Basal Ghazij Sand (BGS) - A Unique Exploration Play in Eastern Part of Pakistan*

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Abstract

A sandstone unit 5-6 m thick underlying the Ghazij Shale of Eocene age was named the Basal Ghazij Sand (BGS) by Tullow Pakistan (Developments) Ltd in 1994 after their first gas discovery in the Sara-1 well. Subsequently, appraisal and exploration in the area proved BGS a unique and discrete sand reservoir with a limited areal extent restricted only in a small area in the eastern part of Pakistan. BGS has so far only been penetrated in wells of the Sara Gas Field in Pakistan and the Dandewala Gas Field in India, while it is absent in the rest of the wells drilled in the region. The Basal Ghazij Sand (BGS) exhibits excellent reservoir quality with 19-30% porosity and > 2 Darcy permeability. Sara-1 tested 17.75 MMscfd with a maximum flow of 42 MMscfd at depth of 982 m to 988 m. The sandstone seems to onlap against Sui Main Limestone in the east and shale-out towards the west. This paper is an attempt to understand distribution and extent of the sand in a sequence stratigraphic framework.

A proper understanding of source, distribution and control on reservoir quality of the BGS has been a major challenge during appraisal and further exploration in the area. Lack of sufficient and relevant data remained one of the major constraints. However, an attempt was made to integrate a well-based sequence stratigraphy with seismic data to understand the genetic relationship and distribution of BGS. BGS was deposited during regression associated with a late stage of HST and an early stage of LST. The Sequence Boundary underlying BGS appears to down-cut slightly into underlying HS (Sui Main Limestone) in the Sara area resulting in relatively thick sand in a localized area. The siliciclastic shoreline moved from west towards the east and appears to have established itself in the region of the Sara wells. The LST varies across the area and is characterized by glauconitic, sideritic and bioclastic sandstone in the Sara wells. The sandy character of LST gives way to basinal facies and northwards becoming dominated by sandy limestone, limestone and shale with either no reservoir quality as in Suri wells or poor reservoir quality as in Khan-1. Overall low reservoir quality wells appear to be in a moderately restricted facies, possibly indicating some sort of lagoon environment. Based on sequence stratigraphic work, the BGS fairway appears to follow a shoreline along an interpreted NW-SE direction. Regional seismic data at

BGS level suggest progradational reflection geometry and brightening at places in some areas in the Central Indus Basin. A proper understanding of BGS system would help in extending and tracking the Sara gas play in the eastern parts of the Middle and Lower Indus Basins of Pakistan.

Introduction

East Badin (Extension) Block B was the first actively operated exploration license of Tullow along with other Joint Venture partners OGDCL, POL and AOC in August, 1991. At that time, Tullow was a small company with a market capitalization of $50 mm (compared to $10 billion today) and had a marketing niche of looking in troubled border regions (e.g. Syria near border with Iraq; Yemen, near border with Saudi Arabia; Iraq (Kurdistan) near border with Turkey). East Badin (Extension) Block-B stretching nearly north-south along the eastern border of Pakistan with India was situated in the Sindh Province, some 100 km southeast of Guddu and 40 km to the east of the town of Dharki (Figure 1).

The primary reservoir objectives in Block-B were a series of sandstone units within Lower Goru Formation, and the top of the underlying Sembar Formation, which have been producing in neighbouring Indian wells. The first exploration well (Sara-1) was intended to test a 6 km x 3 km fault block with four-way dip closure. The fault block was believed to form part of a larger, NNW-SSE trending high which extended across the Indian border. Sara-1 was spudded May 27, 1994 as a commitment well and reached a total depth of 3185 m on July 10,1994 with a good surprise. Gas was discovered from an entirely new sand underlying the Ghazij Shale (Eocene, Figure 2) instead of primary reservoir targets in the Cretaceous. Although Tullow was aware of some successes around the level of Sui Main Limestone in Tanot wells (India), due to diverging stratigraphic nomenclature it was unclear what might correlate with what. Consequently, the significance of Eocene sand was not realized prior to drilling the Sara-1. This discrete sand unit at the basal part of Ghazij Formation was named as Basal Ghazij Sand (BGS) by Tullow.

The gas was tested from BGS and Sui Upper Limestone. Although Sui Main Limestone was also interpreted as gas bearing on wireline logs (Figure 3), due to operational reasons SML could not be tested. The Sara gas discovery opened a new play in the area and was subsequently appraised by wells Sara-2 and Sara -3 in the third Quarter of 1996, before the start of commercial production. A Development and Production Lease was granted over Sara on November 7, 1998 over an area of 82.72 sq km. Sara Gas Field has so far produced > 26 Bcf gas, mostly from BGS (Tullow internal report, 2004). The BGS reservoir remained mysterious and very little was known about its properties and distribution. This paper is an attempt to share our knowledge and experience of this success story and encourage others to extend this play in the region.

Regional Geology and Basal Ghazij Sand (BGS) Play Concept

The Sara area is located on the leading northwestern edge of the Indian Plate. The separation of the Indian Plate from Gondwana is thought to have occurred in Mid-Late Jurassic times. A major progradational build-out occurred as the opening of Tethys spread southwards. From the Late Jurassic until the Late Cretaceous the sedimentary history of Pakistan records a passive margin development. With the separation of Madagascar from the Greater Indian Plate (~80 MY) the passive margin experienced a period of extension. The early Palaeocene witnessed another phase of extensional faulting, caused by mantle plume impingement, as the Indian Plate crossed a "hot-spot" on its journey northward; this led extrusion of the Deccan Trap basalts in northwest India and southern Pakistan. Foreland basin development occurred from the Oligocene onward, as the Indian Plate underthrust the Eurasian Plate. The resulting loading of the Indian Plate caused flexure, leading to the development of a molasses-filled foredeep. A major phase of inversion, caused by the ongoing collision, took place in the Late Pliocene/Early Pleistocene. The Mari High, a major regional structural feature 40 km to the west of Sara and Suri, was formed at this time. The Sara structure was also formed as a result of inversion and is primarily a four-way dip-closed structure oriented along north-south faults. Areal extent of the structure is approximately 8 sq km. A thick shale (>200 m) of Ghazij Formation (Eocene), which is a proven regional seal, overlies 5-6 m thick sand of the Basal Ghazij Sand reservoir sand (Figure 2).

The reservoir sand is relatively thin but exhibits excellent reservoir characteristics. Geochemical analysis indicates that the sections with the greatest source potential are in the Lower Goru and Sembar formations. Migration of the hydrocarbon is believed to have been through vertical faults connecting Cretaceous source to Eocene and other reservoirs. Gas composition in Tertiary reservoirs is different from Cretaceous and deeper reservoirs. A schematic BGS petroleum system is shown in Figure 2.

Sara Gas Field

The Sara Gas Field was discovered in 1994 and was developed as a single well field. Although targeting the Lower Goru, Sara-1 was off structure at this level. However, a hitherto unknown sand was discovered at the base of the Ghazij Shale. This sand had excellent reservoir characteristics, with porosities on the order of 27% and permeabilities >2 Darcy (Tullow internal report, 2003) which is consistent in all three wells drilled in Pakistan. The interval 981-987 mkb flowed at a maximum rate of 17.75 MMscfd through a 96/64" choke. Appraisal wells Sara-2 and Sara-3 were unsuccessful, the objective reservoir being water-bearing. Cumulative production from the field amounted to 26.75 Bcf (Tullow internal report, 2004). As the sand is only 6 metres thick it is not resolvable on seismic. However, the sand directly overlies the SML, which is a very prominent seismic event. Pressure data from within the gas column at the Sara-1 and within the water leg at Sara-2 imply a gas-water contact at 904 m. The depth map shows that Sara-3 is shallower than either of the other two wells and was drilled on the upthrown side of a down-to-the-west fault.

A total 94 RFTs were run between 1904 m and 3094 m to evaluate the well. Two fluid samples from 3089.5 m to 3079 m were recovered. On the basis of wireline logs and RFT results, six DSTs were carried out in the Sara-1. Four DSTs in Cretaceous sandstone were unsuccessful due to lack of closure, however two DSTs in BGS and Sui Upper Limestone of Eocene age were successful. The Sara-1 well successfully tested gas from the BGS interval, 982 to 988 m BRT, and the SUL interval, 900 to 907 m BRT . The well was subsequently completed over the BGS interval as a future production well and re-tested. The Table 1 summarizes the test results and calculated reservoir properties.

Minimal quantities of condensate and condensed water were produced during testing, consistent with the leanness of the separator gas and the relatively low reservoir pressures and temperatures. The gas composition and properties of samples recovered from the BGS reservoirs are shown in Table 2.

Basal Ghazij Sand Depositional Model

The BGS has not been previously documented as a reservoir in Pakistan. It is however, present in a few wells across the international border where it achieves a thickness of up to 14 meters (Figure 4). Nevertheless, BGS is 6 meters thick and unconsolidated in the Sara wells. The sandstone is too thin to be resolved with seismic. High amplitude and brightening attribute are visible on only one 2D seismic line. Well control is also too spare to understand geometry of the sand in the region. Also, access to information pertaining to BGS across the border was quite limited. 3D seismic acquired in 2003 over the Sara Gas Field could not improve understanding.

The sand is fine- to very-coarse-grained, mainly loose, friable and glauconitic with good porosity in most of the wells (Tullow internal report on Sedimentological Study of Tertiary and Cretaceous Reservoirs in Sara area, 2004). The operator tried to core the sand but due to the thin and friable nature of the sand and fast drilling it was not possible to recover a core in any of the three wells drilled in the area. With the given limited control it is hard to properly understand and ultimately conclude its depositional model. Therefore, more than one depositional model could be envisaged and validity of each model requires additional data.

Reservoir quality and its distribution can potentially be predicted within the sequence stratigraphic framework. The reservoir quality appears to be directly linked to facies type and depositional environment. Sequence stratigraphic analysis of the Sui Main Limestone and its relationship with the Basal Ghazij Sand could thus help in understanding the depositional environment and distribution of the BGS. The BGS deposition took place on a widespread carbonate shelf developed from a lagoon in the east, through shoals and into open marine facies in the west. The Sui Main Limestone and BGS in Sara area can be divided into 5 System Tracts (Tullow internal report on Sedimentological Study of Tertiary and Cretaceous Reservoirs in Sara area, 2004). The basal part of SML is interpreted as a transgressive event (E10 TST) which is marked by rapid transition to carbonate-dominated rocks. The TST is controlled by facies containing abundant nummulitic foraminifera, indicating a shallow marine shoal-type environment in the Suri area, while the Sara area reflects a more restricted lagoonal environment during the late TST.

Sara West-1 and Khan-1 are characterized by more open marine facies. E-10 TST was followed by a Maximum Flooding Surface (MFS) and subsequently deposition of carbonates in HST (E-10 HST). The MFS is identified based on abundance of limestone containing planktonic foraminifera. Directly above the MFS, the limestones are dominated by restricted fauna, including algae and ostracods deposited in a probable lagoonal environment. The progradation of late highstand sediments is indicated by nummulitic facies resting on open marine facies. E- 10 HST was followed by a local regression and deposition of mixed carbonate and siliciclastics in the Lowstand System Tract (E-20 LST). The shoreline appears to have established itself in the region of the Sara wells (Figure 5). The basal surface of the E-20 sequence is a Sequence Boundary which appears to down-cut slightly into the underlying E-10 HST in the Sara area, resulting in a thicker LST deposition around the Sara well. The BGS was deposited during down-cutting in E-10 LST. The LST varies across Sara and Suri areas, being characterized by glauconitic, sideritic and bioclastic sandstones in the Sara wells. The BGS changes its character to sandy limestone, limestone and shale towards the north and west. All facies still contain an appreciable amount of siliciclastic material. The limestone facies equivalent to BGS identified in wells like Sara West and Khairgarh indicate a potentially restricted environment with the presence of ostracod and algal facies (Tullow internal report on Sedimentological Study of Tertiary and Cretaceous Reservoirs in Sara area, 2004). After deposition of lowstand facies, a major transgression took place resulting in deposition of carbonate dominated system in TST in open marine conditions (Tullow internal report on Suri Well Biostratigraphy, 1998). The LST BGS facies is overlain by the E-20 TST event which seems to be a regional event in the area and provide top seal to BGS. The overall wireline signature in E-20 TST is very consistent between each well with moderate to high gamma values and intermediate sonic values. The facies appear consistent with shelly carbonates and generally open marine conditions as evidenced by common occurrence of planktonic foraminifera.

The reservoir quality within the mixed carbonate clastic system varies across the area from well to well (Figure 5). BGS was probably deposited along a narrow shoreline developed in LST. All the wells drilled along shoreline appear to have consistent reservoir quality. The quality of the sand is excellent, although its thickness is minimal. The lateral equivalent facies are sandy-shaly carbonate either with no reservoir quality as in Suri wells and Khairgarh wells, or poor to moderate quality as in Khan-1. Overall low reservoir quality wells appear to be in a moderately restricted facies, possibly indicating a lagoonal environment.

Another possible model could include transgressive onlap which envisages a sheet-like, southwest thickening sandstone body onlapping SML (Tullows internal report on Post Well Evaluation of Sara Wells, 1995) (Figure 5). Based on isopaching down from an intra-Ghazij pick, this model requires a thin equivalent of the BGS be present in Tanot, but may not have been recognized if the sampling rate was greater than 3 m (in Sara, it was every 5 m).

The other explanation for possible deposition of this discrete sand could be a variable sand distribution produced by changes in facies which are probably influenced by fault controlled relief at the time of deposition (Tullows internal report on Post Well Evaluation of Sara Wells, 1995). If this model is correct, it opens the possibility that the distribution of hydrocarbons within the basal Ghazij could be stratigraphically as well as structurally controlled.

Reservoir Distribution

Appraisal wells Sara-2 and Sara-3, and subsequently exploration wells Suri-1, Khan-1 and Khairgarh-1 (Figure 1), confirmed extent of the BGS. Sara-2 was drilled 2.7 km west of Sara-1. Quality and thickness of the sand in Sara-2 was almost the same as in Sara-1. However, the sand was water bearing as it was structurally below the GWC. Sara-3 was drilled at a distance of 3.7 km southeast of Sara- 1 to delineate the limit of hydrocarbon bearing sand. Reservoir quality sand was encountered in Sara-3, however it was also water bearing. The BGS was absent in exploration well Suri-1 at a distance of 5.6 km further west of Sara-2, and also absent in Khan-1 located 4.6 km southwest of Sara-2. Similarly, on the Indian side BGS is reportedly present and hydrocarbon bearing in a few wells in the Dandewala Gas Field. However, it is absent in the Tanot Gas Field and other wells (Figure 1). Interestingly, despite increase in thickness from 6 m in Sara-1 to 15 m in Dandewala, the quality of the reservoir gradually deteriorates towards the east in India as vindicated by test results of 2-4 MMscfd of gas at Dandewala-1 compared to 17.7 MMscfd at Sara-1.

BGS is thin and could not be resolved on the seismic. High amplitude and brightening attributes were observed on only one 2D seismic line. Well control is too sparse to resolve thin sand. Also, the information available across the border pertaining to BGS is quite limited. On the basis of available well control and sequence analysis, some efforts were made to map the fairway and limits of BGS reservoir. However, the trend and distribution of the sand is subject to change with the help of additional data. The BGS shoreline seems to be oriented in nearly a northwest-southeast direction (Figure 5). This trend line is primarily based on well data. Additional wells to the north and south of Sara could help further understand geometry of the sand.

Conclusions and Recommendations

● BGS was probably deposited during lowstand as a result of regression over a carbonate platform.

● The distribution and limit of BGS is not constrained with sufficient well and seismic. 3D seismic acquired in the Sara area could not help to resolve distribution of sand due to possibly tuning effect. Probably extensive 3D coverage over a large area including from the Indian side might help to define limits of the sand.

● In view of the thin nature of the sand, it may not be resolved on seismic. Drilling additional exploration wells in the area, mainly to the north and south of Sara-1, could help delineate limits of the sand.

● While BGS is a discrete sand, it could be present elsewhere along the paleo-shoreline outside the Sara area at the semi-regional scale. BGS could be one of the future exploration targets in the proximity of the Sara area, particularly in the concessions to the north and south of Sara-1.

● Viability of a stratigraphic play associated with BGS needs to be explored in the area. A stratigraphic play could turn out to be a major success in the area.

● It is recommended to core BGS (if possible) in future exploration wells for detailed studies. Tullow attempted to cut a core in BGS but was unsuccessful as the sand was friable, thin and drilled very fast.

● Mutual cooperation and sharing of information across the border between Indian and Pakistan could help effectively explore BGS and other similar plays restricted in border regions for betterment of the people on both sides.

● The BGS name needs to be formally approved by the stratigraphy committee of Pakistan.

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Test Interval (mBRT)	982-988
Permeability, (md)	1210
Non-Darcy Skin Factor (1/MMscf/d)	0.07
Darcy Skin Factor	-1.76
Max. Test Rate (MMscf/d)	42.4
Flowing Bottom Hole Pressure, (Psia)	1350
Shut in Bottom Hole Pressure, (Psia)	1416
Bottom Hole Temperature (F)	137.5

Table 1. Test results of Sara-1 well.

Component	BGS /SML
Hydrogen Sulphide	0.00
Carbon Dioxide	1.56
Nitrogen	19.98
Methane	79.27
Ethane	0.19
Propane Plus	<0.01
Gas Gravity	0.648
Gross Heating Value (BTU/scf)	**802**

Table 2. Gas composition of Sara-1 well.

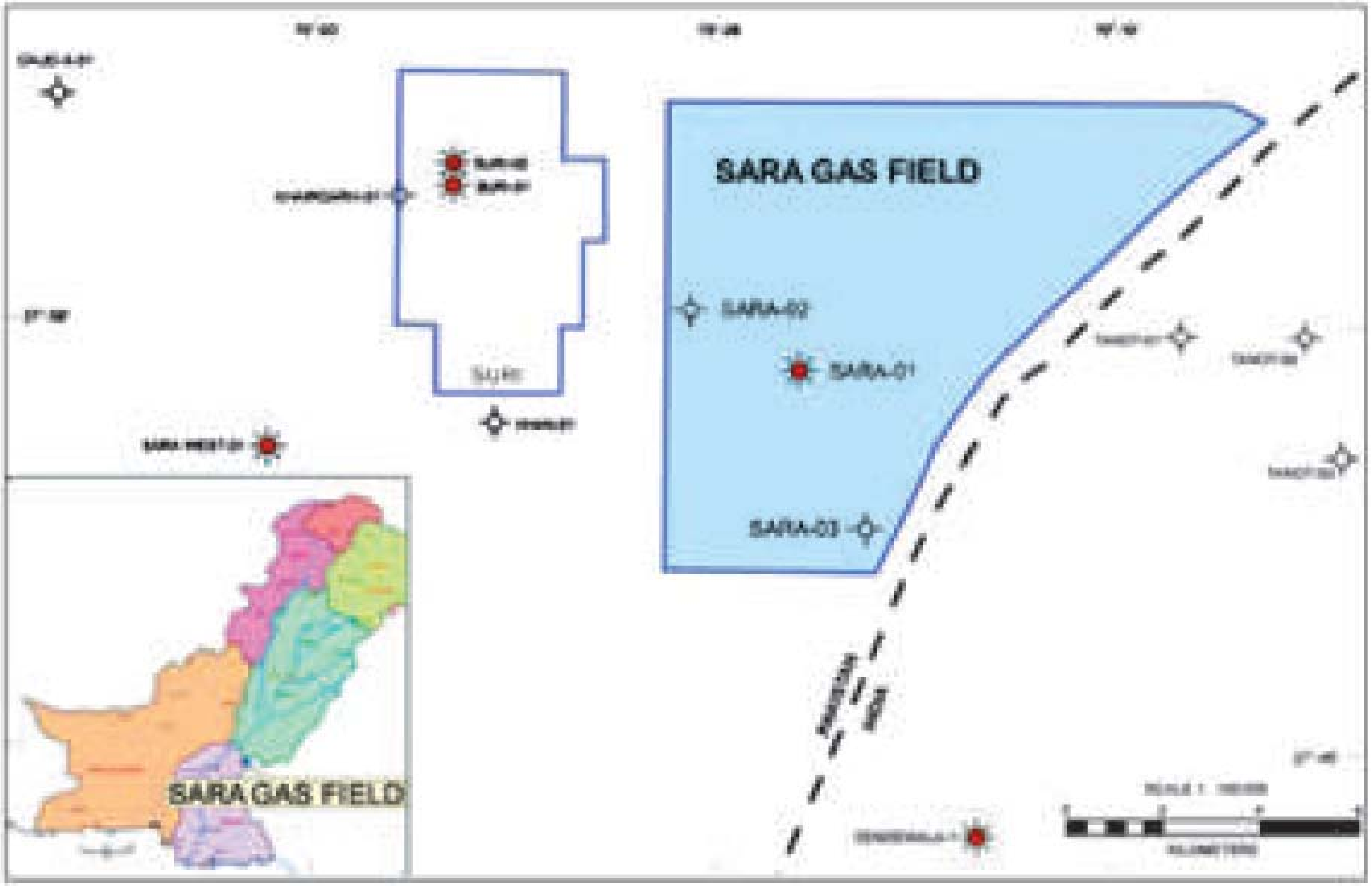

Figure 1. Location map of Sara Gas Field.

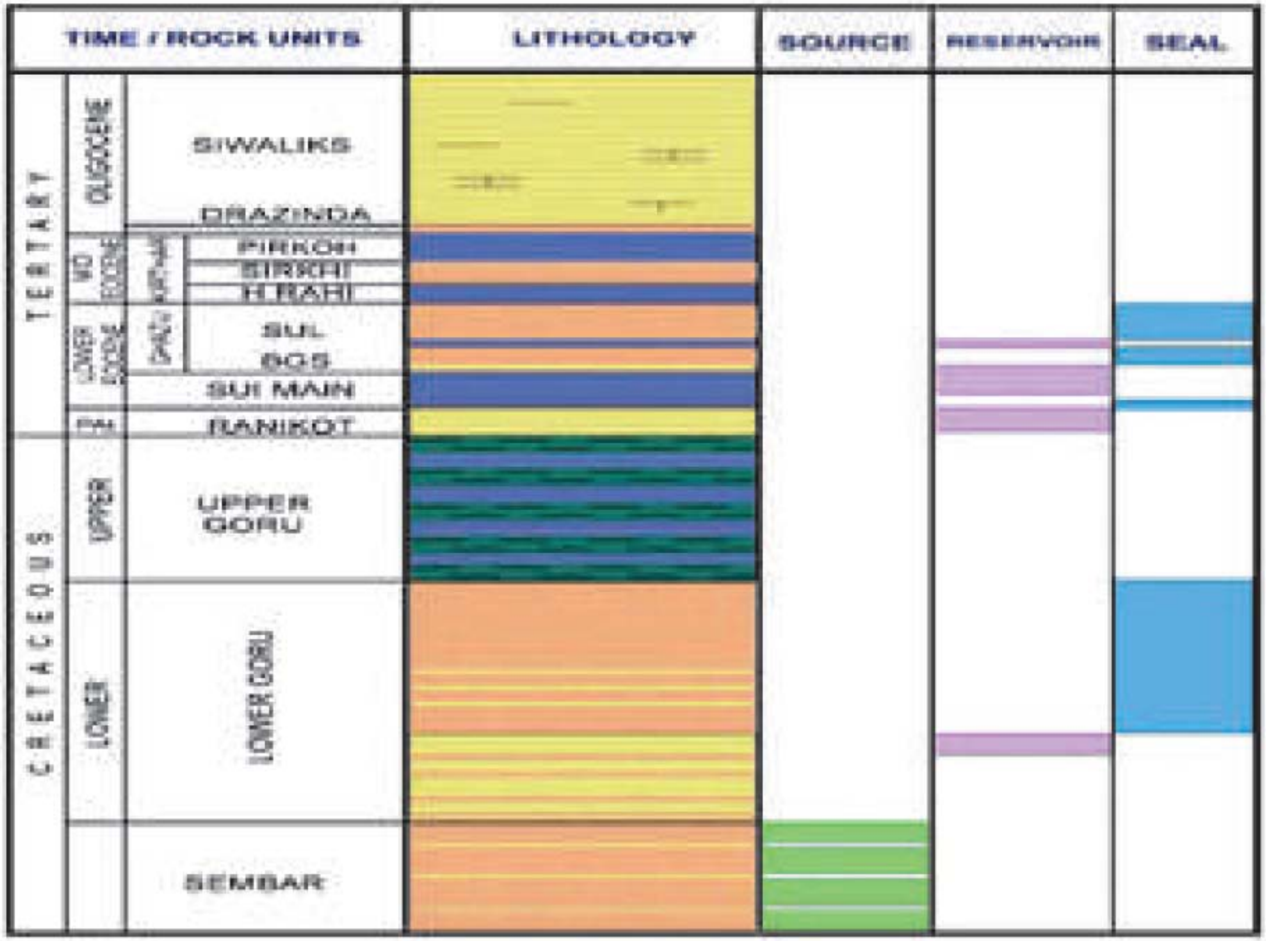

Figure 2. Generalized petroleum system in Sara/Suri area.

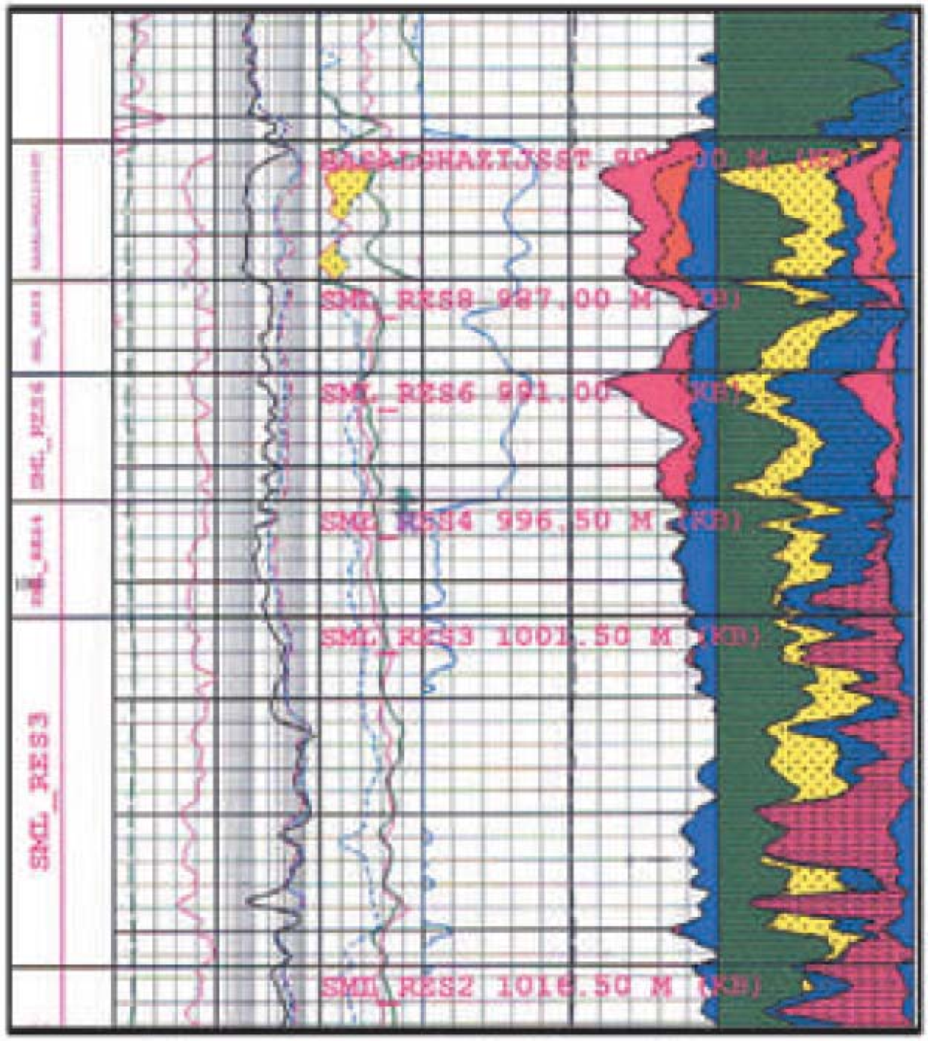

Figure 3. Petrophysical log of Sara-1.

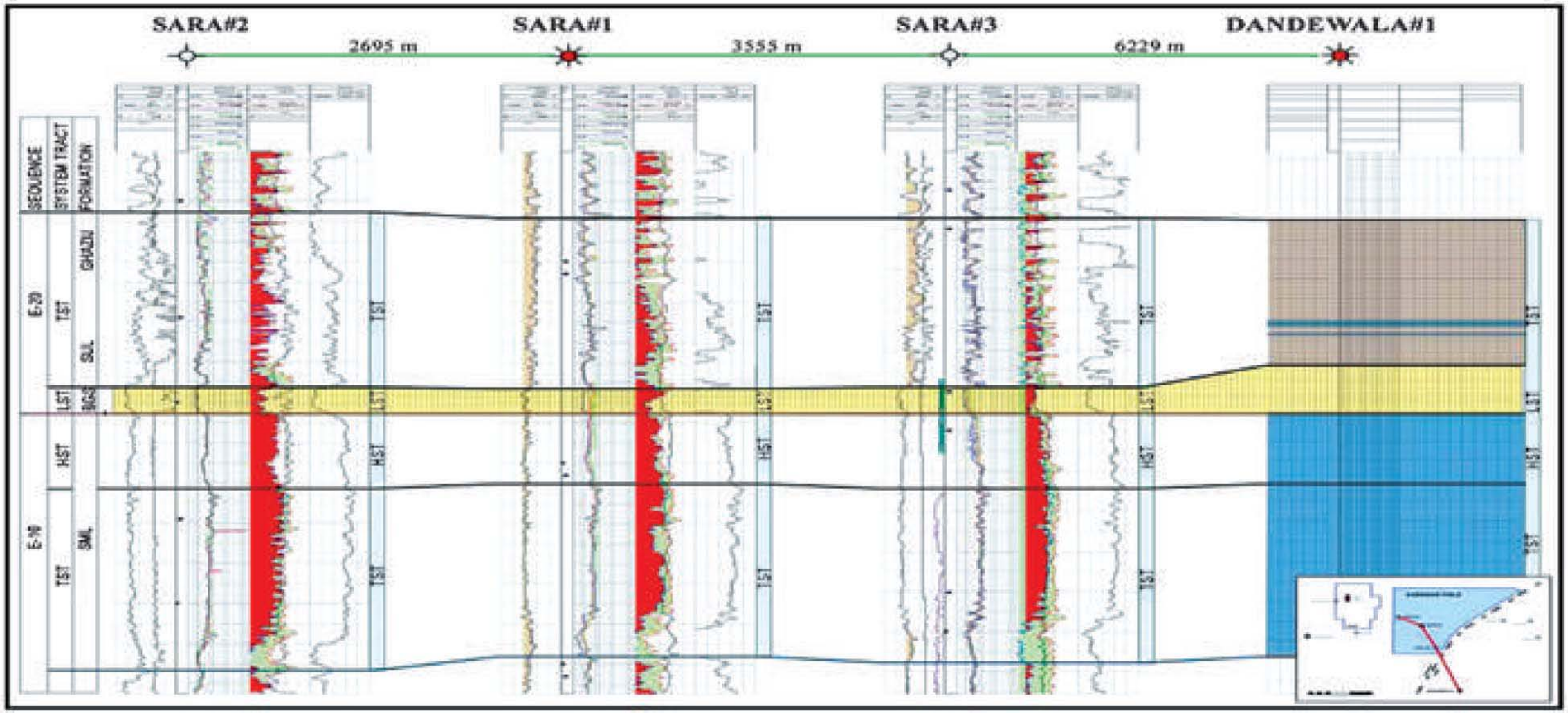

Figure 4. Sequence analysis of regional wells; BGS shown in yellow.

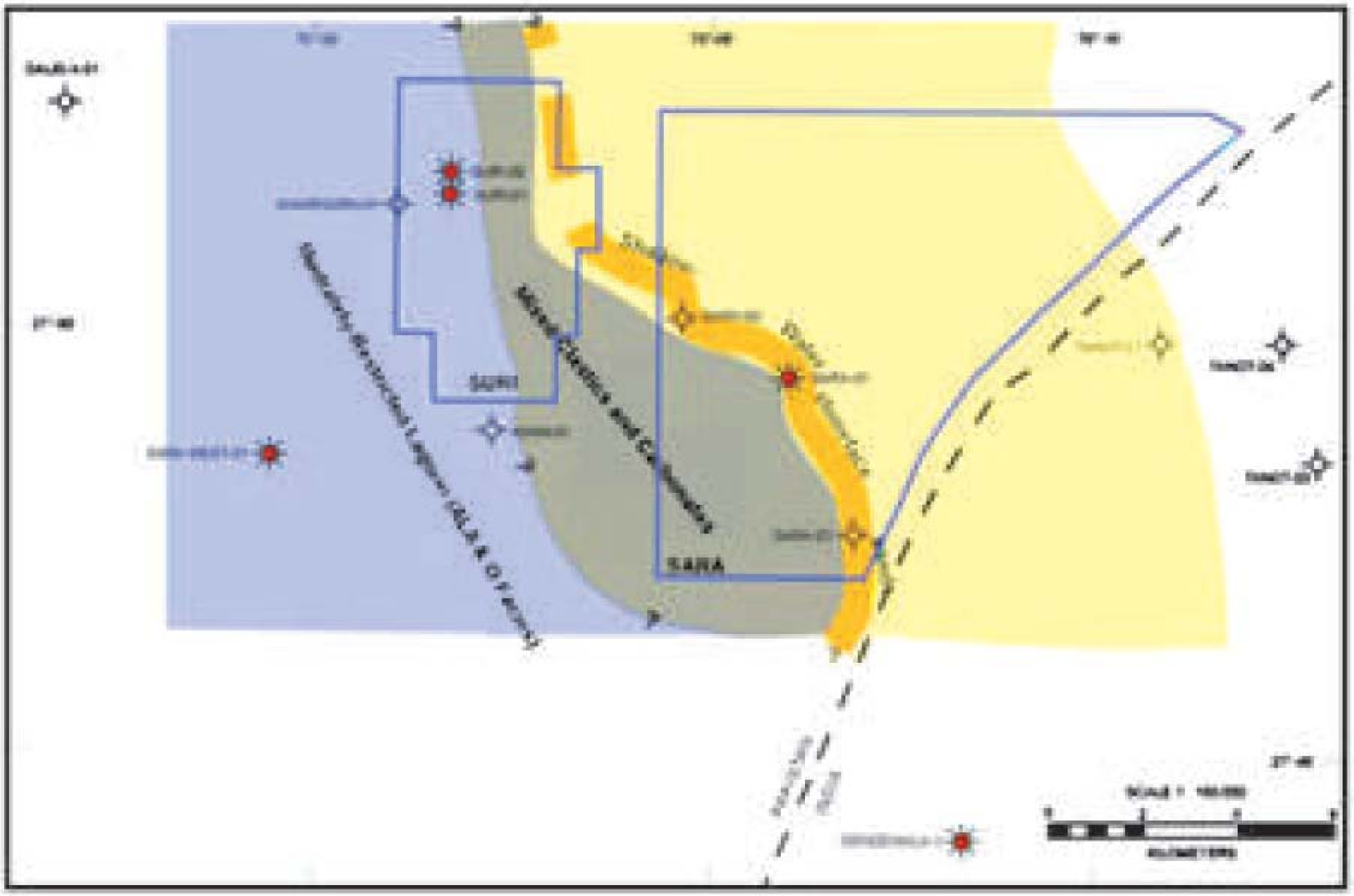

Figure 5. BGS reservoir fairway map.

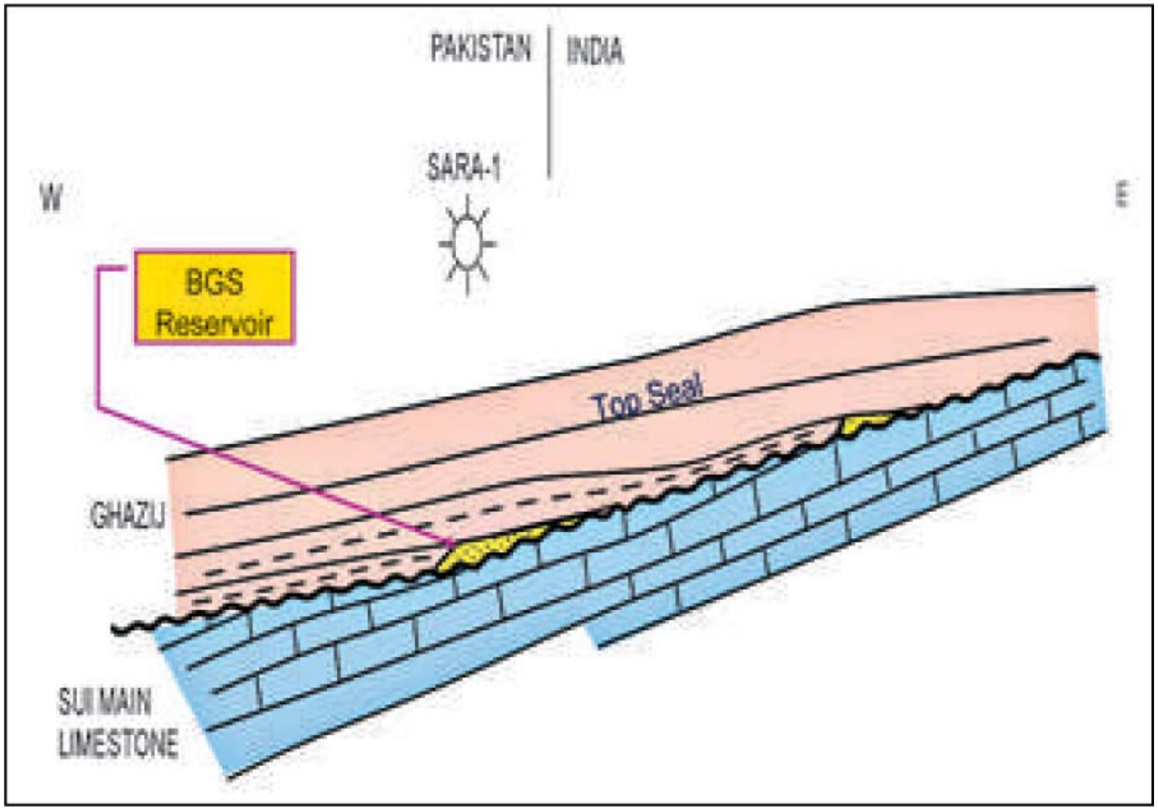

Figure 6. An alternate depositional model of BGS reservoir.