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Characteristics of reservoir facies and diagenetic imprints in Vindhyan sediments of Son Valley, Vindhyan Basin

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Abstract

The paper is an attempt to determine the depositional environment, reservoir characteristics and diagenesis of the subsurface sediments, with special emphasis on Rohtas Limestone and Kaimur sandstones from where hydrocarbon was produced, through high resolution sedimentological techniques. The sediments are exposed in three major sectors, namely Son valley, Bundelkhand and Rajasthan. ONGC has drilled a number of wells in Nohta, Damoh, Jabera and Kharkhari prospect in Son Valley for the search of hydrocarbon and so far has achieved limited success in Nohta, Damoh and Jabera prospects. The present study has been carried out in Nohta area to understand the depositional environment, reservoir characteristics and diagenetic processes in the subsurface sediments, especially in Rohtas Limestone, Kaimur and sandstones. The Basement (granite gneiss) has been encountered for the first time in this area which is equivalent to Bundelkhand gneissic complex. The area has Kajrahat Limestone being the oldest and Maihar Sandstone as the youngest formations ranging in age from Ediacaran to Statherian. The Vindhyan sediments are mainly deposited IDas foreshore to shorefacefacies in fluctuating inner shelf to carbonate tidal flat environment. The Maihar and Kaimur sandstones are mature quartz arenite showing tight framework of grains as evident by concavo-convex contacts, siliceous cement and quartz overgrowth which resulted in deterioration of primary intergranular porosity in them. Diagenetic studies reveal that burial has caused the solution and reprecipitation of silica in the intergranular space of Kaimur Sandstone there by, destroying most of the primary porosity which has adversely affected the reservoir quality. The Rohtas Limestone is chiefly mudstone which is well indurated and recrystallized at places and traversed by low amplitude stylolites indicating post depositional compaction and solution phenomena. The fractures developed have created some secondary porosity which has provided pathways for migration/accumulation of gas in Nohta structure and form characteristic unconventional fractured reservoir.

Introduction

The Vindhyan Basin is a classical example of Proterozoic intra-continental basin that developed in the central part of Indian shield. The basin is bounded by Monghyr-Saharsa ridge in the east and Indo-Gangetic plain in the north. The southern margin of Vindhyan Basin is marked by a major ENE-WSW trending Son-Narmada lineament, to the south of which lies Satpura ranges. The western margin of the basin is demarcated by NE-SW trending Great Boundary Fault which separates Aravalli-Delhi ranges from Vindhyan basin in Rajasthan sector. Bundelkhand massif divides the basin into two parts: a) Son valley in the south-eastern side where exposures occur from Sasaram (Bihar) in the east to Sanwad (Madhya Pradesh) in the west; b) Chambal valley in the north-western side and they cropped out from Agra (Uttar Pradesh) to Chittor (Rajasthan). The present study area falls in north eastern part ofSon valley, Vindhyan Basin, the subsurface section around exploratory wells NOT-A, B and C area (Fig. 1) covering Lower and Upper Vindhyansand detailed sedimentological studies have been undertaken for their depositional pattern, diagenesis and reservoir characteristics identification.

Experimental Details

The study has been carried out on the cuttings, side wall cores and conventional cores from different formations of drilled wells in Nohtastructure. Selected samples are studied for petrographic details to understand the mineralogy and texture. TheSEM-EDX and XRD studies are carried out for reservoir petrography and mineralogy and fracture demarcation. XRD analysis is done to know the bulk mineralogy and the calcite/dolomite proportion.

Result and Discussion

Based on lithofacies analysis of sediments encountered in the well NOT-A, six formations were identified in Lower Vindhyan namely Kajrahat Limestone, JardepaharPorcellanite,Charkaria Olive Shale Member, Mohana Fawn Limestone, BasuhariGlauconite Member and Rohtas Limestone and seven formations in Upper Vindhyan namely Kaimur Sandstone, Jhiri Shale, Rewa Sandstone, Ganurgarh Shale, Nagod Limestone, Sirbu Shale and Maihar Sandstone. Basement (granite gneiss) is encountered for the first time in this area in well NOT-A. The other two wells (i.e.,NOT-B and C) are terminated in the upper part of the LowerVindhyan.

Lithothologically the Lower Vindhyanas a whole is represented by limestone, shale, porcellanite with minor amount of sandstone/siltstone. Limestone is white to dirty white, light gray, massive, pyritic and development of secondary calcite, at places showing healed fractures, very hard and compact. Shale is gray to light gray, poorly fissile, micaceous, at places calcareous, pyritic and silty. Siltstone/sandstone is gray to light gray, occasionally dirty white, hard and compact, with fused grains, rarelymicaceous and feebly calcareous. At the lower part of this group in Kajrahat Limestoneformation some evidences of diagenesis and incipient metamorphism as mica transformation into chlorite, partial development of dolomite crystals with zonningand development of quartzite within limestone and sandstone respectively noticed. (Figs. 3 A, B and C).

The lower most Lower Vindhyansediments belonging to Kajrahat Limestone were deposited in shallow marine environment with changing coastal and tidal flat condition with intermittent supply of detritus as suggested by the presence of limestone and shale interlaminations with minor amount of sandstone. The overlying JardepaharPorcellanite mainly composed of porcellanite, shale, claystone, traces of siltstone and limestone. The litho association and mineralogical suit suggest that this sequence was deposited in lagoons/mud-flats/tidal flat under oscillating conditions. The Charkaria Olive shale member above comprises gray to olive gray shale at places laminated with thin bands of siltstone and limestone is indicative of shelf lagoonal depositional environment. Mohana Fawn Limestone overlying Charkaria Olive shale memberis mainly consisting of limestone-shale alternations deposition inferred to represent carbonate tidal flat environmental settings. BasuhariGlauconite Member above has a monotonous shale sequence with glauconitic composition as indicative of shallow marine tidal flat shelf environment. The upper most Lower VindhyanRohtas Limestone Formation is characterized by limestone and shale alternations appears to be deposited under carbonate tidal flat (mud flat) environment.

In the present study focus has been put on study of Rohtas Limestone as being the main reservoir facies in Lower Vindhyan. Within Rohtas Limestone, one core CC-1; (1567-1576m) was taken for detailed sedimentological studies in well NOT-B. The core represents thinly parallel-interlaminated shale and limestone (Figs. 2 A and B).Petrograpically limestone in Rohtas Limestone Formation reveals recrystallized mudstone with dispersed very fine detrital grained quartz grains,micrite and dolomite. Argillaceous matter is present in the form of thin lamination or asstylolaminations(Figs. 2 C and D).X-ray diffraction of selected cutting samples of Rohtas Limestone indicates presence of calcite (37-81%), quartz (12-57%) and dolomite (5-6%)(Fig. 4A).Back scattered SEM images shows that the overall nature of this reservoir is tight with some micro-fractures in the interval (1670-75m) in well NOT-B. SEM studies in the interval (1705-10m) in well NOT-C shows presence of a colony of acritarchof Late Neo Proterozoic age (Edacarian) (Figs. 4B&C).

An attempt has been made to correlate the Rohtas limestone in all the three wells (NOT-A, B and C) drilled in Nohta Structure. It has been observed that all the three litho-units identified in NOT-C are well correlatable with well NOT-A (Fig. 5), however, the well NOT-B was drilled only upto upper litho-unit. Based on the log signatures, the upper unit can be further divided into three sub layers and is present in all the three wells and dominantly consist of limestone with thin bands of silty shale. Facies in all the three wells is dominantly mudstone which is re-crystallized/sparitized and partially dolomitized at places. All these wells have produced gas from Rohtas Limestone section but from different levels. NOT-A and B have produced from the upper lithounit whereas, NOT-C has produced from the middle and lower lithounits.

Diagenetic studies reveal that Rohtas limestone is chiefly mudstone which is well indurated and recrystallized at places and traversed by low amplitude stylolites, indicating post depositional compaction and solution phenomena. The fractures developed have created some secondary porosity which has provided pathways for migration/accumulation of gas in Nohta structure and form characteristic unconventional fractured reservoir.

Constructive fracture facies, fractures form owing to diagenesis or self-shrinkage indicating constructive reservoir quality. The reservoir seems to be unconventional fractured reservoir.

The Upper Vindhyan section chiefly comprises of sandstone, shale and limestone. Two varieties of sandstone are present, one is dirty white to light gray, fine to medium occasionally very fine grained, variably micaceous, at places calcareous, hard and compact. Other is reddish, fine to medium grained, micaceous, non-calcareous, ferruginous and hard. At the lower part of the group it is chloritic in nature. shale is gray to dark gray, variably reddish brown, incipient fissile, micaceous, silicified, at places feebly-calcareous, at times silty and impregnated with disseminated pyrite. Limestone is brownish gray to dirty white, at times fleshy, variably sparitized, massive and hard.

In Upper Vindhyan, Kaimur sandstone comprising sandstone alternation with shale and thin bands of limestone was deposited at the base of upper Vindhyan. The clastic input corresponds to shoaling-beach complex and is a regressive stack laid down in transitional environment. The overall environment responsible for this litho association deposition is shoreface-tidal flat. The dark grayJhiri shale association with occasionally light gray inter-beds of sandstone correlate well with a sub-tidal & inter-tidal facies association. The predominant monotonous Rewa sandstone facies association with bands of shale facies and minor limestone are indicative of the influx of finer facies infers a foreshore to shoreface beach depositional environment. The ferruginous silty shale of Ganurgarh Shale association with alternate bands of limestone & minor amount of sandstone sequence deposited in shallow sub-tidal environment with fluctuating energy conditions. Nagod Limestone containing repetitive Limestone-shale sequence with thin intercalations of sandstone/siltstone appears to be deposited under carbonate tidal flat (mud flat)-foreshore environment. Sirbu shale is predominantly a shale unit which comprises of gray, occasionally dark gray shale sequence association with interlaminations of siltstone/ sandstone is well fitted in a sub-tidal/inter-tidal depositional environment. The Maihar sandstone section is dominantly arenaceous unit containing sandstone and minor siltstone with inter-beds of shale indicative of winnowing currents are propelling to infer foreshore beach to shoreface depositional environment.

Kaimur sandstone comprising sandstone alternation with shale and thin bands of limestone was deposited at the base of upper Vindhyan.Petrographic study of selected samples from Kaimur sandstone indicates the microfacies is quartz arenite comprising, subangular to subrounded, fine to medium grained, moderate to well sorted quartz , ferruginous cement and silica cement (Figs. 6A and B). Framework of quartz has depicting overgrowth and concavo-convex contacts (Fig. 6A), grain of chlorite held by secondary ferruginous cement (Fig. 6 B).Biotite mica has diagenetically altering into chlorite (Fig. 6C).

SEM study of selected samples show tightly packed quartz grains leading to inhibited porosity and clay lining between tightly packed sand grains adverserly affecting the reservoir quality.(Figs. 7A&B).

Diagenetic studies reveal that burial has caused the solution and reprecipitation of silica in the intergranular space of Kaimur Sandstone there by, destroying most of the primary porosity.

Compaction dense facies and cementation dense facies indicates poor reservoir quality of the Upper Vindhyan group sandstones as a destructive facies.

Conclusion

Based on Sedimentological studies total thirteen formations are presentin Son Valley in Lower Vindhyan and Upper Vindhyan groups. Kajrahat Limestone is the oldest formationwhereas Maihar Sandstone is the youngest formation. Basement (granite gneiss) wasencountered for the first time in this area in well NOT-A.

The Rohtas limestone is mainly mudstone at places recrystallized, selectively dolomitized and sparitized. The sandstone in Kaimursandstone formation is chiefly mature quartz arenite showing tight framework of grains.

The sandstones of Vindhyan sediments with alternate thin beds of shale/siltstone were deposited in foreshore to shoreface environments. Limestone and associated shale facies are deposited in carbonate tidal flat regime.

Diagenetic studies reveal that Rohtas limestone is chiefly mudstone indicating post depositional compaction and solution phenomena. The fractures developed have created some secondary porosity which has provided pathways for migration/accumulation of gas in Nohta structure and form characteristic unconventional fractured reservoir. In case of Kaimur sandstone burial has caused the solution and reprecipitation of silica in the intergranular space of Kaimur Sandstone there by destroying most of the primary porosity.

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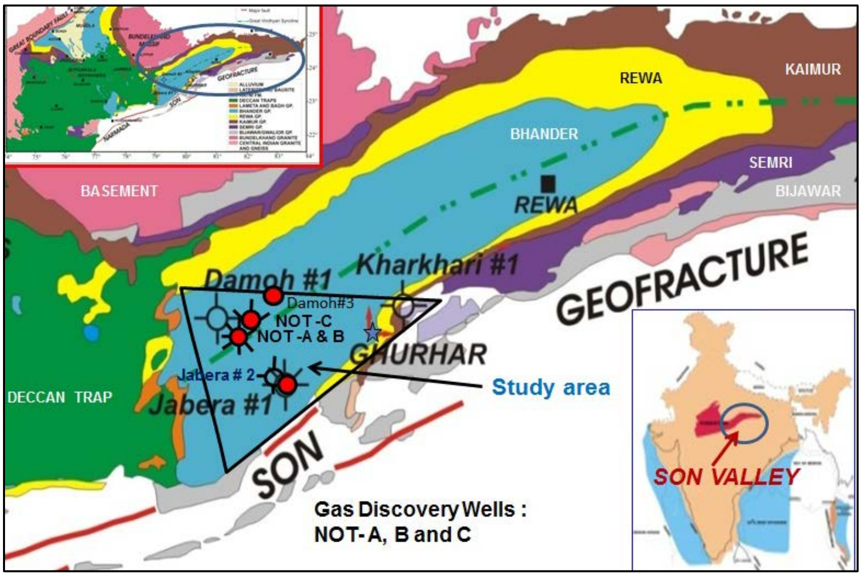


Fig.1: Geological map of Son Valley and location map of the wells in the study area.

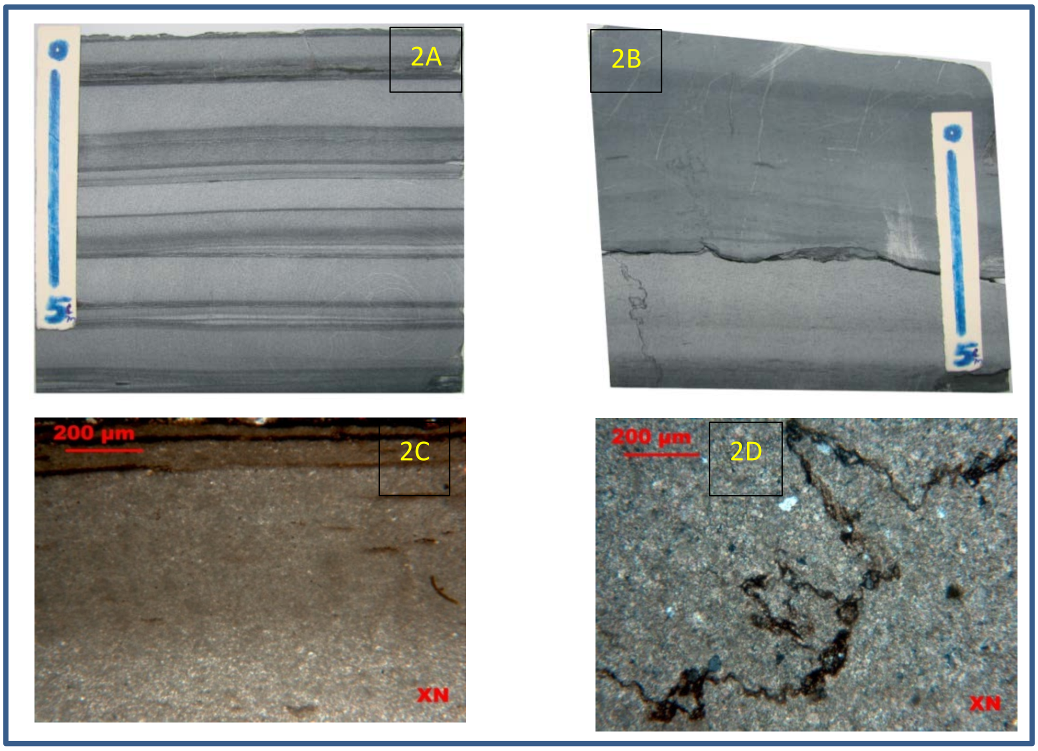


Fig.2: Core photograph of well NOT-B depicting sedimentary structures: lamination & stylolite (2A & 2B respectively) and microfacies details: lamination &stylolites having concentration of carbonaceous matter (2C &2D respectively). Rohtas limestone.

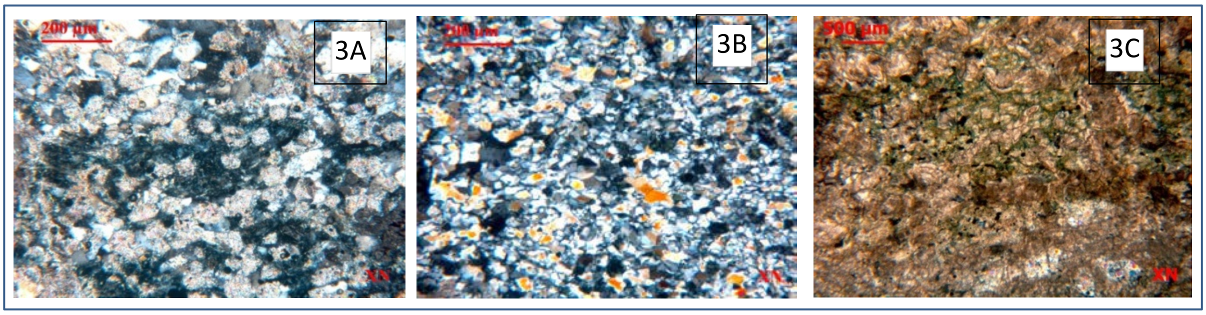


Fig.3:Photomicrographof mica transforming in to chlorite, development of quartzite suggesting incipient metamorphism and partial dolomitization with zoning (3A, 3B & 3C), Kajrahat limestone in NOT-A.

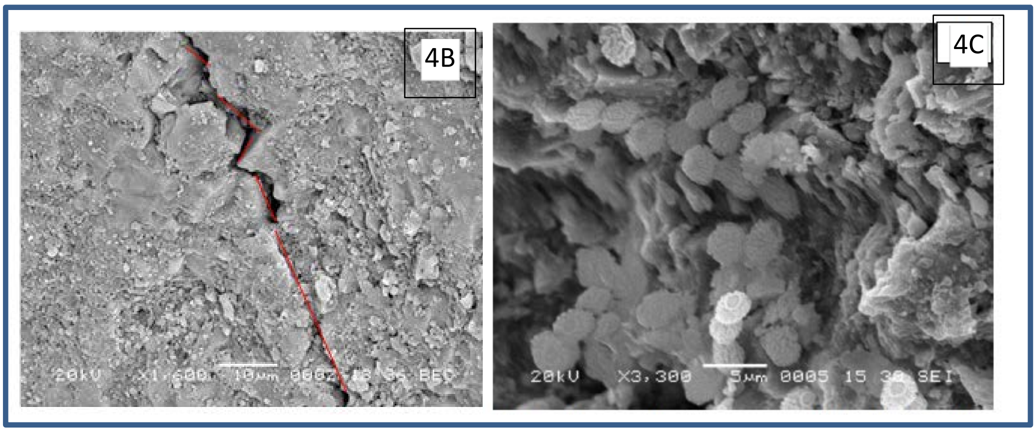
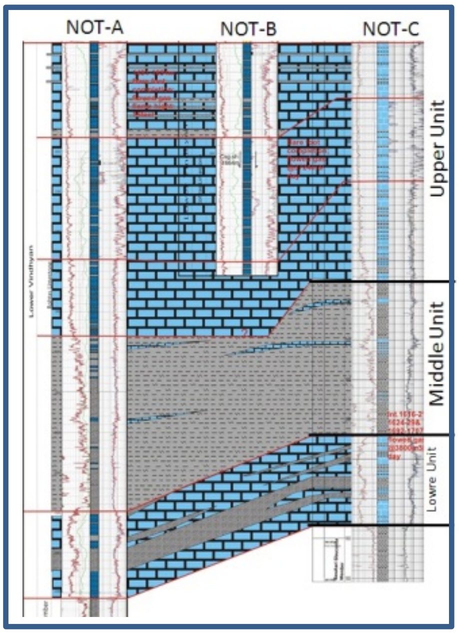
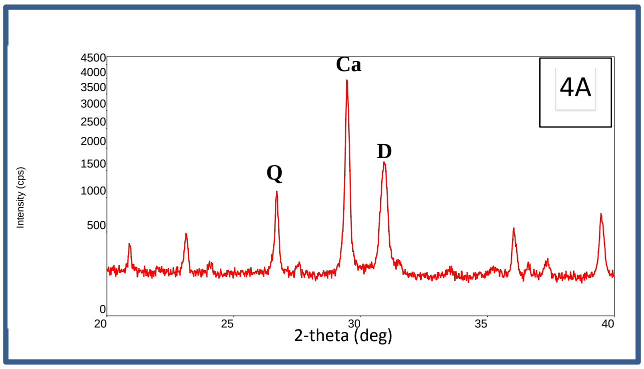


Fig.4 : SEM photographs showing microfracture and presence of Acritarchs and tiny dolomite rhomb in Rohtas limestone.





Ca=Calcite, D=Dolomite, Q=Quartz

Fig.4: X-ray diffractogramshowing bulk mineralogy of CC-1 (1567-1576m) in Rohtas Limestone in NOT-B

Fig.5 :Facies correlation of Rohtas limestone showing three distinct units, The middle unit is more argillaceous and is dominantly shale.

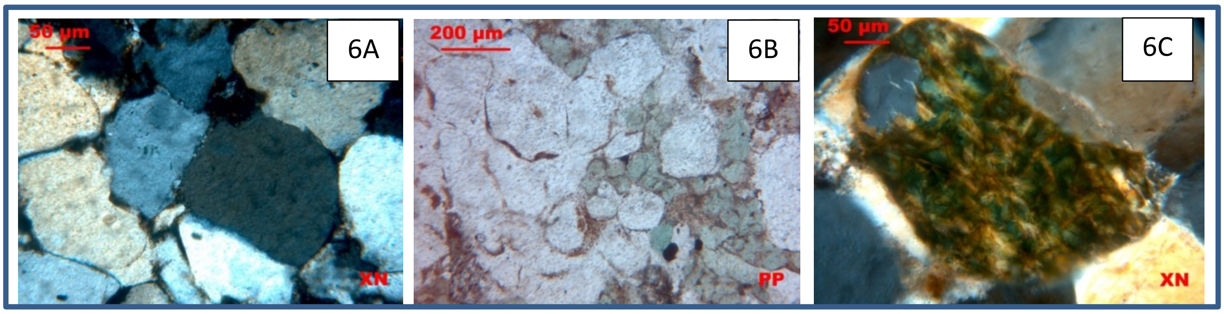


Fig.6: Photomicrographs showing typical quartz overgrowth indicating silica cementation (6A), fine to medium grained, chlorite with ferruginous cement (6B) and depicting biotite mica diagenetically altering in to chlorite (6C), Kaimur sandstone.

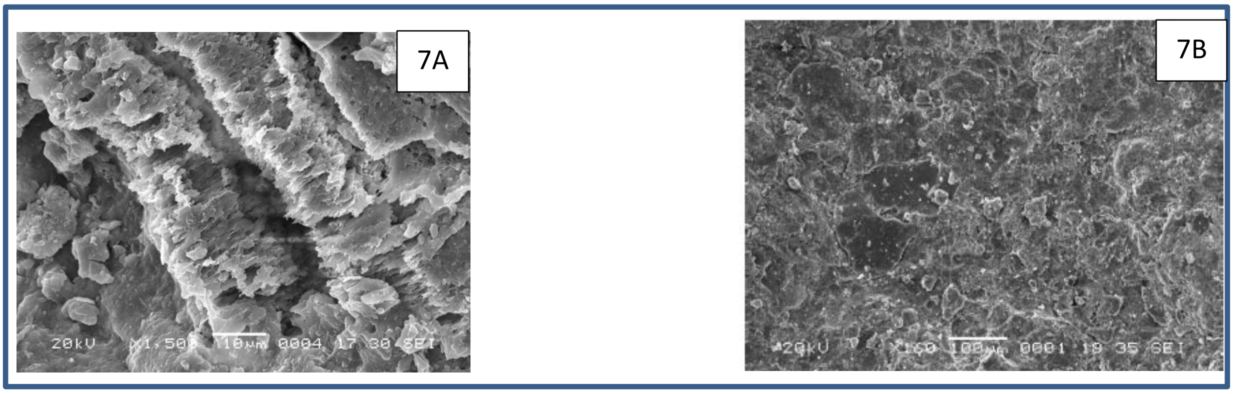


Fig.7: SEM photograph showing clay lining between tightly packed sand grains and thereby destroying porosity (8A) and general view of quartz arenite showing destruction of porosity due to prolonged silification process (8B) in Kaimur sandstone.