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Signatures of Marine Influences in the Gondwana Sandstones of Kalijhora, Darjeeling District, West Bengal, India

Ranjeeta Kar[1,2], Hrishikesh Baruah[1] and Sarat Phukan[2]
[1] Department of Geology, Arya Vidyapeeth College, Guwahati: 781016, India
[2] Department of Geological Sciences, Gauhati University, Guwahati: 781014, India
Email: hbaruah@hotmail.com

ABSTRACT

Kalijhora in Darjeeling district of West Bengal happens to be one of the few places in extra-peninsular India which hosts Gondwana rocks. While Gondwana sedimentation in peninsular India largely took place within a fluviatile regime, marine influences on these rocks have been proved from some areas of Himalayan region mainly based on paleontological attributes which are absent in Kalijhora. The Kalijhora lithostratigraphic column which exudes imprints of Himalayan geodynamism is largely arenaceous with minor carbonaceous shale, sandy shale and coal. These arenaceous units were investigated in detail to locate marine signatures, if any. The sub-arkose to sub-litharenite Kalijhora sandstones having more of calcareous cements show imprints of locomorphic to phyllomorphic stages of diagenesis. Mg/Ca ratio of Kalijhora sandstones hints at possible precipitation of low to high magnesian calcite under a marine influence. The presence of dolomite in pore spaces and the dolomitic accretions in the form of stars indicate a phase of dolomitic intrusion which is a distinct marine signature. Further, both primary euhedral dolomite cement crystals and secondary dolomitized cements represent two phases of cementation that can be inferred to have formed during a possible marine incursion phase as seawater is the common and principal source of Mg in sediments.

Keywords: Gondwana sandstones, Kalijhora, Extra-peninsular India, SEM studies, marine signatures

INTRODUCTION

Accretions of crustal masses to form supercontinents and their subsequent disintegration have been cyclic episodes in the geological history of the Earth. Fragmentation of Gondwanaland into smaller cratonic blocks, colossal deposits of Gondwana sediments along reactivated rifted basins as well as continental margins, formation of Neotethys, luxuriant forest growth; variations in climate and environmental setup with respect to time, crustal sagging and consequent marine incursions etc. were some of the important geological events of the Late Palaeozoic Era. Sustained rifting and breakup of Gondwanaland along the pre-existing zones of weaknesses determined the land-sea distribution on the Earth subsequently. Structural fabric of the Indian Ocean and the Gondwana grabens on the Indian Plate for example, mirrors a broad similarity in the orientation of weak zones on the crustal slab (De, 1977).

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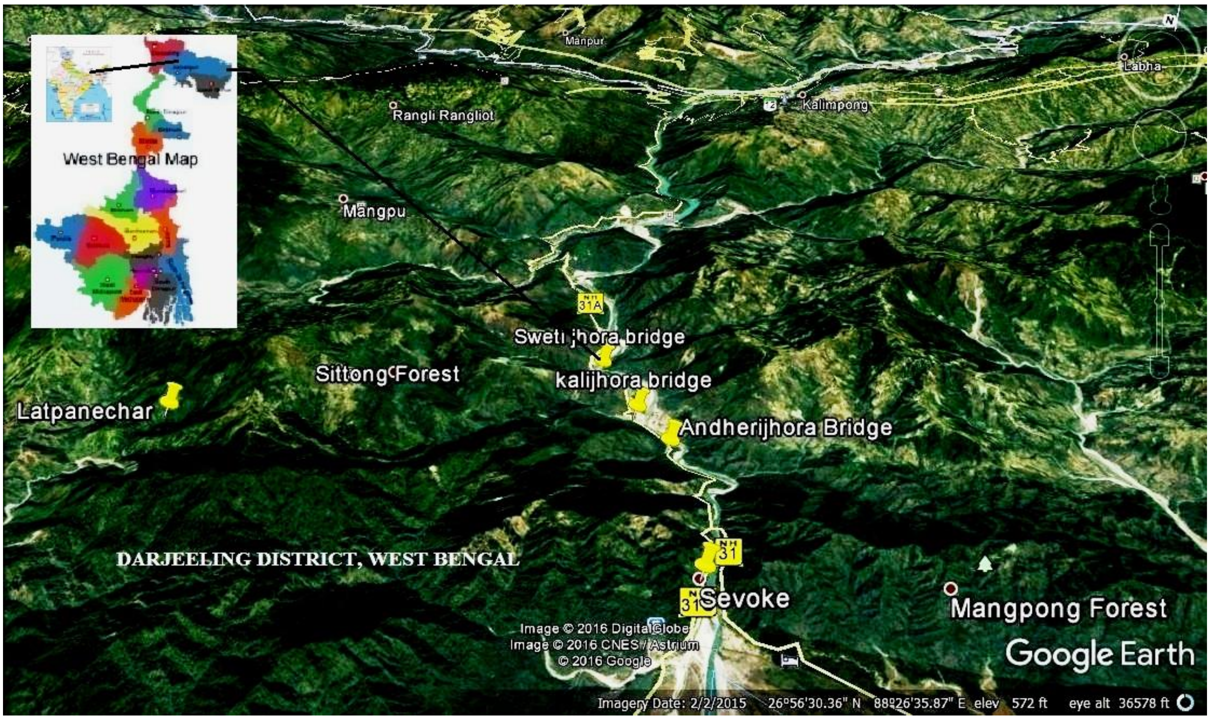

Fig. 1: Location map of Kalijhora in West Bengal of India (Source: Google Earth image).

Gondwana rocks, which are dispersed in many now separated locales, were initially sites of glacial, vigorous fluvial, alluvial, lacustrine and deltaic sedimentation from Early Permian to Early Cretaceous (Valdiya, 2010). Tectonism played a key role in sediment preservation (Chakraborty and Sarkar, 2005) which was mostly sandstone, shale and coal. Making efforts towards understanding tectono-sedimentary evolution of the Gondwana Supergroup and correlation studies at regional and intercontinental dimensions as such have been a global obsession amongst geologists since long. Palaeofloral remnants, lithologic and structural attributes etc. helped a lot in correlation of Gondwana basins. However, determination of the marine influence on Gondwana sedimentation particularly along the Himalayan tracts is challenging if appropriate fossils are not encountered or, absent. Presence of fossils like *Eurydesma, Deltopecten, Consularia, Spirifer* etc. highlights marine incursion in the Himalayan Gondwana exposures (Ghosh, 1956; Acharyya, 1972; Raina, 1982; Singh, 1993; Kumar, 1997). Minor limestone beds intermixed with typical Gondwana exposures in parts of Arunachal, Bhutan and Darjeeling Himalayas further highlights marine influence. In the present endeavour, the Gondwana exposures of Kalijhora in Darjeeling Himalayas have been investigated to find out signatures of marine influences within the said rocks. While thin limestone beds as well as fossils have been reported from Gondwana exposures in Tindharia and Namchi (Ghosh, 1956; Acharyya, 1972; Acharyya, 1989; Singh and Bajpai, 1990; Basu, 2013) no such occurrences have been encountered in the exposures at Kalijhora. The Kalijhora lithostratigraphic column is largely arenaceous and as such the Gondwana sandstones are investigated in detail with the objective of finding out marine signatures.

Sandstone attributes have been used as windows to peep into the past and reconstruct the provenance, palaeoclimate, sediment generative processes, medium and nature of sediment movement, depositional setup, post-depositional effects and stages of diagenesis attained within the regional tectonic framework (Krumbein and Sloss, 1963; Carver, 1971; Pettijohn *et al.,* 1973; Dickinson and Suczek, 1979; Suttner and Dutta, 1986; Uddin and Lunberg, 1998; Prothero and Schwab, 2004; Boggs, 2009; Reading 2009). Mineralogical facets and geochemical signatures help one to accomplish most of the aforesaid objectives. The present endeavour is concerned with deciphering some changes in the palaeo-environmental setup with the help of SEM Analysis. The SEM along with EDX helps researchers to go one step beyond thin section analysis with the high resolution as well as high magnification (between 10X to 20,000X) view of actual three-dimensional grain relationships and details of the inter-granular pore structures (Welton and Link, 1982; Welton, 1984) as well as exploring the textural relations in sandstones to a great extent (Pittman, 1972; Wilson and Pittman, 1977; Glennie *et al.,* 1978; Bjorlykke *et al.,* 1979)

Situated in and around NH 31A, Kalijhora (Fig. 1) in Darjeeling Himalayas hosts Gondwana rocks. These rocks locally known as Rishi Group are sandwiched between Precambrian Dalings towards north and Siwalik rocks towards south in a roughly ENE-WSW to WNW-ESE trend in the vicinity of the MBT (Fig. 3; Table-1). The exposed rocks mostly comprise of sandstones which are relatively more compact than the Siwalik sandstones which are exposed south of the Andherijhora bridge. The arenaceous units are found as dark grey, grey, buff coloured and a little bit recrystallised. Grey sandstones along the river bed host variable calcareous ingredients. Carbonaceous shale, sandy shale, coal are some of the other litho-units (Fig. 2A-B). Coal largely exudes an anthracitic look owing to thrusting. Kalijhora is devoid of fossils.

Two prominent deformational phases are encountered in the field. Across the Kalijhora on its either bank, sandstone beds are dipping oppositely. The beds on the northern bank show a moderate north-westerly dip while those on the southern bank show a moderate southerly dip reflecting the existence of a larger antiform with east-west axial planar trend and a moderately westerly plunging fold axis (Fig. 2C). Consequent to D_1 a weak bedding parallel foliation developed in the sandstones. Subsequent to formation of F_1 folds, NE-SW trending F_2 folds developed. The area is also affected by dextral shearing reflected best by the carbonaceous shale and coal. This whole sequence underwent brittle deformation later (Basu, 2013; Kar *et al.,* 2017).

Table-1: Synthesised lithostratigraphy of Kalijhora area.

AGE	GROUP	LITHOTYPES
Recent		Alluvium
	~ ~ ~ ~ ~ ~ ~ ~ ~ unconformity ~ ~ ~ ~ ~ ~ ~ ~ ~	
Tertiary	Siwalik	Medium grained sandstone, carbonaceous shale intercalated with sandy shale, silt, minor marl and pebbly sandstones, conglomerate: Repetitive sequence
		~ ~ ~ ~ ~ ~ thrusted ~ ~ ~ ~ ~ ~
		Fine to medium sandstone, sandy shale, shale, minor coal, pebbly sandstones, conglomerate
	~ ~ ~ ~ ~ ~ ~ ~ ~ unconformity ~ ~ ~ ~ ~ ~ ~ ~ ~	
Permo-Carboniferous	Gondwana / Rishi	Fine to medium grained buff coloured sandstones Grey coloured intercalated with slaty Shale, carbonaceous shale and coal; minor gritty sandstones; few sandstones exude a calcareous look Grey to dark grey recrystallised sandstone
	~ ~ ~ ~ ~ ~ ~ ~ ~ unconformity ~ ~ ~ ~ ~ ~ ~ ~ ~	
Precambrian	Daling	Massive quartzite Intercalations of foliated quartzites and phyllites

(A) (B) (C)

Fig. 2: (A) Photograph shows alternation of sandstone and coal; Locality: south of Kalijhora bridge; (B) Photograph shows pinching of coal layers sandwiched between sandstone due to shearing; Locality: North bank of Kalijhora river; (C) Photograph shows sandstones warped into an antiform with breakage along the steeper limb of the antiform; Locality: North bank of Kalijhora river (Kar *et al.,* 2017).

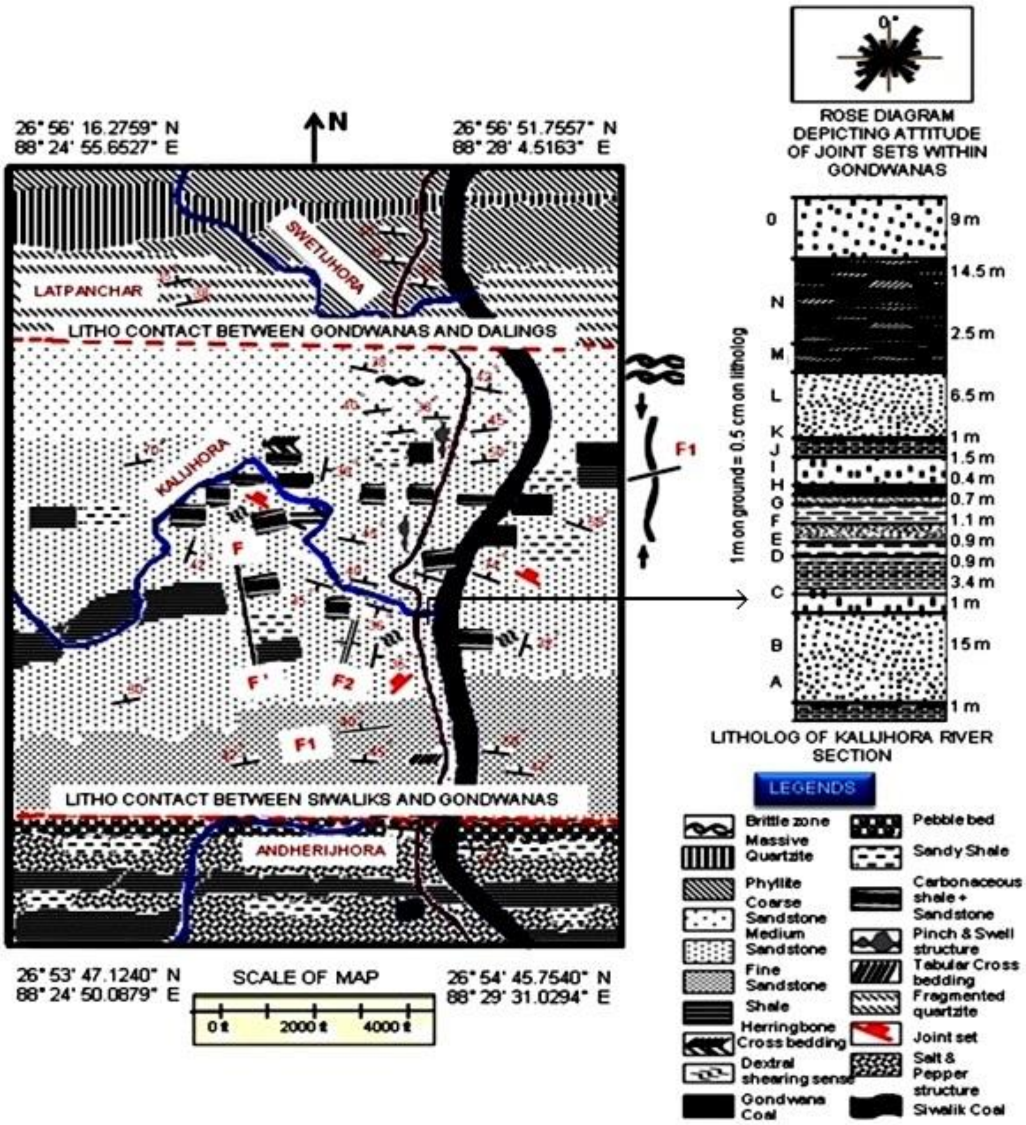

Fig. 3: Geological map of the areas in and around Kalijhora, West Bengal (after Kar *et al.,* 2017)

METHODOLOGY

The work was initiated with detailed conventional thin section analysis of 51 representative samples. 450-500 counts were made per sample to figure out the modal composition using Gazzi-Dickinson point counting method. Detailed petrographic analyses were done to help identify better samples for SEM studies. To accomplish the objective, a total of 10 samples were chosen for SEM analysis at the Institute of Advanced Study in Science & Technology (IASST), Guwahati using Sigma VP ZEISS. Twenty representative samples were selected for geochemical study which was carried out in Wadia Institute of Himalayan Geology, Dehradun using XRF spectrometry. Further, EDX or EDS Analysis *i. e.* Energy Dispersive X-ray analysis was also undertaken for a few samples in order to identify the elemental composition of the specimen or any area of interest. The EDX analysis system is an integrated feature of SEM and cannot operate on its own without the latter. Extracts from petrographic and geochemical studies have been utilized to substantiate SEM findings.

NOTABLE OBSERVATIONS FROM THIN SECTION ANALYSIS

Based on physical attributes, Gondwana sandstones of Kalijhora have been grouped into three units: Ar_1 (Fine to medium grained buff coloured sandstones), Ar_2 (sandstones intercalated with shale, coal and few having calcareous look) and Ar_3 (Grey to dark grey recrystallised sandstone) from south to north in the field.

Petrographically, the sandstones are mostly sub-arkose to sub lith-arenite. Quartz, the most ubiquitous mineral of sandstone, shows virtual dominance over the other detritals with its share fluctuating between 18.95% and 65.11% with an average value of 62.61% in Ar_1 unit, 53.34% in Ar_2 unit and 56.91% in Ar_3 unit. Quartz grains of sandstones consists of a single crystal *i.e.* monocrystalline, or an aggregate of crystals *i.e.* polycrystalline (Conolly, 1965; Blatt, 1967) where the former is preponderant over the latter. In the present case, out of all the varieties of quartz, undulose quartz grains are maximum with volumetric percentage varying between 30.13% to 76.23 % with an average value of 47.72% in Ar_1 unit, 43.93% in Ar_2 unit and 47.88% in Ar_3 unit.

Feldspar present in Kalijhora sandstones are more or less clearly recognisable and have been found to be K-rich feldspar (Pittman, 1970) include microcline and orthoclase to plagioclase. Volumetrically, the total percentage of feldspar ranges from 0.12% to 10.85% with an average value of 2.12% in Ar_1 unit, 4.02% in Ar_2 unit and 2.67% in Ar_3 unit. The K-feldspars, are altered and fractured and; along the fracture planes are occupied by calcitic and siliceous cements are visible (Fig. 4A).

The matrix dominantly consists of epimatrix and pseudomatrix varieties where quartz grains mostly make up the matrix followed by a substantial amount of flaky (muscovite) minerals and clay. The volumetric percentage ranges from 1.30% to 7.88% with an average of 4.15% in Ar_1 unit, 3.95% in Ar_2 unit and 3.39% in Ar_3 unit. Epimatrix component includes authigenic interstitial materials that grow in open interstices. They lack the homogeneity of clay cements whereas pseudomatrix contain discontinuous matrix-like materials that have developed as a result of squeezing and flowing of weak detrital grains like phyllite or shale fragments into adjacent pore spaces (Dickinson, 1970). They are thought to be formed on deformation and squashing of pelitic fragments (Pettijohn, 1984).

The cementing material in Kalijhora sandstones is dominantly calcareous followed by silica and ferruginous cements. Volumetrically, the percentage content of calcite cement ranges from 4.68% to 28.55%; silica cement is between 2.59% to 20.74% and ferruginous cement is between 0% - 0.46% up to 7.25%. Calcite show higher interference colour, ferruginous cements are red pigments and, the siliceous ones are colourless. Calcite cement is seen as corroding the grain boundaries and often shows kinking under impact of stress. The relatively high amount of carbonate cement content with an average of 14.62% in Ar1 unit, 20.59% in Ar2 unit (max.: 28.65%) in sandstones from the Kalijhora river banks and

19.34% in Ar3 unit detected during thin section modal analysis was a reason behind the idea of analysing the finer component of sandstones through application of SEM.

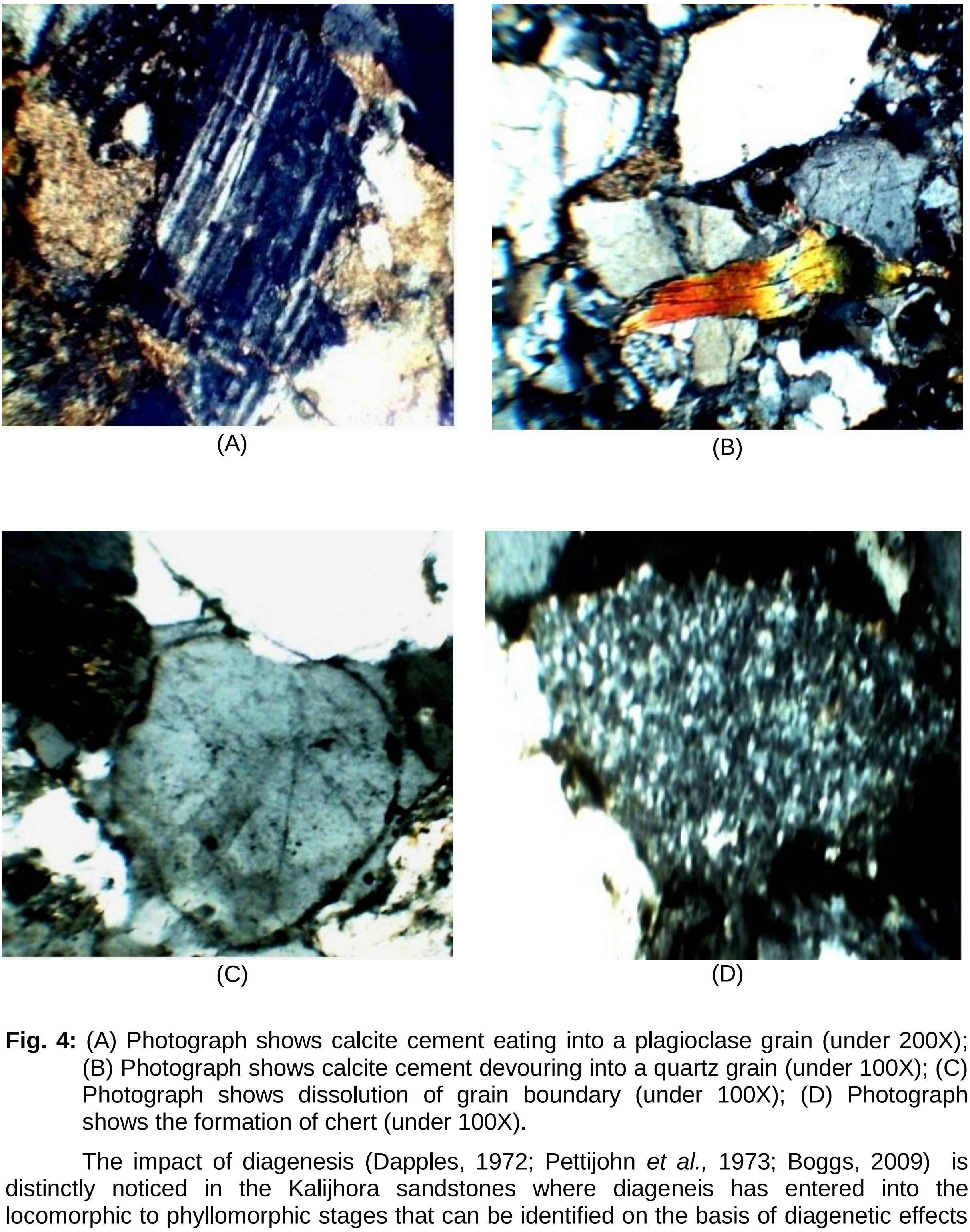

Fig. 4: (A) Photograph shows calcite cement eating into a plagioclase grain (under 200X); (B) Photograph shows calcite cement devouring into a quartz grain (under 100X); (C) Photograph shows dissolution of grain boundary (under 100X); (D) Photograph shows the formation of chert (under 100X).

The impact of diagenesis (Dapples, 1972; Pettijohn *et al.,* 1973; Boggs, 2009) is distinctly noticed in the Kalijhora sandstones where diageneis has entered into the locomorphic to phyllomorphic stages that can be identified on the basis of diagenetic effects observed such as authigenic formation of silica cement at the grain boundary junction, microstylolites within quartz grains, chertification, obliteration of grain boundaries, mica bandings, devour of quartz and feldspar by calcite cement as well as Fe cement, intrusion of calcite or silica cement along the cleavages of feldspar particularly orthoclase and their corrosion and secondary mica (muscovite) formation (Fig. 4A-D). In marine sediments, the eogenetic reactions are more conspicuously dominated by dissolution of unstable, fine grained components along with formation of characteristic new minerals. Important reactions in this regard are commonly displayed through formation of authigenic illite (mostly in oxygenated pore waters), pore-filling clay minerals (Fig. 5A), precipitation of quartz overgrowths (Fig. 5B) and precipitation of carbonate cements (Burley et al., 1985; Bjorlykke, 1983) which have been vividly evidenced in the Kalijhora sandstones.

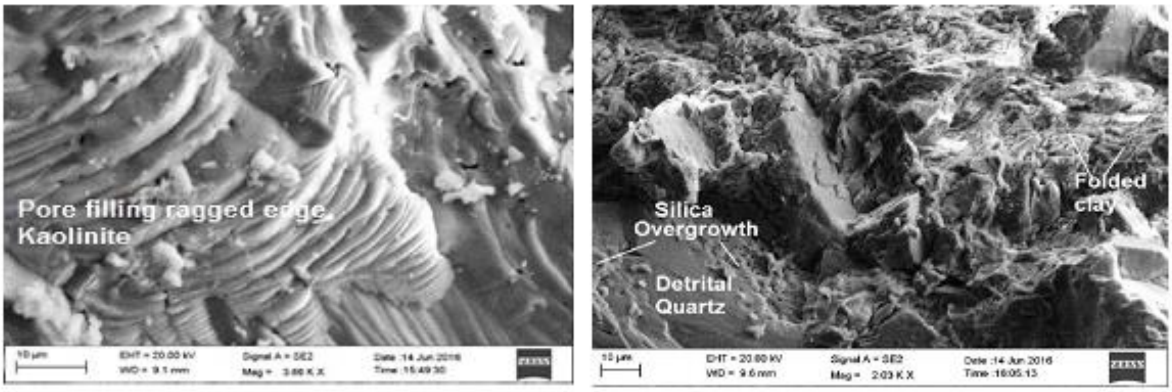

Fig. 5: (A) Pore filling ragged edge Kaolinite (B) Silica overgrowths and folded authigenic clay filaments

SIGNIFICANT GEOCHEMICAL ATTRIBUTES

The average values of major oxides such as Na_2O, MgO, Al_2O_3, SiO_2, P_2O_5, K_2O, CaO, TiO_2, MnO, Fe_2O_3 are 1.25%, 1.40%, 11.48, 70.61, 0.15, 2.31, 3.61%, 0.44%, 0.08%, and 3.42% respectively. The geochemical classification plots of the Kalijhora sandstones falls mainly in litharenite and arkose field. A minor shift is also indicated to wacke field as a result of a wide range in the variation of relative proportions of matrix components, feldspars and lithic components (Lindsey *et al.,* 2003) which play a more influential role during the whole rock geochemical analysis. This was another factor generating interest in detailed study of the finer components of Kalijhora sandstones through SEM.

The wt% of CaO as well as MgO in the sandstones obtained from geochemical study was found to be relatively high for 40% of the samples with indication of presence of a dolomitic layer having CaO wt% as high as 28.62%, MgO wt% of 6.72% and Sr content of 687 ppm. The MgO/CaO ratio for all the samples considered together is between 0.05% and 12.94% with an average value of 2.32% while the CaO/MgO ratio ranges between 0.08% and 19% with an average of 2.86%.

Explanatory reason for high MgO content in the sedimentary rocks can be provided in the form of dissolution of magnesium carbonates with acidic water which in turn hints at the occurrence of high magnesium carbonates in these rocks; the reasons behind being diverse and complex. Some dolomitic type of rocks are known to appear as primary precipitates while others have been considered to have first deposited as $CaCO_3$ and later on converted entirely or partially to dolomite, prior to the deposition of another succeeding layer; still others have faced dolomitization under action of migrating underground waters, tens or hundreds of millions of years after the primary deposition (Morse and Mackenzie, 1990). Noteworthy observations in pelagic limestones that have not been uplifted or undergone tectogenesis indicate that their magnesium content increases with increasing age suggesting that the magnesium and calcium trends are primary features of carbonate rocks and are not influenced by factors such as recycling or diagenesis. A word of caution is, however, required concerning the above mentioned statement since it is also an established fact that waters circulating between the upper basaltic oceanic crust and overlying sediments conceivably have the capability to bring alteration in pelagic calcite leading to genesis of a more magnesium rich phase (Morse and Mackenzie, 1990).

According to conventional knowledge, the primary factor governing whether the abiotic/inorganic carbonate minerals formed will be calcite, high magnesian calcite or aragonite is the Mg/Ca ratio of the water (Mucci and Morse, 1983) and salinity (Folk and Land, 1975). It has been postulated that the precipitation of calcite is strongly inhibited by Mg^{2+} in seawater and magnesian calcite or aragonite is known to precipitate preferentially in the presence of Mg^{2+} in seawater (Berner, 1975; Reddy and Wang, 1980; Mucci and Morse, 1983). During the precipitation of abiotic carbonates, kinetics of surface nucleation also plays a significant role (Given and Wilkinson, 1985). The formation of low magnesian calcite is usually brought about by low Mg/Ca ratios (<2) while high magnesian calcite forms at a relatively higher Mg/Ca ratio between 2 to 12; and very high Mg/Ca ratios greater than 12 lead to precipitation of aragonite and magnesite (Bogg, 2009). Thus, in the present endeavor, the Mg/Ca ratio of Kalijhora sandstones with an average value of 2.32%, hints at possible precipitation of low to high magnesian calcite. Furthermore, since cations like Mg^{2+} are strongly hydrated at surface temperature, these cations do not have the tendency to readily enter the lattice of a carbonate mineral under low temperature conditions; a fact well documented through the observed reluctance of dolomite formation in seawater at low temperatures, unless the Mg/Ca ratios are high. It has been witnessed that in mesogenetic regime of diagenesis, when the temperature increases to around 60˚C or more, these cations become less hydrated, thus leading to easier precipitation of magnesium carbonates in pore waters bearing relatively low Mg/Ca ratios. As a result, those carbonates that have precipitated during mesodiagenesis, commonly display occurrence of magnesium rich varieties such as dolomite (Bogg, 2009). Moreover, Morse and Mackenzie (1990) have also inferred that increased temperature along with increasing sea water Mg/Ca ratio favour the genesis of dolomite and magnesium rich calcite.

OBSERVATIONS AND DISCUSSIONS BASED ON SEM ANALYSIS

While petrographic investigations help one to examine two dimensional cross-sections through rocks, identify minerals, observe fabric and texture and carry out modal analyses, application of SEM in this field has increased the scope of studies exponentially. SEM helps the investigator to have a highly magnified view of the specimen and thereby peep into the pores, identify the smallest minerals, analyses their distribution and figure out the chemistry. Following are some of the salient observations from the SEM studies:

(1) The surface texture reflections mark the presence of scratches, a lot of percussion marks and pits suggesting the influence of a hydrodynamic regime (Fig. 6) or can also be considered as sites of chemical dynamism.

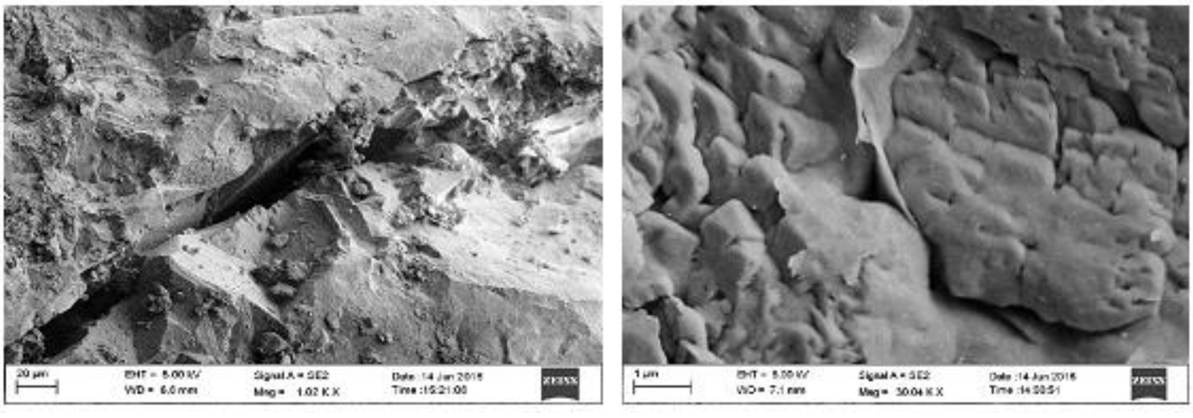

Fig. 6: SEM photomicrographs indicating the influence of hydrodynamic regime.

(2) The elemental distribution of Kalijhora sandstones reflects the typical major sandstone elements of O, Al, Si, K, Na, Ca, Mg and Fe. Distinct peaks of Al along with Si in EDX result obtained from the pore-filling materials indicate the dominant presence of detrital clayey matter. Massive detrital illite composed of irregular, flake-like clay platelets oriented parallel to each other. The flaky morphology of this detrital illite is not only unique to illite, but is a common morphology of other detrital clays too and hence, helpful in separating detrital and authigenic clays. The presence of microcanal/cavity or cracks visible on a quartz grain having detrital clay in between can be tectonically induced when quartz experiences brittle deformation under very low grade metamorphic conditions (Bernet and Basset, 2005), (Fig. 7C). Microcanals in quartz and plagioclase feldspars (Fig. 7D) also act as conduits wherein alteration and authigenic growths are seen to take place.

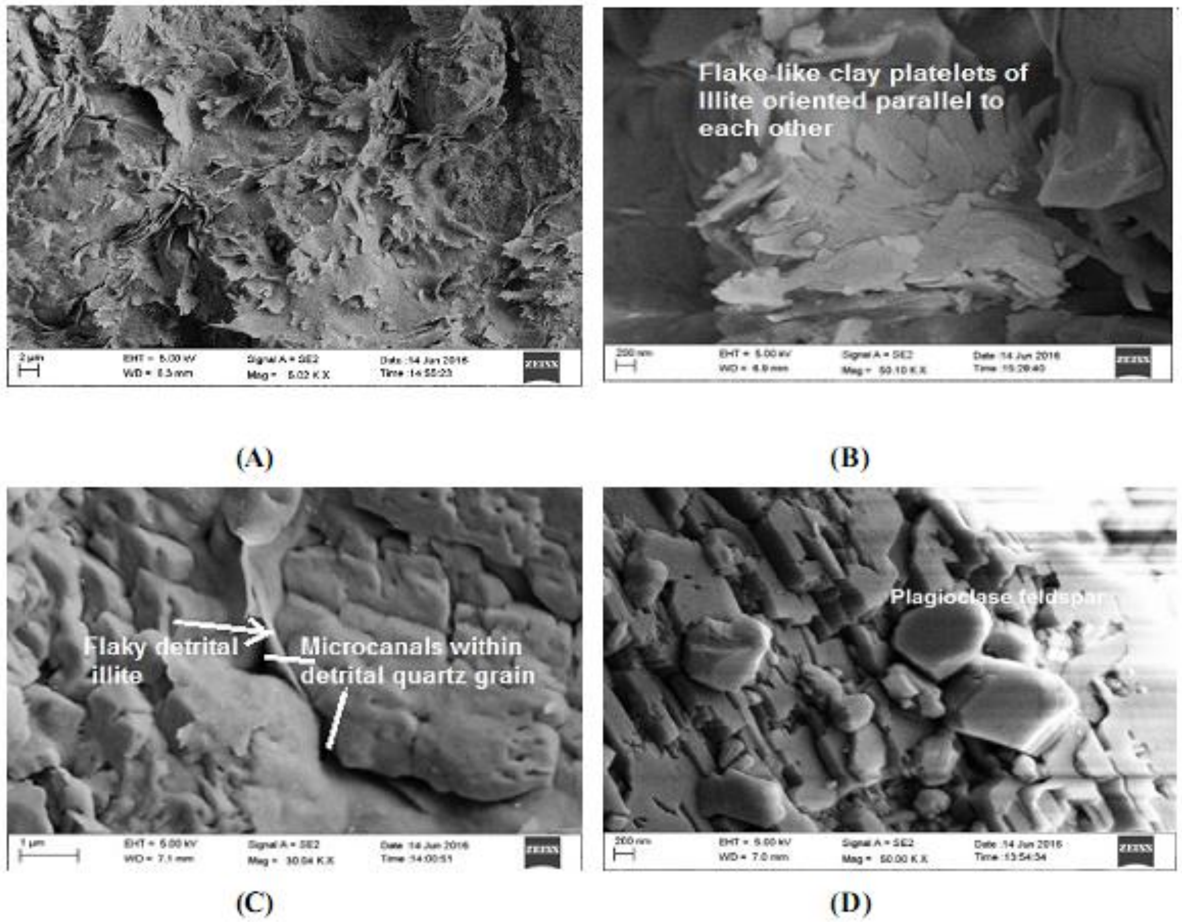

Fig. 7: (A) Detrital Illite mat flaky; (B) Detrital illite platelets oriented parallel to each other; (C) Microcanal/cavity/crack within detrital quartz grain (D) Microcanals in detrital plagioclase feldspar grains.

Authigenic illite mat rimming area of grain contact on a detrital quartz grain (Fig. 5B) shows individual illite ribbons, less than 0.1 micrometre thick that were trapped during pressure solution and compressed into a thin, smooth mat. Distinctly oriented micro-folding is visible on the clay mat that substantiates the micro-level imprints of stress. The authigenic illite visible through SEM images can be very well correlated with the phyllomorphic stage of diagenesis witnessed during thin section study.

Pore-filling, ragged edge kaolinite stacks and elongate ''verms'' of kaolinite appear to completely fill a micropore between detrital grain boundaries (Fig. 5A). Such kaolinite verms also appear within a detrital feldspar fragment as alteration product of feldspar.

(3) Presence of dolomite is evident from the SEM images (Fig. 8A-E). The tiny star-like dolomitic accretions are notable, precisely identified by their corresponding EDX data (Fig. 8A) providing an elemental composition with Mg and/or Ca peaks. The presence of frequent Ca peaks in EDX data within samples of Ar_2 unit further substantiate the high amount of Calcite cement obtained in the petrographic results. The appearance of dolomite and/or calcite in the pore spaces as void filling dolomite/ calcite explain a very interesting phenomenon of possible dolomite or calcite intrusion through marine incursion during ongoing sediment deposition of sediments of Ar_2 unit in an otherwise fluvio-deltaic terrain.

The primary dolomite cement with euhedral crystals corresponding to the first generation of the marine-phreatic cementation (Tunik *et al.,* 2009**)** during which meteoric waters first mixed with seawater (Kaldi and Gidman, 1982), can be differentiated from the void-filling dolomite (Sibley and Gregg, 1987) or secondary dolomitized cement formed by replacement of primary dolomite cement during later dolomitic cementation phase (Tunik *et al.,* 2009) with increased Mg/Ca ratio of the seawater, by the textural details of the primary dolomite crystals (Kaldi and Gidman, 1982) such as: (a) euhedral rhombs which are clear of any inclusion, (b) relict structures such as those expected in replacement crystals are absent, (c) contacts between dolomite rhombs and the secondary dolomitized envelopes are sharp, (d) the margins of the secondary dolomitized cement coincide with the original surface of the primary cements, and (e) the inter-crystalline boundaries of euhedral dolomites are planar (Fig. 8E).

Melim *et al.* (1995) had postulated that both primary euhedral dolomite and granular pore-filling dolomite cements, could also possibly reflect burial diagenesis, but since no such features of this type of environment like poikilotopic calcite postdating compactation, equant mosaic calcspar postdating microstylolites or cement that fill tectonic fractures were recognized in the samples under study, these primary and secondary dolomitized cements can be inferred to have formed during a possible marine incursion phase as seawater is the common and principal source of Mg in sediments (Machel, 2004).

Relationships have been drawn between plate tectonics, chemical changes in Phanerozoic ocean-atmosphere, and the composition of marine carbonate precipitates by several authors (Mackenzie and Pigott, 1981; Sandberg, 1985; Wilkinson and Given, 1986 and others) on grounds that the PCO_2 of the atmosphere, the Mg/Ca ratio as well as saturation state of seawater can undergo changes under action of plate tectonic processes. Thus, it has been almost agreed upon that the relative amount of aragonite and calcites precipitated from the world's oceans during the Phanerozoic times have been influenced by these changes on a global scale. On the basis of the above stated facts, it can be stated that the composition of carbonate particles deposited and thus, available for diagenesis can be controlled by plate tectonics owing to its influence on the Earth's surface environment chemistry (Morse and Mackenzie, 1990). The photosynthetic formation of organic matter may also accelerate PCO_2 changes and variations in degree of saturation of ocean water as their formation leads to a decrease in the PCO_2 of the water, ultimately causing a rise in the degree of saturation; but this effect is however, moderated by oxidation of organic matter and air-sea exchange of CO_2 (Morse and Mackenzie, 1990). Thus, it is noteworthy that tectonics also plays a pivotal role in formulating the Mg/Ca ratio of seawater.

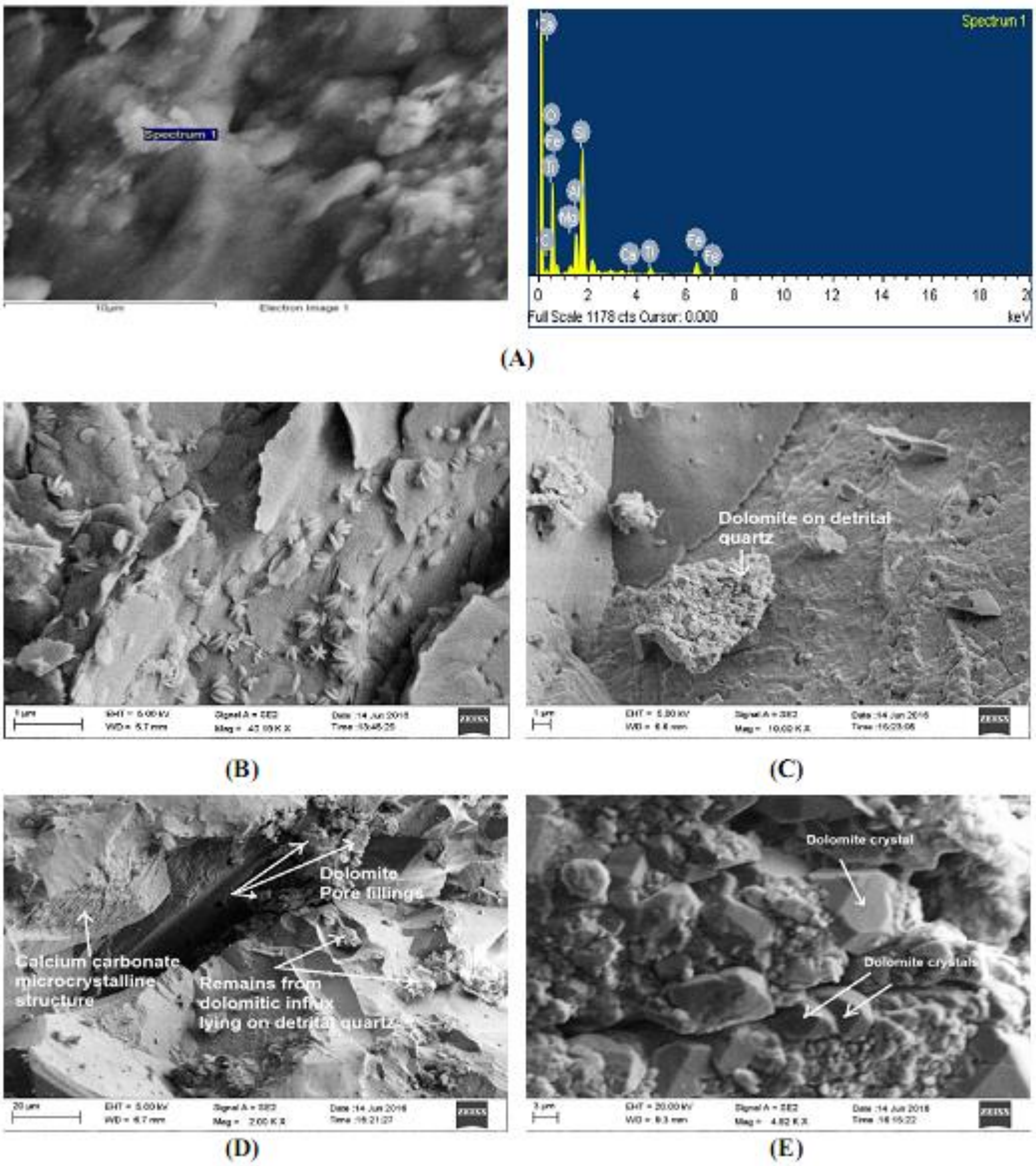

Fig. 8: (A): Dolomitic accretions in the form of stars (left) and corresponding EDX image showing the Mg peak during EDX study; (B) Initial dolomitic accretions in the form of stars; (C) Occurrence of dolomite as lumps; (D) View of pore or void filling dolomite and calcium carbonate microcrystalline structure; (E) Dolomite crystals and associated secondary dolomitized cement.

CONCLUDING REMARKS

(1) From the petrographic modal composition, the sandstones are found to be quartz rich; mainly being sub-arkose to sub-litharenite types and the matrix primarily consists of epimatrix to pseudomatrix. The cementing material is dominantly calcareous followed by silica and then by iron cements. Diagenetically, the sandstones show imprints of locomorphic to phyllomorphic stages of diagenesis depicted in the form of certain important reactions including formation of authigenic illite, precipitation of quartz overgrowths and carbonate cements which are also some of the conspicuous eogenetic reactions in marine sediments.

(2) Geochemically, the Kalijhora sandstones falls mainly in litharenite and in arkose field. A minor shift is also indicated to wacke field as a result of a wide range in the variation of relative proportions of matrix components (relatively high Al_2O_3 content) which play a

more influential role during the whole rock geochemical analysis. Mg/Ca ratio of Kalijhora sandstones with an average value of 2.32%, hints at possible precipitation of low to high magnesian calcite under a marine influence.

(3) During SEM study, the surface texture reflections mark the presence of scratch marks, pits, micro-canals suggesting the influence of a hydrodynamic regime or can also be considered as sites of chemical dynamism.

(4) The detrital illite could be very well differentiated from authigenic illite mat that display certain micro-folds suggesting the micro-level imprint of stress that can be correlated with presence of pseudomatrix observed during thin section study.

(5) The presence of dolomite in pore spaces and the dolomitic accretions in the form of stars indicate a phase of dolomitic intrusion which is a distinct marine signature. Both primary euhedral dolomite cement crystals and secondary dolomitized cements represent two phases of cementation that can be inferred to have formed during a possible marine incursion phase as seawater is the common and principal source of Mg in sediments.

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