Introduction

Some of the best reservoir facies are beds of well sorted sands deposited in sandy deserts and shallow seas, because they contain a high primary porosity. While sands that are being deposited in deltaic channels and other marginal marine environments, possess also great potential to act as a reservoir. Siliciclastic reservoirs especially sandstone usually possess only homogeneous porosity due to their simple diagenetic evolution in contrast to carbonates which have a complex diagenetic history and possess heterogeneous porosity. Sometimes, bioturbations can disturb that porosity with time.

Diagenesis has a significant control on porosity and permeability of deeply buried sedimentary rocks, comprising the petroleum system that contains fine siliciclastic source beds, the coarser reservoir rocks, and the seals that cause those reservoir rocks to be petroleum reservoirs.

Method and Theory

The Hangu formation of Paleocene age covers an extensive area in the north and north west of Pakistan. The formation is deposited and exposed over a wide area of the Kohat-Samana Ranges, Attock Hazara Fold and Thrust Belt and Surgar and Salt Ranges. To evaluate diagenetic properties, depositional model and stratigraphic evolution of the Hangu Formation, five stratigraphic sections including Khurra 1, Khurra 2, Kuradhi, Saraki and Dhok Chapri of the salt range were measured and 6 samples from each section were collected to make thin sections for petrographic and lithofacies analysis. In the measured sections, formation has an average thickness of 24 metre.

The Hangu formation unconformably overlies the Late Cretaceous Lumshiwal Formation in the Salt Range and Late Cretaceous Kawagarh Formation in the Hazara area, and is conformably overlain by the Middle Palaeocene Lockhart Limestone. The Hangu Formation predominantly consists of light gray to reddish brown and medium to thick bedded quartzose sandstone. The range of grain size for Hangu Formation is fine to medium in which prominent cement is Silica. The common sedimentary structures are graded bedding and cross bedding. At some places, tabular and herringbone cross bedding are also observed. A 1-2m thick laterite bed marks the base of the formation. The laterite is dark brown to reddish brown in colour and pisolitic in nature. The coal seams ranging in thickness from 1-2m is present near the upper contact with Lockhart Limestone. Anyway, the subjected formation is stratigraphically important throughout the Indus Basin to mark significant Cretaceous-Tertiary Boundary known as K-T Boundary.

The Hangu Formation has been divided into ten lithofacies (Fig 2) namely Marly Limestone lithofacies (LF10), Olive Green shale lithofacies (LF9), Brownish grey shale lithofacies (LF8), Pebbly coarse grained sandstone lithofacies (LF7), Pale grey shale (LF6), Pisolitic sandstone lithofacies (LF5), Claystone Lithofacies (LF4), Bioturbated Sandstone lithofacies (LF3), Coal/Carbonaceous shale lithofacies (LF2) and Lateritic/Bauxitic lithofacies (LF1).

Depositional Environment of the Hangu Formation

Although sands are deposited in a wide range of depositional environments ranging from terrestrial to deep marine shelves. Since described formation comprised a variety of lithofacies. So, after analysing those facies, it became possible to characterize its deposition in different phases and environments. Lateritic and bauxite lithofacies characterizes the deposition during the Late Cretaceous and early Paleocene regressive phase of the sea which developed a major unconformity in North and North West of Pakistan, characterized by large scale erosion and development of laterite, ferruginous pisolites and bauxite deposits.

Presence of coal bed and shaly sediments is unique because it represents a transition of environments of deposition from those initially associated with subaerial exposure and lateritic paleosol development to those associated with mire development deltaic environments in the upper part of the Hangu Formation.
Sandy sediments of the Hangu Formation are characterized by herringbone cross stratification. These structures are generally considered to be diagnostic features of tidal and estuarine environments characterized by by-directional currents.

**Diagenesis of the Hangu Formation**

Diagenesis is the term used for all of the changes that sediment undergoes after deposition and before the transition to metamorphism. The term diagenesis includes all physical, chemical and biological changes. These changes include compaction, deformation, dissolution, cementation, authigenesis, replacement, recrystallization, hydration, bacterial action, and development of corrections.

Solution can reverse the trend of cementation. Schmidt had outlined the petrographic criteria of the recognition of secondary porosity in sands. It generally involves the leaching of carbonate sediments. Leaching porosity in sands is generally associated with kaolin.

The effect of diagenesis on sandstone reservoir including destruction of porosity by compaction and cementation enhancement of porosity by solution. A small amount of cementation is beneficial to a sandstone reservoir because it prevents sands from being produces with the oil. The presence of sand in the oil not only damages the reservoir but also production itself. Excessive cementation is poisonous because it diminishes the porosity and cementation. Many minerals grown in the pores of sandstone but only three are of major significance; quartz, calcite and clays. Quartz is common cement (Fig 1).

Calcium carbonate is another cement. It generally occurs as calcite crystals, which grow from pore to pore. Clay may be present in the sandstone as an authigenic cement. The presence of clays in the reservoir destroys porosity and permeability.

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**Figure 1** QFL Diagram of Sandstone of Hangu Formation (modified after Pettijohn 1975)
Figure 2 Sedimentological Log of the Early Paleocene Hangu Formation, Khura area Central Salt Range, Pakistan
Sequence of the Hangu Formation

Based on field data, two depositional sequences are identified. The lower depositional sequence is the initial sequence which consists of falling stage system tract, late lowstand, transgressive and highstand system tract. The upper depositional sequence consists of lowstand and transgressive system tract. The base of Hangu Formation marks the sequence boundary (SB1). This boundary is of type 1 sequence boundary and is recognized globally. In the observed sections the strata from late Permian to Cretaceous is missing.

The base of coarse grained channelized sandstone marks another sequence boundary (SB2) in Hangu Formation. This sequence boundary is generally localized and is type 2 sequence boundary. At base of SB2, alternate shale and sandstone beds of lower depositional sequence are present. The depositional sequence of Hangu Formation is composed initially of falling stage system tract. This system tract is composed of laterite and bauxite. The laterite varies in thickness from 10 cm to 2 m. After falling stage system tract, thin layer of coal (less than 10 cm thick) and carbonaceous shale is deposited when sea level starts to rise. The thin, laterally discontinuous carbonaceous shale and coal beds in the lower of the Hangu probably represent short-lived periods of peat accumulation (Warwick, et al. 1995). The bioturbated sandstone bed marks the transgressive system tract. This bioturbation indicates starved sedimentation. These thick deposits (up to 7 meter) are characteristics of transgressive system tract. The alternate shale and sandstone beds overlying the transgressive system tract marks the highstand system tract. The coarse grained sandstone above the highstand system tract of lower depositional sequence indicate lowstand system tract. The sandstone is channelized and contains conglomerates and pebbles in few sections. The brownish grey shale, olive green shale and marly limestone are part of transgressive system tract. This indicates the transition towards marine conditions.

Conclusion

The lithofacies analysis of the Hangu Formation represents deposition from subaqueous to marginal marine environment. Economic deposits like coal, laterite, bauxite, iron, silica and porous sands for hydrocarbon reservoir are found in this formation. The diagenesis of the Hangu Formation is not much complex as it is revealed by petrographic studies. The calcitic, silicic and clayey cements have been observed which results in porosity loss. The sequence stratigraphic studies of the formation indicates two depositional sequences i.e., the lower one consists of falling stage system tract and the upper one consists of lowstand and transgressive system tract.

References


