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Lithofacies and Reservoir Quality of Proterozoic Sediments of Chambal Valley, Vindhyan Basin: A Step Forward for Exploration in Frontier Areas

Balram Bhadu, Anumita Mondal and G. D. Gupta
K.D.M. Institute of Petroleum Exploration, ONGC, Dehradun
Presenting author Email: balrambhadu@rediffmail.com

Abstract

After exploratory success in Son Valley, focus has also shifted to Chambal Valley sector of the Vindhyan Basin. In the present study, three exploratory wells (CHT-R, SKT-S and PLT-Q) of Chambal Valley drilled upto basement have been discussed. Wells CHT-R and SKT-S, have penetrated only Lower Vindhyan sequence (around 1800m), whereas well PLT-Q has encountered both Upper Vindhyan (around 2500m) and Lower Vindhyan (around 800m) sediments.

The Lower Vindhyan sequence (Mesoproterozoic) in the wells CHT-R and SKT-S consists of thick sandstone and shale units overlying a complex basement. The calcareous units of Lower Vindhyan, *viz.* Bhagwanpura Limestone and Nimbahera Limestone in the type area around Chittaurgarh in Rajasthan have laterally developed as equivalent arenaceous facies in these wells. Sedimentological studies of the cutting samples and cores from these wells indicate that the sandstone units are texturally and mineralogically mature and are represented mainly by quartz arenite with subordinate quartz wacke and lithic arenite. Intense grain packing and higher degree of cementation has led to poor reservoir quality.

In the well PLT-Q, Lower Vindhyan Group is represented by Suket Shale which rests over the granitic basement. The Neoproterozoic Upper Vindhyan sequence comprises of Kaimur, Rewa and Bhander Groups which are dominantly arenaceous with calcareous units present in Bhander Group only. Petrographic analysis of the sandstone microfacies shows presence of dominantly quartz arenite with poor reservoir quality owing to tight grain packing and cementation by silica and calcite. XRD analysis of clay mineral fractions reveals persistent presence of illite and kaolinite along with minor chlorite and illite-smectite mixed layers. Based on lithofacies association of different stratigraphic units, a shallow marine set up in intertidal to subtidal depositional environment has been inferred. Poor organic richness of source sediments has restricted hydrocarbon generation potential.

Evaluation of hydrocarbon prospectivity in Chambal Valley requires more data to confidently explain the reservoir behaviour.

Introduction

The Vindhyan Basin, a noticeable physiographic feature of Peninsular India, is arcuate shaped largest sedimentary basin in terms of sedimentary volume and acreage. This intracratonic basin, east of Aravalli-Delhi Fold Belt, covers an area of about 1,62,000 sq. km. with sedimentary thickness of more than 5000m comprising undeformed and unmetamorphosed siliciclastics and carbonates. Large part of the basin is covered by Deccan Trap volcanics in the south-western part and by Recent alluvium of Gangetic Plain in the northern part (Chakrabarti et al., 2007).

The Great Boundary Fault (GBF) and the Narmada-Son Lineament delineate the north-western and south-eastern margins of the basin respectively. The Archaean Bundelkhand Granite Massif at the centre divides the basin into two parts - Son Valley in the east and Chambal Valley in the west (Zutshi and Panwar, 1997). Chambal Valley exhibits near orthogonal grain in relation to the Son Valley and evidences indicate that extensional tectonics prevailed during initial phase of sedimentation and compressive tectonics subsequently modified the fill as inversion structures (Sharma et al., 2013).

Mallet (1869) proposed Lower and Upper Vindhyan classification in which Semri Group constitutes Lower Vindhyan while Kaimur, Rewa and Bhander constitute Upper Vindhyans. Heron (1936) observed gradational contact between Suket Shale (Lower Vindhyan) and Kaimur Sandstone (Upper Vindhyan) around Chittaurgarh in Rajasthan.

Present study

ONGC has drilled several exploratory wells in the Vindhyan Basin both in Son Valley and Chambal Valley. Preliminary success in Son Valley part has also encouraged explorationists to look into shallow marine sedimentary sequences and huge sediment fill of Chambal Valley from where thermogenic gas shows are reported (Singh and Srivastava, 2013). In the present paper, authors attempt to present detailed sedimentological study carried out in three exploratory wells namely PLT-Q, CHT-R and SKT-S drilled by ONGC in Chambal Valley (Fig. 1). Generalised stratigraphy of Chambal Valley is summarised in figure 2.

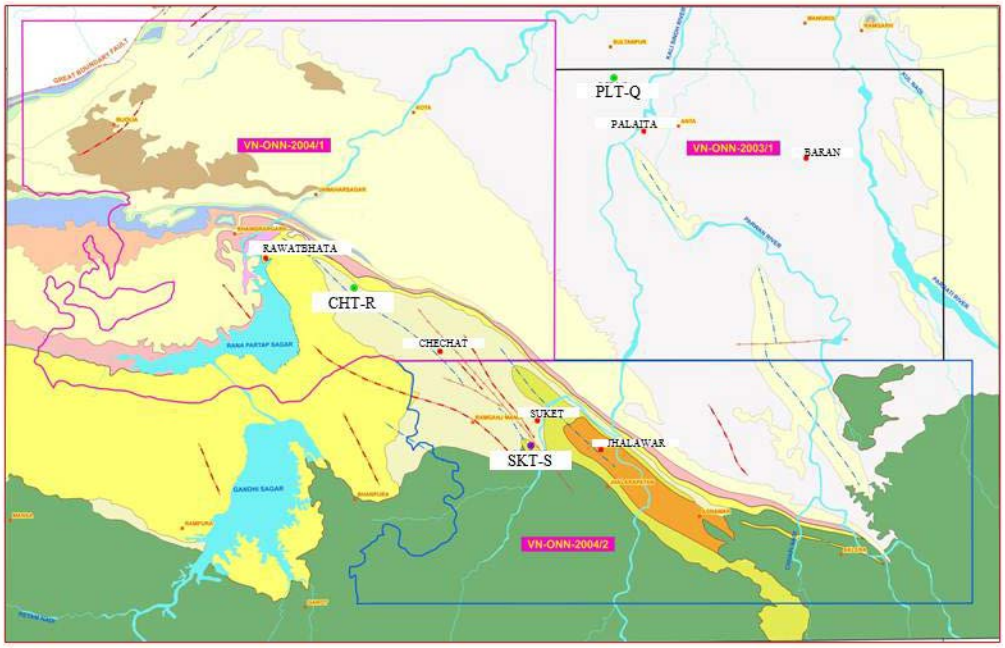

Fig. 1: Location map of studied wells PLT-Q, CHT-R and SKT-S, Chambal Valley, Vindhyan Basin

All the wells under study are drilled upto the basement. Drill cutting samples of the wells are first subjected to megascopic study to understand the lithology and lithofacies variations. Same have been calibrated with electrologs (Gamma Ray, Spontaneous Potential, Resistivity, Neutron Porosity and Density, Sonic logs). Thin section petrography carried out for the selected samples to understand reservoir facies, mineral association, textural and mineralogical maturity, fabric and structure. Similarly, clay mineral assemblages and bulk mineral identification study was carried out using X-ray diffractometer (XRD) at various intervals.

Lithostratigraphically, well PLT-Q (Drilled Depth: 3358m) encompasses mainly Upper Vindhyan sediments (upto 2530m) and 775m thick (2530 to 3305m) column of Lower Vindhyan sediments. Granitic basement encountered at 3305m has been drilled upto 3358m.

In the well CHT-R (Drilled Depth: 1885m), only Lower Vindhyan sequence is observed wherein metamorphic granulite facies at 1871m marks the top of basement. Similarly, in the well SKT-S (Drilled Depth: 1786m) in which granitic basement encountered at 1752m consists of Lower Vindhyan strata.

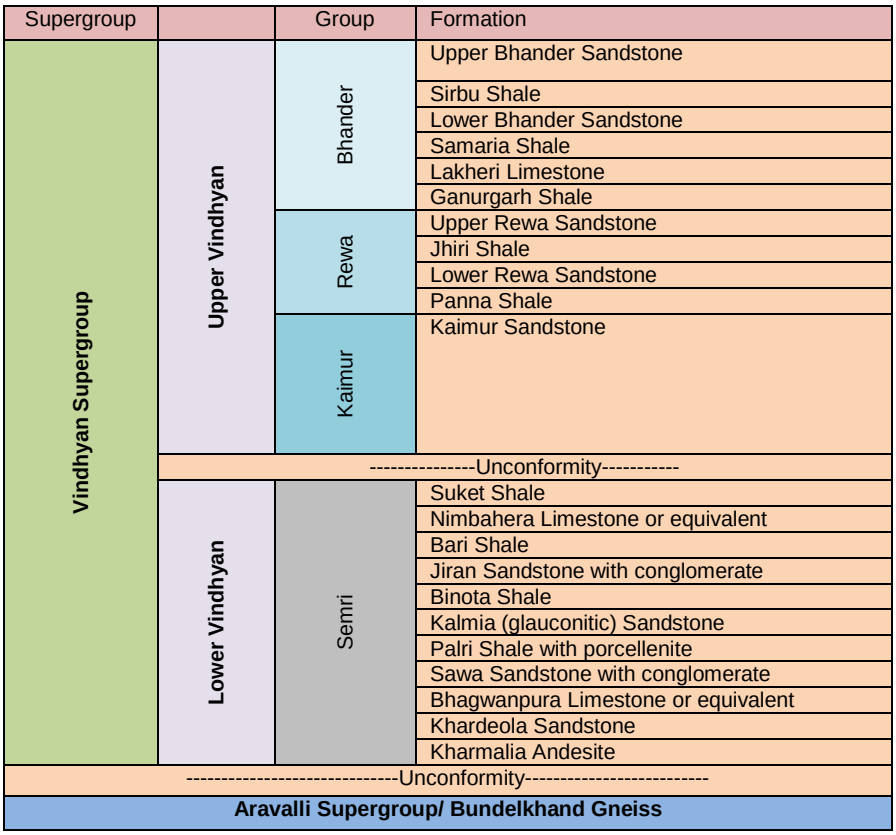

Fig. 2: Generalised stratigraphy of Chambal Valley, Vindhyan Basin (modified after Prasad, 1976)

Discussions

Well PLT-Q, has been drilled to assess hydrocarbon potential of Upper Vindhyan and Lower Vindhyan sediments and to test the basement. Suket Shale of Lower Vindhyan (Semri Group), overlying basement, is composed of mainly shale with alternate bands of siltstone and sandstone. Petrographic analysis of shale reveals its silty nature with associated mica and pigments of hematite, while sandstone microfacies is very fine grained quartz arenite with concavo-convex contacts of framework grains having quartz over-growth. XRD analysis indicates dominance of kaolinite (60-65%) over illite (35-40%) with traces of chlorite in the upper and middle part of the section while equal distribution in the lower part.

Unconformably overlying, Kaimur Sandstone of Upper Vindhyan, with more than 300m thickness, is represented by sandstone with alternations of shale and siltstone. Thin section petrography of sandstone represents fine to coarse grained quartz wacke and fine grained quartz arenite microfacies with sericitised micaceous clay and patchy calcite cement. Clay mineralogy analysis shows predominance of illite (55-65%) over kaolinite (35-45%) with traces of chlorite (Fig. 3; Plates- I & II).

Conformably overlying Rewa Group sediments of Upper Vindhyan consisting Panna Shale, Lower Rewa Sandstone, Jhiri Shale and Upper Rewa Sandstone are observed with thickness of more than 700m. Lower Rewa Sandstone is profusely developed sandstone with minor shale bands. Petrographically, sandstone is quartz arenite, quartz wacke, sub-lithic calcareous quartz wacke consisting very fine to medium grained quartz, feldspar, mica, rock fragments in clay matrix and calcite cement. Upper Rewa Sandstone, a monotonous sandstone unit with minor development of siltstone and shale in between shows tightly packed poorly sorted quartz arenite microfacies.

Bhander Group comprising Ganurgarh Shale, Lakheri Limestone, Samaria Shale, Lower Bhander Sandstone, Sirbu Shale and Upper Bhander Sandstone formations. Sandstone dominantly shows quartz arenite and quartz wacke microfacies consisting densely packed very fine to medium grained quartz, feldspar, mica and calcite cement (Fig. 3; Plates- I & II).

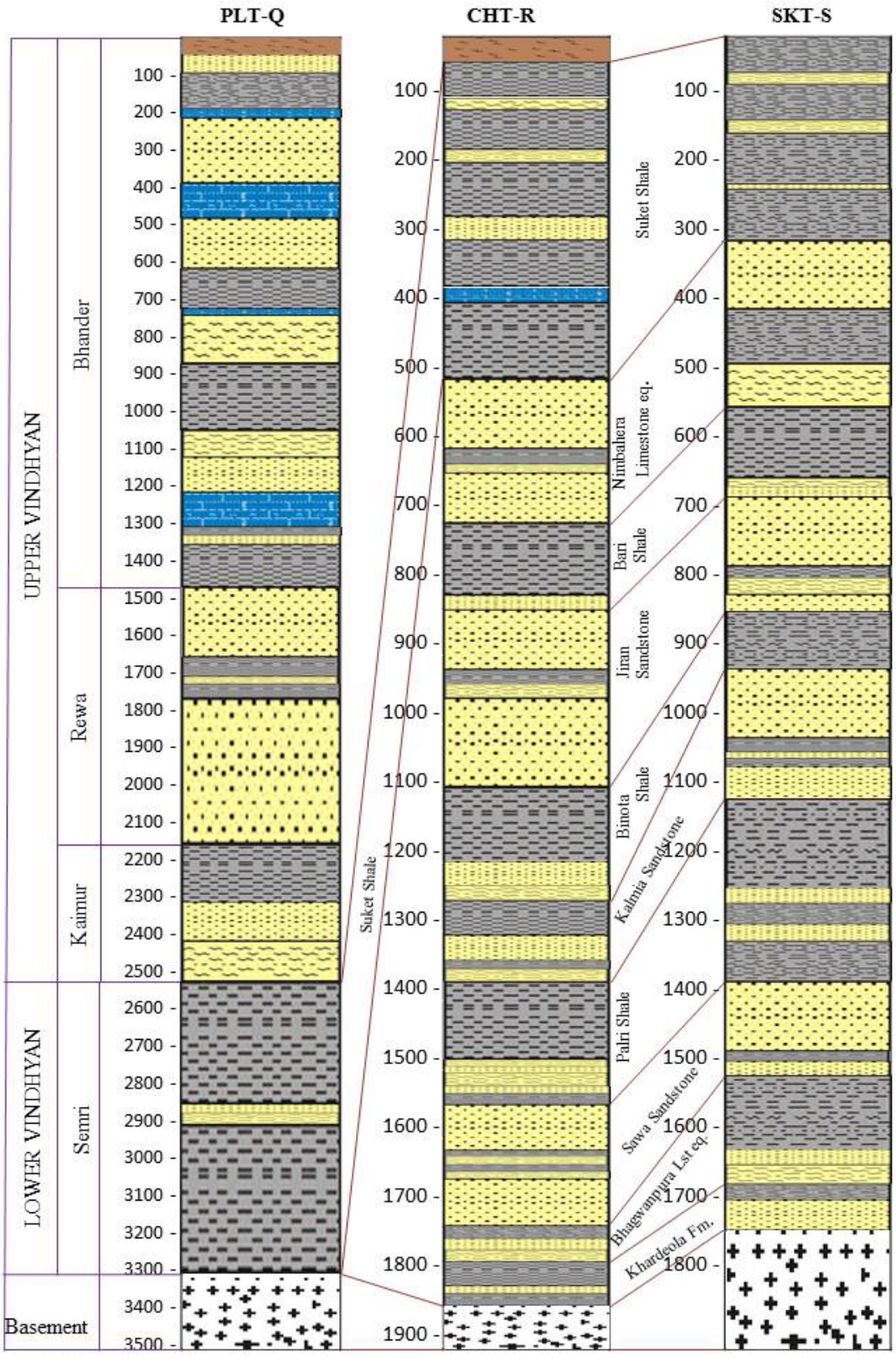

Fig. 3: Lithostratigraphic correlation of studied wells

Wells CHT-R and SKT-S, were drilled to evaluate hydrocarbon prospectivity of the Lower Vindhyan sediments in Chambal Valley extending in Rajasthan. Lithostratigraphically, Lower Vindhayan sequences observed are- Khardeola Formation, Bhagwanpura Limestone equivalent, Sawa

Sandstone, Palri Shale, Kalmia Sandstone, Binota Shale, Jiran Sandstone, Bari Shale, Nimbahera Limestone equivalent and Suket Shale in younging order (Fig. 3).

Overlying basement, Khardeola Formation in both the wells mainly consists of silty shale and sandstone with minor interlaminations of siltstone. Sandstone is dark grey, brown, hard and compact, very fine to fine grained, occasionally medium grained, quartzose and non-calcareous.

Bhagwanpura Limestone overlies the Khardeola Formation conformably in the type area and mainly consists of dolomitic limestone with thin conglomerate beds. In the wells under study, typical lithology of the Bhagwanpura Limestone is not observed but equivalent association of silty shale with sandstone and siltstone of considerable thickness is observed. Hence, Bhagwanpura Limestone equivalent term is used. Thin section study of sandstone exhibits mainly quartz wacke consisting of fine to coarse grained quartz grains embedded in clay matrix with associated mica.

Sawa Sandstone reveals quartz arenite microfacies consisting fine to medium grained quartz grains with moderate to good sorting. Overlying Palri Shale is dominantly argillaceous section containing mainly shale with siltstone and sandstone interlaminations.

Kalmia Sandstone unit is shows fine to coarse grained quartz arenite with chert fragments. Quartz overgrowth and intense packing have reduced the porosity drastically. Binota Shale is represented mainly by shale with minor siltstone and sandstone interlaminations.

Jiran Sandstone in the both the wells show quartz arenite microfacies. Bari Shale section is made up predominantly of shale with minor sandstone.

Nimbahera Limestone equivalent unit represents limestone facies in the type area but only arenaceous and argillaceous sediments are encountered in the wells CHT-R and SKT-S. Uppermost unit of Lower Vindhyan i.e. Suket Shale comprises of silty shale, siltstone sandstone and limestone. In the well CHT-R, this formation has been divided into four memebers viz. Lower Shale Member, Jhalarapatan Sandstone, Kota Stone and Upper Shale Member.

XRD analysis in the well CHT-R and SKT-S indicates dominance of illite and kaolinite clay mineral association with minor chlorite. Illite-smectite mixed layer has been noticed in Khradeeola Formation (Fig. 3; Plates- I & II).

Conclusions

In the well PLT-Q, sandstone encountered in various stratigraphic units are categorised as quartz arenite, calcareous quartz arenite, quartz wacke and sublithic quartz wacke. These contain variable size of quartz, mica and minor feldspars held in micaceous and ferruginous clay matrix with siliceous and calcareous cements formed diagenetically. Intense grain packing and poor sorting lead to poor reservoir facies development. Thin section study of carbonate units in Lakheri Limestone, Sirbu Shale and Upper Bhander Sandstone formations indicate that microfacies are mainly mudstone, dolomitic mudstone and evaporatic dolomite consisting bladed anhydrite, silt size quartz, occasional feldspar and glauconite.

In the wells CHT-R and SKT-S, sandstone units encountered in various stratigraphic sequences under thin section show mainly quartz arenite with subordinate quartz wacke and lithic arenite. Though the sediments show textural and mineralogical maturity, feldspar in few samples has been reported. Owing to intense grain packing, poor to moderate sorting and higher degree of cementation these sandstones show poor reservoir quality resulting in extreme low holding capacity. Based on lithofacies association studied, sediments of Chambal Valley part are likely to be deposited in shallow marine regime.

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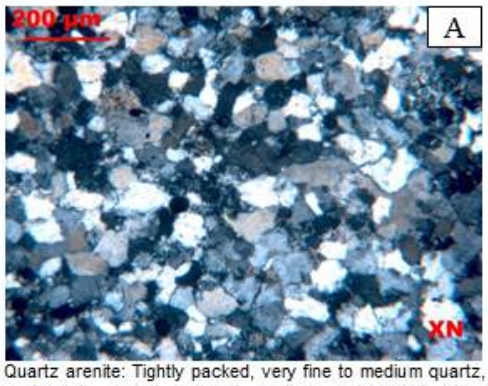
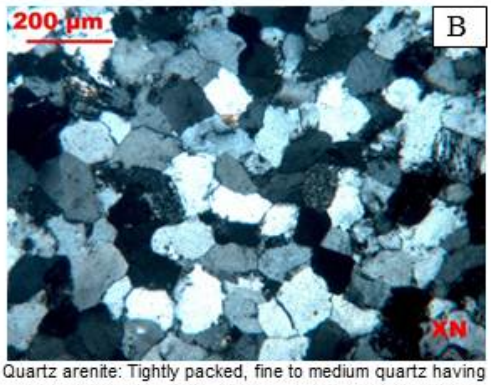
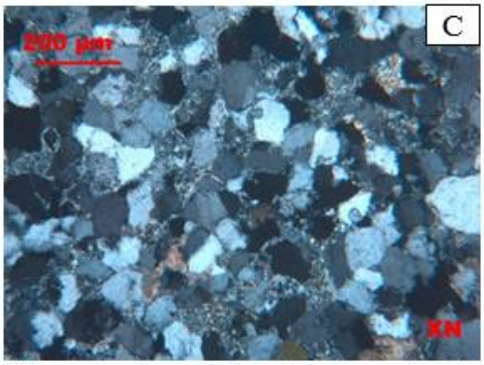
Petrographic attributes of selected cutting samples of well PLT-Q, CHT-R and SKT-S



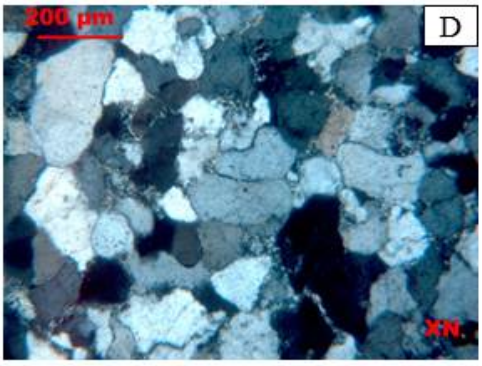
Quartz arenite: Tightly packed, very fine to medium quartz, moderately sorted, sutured contacts, mica and minor feldspar, clay matrix, patchy calcite cement, 2350-55m (Kaimur Sandstone, Well PLT-Q)



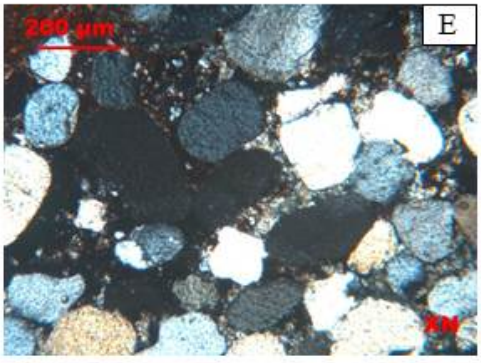
Quartz arenite: Tightly packed, fine to medium quartz having concavo-convex contacts, minor feldspar and mica held by clay matrix and patchy calcite cement, 1560-1565m (Upper Rewa Sandstone, Well PLT-Q)



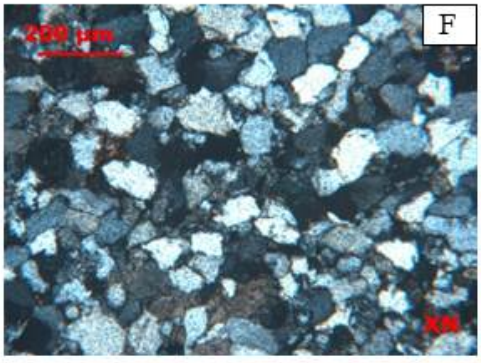
Lithic arenite: Fine grained, moderately sorted quartz grains set in siliceous/calcareous cement with chert rock fragments, 1060-1065m (Jiran Sandstone, Well CHT-R).



Quartz arenite: Fine to medium grained, moderately sorted quartz grains, siliceous matrix, calcite cement. Framework grains show sutured/concavo-convex contact, 620-625m (Nimbahera Limestone equivalent, Well CHT-R).

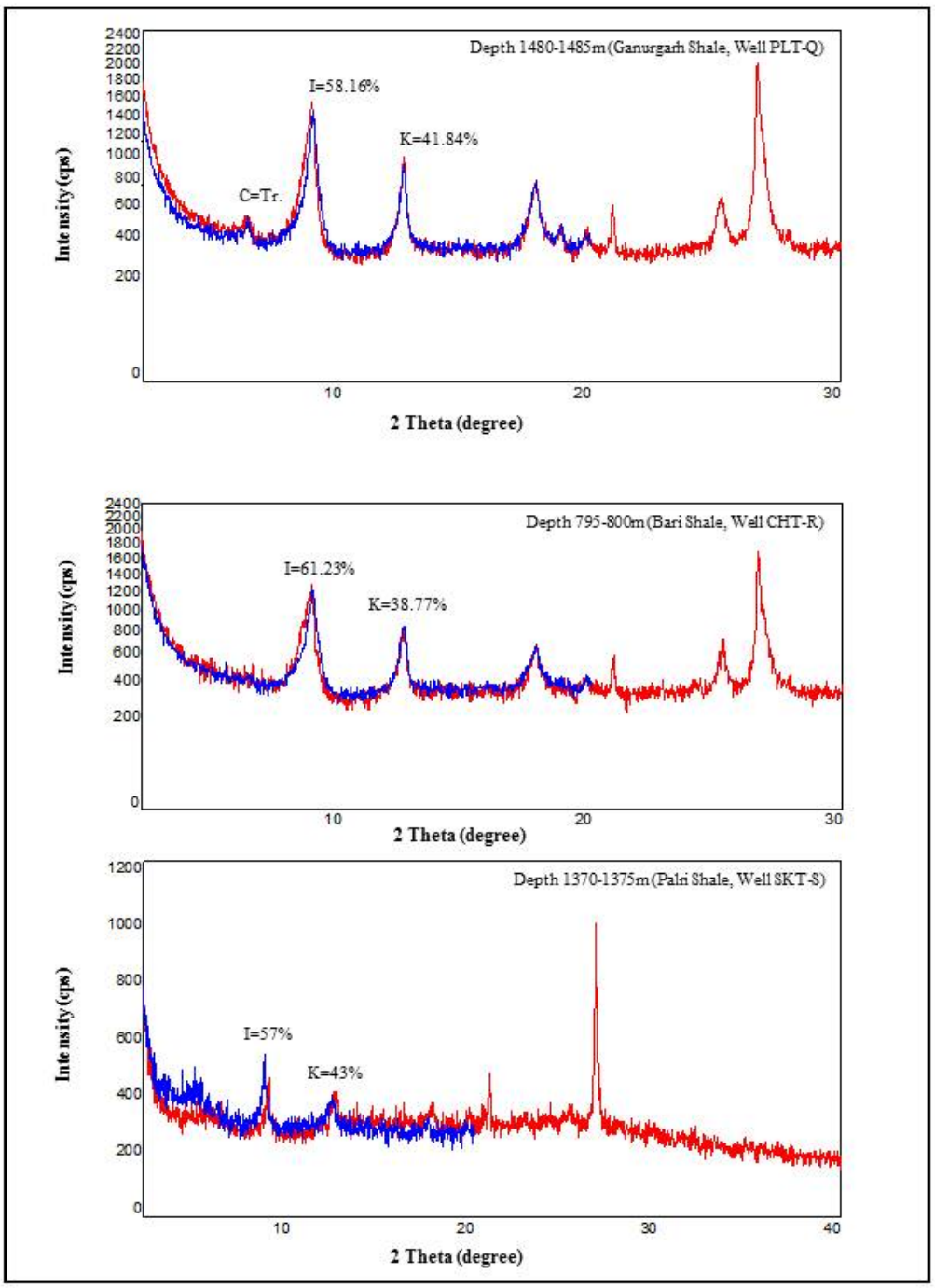


Quartz arenite: Fine to medium grained quartz grains, poorly sorted, sub-angular framework grains, secondary calcite and silica, ferruginous clay matrix, 1495-1500m (Sawa Sandstone, Well SKT-S).



Quartz arenite: Fine to coarse grained, chert fragments, quartz over growth, microcline- plagioclase feldspar, mica and heavy mineral, calcite cement corroding quartz grains, silica and calcite cement, 1050-1055m (Kalmia Sandstone, Well SKT-S).

X-Ray Diffractograms of selected samples from well PLT-Q, CHT-R and SKT-S



C=Chlorite, I=Illite, I/S=Illite-Smectite Mix Layer, K=Kaolinite