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Diagenesis of Basal Sands of The Cretaceous Lower Goru Formation of The Badin Area, Sindh, Pakistan.

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ABSTRACT

The basal sands of Lower Goru Formation are reservoirs for over twenty (20) fields of the Badin Platform which is the eastern part of Sindh Platform of Indian Shield. They are divided into the Upper and the Lower Basal Sands separated by Talhar Shale.

Thirty seven core samples were selected from seven wells reaching 5000ft to study the reservoir characteristics of the Lower Basal Sands in the Badin Area. Thirteen samples were poorly sorted, fine-grained sandstones with grain size less than 0.5mm. The other fourteen samples were well sorted, medium grained sands of 0.5 mm to 1 mm grain size. The remaining ten showed little pore spaces 1-5% porosity between the mosaics of the quartz grains. Destruction of the original porosity was mainly due to intense phase of quartz overgrowth during the diagenetic stage. The precipitation of the authigenic clay from dissolution of feldspar minerals have also acted towards reduction in porosity.

Appreciable secondary porosity 5-10% was observed in only four samples. Partial dissolution of unstable grains of feldspar resulted in intragranular porosity. Local complete dissolution resulted in moldic porosity. The two processes produced isolated pore spaces which did not affect imparting permeability to the rock. Vuggy porosity was formed by the leaching of framework grains and some matrix material. Where this type of porosity is present, the sandstones form tight reservoirs for gas. Well completion and stimulation may require the hydraulic fracturing of these tight sandstones to produce economic flow rates.

The entire basal sands were deposited in marginal and shallow marine environment. The presence of coal, carbonaceous mud and siderite/glauconite in the sands reflects the intimate marine/non-marine intercalation probably the result of tidal activity.

Lower Goru is a tight sand reservoir. It has produced and will continue to produce with proper fracturing job.

INTRODUCTION

The Basal Sands of Lower Goru (Cretaceous) are the main hydrocarbon producing reservoirs in and around the Badin Block. The Badin Platform is an eastern part of Sindh Platform of Indian Shield (Forshori, M.Z., 1972). These sandstones were formed as a result of erosion from Indian Shield during the Early Cretaceous rifting episode. The Basal Sands are characterized by marginal marine and in parts, shallow marine deposits. UTPI drilled the oil well of Khaskheli in mid-1981, where oil was discovered in Lower Goru Sands of Cretaceous age.

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Goru Formation

The Goru Formation overlies Sembar Formation of Neocomain to Bermain age (Iqbal, M., 1990). During mid-Aptian the Goru Formation deposition started in the Badin Platform. The generalized stratigraphy of the Badin area (modified after Alam, S.M., M.Wasimuddin, and S.Ahmad, 2002) is shown in Figure1.

Based on the wells drilled in the Sindh Monocline the Goru Formation is divided into two units. These units are named as Upper Goru and Lower Goru formations.

Lower Goru Formation

The Lower Goru Formation overlies the Sembar Formation and is the main reservoir rock in the Badin Block (Kadri, I.B., 1995). It is a distinct lithological unit, which cannot be met in outcrops. In the eastern part of the Sindh Monocline the Lower Goru Formation is predominantly fine to coarse grained sandstone with shale/siltstone intercalations interbeds. Sands of the Lower Goru Formation possess excellent reservoir characteristics. Porosities range from 5% to 30% and permeability in many places exceed 1 Darcy (Quadri,V., and Shoaib S.M., 1986). Generally, decrease in reservoir quality occurs in Lower Goru Formation from east to west (Hussain, M., S.L.Getz, and R.Oliver, 1991). The depth to the top of Lower Goru Formation varies in different areas. It is at 1000 meters in Khaskheli but is encountered at 2400 meters (7874 ft) in Thatta region. The maximum thickness of Lower Goru Formation is 1563m (5127ft) found in Khaskheli Oil Field (Hussain, M., S.L.Getz, and R.Oliver, 1991). Khaskheli field is marked as depocenter, from where the thickness decreases in all directions. On the eastern side of Sindh Monocline in the Nabisar well, the thickness of Lower Goru Formation is only 386 m (1266ft). This is due to westward dip of Sindh Monocline and post Lower Goru erosion. This variation in thicknesses represents erosion; which is evident from the presence of an unconformity between Cretaceous and Paleocene strata in Marvi-1, Nabisar X-1 and Digh-IX Wells. The top of Lower Goru is an unconformable surface.

The Basal Sand Unit of Lower Goru overlying the Sembar Shale is predominantly sandstone. The general range of porosity in the Lower Goru Sandstone in the Badin Block is 5-22%. In some cases in the Badin Block the porosity goes up to 30 % (Quadri,V., and Shoaib S.M., 1986).

Diagenesis has resulted in the significant loss of original porosity in the Basal Sands. A detailed petrographic study has revealed that any appreciable porosity present in the Basal Sands is secondary porosity. This secondary porosity is a result of dissolution of either detrital grains or authigenic cements.

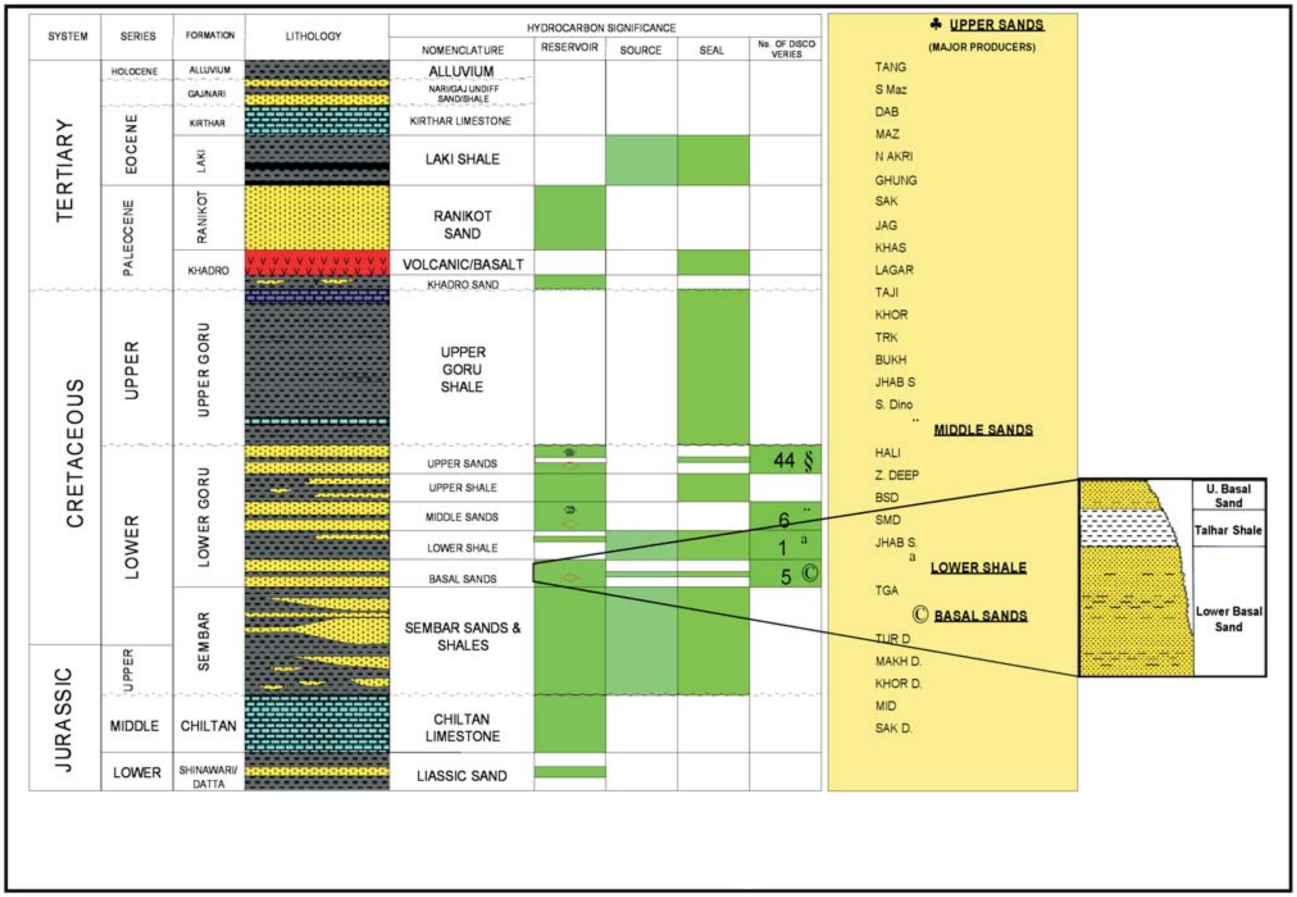


Figure 1- Generalized stratigraphy of Badin area (modified after Alam, et al 2002).

MINERALOGY and PETROGRAPHY

Thirty seven samples from cores of seven wells were selected for petrographic studies of Basal Sandstone in Badin area (Table-1).

The main mineralogical component of Basal Sandstone is quartz and the rock type classified as quartz arenite. Mica flakes have been seen in most of the thin sections; glauconite, siderite and iron oxide patches occur as accessory minerals. The sandstone generally consists of fine grains with few medium sized grains. This sandstone is generally poorly to moderately sorted, however, quite a few samples are well sorted.

Generally insignificant porosity has been observed except for four to five samples which have appreciable porosity mainly vuggy which are secondary porosity. Cements that bind the grains are argillaceous, ferruginous but more often quartz over-growth.

DIAGENETIC ALTERATIONS

Diagenetic processes in sandstone reservoir rocks may either introduce material into the pore spaces, or create pore spaces by removing material from the rock. The former process is by far the more important and widespread.

Inorganic diagenetic processes involve the mass transfer of material into or out of the pores of the sedimentary rocks by connective fluid flow (Folk, R.L., 1968). Fluid dynamics in the subsurface in turn involve the chemistries and stabilities of the fluids and the patterns and velocities of their flows. The transfer of material through fluid flow is from areas of higher solubility to the areas of lower solubility. Precipitations of the material takes place in the lower solubility areas.

CEMENTATION OF BASAL SANDS

Silica Cements

In sandstone the most common type of silica cement is quartz overgrowth (Hayes, J.B., 1979). The Basal Sands have experienced the intense phase of quartz overgrowths [Plate 1: C-3 and D-3]. These authigenic overgrowths develop in a variety of styles. During early cementation euhedral overgrowths form with well-defined crystal faces.

As cementation continues, these pore spaces are completely filled with quartz. It is not always apparent whether the resultant fabric has been produced only by continuous development of the initial quartz overgrowths or alternately solution may have taken place where grains are in contact, and the dissolved silica reprecipitated in the adjacent pore space. This process is termed pressure solution (Hayes, J.B., 1979).

Table 1 - Petrographic data of Basal Sandstone in Badin area (continued).

Thin Sections		Grain Size (mm)	Sorting	Porosity	Rock Type	Cement	Additional features/ characters
Well T	C-2 7751'	0.2–0.45	Poor	Insignificant	Subfeldspathic Arenite	Argillaceous & Ferruginous	Mica flakes, Vertical burrow
	C-3 7756'	0.2-0.45	Poor	Insignificant	Subfeldspathic Arenite	Argillaceous & Ferruginous	Mica flakes
	C-1 7749'	0.2-0.45	Poor	Insignificant	Subfeldspathic Arenite	Argillaceous & Ferruginous	Mica flakes
Well K	E-3 8823'	0.1-0.2	Moderate	Insignificant	Quartz Arenite	Argillaceous, Iron oxide patches	Glauconite
	E-7 8834'	0.05-1	Poor	Insignificant	Quartz Arenite	Argillaceous, Iron oxide patches	
	E-8 8837'	0.02-0.1	Poor	Insignificant	Silty shale with sand fill burrows	Argillaceous	Glauconite
	E-9 8843'	0.02-0.04	Poor	Insignificant	Silty shale with sand fill burrows	Argillaceous & Ferruginous	Glauconite
	E-1 8820'	0.08-0.15	Poor	Insignificant	Quartz Arenite	Argillaceous & Ferruginous	Glauconite
	E-4 8825'	0.05-0.6	Poor	Interconnec-ted Vuggy	Quartz Arenite	Argillaceous & Ferruginous	Glauconite
Well I	G-2 10836'	0.25-0.75	Well	Insignificant	Clean sand stone	Quartz overgrowth	Dead oil
	G-1 10821'	0.25-0.8	Moderately well	Insignificant	Quartz Arenite	Quartz overgrowth	Bitumen
Well U	H-5 9782'	0.05-0.2	Poor	Insignificant	Quartz Arenite	Quartz overgrowth	Mica flakes
	H-7 9784'	0.04	Poor	Insignificant	Silty shale	Clay & Iron oxide	
	H-8 9784'	0.04-0.16	Poor	Insignificant	Quartz Arenite	Quartz overgrowth	Mica flakes
	H-2 9777'	0.1-0.45	Moderately well	Insignificant	Quartz Arenite	Quartz overgrowth, Iron oxide patches	Mosaic texture
	H-9 9788'	0.2-0.35	Moderately well	Insignificant	Quartz Arenite	Quartz overgrowth, Iron oxide patches	
	H-9 9788'	0.2-1	Moderately well	Insignificant	Quartz Arenite	Quartz overgrowth, Iron oxide patches	
Well E	N-1 9659'	0.07-0.03	Moderately well	Insignificant	Quartz Arenite	Quartz overgrowth, Iron oxide patches	
	N-4 9679'	0.05-0.25	Moderately well	Insignificant	Quartz Arenite	Quartz overgrowth, Iron oxide patches	Mica flakes
	N-7 9687'(A	0.03	Moderately well	Insignificant	Calcareous siltstone	Clay, Calcite, siderite	Mica flakes
	N-3 9667'	0.4-0.65	Well	Moderately good, vuggy	Quartz Arenite	Quartz overgrowth, Iron oxide patches	
	N-6 9686'	0.25-0.6	Well	Insignificant	Quartz Arenite	Quartz overgrowth	Mosaic texture
	N-3 10654'	0.25-0.85	Moderately well	Insignificant	Quartz Arenite	Quartz overgrowth, Iron oxide patches	
	N-5 10658'	0.07-0.2	Poor	Insignificant	Sideritic sandstone	Siderite matrix	Mica flakes
	N-2 10651'	0.05-0.2	Poor	Insignificant	Quartz Arenite	Quartz overgrowth, Iron oxide patches	Mosaic texture
	N-7 10666'	0.04-0.17	Moderately	Insignificant	Quartz Arenite	Quartz overgrowth, Argillaceous & Iron oxide patches	Glauconite, Mosaic texture
Well B	P-5 8960'	0.2-0.45	Moderately	Insignificant	Quartz Arenite	Quartz overgrowth, Iron oxide patches	mosaic texture
	P-7 8970'	0.08-0.25	Moderately	Insignificant	Lintharenite	Quartz overgrowth, Argillaceous	Glauconite, Mosaic texture
	P-1 8946'	0.25-0.7	Well	Insignificant	Quartz Arenite	Quartz overgrowth, Argillaceous	Mica flakes
	P-3 8949'	01	Well	Insignificant	Quartz Arenite	Quartz overgrowth, Iron oxide patches	
	P-8 8971'	0.15-0.6	Poor	Insignificant	Quartz Arenite	Quartz overgrowth, Argillaceous & Iron oxide patches	Mica flakes, Unconnected pores
	W-1 7090'	0.05-0.2	Poor	Insignificant	Dirty sandstone	Iron oxide	
Well O	W-2 7091'	0.04	Poor	Insignificant	Silty shale	Clay & Siderite	Mica Flakes
	W-4 7094'	0.06-0.25	Poor	Insignificant	Dirty sandstone	Iron oxide	
	W-10 7114'	0.25-0.6	Very well	Insignificant	Quartz Arenite	Quartz overgrowth	Mosaic texture
	W-7 7100'	0.25-0.65	Moderately well	Vuggy	Dirty sandstone	Argillaceous & Ferruginous	Interconnected Vuggy porosity
	W-9 7105'	0.25-0.65	Well	Vuggy	Quartz Arenite	Iron oxide	

This study shows how the nature of the grain contacts changed with increasing burial depth. At shallow depths tangential or point contacts are typical. These grades down into long contacts where grain margins lie side by side. At greater depths still, concavo-convex and sutured grain boundaries prevail, where there has been extensive pressure solution. These changes in the number and nature of grain contacts are accompanied by a gradual decrease in porosity.

As a result of extensive quartz overgrowth many thin sections have very low porosity [Plate 2: C-12 & F-13 and Plate 3: B-3, F-6]

Clay Cements

Precipitation of clay in the Basal Sands has been observed in some thin sections [Plate 4: D-9 & H-10 and Plate 5: G-10].

The precipitation of even small amounts of clay in sandstone can have a great effect on the permeability and other properties of rocks (Wilson and Pittman, 1977). Chemically precipitated clays are by far the most common and important cement. It is widely accepted that clay minerals plugging porosity in sandstones are likely to be authigenic (North, 1985).The clay minerals capacity to adsorb and retain water reduces the sandstone's (Folk, R.L., 1968). If colloids are formed and certain ions introduced, the water films are disrupted and flocculation occurs, affecting permeability still further. There are four types of clay to consider: kaolinite, illite, montmorillonite and chlorite. These various clay minerals affect the pore spaces in different ways and it creates worst effect on permeability of Basal Sandstone.

Carbonate Cements

The Basal Sands are least effected by carbonate cement. It is occasionally observed in one or two thin sections [Plate 6: G-8]. The presence of carbonate cement indicates that the sand has been bathed in alkaline pore fluids; this is because the carbonate cements will form in alkaline pore fluids, irrespective of Eh.

PORE SPACE DEVELOPMENT

A strong interdependence of porosity and cement type is observed. Diagenesis has resulted in significant loss of original porosity in the Basal Sands. This reduction in porosity occurred particularly in response to quartz overgrowths and secondarily by the precipitation of clay minerals.

Detailed petrographic study has revealed that much of the porosity present in the Basal Sands is secondary porosity. This secondary porosity resulted from dissolution of either detrital grains or authigenic cements [Plate 7 and Plate 8]. Most secondary porosity is formed through the action of acidic waters which are produced in the subsurface.

Porosity Types

The type of porosity which is the end product of burial diagenesis is important to consider in evaluating the reservoir potential of sandstone. The four most common types of porosity are: 1) intergranular, 2) intragranular, 3) moldic, and 4) vuggy. The Basal Sandstone characterized by intragranular, moldic, and vuggy porosities. Whereas intergranular porosity is very rarely observed in the Basal Sandstones.

Intragranular porosity

This type of porosity has been observed in Basal Sandstone but is not common [Plate 2]. It is the porosity which is present within the grains themselves. This porosity is secondary and has been formed through the partial dissolution of unstable grains, i.e. feldspar (Adams & Mackenzie, 1984). This type of porosity by itself generally forms poor reservoir because the pores are isolated and are not interconnected. Intragranular porosity may be volumetrically important in some immature sandstones, but generally constitutes only a small percentage of porosity in Basal Sandstones.

Moldic porosity

It is similar to intragranular porosity in that it forms through the dissolution of framework grains [Plate 9: B-7]. The difference is that with moldic porosity, the grain is completely dissolved, leaving only an outer ring or an oversize pore (Adams & Mackenzie, 1984). Moldic pores are isolated in the studied thin sections and may not form effective porosity. This type of porosity may be significant in some sandstone, especially arkoses and sublith arenites. In Basal Sands, the percentages of unstable grains are not sufficient to create significant porosity. In arkoses and litharenites, the percentage of unstable grains is so high that the acidic pore waters are unable to completely leach any grain. This leaves partially leached grains, creating intragranular porosity (Schmidt, 1979).

Vuggy

This type of porosity has been observed in Basal Sandstones [Plate 7, Plate 8 and Plate 10: C-10]. It is interconnected porosity and always leads to better permeability in sandstones. It is generally called permeable porosity.

PERMEABILITY OF RESERVOIR

Porosity and permeability are the main characteristics of a reservoir. Rock fragments and feldspar rich sands, as dictated by the provenance, rarely contain reservoir quality porosity and permeability in the subsurface. Rapid depositional rates reduce the winnowing effect of water, thus clay content may be high, resulting in the non-development of primary porosity.

Minor pressure solution between grains and the formation of quartz overgrowth also helped in tighter packing of Basal Sands [Plate 1: C-3 & D-3, Plate 2 and Plate 3: B-13]. Silica dissolved by pressure solution in areas of high thermal maturity migrated down the temperature gradient within the quartz arenitic Basal Sands and precipitated as quartz cement in areas of low thermal maturity.

Unstable or chemically immature minerals (pyroxene, amphibole, mica, feldspar) will alter to clay minerals. These clay minerals have invaded the pore spaces and reduce the porosity and permeability [Plate 4: C-3 & E-7 and Plate 5: G-10].

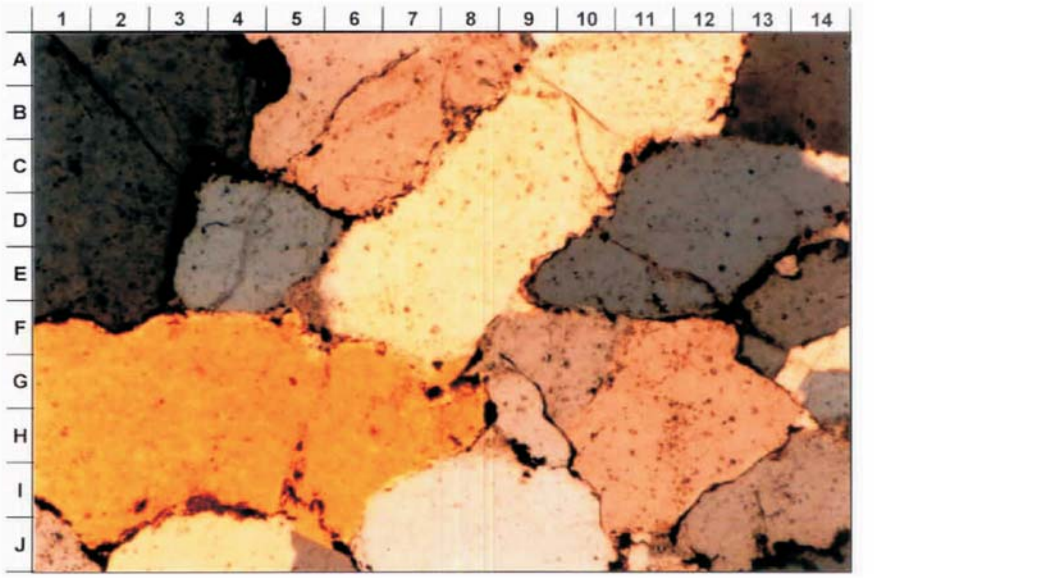


Plate 1 (Cross Nicols) Medium to coarse grain, well sorted, clean sandstone. Framework grains are subangular to subround. Detrital grain variety is exclusively quartz. These grains are bounded by intense quartz overgrowth.

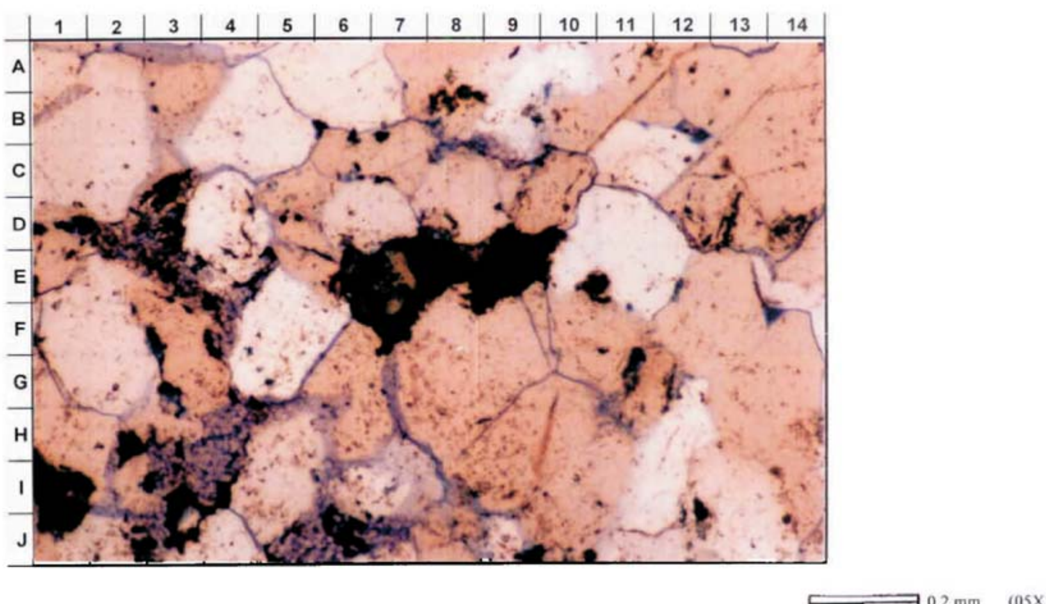
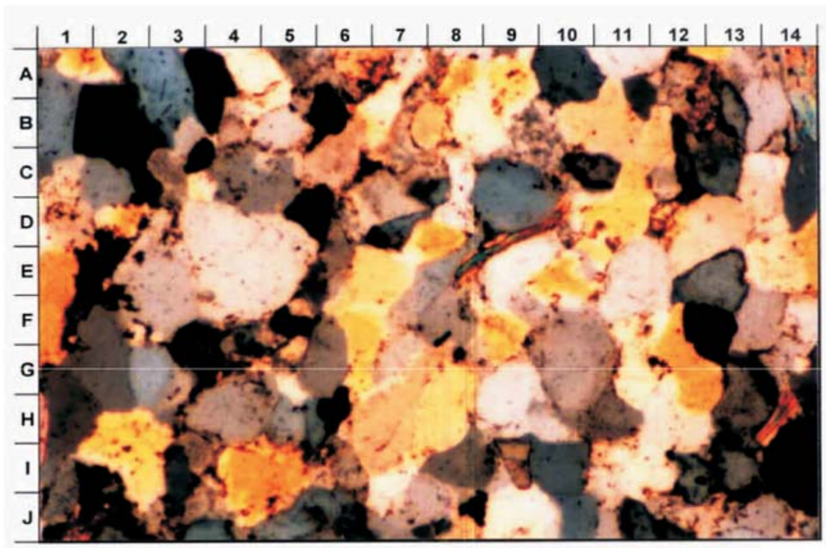


Plate 2 (Parallel Nicols) fine to medium grain, moderately well sorted, quartz arenite. Moderately to tightly packed. Cements include silica in the form of extensive quartz overgrowth and patches of iron oxide. Very few unconnected pore spaces.



0.2 mm (05X)

Plate 3 (Cross Nicols) Fine to medium grain, moderately well sorted quartz arenite, tightly packed. Cement is silica in the form of extensive quartz overgrowth and patches of iron oxide.

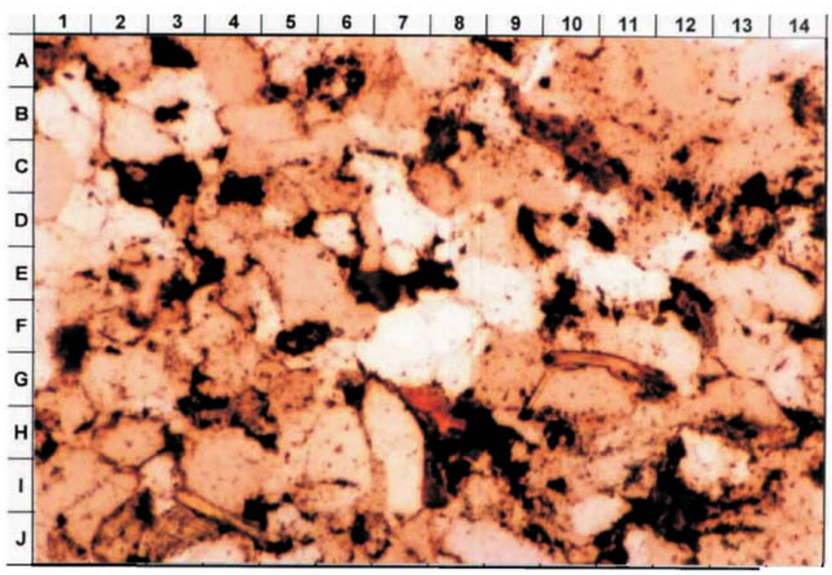


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Plate 4 (Parallel Nicols) Fine grain, poorly sorted quartz arenite. Detrital grains consist principally of quartz and are bounded by quartz overgrowth, argillaceous and ferruginous substance.

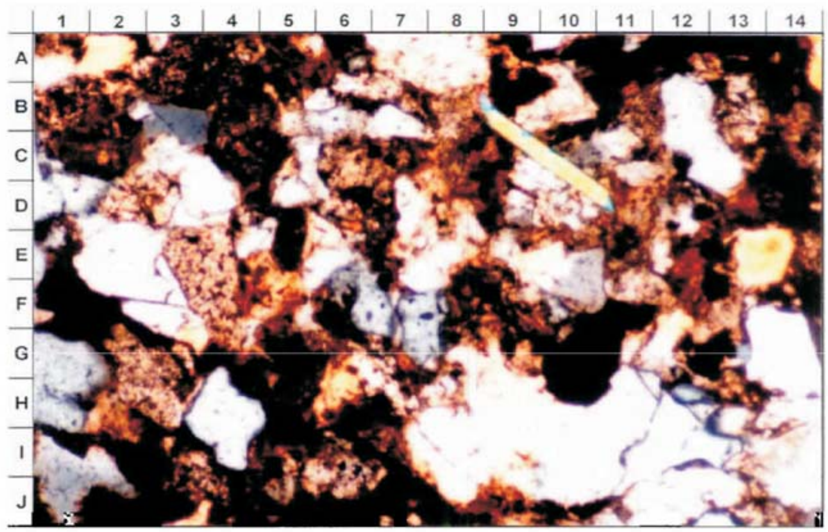

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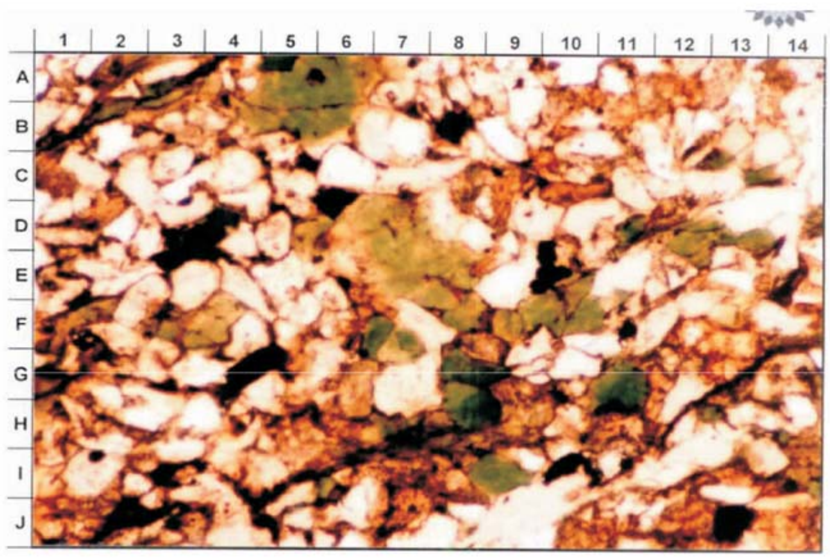
Plate 5 (Cross Nicols) Fine to medium grain subfeldspathic arenite, poorly sorted, detrital grains are quartz and few altered feldspar. Cements include argillaceous and ferruginous substance.



0.2 mm (05X)

Plate 6 (Parallel Nicols) Fine grain, moderately sorted quartz arenite. Detrital grains are mainly composed of quartz (white) with some green glauconite grains. Grains are bounded by argillaceous substance and patches of iron oxide cement.

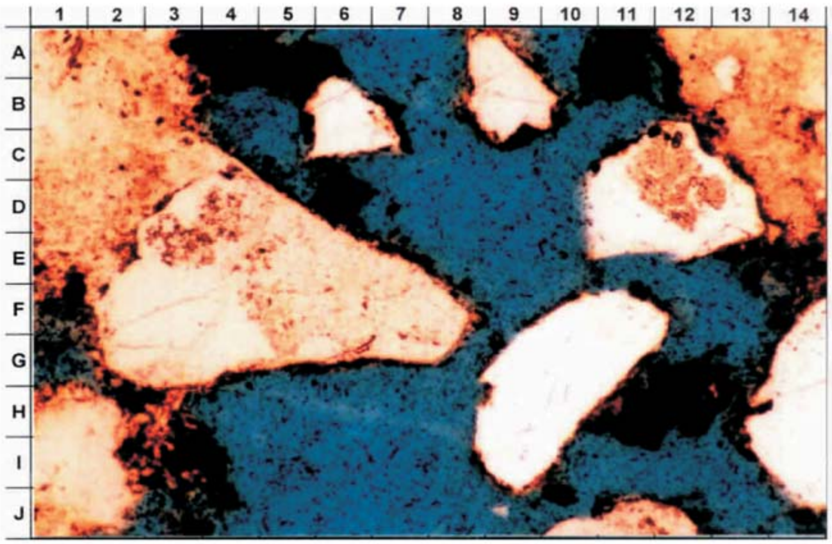


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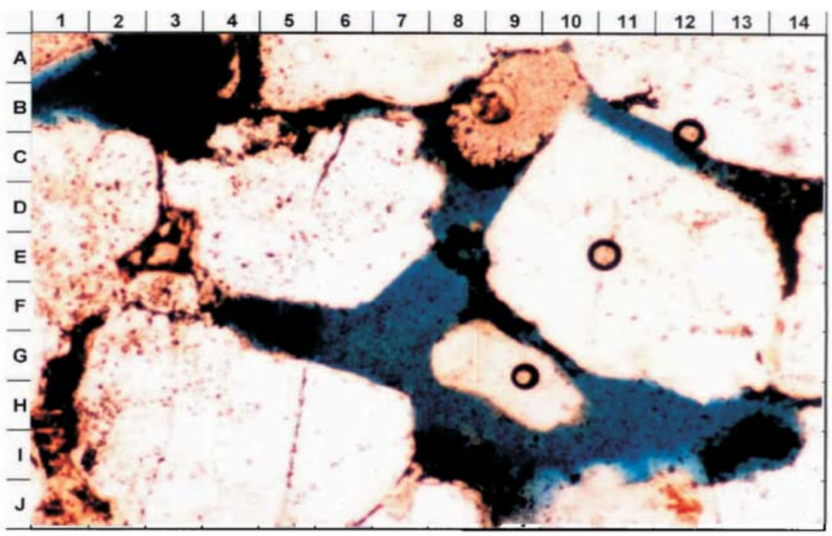
Plate 7 (Parallel Nicols) Medium to coarse grain, moderately well sorted, dirty sandstone. Quartz grains bounded by argillaceous and ferruginous substance. Interconnected vuggy porosity is developed and is marked by blue resin.



0.2 mm (05X)

Plate 8 (Parallel Nicols) Medium to coarse grain, well sorted, quartz arenite. Detrital grains are almost exclusively of quartz. Cement is iron oxide (siderite). Vuggy porosity has developed due to leaching of cement and is marked by blue resin.

CONCLUSION AND RECOMMENDATION

Basal Sandstones of Lower Goru Formation were deposited predominantly in marginal marine to shallow marine environments.

Silica cement in the form of quartz overgrowth is the most common cementing material. The main process of releasing silica for the cementation of Basal Sands is the pressure solution. Relatively fine grained quartz arenites tend to be silica exporters, whereas relatively coarse grained quartz arenites tend to be silica importers and thus they show more quartz cement.

Basal Sandstones contain dominantly intragranular, vuggy porosity, as it is evident from thin section study. These porosity types are originated by the dissolution of authigenic cement and unstable grains.

Basal Sands possess low permeability. That makes them a strong candidate for tight and near tight gas reservoirs. Tight reservoirs are rocks with insitu permeability of 0.1 md (or less) for gas. Rocks with permeability of 0.1 1.0 md are categorized as near tight. These Basal Sandstones are tight because of the scattered pore spaces throughout the reservoir.

Scanning Electron Microscopy (SEM) and X-ray diffraction analysis of studied thin sections is highly recommended in the geological evaluation of Basal Sands tight gas reservoir. This will help in determining the type of clay minerals associated with Basal Sands. Since, the occurrence of these minerals can be quite variable within a depositional system and can be facies dependent, a broad range of porosities, permeability and gas saturation values often exist in any reservoir. Identifying and mapping those units of greatest reservoir potential are key to a successive evaluation.

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