Microfacies, Depositional Environment and Origin of low resistivity sandstone in Lower Cretaceous Pariwar Formation, Jaisalmer Basin, India

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Abstract

This paper documents the omnipresence of low resistivity sandstones occurring within the Lower Cretaceous Pariwar Formation, typically in order of 2-6 ohm-m. The formation conformably overlies the Baisakhi-Bhadasar Formation while its upper contact with overlying Lower Goru Formation represents an unconformity and is known to be hydrocarbon producing, albeit having low resistivity values. Thickly developed Pariwar Formation (ca. 650m-thick) consists mainly of sandstone with coarsening and thickening up trend intervening with thin shale layers. Sandstone is characterized as dirty white, light grey, hard and compact, fine to coarse grained occasionally very coarse, poorly sorted, glauconitic and calcareous at places. Intervening shale is grey to dark grey, occasionally greenish and brownish grey, hard, silty, fissile and calcareous in nature. The lower and middle part of Pariwar Formation show aggradational box-type to fining-up electrolog motifs representing distributary channels and inter distributary tidal flats of lower delta plain. The sands of distributary channels are poorly sorted, matrix rich quartz wacke with rip-up clasts. The interdistributary plains are characterized by alternations of sandstone-shale (heterolithic facies) of tidal origin with medium to fine grained, moderately sorted quartz arenite. The top part of Pariwar Formation is characterized by coarsening-up electrolog motifs. Petrographic study reveals dominant quartz wacke in the lower part of the coarsening-up sands while the top part of each cycle represents relatively better sorted quartz arenite. This progradational coarsening-up sandstone in the top part represents mouth bars in the delta front environment.

In the present paper, 8 wells are studied and detail sedimentological data from Pariwar Formation is generated in terms of petrography, SEM and XRD analysis. It can be concluded from the present study that the lowering of resistivity in sandstones of Pariwar Formation may be caused due to presence of one of the following minerals, viz. Fe-rich cements, like hematite, diagenetically formed Pyrite crystal, glauconitic pellets and chloritic matrix. Presence of each of these conductive minerals has significantly suppressed the resistivity value to a great extent and thereby enhancing the probability of misleading interpretation about the occurrences of hydrocarbon.

Introduction

The chiefly arenaceous Pariwar Formation has been dated Neocomian to Aptian on the basis of foraminiferal studies and deposited in nearshore to inner neritic 30-50m paleo-bathymetry. This paper documents detailed sedimentological studies of Early Cretaceous Pariwar Formation in 8 wells including the newly drilled well CT-E. The existing laboratory data is integrated for microfacies and reservoir data and the facies map was prepared to envisage depositional model of Pariwar Formation. The Formation is characterized by occurrences of low resistivity sandstones. This paper also documents the reason for occurrences of these low resistivity sandstone.

Geological Background

The Jaisalmer Basin is a pericratonic shelf and represents westerly dipping south eastern flank of the Indus Basin (Fig.1). The basin is bounded by Devikot-Nachna uplift towards east and south east while Fatehgarh Fault marks its southern limit. The Pre-Cambrian Malani suite of igneous and metamorphic rocks constitute the floor of this basin over which thick (7 km+) Cambrian to Recent sediments were deposited and has a well-documented Mesozoic and Cenozoic history. The basin deepens towards north and west at a gentle dip of 3^{o} to 5^{o}. Three major structural trends viz. NE–SW (Aravalli grain), ENE-WSW / E-W (Satpura grain) and NNW-SSE (Dharwarian grain) influenced the basin evolution and structural configuration from time to time. The basin is mostly covered by sands of the Thar Desert. From north to south, the Jaisalmer Basin is divided into four tectonic units. These are, Kishangarh Shelf, Jaisalmer-Mari High, Shahgarh Depression and Miajlar Depression respectively. Kishangarh Shelf is relatively stable unfaulted area and falls between Ramgarh Fault to the west and Bikaner-Nagaur Basin to the east. The area has appreciable thickness of Mesozoic and Tertiary sediments and has NE-SW depositional strike and is separated from the Shahgarh depression by Jaisalmer-Mari High which is present day gravity high located along the shoulder zone of the Kanoi Fault and is

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affected by up thrusting and wrench faulting during late Cenozoic time (Mishra, 1986). Shahgarh depression is relatively better explored and represents the area west of Ramgarh Fault that runs almost North - South and is structurally disturbed with numerous N-S trending faults forming north to south trending horst and grabens. The Miajlar sub-basin is structurally simpler westerly gently dipping homocline.

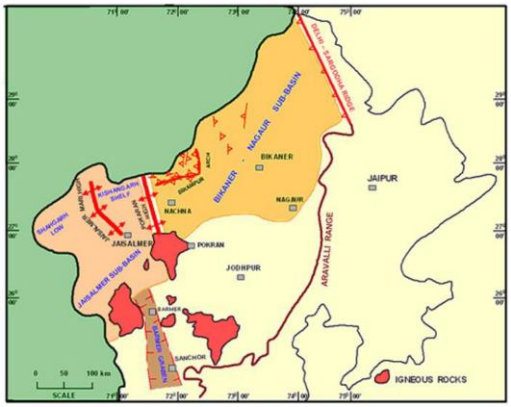

Fig.1: Geological map of Pariwar Formation.

Subsurface Stratigraphy (Mishra, 1993) of the area based on the integration of surface geological data along with wells has been established considering the lithological changes, biostratigraphic data (paleontological/ palynological studies), core data and log data.

Methodology

The present work involves facies and microfacies documentation of sandstones of Pariwar Formation as well as laboratory investigations of the samples collected from cores and cuttings from different wells of Jaisalmer Basin. Megascopic, petrographic, XRD and SEM studies have been carried out from cores and selected samples to identify and infer facies, microfacies, mineral association, type of matrix/ cement, texture and diagenetic imprints. Basic electrolog data incorporating mainly four conventional logs; Gamma-Ray, Resistivity, Neutron and Density logs have been calibrated with lithology and the electrolog motifs were used for regional correlation (8 wells along 2 dip, and 1 strike profiles) of different formations present within Pariwar Formation.

Facies:

Pariwar Formation is more than 600m (+) thick clastic sequence comprising of a thick sequence of alternating fine to medium grained occasionally pyritic sandstone and white, bluish white, dark bluish white, soft, sticky claystones/shale and siltstone at places in the upper part. Sandstone is characterized as dirty white, light grey, hard and compact, fine to coarse grained occasionally very coarse, poorly sorted, glauconitic and calcareous as well as non-calcareous in nature. Mica along with pyrite are commonly present. Shale is grey to dark grey, occasionally greenish and brownish grey, hard, silty, fissile and calcareous in nature. Lower part is fine to medium grained, sub-angular to sub-rounded sandstone. Pariwar Formation is deposited under a regressive phase with intermittent marine influences. The subsurface section in wells Bakhri Tibba-A (820-1388m) and Lang-B (2940-3790m) has been considered as hypostratotype or type well for Pariwar formation (Mishra et al.1993). The Formation is having an unconformable contact with underlying Bhadasar Formation, whereas the upper contact with overlying Goru Formation is conformable.

The subsurface section in the well AT#A has been divided in to three broad units on the basis of their litho-association and is correlated with the four informal units H8, H6 and H4 & H2 already established in reference sections. The bottom most units between 2498-2275m is medium to coarse grained and at times pebbly sandstone with minor shale. A number of instances of occurrence of fossil wood and leaf impressions have been reported (Dasgupta, 1975) from the sandstone bed in the area. This stacked sandstone unit definitely suggest a very high sedimentation rate caused due to base level fall, started towards the end of deposition of underlying Bhadsar Formation, thereby triggering an initiation of large terrestrial supply under normal regressive phase. This unit, which is equivalent to H8 unit, is deposited under shallow marine environment

Due to gradual rise in base level, there was less contribution from the terrestrial agencies and the second unit (2275-2200m), which is roughly equivalent to H6 informal unit was deposited under an intertidal environment with regular interbedded sandstone and shale. Due to further shallowing, there was increasing influence of tidal currents in the area, which led to deposition of the uppermost laminated shale - glauconitic sandstone unit (2200-2110m), equivalent to H4 & H2 informal units and deposited as mixed flat and tidal channel facies.

Microfacies:

The Pariwar Formation is mostly comprised of poorly sorted sandstone having good reservoir characteristics and minor shale interlayers. Petrographically, the sandstone/ siltstone is mainly quartzwacke. The microfacies towards bottom are silty quartz wacke having lensoid silty pods along with preferentially oriented muscovite, thin carbonaceous laminae and fine grained pyrite crystals.

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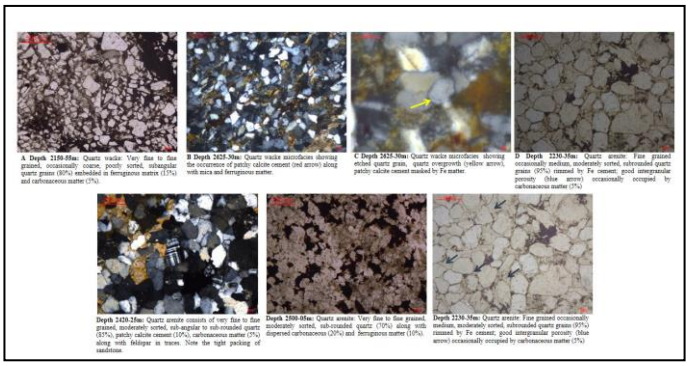

Fig.2: Petrographic attributes of Pariwar Formation

Pariwar Formation is characterized by coarsening up electrolog motifs in the upper part. Petrographic study reveals dominant quartz wacke in the lower part of the coarsening up sands while the top part of each cycle represents relatively better sorted quartz arenite. In the recently drilled well CT-E, lower and middle part of Pariwar Formation show aggradational to fining up electrolog motifs representing lower distributary channels and inter distributary tidal flats. The sands of distributary channels are poorly sorted, matrix rich quartz wacke with rip up clasts. The interdistributary sands of tidal origin are medium to fine grained, moderately sorted quartz arenite. Quartz wacke (2150-2155m and 2625-2630m in CT-E) consists of very fine to fine grained occasionally coarse, poorly sorted, sub angular to sub rounded quartz grains (70-80%) and carbonaceous matter (5-10%) embedded in ferruginous clay matrix (15-20%). (Fig.2A-B). Quartz overgrowth, etched quartz grains and patchy calcite cement in traces are also observed (Fig.2C). Quartz arenite (2230-2235m, 2375-2380m, 2390-2395m, 2420-2425m, 2490-2495m & 2500-2505m in CT-E) consists of fine grained occasionally medium grained, moderately sorted, sub angular to sub rounded quartz grains (60-85%), altered glauconite pellets (0-5%) and carbonaceous matter (0-10%) bounded by calcite cement (10-35%) and iron cement (0-5%) (Fig.2D-F). Etched quartz grains and intergranular porosity are also observed (Fig.2G).

XRD and SEM analysis:

Bulk mineralogy of the selected samples indicate presence of chlorite, kaolinite, plagioclase feldspar, calcite, dolomite and quartz minerals (Fig.3A). Clay mineralogy of the selected samples indicates kaolinite as a dominant mineral along with illite apart from associated quartz (Fig.3B).

SEM study reveals poor to moderate reservoir characteristics. Porosity is being affected by pores filled with smectite, kaolinite clays. Porosity is also diminishing due to quartz overgrowth. Occurrence of pyrite and detrital clay are also observed (Fig.3C). The studies show that the sandstone is

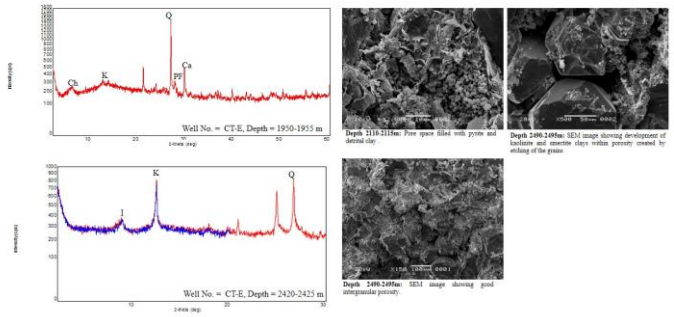

Fig.3: XRD and SEM attributes of Pariwar Formation

fine to coarse grained with poor to moderate porosity in general with good intergranular porosity at many places (Fig.3D). The matrix is kaolinite with minor smectite. All the samples show similar diagenetic changes in the form of abundant quartz overgrowth, authigenic kaolinite, minor pyrite crystals and traces of chlorite have led to partial occlusion and at places extensive loss of porosity. Smectite at few places is transformed to tiny threads of illite. Euhedral quartz grains with projection of crystal faces are very prominent (Fig.3E).

Regional Correlation:

Stratigraphic correlation, based on electrolog signatures along with geological data and sedimentological input, has been carried out to understand the regional variation in nature and thickness of various stratigraphic units/formations in Jaisalmer Basin. In order to understand the

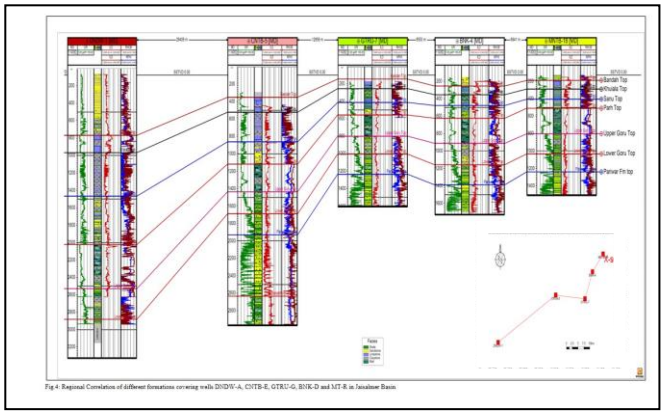

Fig.4: Regional Correlation of different formations covering wells DNDW-A, CNTB-E, GTRU-G, BNK-D and MT-R in Jaisalmer Basin

lateral and vertical thickness variation of different formations/stratigraphic units, two correlation profiles are chosen, viz. (a) NE-SW correlation profile was chosen consists of wells MT-R, BK-D, GTRU-G, CT-E and DNDW-A (Fig.4)

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and (b) NW-SE correlation profile consists of wells VKNT-A, BT-E, GTRU-G and CT-E (Fig.5).

The different formation boundaries are well correlatable in all the wells and as the 3 wells in Profile-1 consisting of MT-R, BK-D and GTRU-G in the NE-part are strike-parallel, there is no major thickness variation in these 3 wells. However, the well CT-E and the further basinward well, DNDW-A shows thicknening-up trends of all the formations towards the basin indicating basinward depocentre and progradation of facies-units towards basin. The 2 basinward wells (CT-E and DNDW-A) also are structurally down w.r.t the 3 wells drilled in basin margin part. Also in Profile-2, the basinward wells GTRU-G and CT-E are structurally deeper than the two basin margin wells VKNT-A and BT-E and the formations are thicker gradually towards basin.

Fig.5: Regional Correlation of different formations covering wells CT-E, GTRU-G, BT-E and VKNI-A in Jaisalmer Basin

The Pariwar Formation has been highlighted in the present correlation which records a Highstand Systems Tract (HST) after deposition of Baishakhi-Bhadesar and the boundary between the 2 formations represent a Maximum Flooding Surface (MFS). This HST can be subdivided into a basal aggradational parasequence, represented by lower delta plain deposits (distributaries and inter-distributary tidal flats characterized by alternations of sandstone-shale heterolithics) followed up by a coarsening-up prograding bars (mouth bars of delta front). The tidalites show a vertical stacking-up of facies indicating that the relative sea-level change and sedimentation rate are almost balancing each other. These two parasequences within the Pariwar Formation are well correlatable and the top of Pariwar Formation represents an unconformity in basin margin, when due to progradation the paleoshoreline has shifted basinward considerably. After deposition of Pariwar the Lower Goru again represents a rise in relative sea-level and thereby representing destructive delta favoring estuarine conditions.

Facies Map:

The facies maps are prepared at Pariwar level by incorporating all drilled well data. The facies map indicates a basinward shift of paleoshoreline during Pariwar time representing an event of regression followed by delta building. Sediments were delivered from eastern part during this relative sea-level fall resulting constructive delta-development. Initially the lower delta plains consist of distributaries and inter-distributary tidal flat sediments were deposited. The electrolog motif shows an aggradational facies development when the relative sea-level change kept pace with sediment supply. However, afterwards the increase in sedimentation rate promotes progradation of delta further west of present well CT-E (Fig.6).

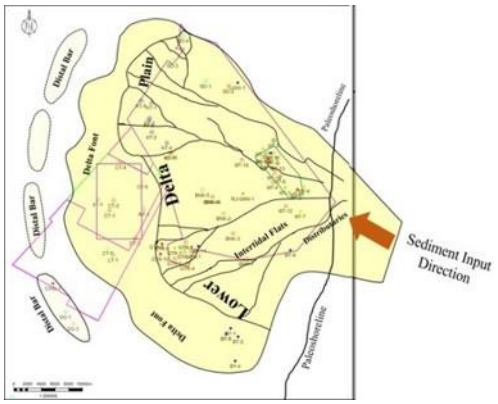

Fig.6: Facies map of Pariwar Formation

The progradational limit is marked in the facies map, which lies just east of wells SG-A and SG-B in the basinward side where continuous finer grained basinal indigenous sedimentation took place in the pro-delta region. The very fine to fine grained, relatively well sorted sandstones in wells SG-A and SG-B may represent distal wave reworked bars in front of prograding delta. The available sediments in delta mouth may have reworked by waves and possibly developed these offshore shore-parallel wave dominated bars.

Occurrences of Low resistivity sands:

Pariwar Formation is characterized by occurrences of sandstone having low resistivity values, typically fall within 1-3 ohm-m (Fig.7). In many intervals, these sands (viz., CT-A, C,D, BK-D) are hydrocarbon producing. To know the reason of low resistivity, core and cutting samples from different drilled

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depths against low resistivity zones were analyzed. In this paper a total of 4 wells are considered for the study. The results were summarised below:

Well-A:

The sandstones of Pariwar Formation are characterized as dirty white, light grey, hard and compact, fine to coarse grained occasionally very coarse, poorly sorted, glauconitic and calcareous as well as non-calcareous in nature. Mica along with pyrite are commonly present. Petrographic analysis of the sandstone indicate presence of ferruginous clay matrix, pyrite and glaucoite pellets which is lowering the resisitivity of sandstone in Pariwar Formation. Presence of pyrite is also confirmed by the SEM study.

Well Name	Reason for Low Resistivity	Sample Details	Petrography
A	Siderite, Glauconite	CC-4, 1041-1050m	Quartz wacke
	Pyrite and Glauconite	CC-5, 2247-2251.30	Galuconitic Sandstone
	Iron Cement	CC-4, 2135-2140	Fine grained Sandstone
B	Glauconite, Pyrite, iron cement		Quartz wacke and quartz arenite
C	Iron cement, Glauconite, Pyrite, pyrite cement, siderite	1235-1240, CC-2(1252.23, 1253.92, 1254.03, 1258.88, 1260.14) & CC-3	Quartz wacke, Quartz arenite
D	Glauconite, Ferruginous Clay Matrix	CC-1, 1420-1425, 1550-1555	Quartz wacke and quartz arenite

Table1: Tables should be properly annotated with each column head giving units of measurement.

Samples collected in the interval 2150-2155m (Well: CT-E) shows profuse presence are mainly caused by presence of chloritic matrix and Fe-rich cements (Fig.7). The resistivity values are 3-4 ohm-m as seen in electrolog.

Samples from 2375-2380m also show low resistivity values in order of 1-3 ohm-m and samples reveal presence of chloritic matrix and pyrite crystals that may act as good conductors to suppress the resistivity values (Fig.8).

The samples in the interval 2390-2395m also shows low resistivity values (2-4 ohm-m) and are characterised by presence of well-developed glauconitised pellets. These glauconite pellets have developed due to marine authigenesis by gradual replacement of Fe and Mg intake by pallet grains. The glauconitisation process has increased the conductivity of the formation as a result of which the resistivity is supressed (Fig.8).

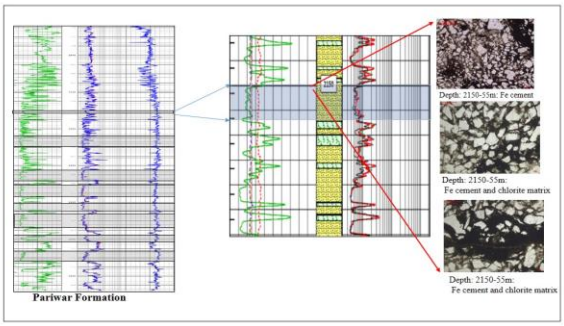

Fig.:7: Petrographic attributes showing Fe cements and chloritic matrix in sandstones of Pariwar Formation of well-A

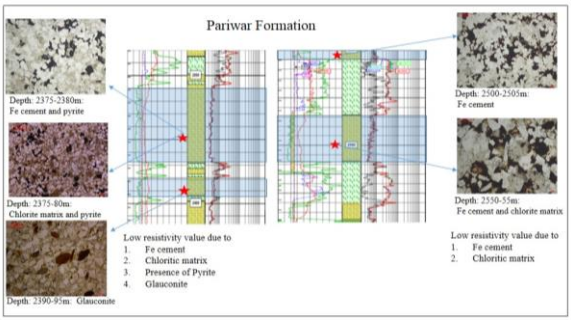

Fig.:8: Petrographic attributes showing glauconite, Fe cements and chloritic matrix in sandstones of Pariwar Formation of well-A

The samples in the interval 2500-2505m have also shown low resistivity values (5 ohm-m) and petrographic studies show presence of omnipresence of Fe-rich cements (Fig.8).

The samples in the interval 2550-2555m have also shown low resistivity values (5 ohm-m) and petrographic studies show presence of chloritic matrix and Fe-rich cements (Fig.8).

Well-B: The sandstones of Pariwar Formation

Samples collected in the interval 1387m (Well:B) shows profuse presence of glauconite (Fig.9). The resistivity values are 3-4 ohm-m as seen in electrolog.

Samples from 1391.70m also show low resistivity values in order of 1-3 ohm-m and samples reveal presence of Fe- cement that may act as good conductors to suppress the resistivity values (Fig.9).

Samples from 1420-25m and 1550-1555m intervals also shows low resistivity values (2-4 ohm-m) and are characterised by presence of well-developed glauconitised pellets and pyrite. These glauconite pellets have developed

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due to marine authigenesis by gradual replacement of Fe and Mg intake by pallet grains. The glauconitisation process has increased the conductivity of the formation as a result of which the resistivity is supressed (Fig.9).

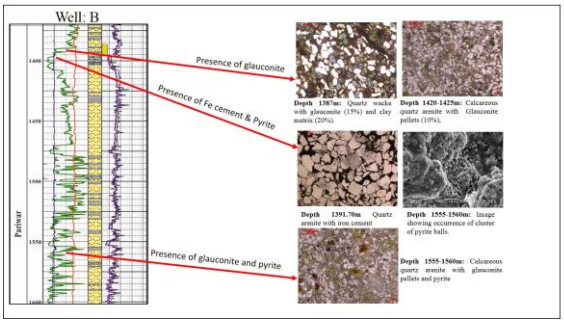

Fig.9: Petrographic attributes showing presence of glauconite, Fe cements, and chloritic matrix in sandstones of Pariwar Formation in well-B

Well-C: The sandstones of Pariwar Formation

Samples at depth 1252.23m (Well:C) shows presence of glauconite (Fig.10). The resistivity values are 3-4 ohm-m as seen in electrolog.

Samples from 1252.92m also show low resistivity values in order of 1-3 ohm-m and samples reveal presence of ferruginous clay matrix along with glauconite and (Fig.10).

The samples in the interval 1380-1385m have also shown low resistivity values (5 ohm-m) and petrographic studies show presence of omnipresence of Fe-rich cements (Fig.10).

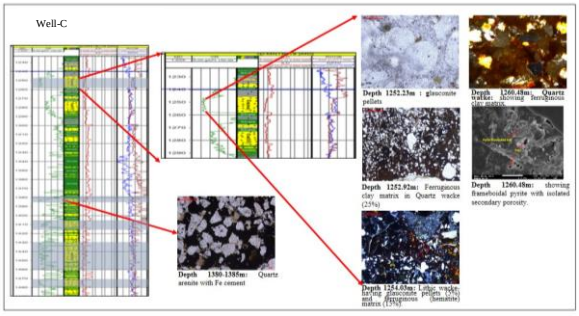

Fig.10: Petrographic attributes showing presence of glauconite, Fe cements, and chloritic matrix in sandstones of Pariwar Formation in well-C

Conclusions:

1. Detailed sedimentological analysis of Pariwar Formation indicate deposition in a shallow marine lower delta paleo-environment. The sediment dispersal is from ESE in Jaisalmer Basin.
2. The facies map indicates a NNE-SSW paleoshoreline orientation and a basinward shift of paleoshoreline during Pariwar time representing an event of regression as is indicated by constructive delta building.
3. Pariwar Formation is characterized by low resistivity sands. By integrating different well data, it can be concluded from the present study that the lowering of resistivity in sandstones of Pariwar Formation may be caused due to presence of one of the following minerals, viz. a) Fe-rich cements, like hematite and Ferruginous clay matrix, b) diagenetically formed Pyrite crystals, c) Glauconitic pellets and d) Chloritic matrix.
4. Statistically, it has been observed that presence of glauconite and Fe cement are mainly responsible for low resistivity sandstone reservoirs. Therefore, mineralogical parameters of these sandstones are important while calculating HC saturation, as in many places these sands are HC producing.

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