Facies Analysis, Reservoir characterization and Depositional Environment study of Hydrocarbon bearing Tertiary Sequences in Jaisalmer Basin, Rajasthan

Rajesh Pandey[1], Dinesh Kumar[1] and A.S. Maurya[2]
[1] Frontier Basin, ONGC, Dehradun-248195
[2]Department of Earth Sciences, Indian Institute of Technology, Roorkee-247667

ABSTRACT

Systematic geological investigation has been carried out in Tertiary sequences of Jaisalmer Basin, which includes understanding of widespread heterogeneity within lithofacies of Paleocene and Eocene sequences deposited under various depositional environments. These sequences are gas bearing in Manhera Tibba, Ghotaru and Kharatar gas fields in India and Sui and Mari gas fields of Pakistan. On surface exposures base of Tertiary is demarcated by Habur Formation, which is a fossiliferous sequence of calcareous sandstone, sandy limestone and coquinoidal limestone, while in subsurface, Marly Parh Formation. Overlying, Sanu Formation is represented by an arenaceous sequence of fine to medium grained highly current bedded. Sanu Formation has been divided in three main gas bearing reservoirs D2, D4 and D6. D2 and D6 units are represented by fine grained, subangular to subrounded detrital quartz grain with calcareous and ferruginous matrix while D4 unit is carbonate mudstone and wackestone. Petrographic and clay mineralogy suggest that Sanu Formation is deposited in warm, arid or semi-arid alkaline continental environment (deltic) with marine influences at the base and top. Khuiala and Bandah formations are represented by fossiliferous limestone, shales, marls, bentonitic clays and fullers' earth of 25m-30m thickness. Khuiala Formation has been subdivided into two main reservoirs B4 and C2-C4. B4 unit is carbonate mudstone while C2-C4 limestone is mainly packestone and algal wackestone with good porosity, resulted due to dolomitization and solution activity. Contact between Khuiala and Bandah are gradational. Bandah Formation has two established reservoirs A4 and B2. A4 unit has carbonate mudstone with lower porosity, B2 has nummulitic wackestone and packestone. Khuiala and Bandah formations represent inner to middle shelf environment. Recent Shumar Formation unconformably overlies the Bandah Formation.

INTRODUCTION

In order to bring out the detailed litho-stratigraphy of hydrocarbon bearing Tertiary strata in the Jaisalmer Basin, systematic geological investigation and sampling of the area lying between latitudes 27°0' and 27°25' and longitudes 70°22' and 70°39' was carried out on 1:100000 scale. The area covered comprises a desertic terrain, for the most part. The geological map prepared is on the basis of scarp faces, outcrops intervening between sandy strata and trenching along the roads and dug wells (Fig.1).

The oldest rock formation exposed in the study area is the Habur Formation (Goru Formation in sub-surface), comprise of coarse-gritty calcareous to ferruginous sandstone, sandy limestone and coquinoidal limestone containing fossils like ammonite and bivalve (Lower to Middle Cretaceous). In sub-surface Parh Formation marks the contact of K-T boundary. The overlying Sanu Formation in unconformable contact is made up of fine to medium grained, highly current bedded micaceous friable sandstone and Iron stone shale (Paleocene). The Khuiala Formation (Lower Eocene) overlies and overlaps the Sanu and Habur Formation. Khuiala Formationis divided into Lower

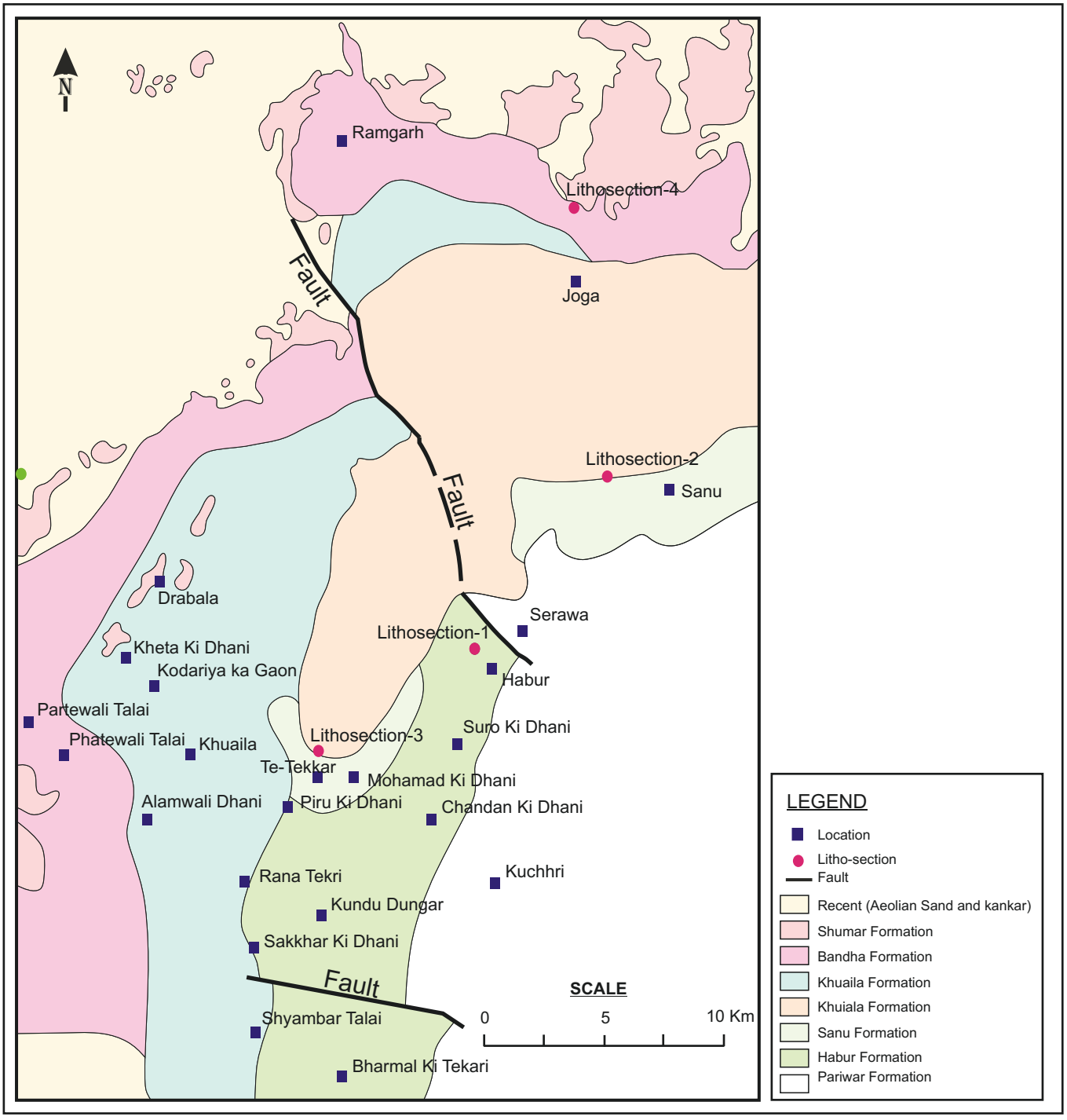


Fig.1: Geological map of Tertiary Sequences of Jaisalmer Basin (Modifed after Misra, 1993)

and Upper Members. Lower Member consists of foraminiferal limestone, marly limestone together with rarely exposed bentonitic gypseous clays and Fullers' earth.

Whereas, Upper Member has massive crystalline limestone and fossiliferous chalky limestone. The Bandah Formation (Lower to Middle Eocene) is in gradational contact and consists of massive limestone boulder and foraminifera limestone with marl. All formations other than the Sanu are highly fossiliferous. The Sub-recent Shumar Formation unconformably overlies the Bandah Formation and consists of coarse-gritty ferruginous sandstone. Ironstone and conglomerate containing reworked fossils. The rock formations are horizontally to sub-

horizontally disposed with undulating rolling dips of 3° to 5°, in general, towards west-northwest, relatively higher dips (more than 5°) have been recorded north of Alamwali-Dhani.

The accessibility of the area is only through the east-north eastern part of the area mapped, since sand dunes, as high as 35 metres, from the general ground level traverse through the western part of the area. The Dhanis' and important places are interconnected by sandy track.

The earliest geological work in western Rajasthan is by Blanford (l876), who attempted to delineate the stratigraphy. Oldham (1886) gave detailed account of the geology of the area accompanied by a sketch map; the different lithological members were grouped and described with type sections. The "Ammonite bed" of Kuchhri (Blanford, 1879) was named as "Habur group" Detailed traverses in the Jaisalmer-Ramgarh area were taken by Swami nath et al., (1957); their work, however, did not include the entire area covered by the author. The Oil and Natural Gas Corporation (ONGC) commenced drilling for oil and the sub surface data, helped in building up the stratigraphy of the region (Narayanan, 1964; Das Gupta, 1975). Lukose (1974, 1977) studied the Palynology of sub-surface samples and presented conclusions towards the possible palaeogeographic limits and palaeo-environment of the Jaisalmer Basin.

The present work included preparation of out crop based geological map of the area and presents a detailed petrographic study of the mappable units to determine reservoir potential of these clastic and non-clastic units.

MATERIAL AND METHODS

Extensive field geological mapping had been carried out in the area; well exposed sections of Sanu, Khuiala and Bandah formations were studied. Megascopic, Microscopy and XRD (clay and bulk mineralogy) analysis have been carried out to identify microfacies, mineral association, type of matrix/cement, texture and infer depositional environment and reservoir characteristics. Formation wise field geological observations are discussed in the following paragraphs.

SANU FORMATION

The Tertiary-sequence commences with the araneceous unfosiliferous -Sanu Formation which stratigraphically overlies fossiliferous Habur Formation. The outcrop pattern, structural behaviour and contrasting lithological association however, suggest an unconformable contact between them. It was designated by Dasgupta et al. (1973) after village Sanu Misra et al., (1993) have identified two members in this formation Mohammad Dhani Member and Kharatar Member. Mohammad Dhani Member comprises fine to medium grained, highly current bedded, micaceous friable, yellowish to brownish, deep brown and maroon sandstone with deep brown iron stone shale, the outcrops occupy the low-lying ground rising not more than 2 m from the ground level. Kharatar Member is mainly represented by greyish-green shale with thin interbed of sandstone in the upper part and grey soft glauconitic marl in the lower part.

Road section near Sanu village: This section is exposed at 3Km NW of Sanu village along Sanu-Ramgarh road (Fig. 2). The section exposes about 7.16 m thick sedimentary sequences of Sanu Formation and Khuiala Formation. Sanu Formation is represented by unfossiliferous yellowish red colour variegated to brownish ferruginous sandstone. The Khuiala Formation consists of thick yellow marl bed, containing shell fragments of *Ostrea* and *Foraminifera* followed by yellowish to greenish shale. Yellowish white coloured marl contains burrowing and worm tubes (at the lower part) fossils of bivalves, solitary corals and foraminifers and thick shale (occasionally marly) horizon. In the topmost part of this section, hard compact crystalline limestone is exposed.

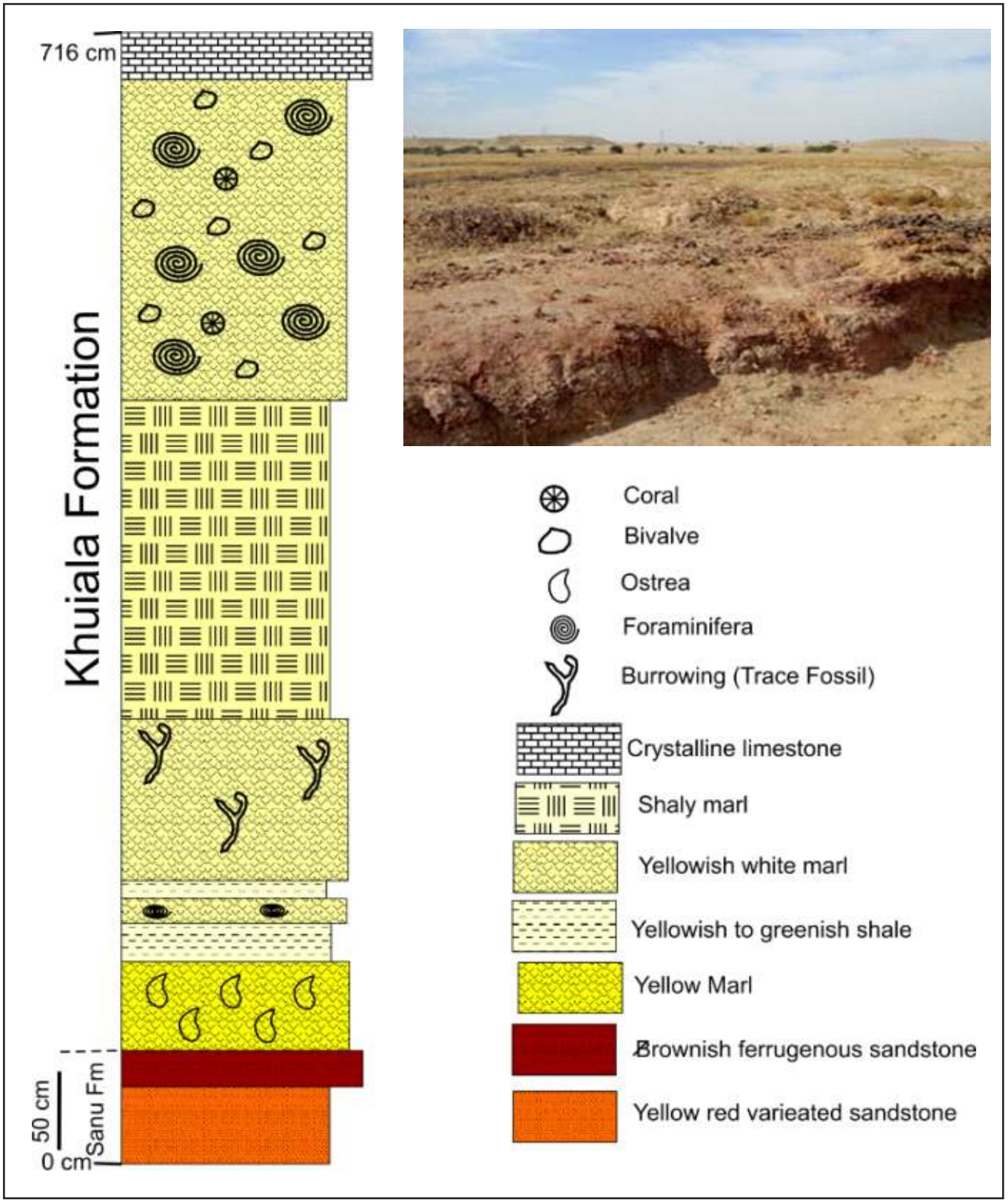


Fig. 2: Field photograph & Litho-column of Road section, 3Km NW of Sanu village

KHUIALA FORMATION

The Khuiala Formation is designated by Narayanan et al., (1961) after Khuiala village and it unconformably overlies the Sanu Formations. Dasgupta (1975) sub-divided this formation in two members namely Dunghan Member and Ghazij Member. Misra et al., (1993) replaced the names Dunghan Member with TeTakkar and Ghazij Member with Kinsar. Kinsar Member is further subdivided in to Lower Kinsar, Sirhera and Upper Kinsar Members. Khuiala formation comprises a 30m thick exposed sequence of argillaceous to calcareous rocks.

Lower Member (Te-Takkar Member)

Marly limestone, foraminiferal limestone, bentonitic gypseous clay and fullers' earth form the lower Member, having an exposed thickness of 2 m to 15 m. The sequence forms cuesta scarps running between north of Mohamad-Ki-Dhani, in the south, and Hingola, in the north, over a strike length of about 12 Km. The contact between this sequence with that of underlying Sanu Formation is exposed to the north of the village Mohamad-Ki- Dhani, at the base of the Te-Tekkar scarp.

The fullers' earth and bentonitic gypseous clay are greyish-white to buff in colour, loose, friable and at places iron-stained. They are alternately disposed and the thickness of their individual bands varies from 6 cm to 60 cms. They form the lower-most part of the sequence successively overlain by the foraminiferal limestone. The foraminiferal limestone is dirty yellow to buff and greyish white in colour, massive hard and compact, but friable on weathered surface. Aggregates of foraminifers, particularly the Nummulites and Assilina (small sized) are embedded in the rock. The marly limestone occurs as boulders of greyish white in colour, massive, hard, compact and glossy in nature. They overlie the foraminiferal limestone and constitute the top most bed of the sequence. Generally, they occur as capping and their thickness does not exceed 2 m. They very often contain fossils of gastropod, echinoid and lamellibranches. The litholog of maximum exposed, thickness of the sequence of Te-Tekkar is given in Fig. 3.

Upper Member (Kinsar Member)

Massive crystalline limestone and fossiliferous chalky limestone constitute the Upper Member extending from Khuiala to Hingola in the north and Alamwali-Dhani, in the south. Isolated exposures have also been observed around Rana Tekri end Shyambar Talai area. The exposures are typically found to occur as isolated small mounds and knolls rising more than 8 m from the ground level. At places, the interdunal areas are also covered by the patchy exposures.

The chalky limestone is yellowish-white to buff in colour, occasionally gypseous and contains innumerable shells and broken tests of pelecypods echinoids and gastropods. It forms the basal part of the sequence having 20 cm to 3 m thickness due 1.5 Km north of Alamwali-Dhani. It is in persistent and forms lensoid bodies underlying the massive crystalline limestone.

The massive crystalline limestone, forms the upper most bed and is buff to grey, yellowish and purplish, very hard, compact, massive and fine crystalline. At places, the exposure of massive crystalline limestone shows the effect of wind abrasion in the form of development of grooves and hollows.

BANDAH FORMATION

The Bandah Formation, named after the village Bandah (Narayanan, 1959) where it is typically exposed, comprises massive bouldery, fragmental and foraminiferal limestone with sub-bentonitic clay and ochreous marly layers with thickness of around 75m. Das Gupta (1975) identified two members: Habib Rahi Limestone Member and Bakhri Tibba Limestone Member separated by shale. Misra et al., (1993), has renamed them as Batrewala Member and Bakhri Tibba Member with the lower limit of Batrewala Member placed at the top of intervening shale section.

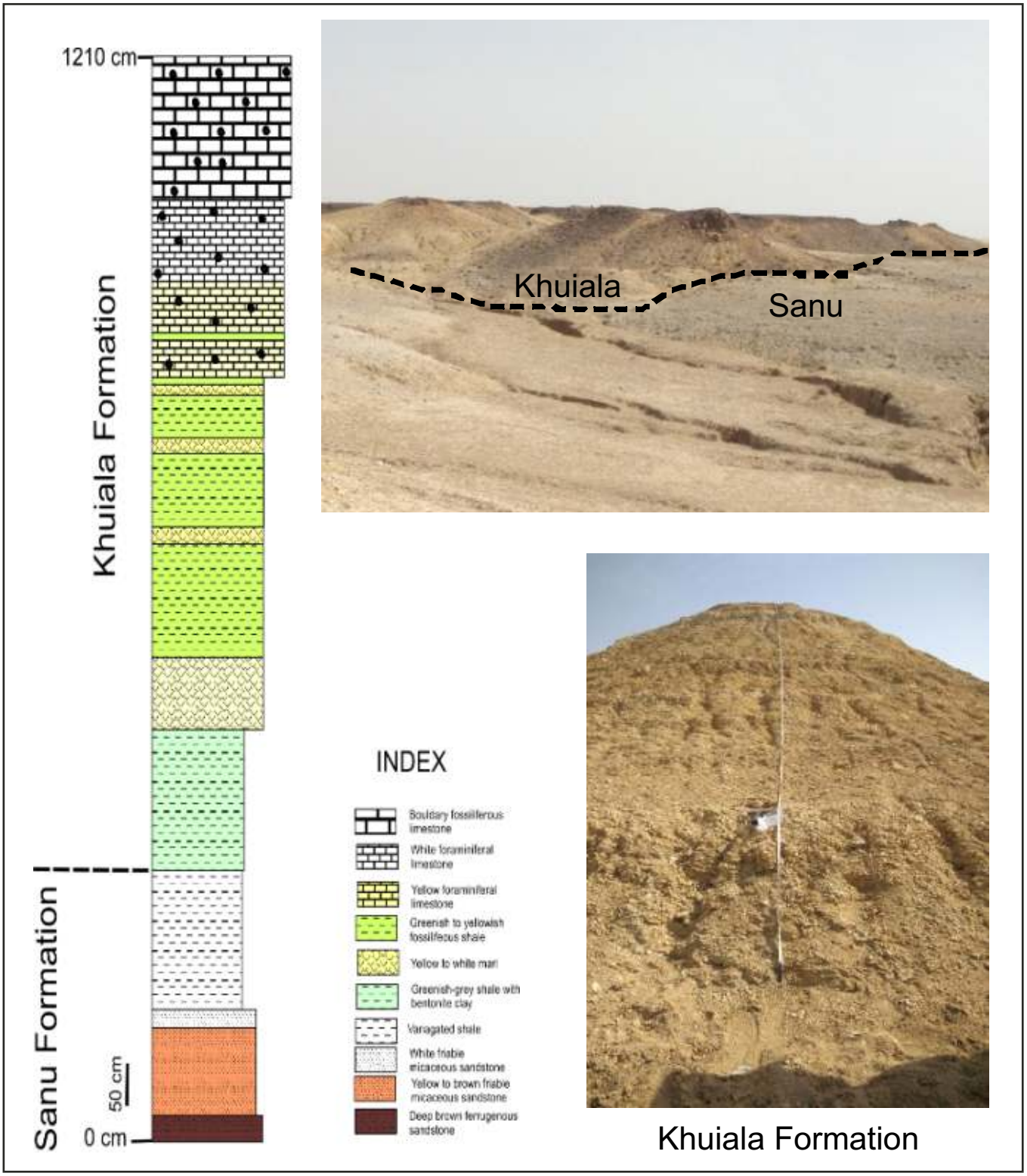


Fig. 3: Litho-column and Field photograph of Te-Tekkar scarp section, north of Mohamad-ki-Dhani.

The sequence is poorly exposed between Bandha in the north and Bhuroi Tekri, in the southwest, isolated exposures of this formation are seen as small knolls and mounds of 8-10 m high near Ajre-Ki-Dhani, Betrawala Tibba and around Phatewali Talai, Girdhariwali Talai exposures occur in the interdunal areas.The section exposed at 1Km north of Joga village is used for sedimentological and

palaeontological studies. The lithounits of the Joga section include pale yellow coloured gypseous shale at the base interlayered by 3 to 4 calcareous units (Fig.4).

The contact between this formation with that of underlying Khuiala Formation is not exposed. Lithological similarities, fossil assemblages and structural conformity are suggestive of a graded

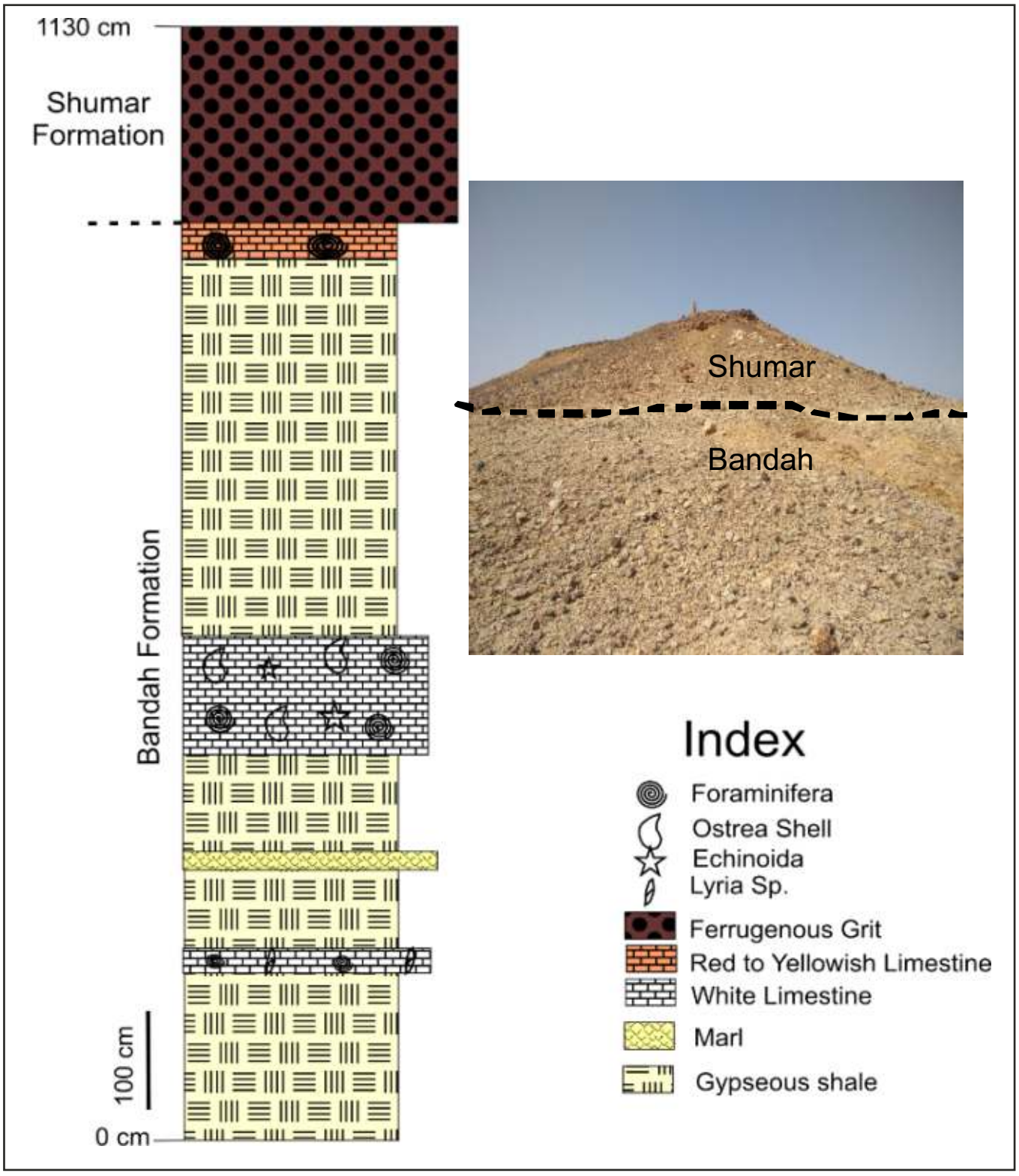


Fig. 4: Field photograph and Litho-column of Joga section, 1Km north of Joga village, Jaisalmer

conformable contact. Nowhere, in the area mapped, the full thickness of the sequence is encountered, but computed thickness is of the order of about 25 m.

Thinly bedded sequence of subbentonitic clay and ochreous marl together constitute the lower part of Bandha Formation. They are typically exposed in the nala cutting of Bangwar-wali-Nay and dug out pits, located north-east of Bandha village with variable exposed thickness measuring 6-30cm. This unit of marl and subbentonitic clay grades upward into a calcareous unit represented by foraminiferal limestone and massive bouldery fragmental limestone which constitute the upper part of the sequence.

The ochreous marl is yellowish to brownish in colour, very soft and friable and associated occasionally with pockets of greyish-white to buff, loose and friable sub-bentonitic clays. The foraminiferal limestone is dirty yellow to buff and greyish white, massive, hard and compact but friable on weathered surface. Aggregates of foraminifers, particularly Assilina (large sized) and Nummulites are embedded in the calcareous matrix. The limestone is bluish grey, hard and compact, massive, bouldary and fragmental with fossil casts.

SHUMAR FORMATION

Coarse-gritty ferruginous sandstone, ironstone, and conglomerate constitute the Shumar Formation. It is restricted to the northern and northwestern part of the area. The formation status to these beds was first given by Narayanan (1964).

Coarse-gritty Ferruginous Sandstone and Ironstones: Coarse-gritty ferruginous sandstone and ironstone are exposed as isolated mounds and hillocks around Shumarwali Talai, Ganwarwali Talai. To the east of Khenwaroni-Ki-Dhani and to the north of Jiyawali Talai, they form outliers, within the Bandah Formation. Their thickness varies from a few centimeters upto one metre, being 15 m in the hill, to the east of Shumarwali Talai. The sandstones very often upward grade into and are capped by ironstone and iron nodules.

In hand specimen, the sandstone is brown to deep brown and maroon in colours, very hard, compact and highly gritty. The ironstones are dark brown to black, massive, very hard and compact, at places, showing the effects of desert polish.

Conglomerate Horizon

The conglomerate horizon is typically exposed around the village Drabala, to the north of Kheta-Ki-Dhani, and about 2 Km north-east of Partewali Talai, and are found to occur as small isolated knolls and mounds rising maximum upto 2 m from the general ground level. The general trend of the conglomerate horizon is N 40°W-S40°E, due up to 2 Km north east of Partewali Talai, the length of this horizon along the trend is 500 m with 30 m width.

It comprises gravels, cobbles, and pebbles of massive brownish-grey to buff coloured limestone (Khuiala Formation), bluish grey-massive bouldery limestone (Bandah Formation), ferruginous nodules and reworked foraminifers. The matrix is predominantly siliceous, although calcareous matrix is not uncommon. The gravels, cobbles and pebbles are of different size and angularity. Some of the pebbles are subrounded with longer axes measuring even 15 cm.

SAND DUNES

Windblown sand covers a large part of the area, Sand dunes are of transverse type with northeast-southwest trend. They rise as much as 35 m, from the ground level.

RESERVOIR DESCRIPTION

Tertiary reservoirs in Jaisalmer Basin are mainly localized along Jaisalmer Mari high (Pandey et al., 2018). Established Tertiary reservoirs are A4 and B2 limestones separated by clay layers in Bandah Formation equivalent to Habib Rahi Limestone Member and Bakhri Tibba Limestone Member discussed earlier. Similarly, Khuiala Formation has B4 and C2-C4 limestone reservoirs separated by clay/shale are referred as TeTakkar and Kinsar

Member on surface. Sanu Formation has three established reservoirs D2, D4 and D6. D2 and D6 are sandstone reservoirs whereas D4 is limestone. D6 corresponds to Mohammad Dani Member while D2 and D4 corresponds to Kharatar member. Charging of these reservoirs is mainly from Mesozoic sources through vertical/sub-vertical strike slip faults.

MICROFACIES ANALYSIS

D6 and D2 reservoir of Sanu Formation have an interlocking mosaic of subangular to subrounded detrital quartz grain and subordinate minute flakes of muscovite. The grain boundaries of detrital quarts and the interspaces filled with calcareous and ferruginous material, which, in turn, acts as cementing material (Fig. 5a) Some of the quartz grains show sutured margin, particularly the larger ones, minute flakes of mica and feldspar is present (Fig. 5b). Carbonate section D4 limestone is represented by sparitized mudstone and wackstone microfacies. The bioclast mainly includes larger as well as smaller forams, algae and calcispheres. Mudstone facies at places show selective dolomitisation.

C2-C4 limestone of Khuiala Formation is characterised by packestone, algal wackestone and mudstone facies. Forams (Nummulites and Assilina), echinoderms and algae dominant grain scattered in micritic matrix (Fig. 6 a-d). The smaller forams are completely sparitized and embedded in a cryptocrystalline calcitic mosaic, occasionally dolomitized (6e & f). The calcite grains are sub-angular to subrounded showing mutual boundary relationship. At places the calcite mosaic is characterised by microstylolitic grain boundaries stained by iron oxides.

A4 limestone of Bandah Formation is carbonate mudstone with minor association of wackestone facies. The mudstone is at places dolomitised. Bioclast includes nummulites, molluscan shell and echinoids plate fragments set in a microcrystalline calcitic mosaic (Fig. 7a & b). Microfacies of upper part of B2 limestone is mainly nummulitic wackestone/packestone with rare association of nummulitic grainstone and mudstone. The Bandah Formation has released fossils of Discocyclina, Assilina 'large sized, Nummulites, Gastropod Sp. Echinoids and Lamellibranch Sp.

Bandah Formation is distinct from the Khuiala in containing Discocyclina shells, larger sized Assilina and associated with yellowish to brownish ochreous marly layers.

Based on reservoir microfaceis studies of Bandah and Khuiala Formations, it is concluded that the

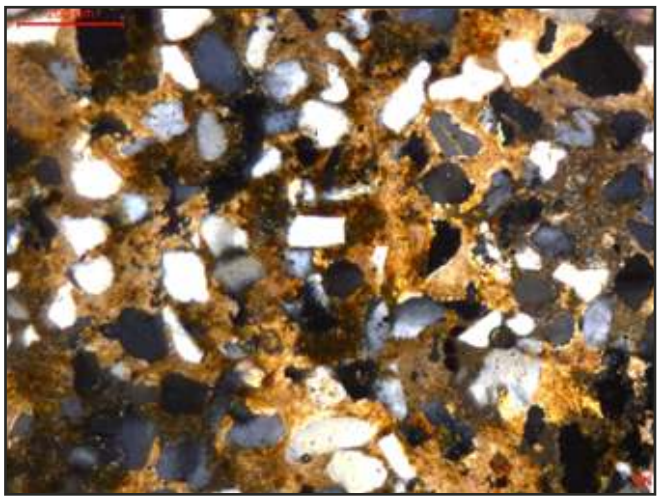


Fig. 5a: Quartz arenite: Very fine grained, well sorted, sub-angular to sub-rounded quartz (60%) bounded by calcite cement (30%). At places ferruginous matrix (10%) observed.

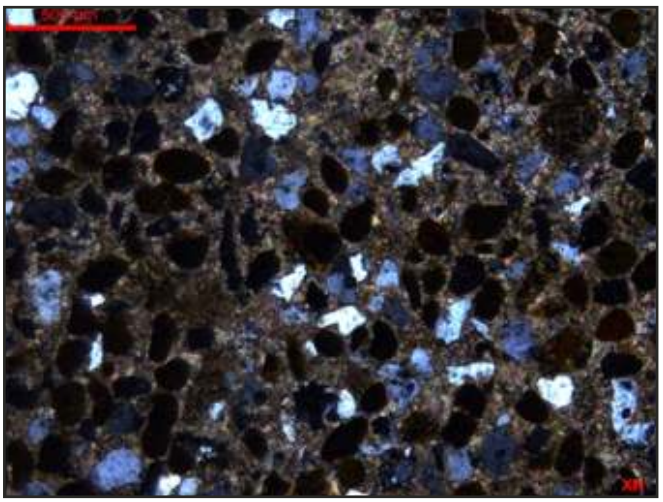
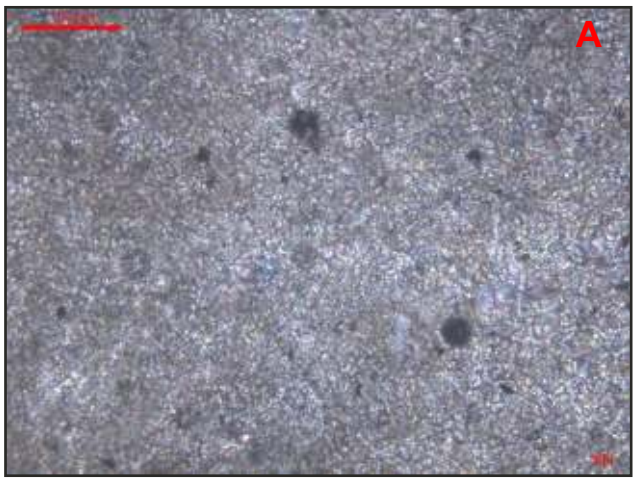
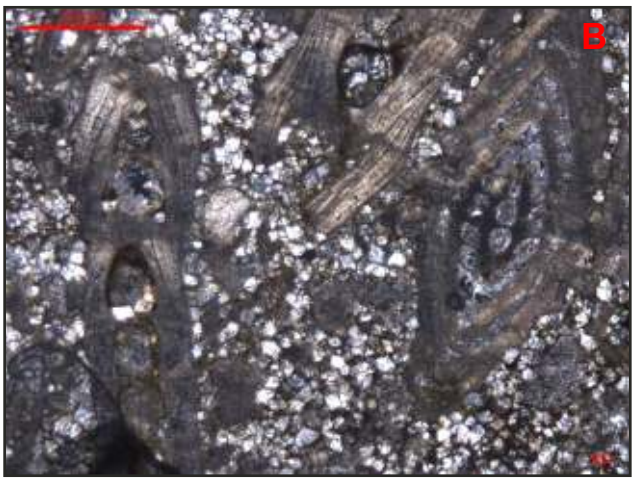


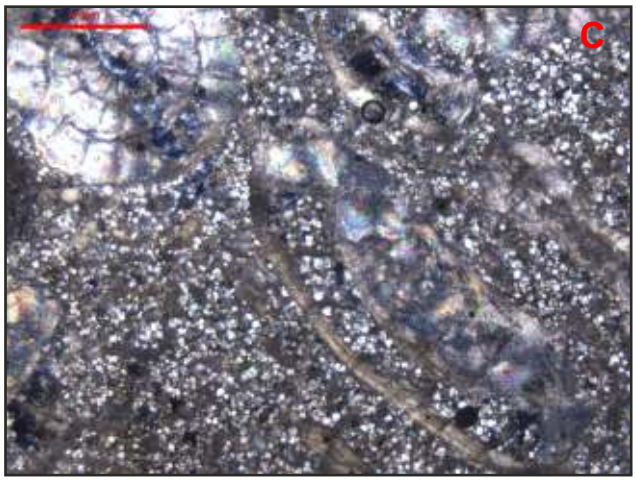
Fig. 5b: Very fine to fine grained, moderately sorted, quartz (~40%), ferruginous matrix (~35%) along with mica and feldspar in traces cemented by calcite (25%) with floating contact.



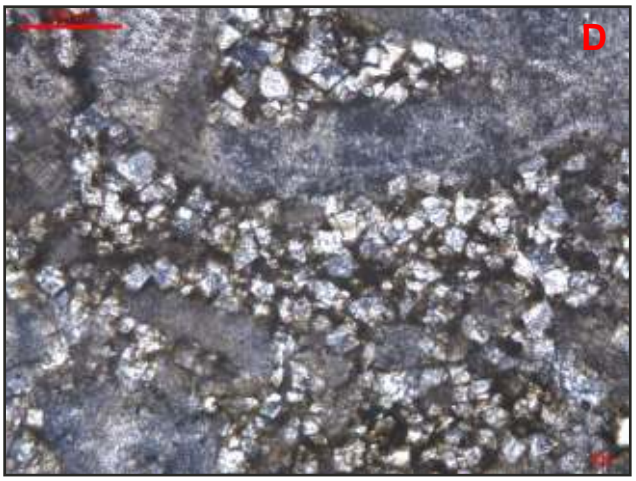
(a) Sparitised mudstone facies of C2-C4 reservoir, Khuiala Formation



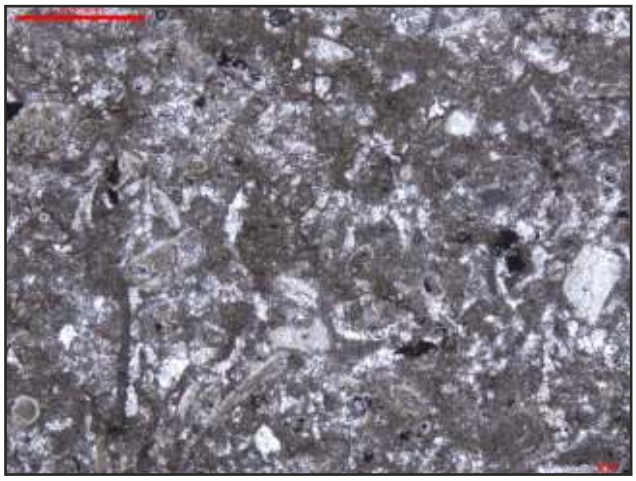
(b) Packestone containing Assilina Sp., Nummulites. Fossil chamber is sparitised. Well-developed dolomite rhombs.



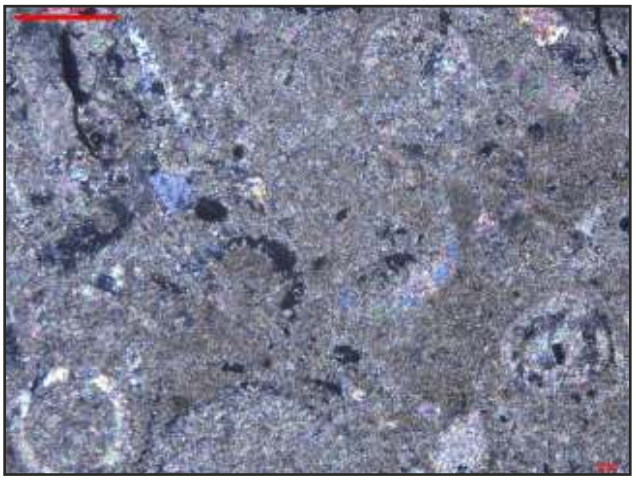
(c) Packestone containing Nummulites. Fossil chamber is sparitised.



(d) Well developed dolomite rhomb in Packestone.



(e) Wackestone microfacies with abundant fossil fragments and disseminated pyrite



(f) Wackestone- fossil chamber is completely sparitised,

Fig. 6: Petrographic attributes: Khuiala Formation

carbonate microfacies are mainly mudstone, wackestone, nummulitic packestone, with rare occurrence of grainstone microfacies. Association of dolomitic mudstone at various levels suggest shallowing of the basin. These microfacies indicates low to moderate energy condition during deposition.

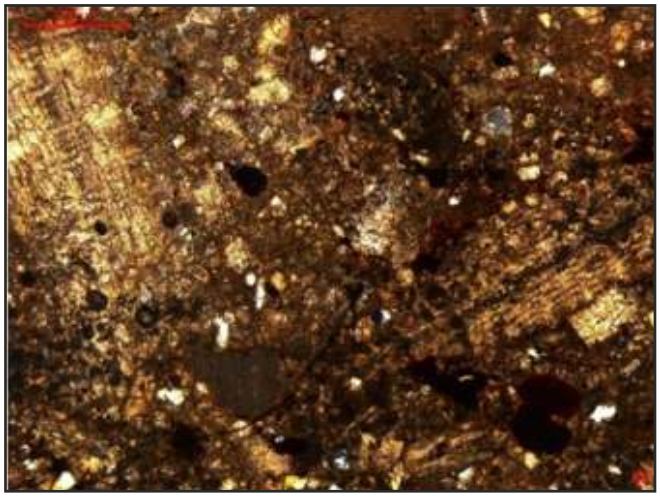


Fig. 7a: Wackestone microfacies containing fossil and fossil fragments with some silt sized quartz withpatches of ferruginous matter.

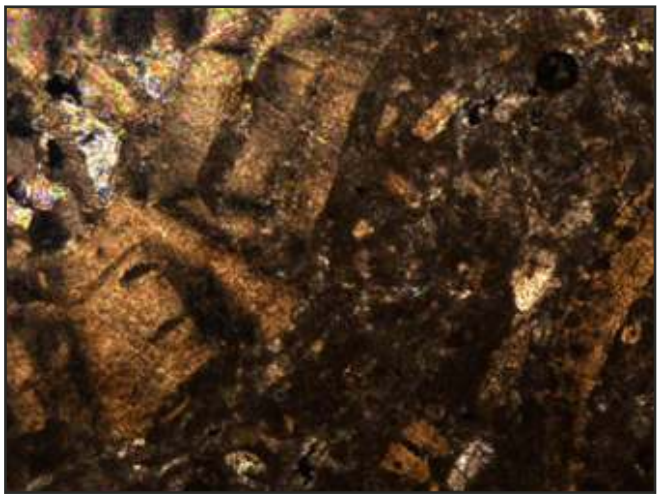


Fig. 7b: Wackestone microfacies containing fossil and fossil fragments. Fossil chamber completely sparitised.

XRD ANALYSIS

XRD analysis of selected sample from Sanu Formation shows dominance of montmorillonite (~49%), kaolinite (~30%) and illite (~21%) clay (Fig. 8). Calcite percentage in D4 reservoir ranges from 90-100% with dolomite up to 10%. C2-C4 and B4 reservoir mainly contains 95-100% calcite, 5% dolomite and traces of quartz. Clay mineralogy is characterized with dominance of stilpnomelane, Illite, Chlorite and Kaolinite (Fig. 9a & b). The mineralogical composition of A4 limestone of Bandah Formation reveals calcite (55-85%), dolomite (15-45%) and Quartz (up to 5%) whereas B2 limestone is chiefly 100% calcite with traces of quartz and dolomite. Clay mineralogy can also be used to decipher the difference in Bandah and Khuiala Formation as Bandah Formation does not have dominant pick of Illite and Kaolinites (Fig. 10).

DEPOSITIONAL ENVIRONMENT

Tertiary sequences of Jaisalmer Basin are represented by Sanu, Khuiala and Bandah formations. The Sanu Formation is chiefly an arenaceous sequence. The lower part of this formation is mainly composed of medium to fine grained, clean sandstone with the intercalation of calcareous glauconitic sandstone and shale, deposited in regressive phase in a fluvial regime

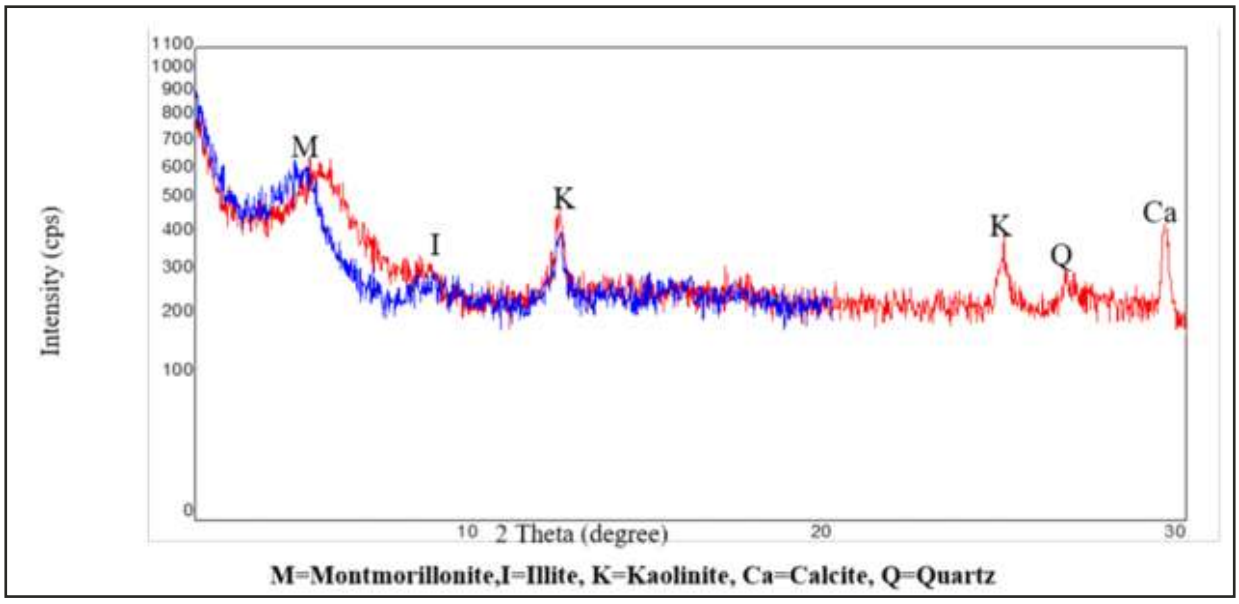


Fig. 8: XRD result of selected samples from Sanu Formation.

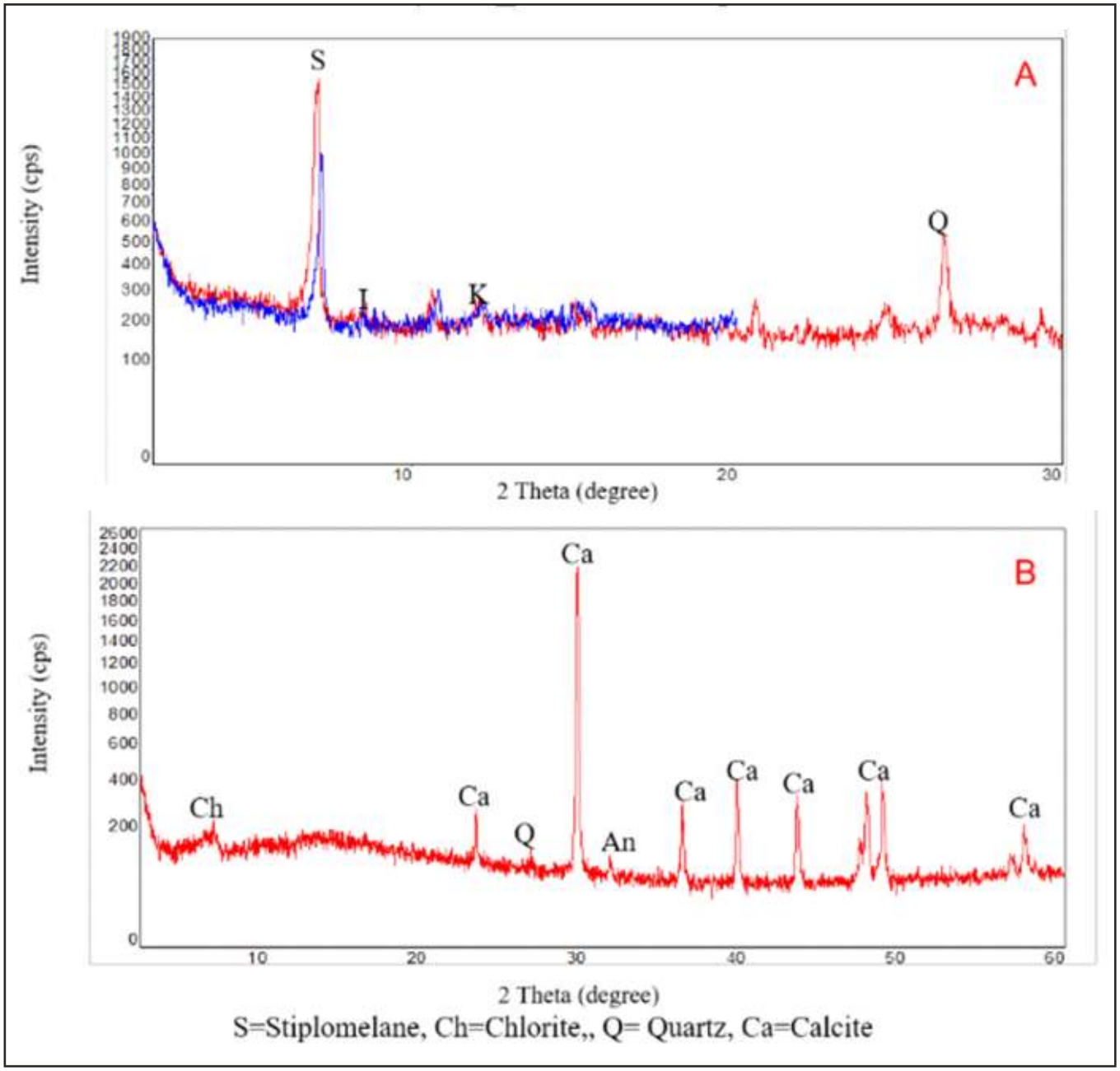


Fig. 9: XRD results of selected samples from Khuiala Formation

with influence of periodic marine incursions. The thick chocolate brown and grey claystone represent coastal deposits. The upper part of Sanu Formation comprises argillaceous glauconitic limestone, shale and calcareous claystone. The litho-association suggests its deposition in shallow marine conditions. Presence of illite-montmorillonite clays are indicator of warm, arid or semi-arid alkaline environment (Dixon and Weed, 1977). Sanu Formation has randomly-oriented mixed layered illite-montmorillonite clays show stable marine sediments and the elevated temperatures are not very high of deeper diagenesis to change their composition (Srodon, 1984; Jones and Sellwood, 1989). The source for montmorillnite may be Deccan volcanic (Grim, 1951), the equivalent formation in Barmer Basin (Fatehgarh Sandstone) has abundant montmorillonite supports the same (Campton, 2009).

The TeTakkar Member of Khuiala Formation is chiefly composed of wackestone, algal wackestone

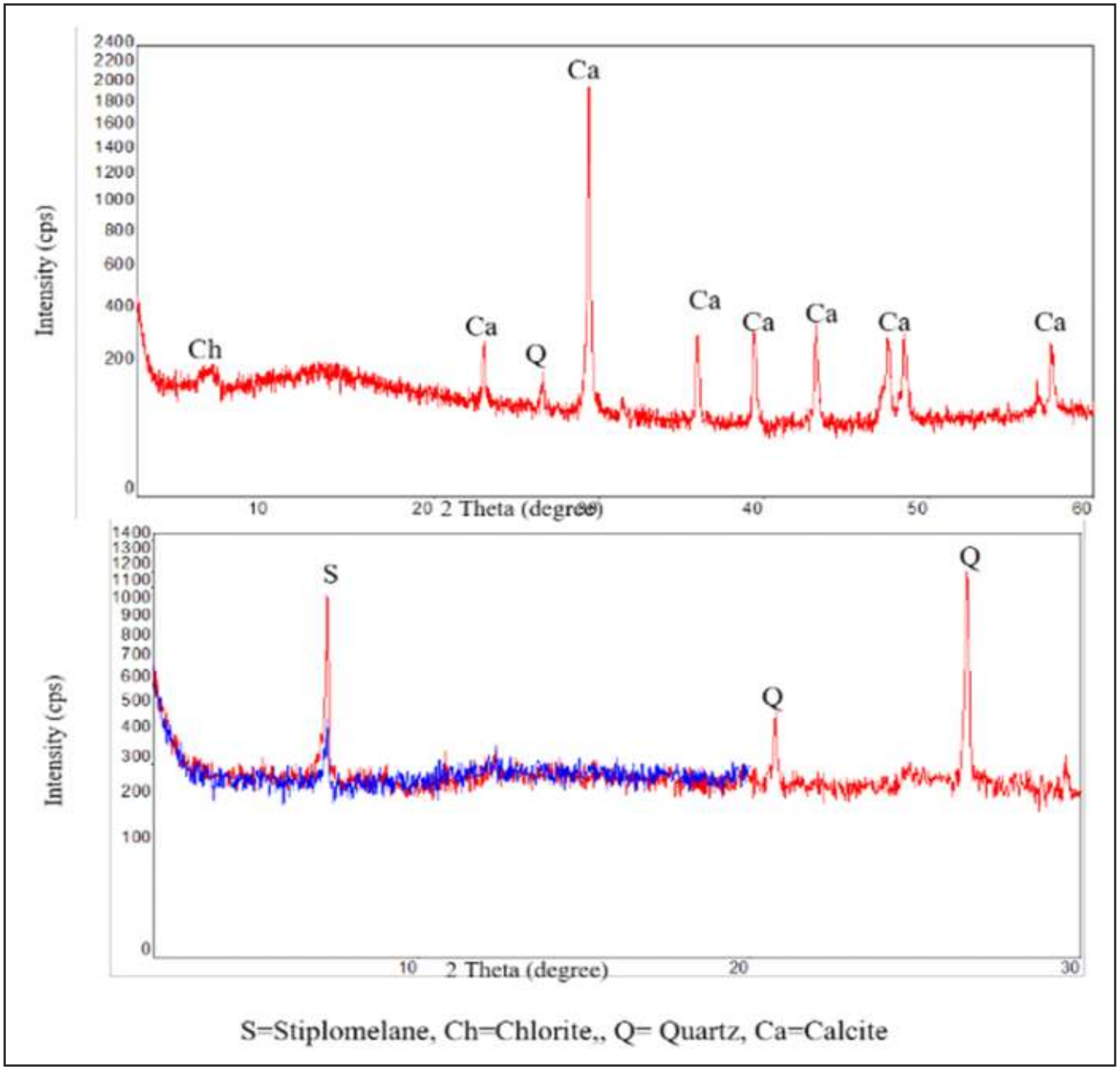


Fig. 10: XRD result of selected samples from Bandah Formation

and mudstone facies in upper part whereas bioclastic packestone and wackestone microfacies in lower part. B2 reservoir of Bandah Formation is nummulitic packestone and wackestone with rare association of nummulitic grainstone while A4 reservoir is mainly comprises mudstone with minor association of wackestone microfacies. The lithoassociation suggests its deposition in low to moderate energy, shelf lagoonal environment. Presence of nummulitic packestone and grainstone in Khuiala Formation suggests high energy intertidal environment. Association of dolomitic mudstone facies is suggestive of shallowing of the basin. The variation of microfacies in vertical sequence are caused be fluctuation of sea level. Kaolinite of these limestone is probably derived (Millot, 1953) in marine diagenesis that marine sediments are rich in organic matter and sulfides with lesser amount of calcite and are relatively rich in kaolinite. In such condition kaolinites are formed by an acid reaction in an anaerobic medium.

CONCLUSIONS

Current study suggests that Habur Formation deposited under shallow marine condition during the Lower to Middle Cretaceous period form base for Tertiary sediments in study area. The overlying Sanu Formation comprises thinly to thickly bedded sediments medium to fine grained with silt and clay. Current bedding is profuse, these are some of the criteria to suggest deposition in a deltaic complex. The existence of iron-oxides in the interspaces between detrital quartz grains is indicative oxidising condition prevailing then. Sub-angular to sub-roundednature of quarts grains reflects moderate distance of transportation.The succeeding Khuiala and Bandah Formations have paucity of clastic materials, dominance of carbonate rocks and abundance of foraminifers and other fossils; these indicate shallow marine environment of deposition. The carbonate sequences of Khuiala and Bandah formations are dense and lithified. However, presence of fair amount of secondary porosity viz. solution and moldic porosities make these sediments a good reservoir rock. In Shumar Formation, fast cycle of sedimentation took place under lacustrine (?) to fluviatile environments, the presence of rounded to well-rounded grains of quarts, fair distribution of reworked foraminifers and the occurrence of variegated Clays, at places, in Shumar Sediments indicates weathering, erosion, and fairly long transportation by fluvial agencies and reworking of sediments. The moderate relief in the provenance is reflected by the presence of feldspar in the sediments. The presence of desert polish in the ironstone and absence of Pteridophytic elements (Lukose, 1977) in particular, suggest that the sediments were deposited undernon-marine environment and the prevailing aridity around the basin.

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