tectonic regime at the moment of their formation.
- The simultaneous presence of breakouts and drilling-induced fractures in the same well is an indicator of a strike-slip tectonic regime. One may conclude that a change in the tectonic stress regime took place, from a compressive one to a strike-slip one.
- The maximum tectonic stress orientation, normal to the fractures propagation direction, lead to closure of their apparatus. This explains why an area characterized by necks, as a result of the fault presence, porosity is less than 2% and fracture apertures are, generally, less than 0.5mm.
- Knowledge of the fractures’ propagation direction with respect to the maximum stress is extremely important for the potential design of horizontal wells, attempting to keep the fracture apertures as open as possible.