Proc Indian Natn Sci Acad **79** No. 4 December 2013, Spl Issue Part A, pp. 895-901

Research Paper

Petrography and Diagenetic History of the Jajiya Member Sediments, Jaisalmer Formation (Middle to Late Jurassic), Western India.

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(Received 27 December 2011; Revised 26 July 2013; Accepted 29 August 2013)

Jajiya is the topmost Member of Jaisalmer Formation and is mainly represented by oolitic limestone with interbeded sandstone and shale. In the studied carbonates bioclasts, ooids, pellets, intraclasts, sparry calcite and micrite are present. The sandstones are mainly composed of several varieties of quartz, feldspar, mica, rocks fragments and heavy minerals.

The petrographic study reveals that chemical compaction was followed by two phases of early mechanical compaction that largely governed the porosity of the limestone. However, cementation, micritization and neomorphism also contributed significantly in this respect. Diagenetic signatures in these carbonates suggest that marine phreatic and fresh water phreatic environments dominated, but deep burial diagenesis also played its role in shaping these rocks. Mechanical and chemical compaction are commonly also played its role in shaping these rocks. Among the various cements in the studied sandstones calcite is the earliest followed by iron oxide, while silica cementation occurred probably at a late stage. The development of secondary porosity is mainly due to microfractures in grains, dissolution pores in iron oxide and calcite cements and intragranular dissolution micropores in feldspar.

Key Words: Diagenetic History; Jajiya Member; Jaisalmer Formation; Western India

1. Introduction

Jaisalmer basin is a pericratonic rift basin which deepens to the southwest. Sedimentation in this basin during the Permo-Triassic commenced with the deposition of the arenaceous Bhuama Formation (Misra *et al*., 1993) followed by fluvial to deltaic deposition of the Lathi Formation (Middle Jurassic). During the Middle to Late Jurassic a thick sequence of carbonate rocks with basal sandstone developed on the extensive stable shelf. The sandstones were derived from the north and northeast by a fluvial system draining the western Rajasthan shelf and were deposited in shallow marine environment in the Jaisalmer basin (Fig. 1). Jaisalmer Formation has been studied by many workers in the past. The main focus of these workers has been stratigraphy (Kachhara and Jodhawat, 1981; Fursich *et al*., 1991; Prasad, 2006) depositional environment (Mahender and Banerji, 1989; Mahender and Banerji, 1990; Mahender *et al*., 1991; Mahender, 1992; Pandey *et al*., 2010; Mudel *et al*., 2012). In the present paper an attempt is made to evaluate diagenetic signatures reported in the Jajiya Member sediments in the light of depositional environment.

2. Geological Setting

The sedimentry basins developed on the Rajasthan shelf were Bikaner-Nagaur basin, Jaisalmer basin and Barmer basin (Misra *et al*., 1993). The Bikaner-Nagaur basin juxtaposed to Aravali-Delhi Frontal Belt (ADFB) is the oldest of these basins. Clastic, carbonates and evaporites were deposited in this basin during Neoproterozoic-Early Cambrian times and to represented by the Marwar Supergroup. The

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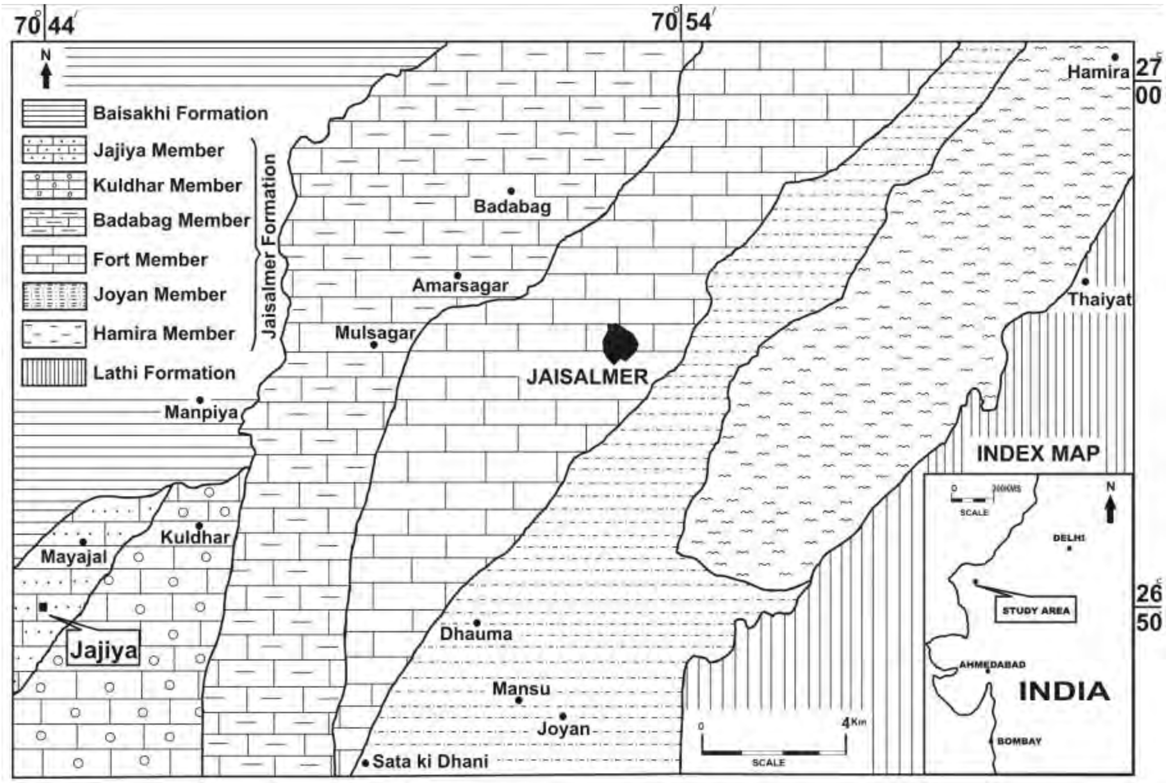

Fig. 1: Geological map of the Jaisalmer Basin (after Jodhawat and Kachhara, 2000)

Jaisalmer and Barmer basins are of Mesozoic age. The two basins are separated by the basement high of Malani Igneous Suite (MIS) of rocks and acted as drainage divide (Siddiqui, 1963). The detritus to the Jaisalmer basin was largely supplied from the northeast and to the Barmer basin from the southeast of ADFB (Siddiqui, 1963). Jajiya Member is the topmost stratigraphic unit of the Jaisalmer Formation (Table 1) and is represented by massive limestone with interbedded sandstone and shale and oolitic limestone (Fig. 2).

3. Methodology

We measured and sampled the section near Jajiya village. Sedimentary structure present includes wavy-bedding, cross-bedding and ripple marks. Oriented standard thin section were prepared of 21 samples for petrographic and the study of the types of cements and diagenetic signatures. The diagenetic study involved observations on compaction, porosity evolution cementation, micritization and neomorphism.

Table 1. Lithostratigraphic classification of Lower Jurassic to Upper Jurassic (Oxfordian) Sediments, Jaisalmer Basin, western India (after kachhara and Jodhawat 1981)

Formation	Member	Age
Jaisalmer formation	Jajiya Member	Callovian to Oxfordian
	Kuldhar Member	
	Badabag Member	Bajocian to Bathonian
	Fort Member	
	Joyan Member	
	Hamira Member	
	Thaiat Member	
Lathi formation	Lower Jurassic	Odania Member

Basement rocks (Proterozoic/Cambrian/Permian-Triassic)

4. Petrography

In the studied carbonates from Jajiya Member bioclasts, ooids, pellets, intraclast, sparry calcite and micrite are present in various proportions. Terriginous admixture is present in most of the samples. The carbonates are mostly medium grained however, few samples are coarse grained. The carbonates are poorly

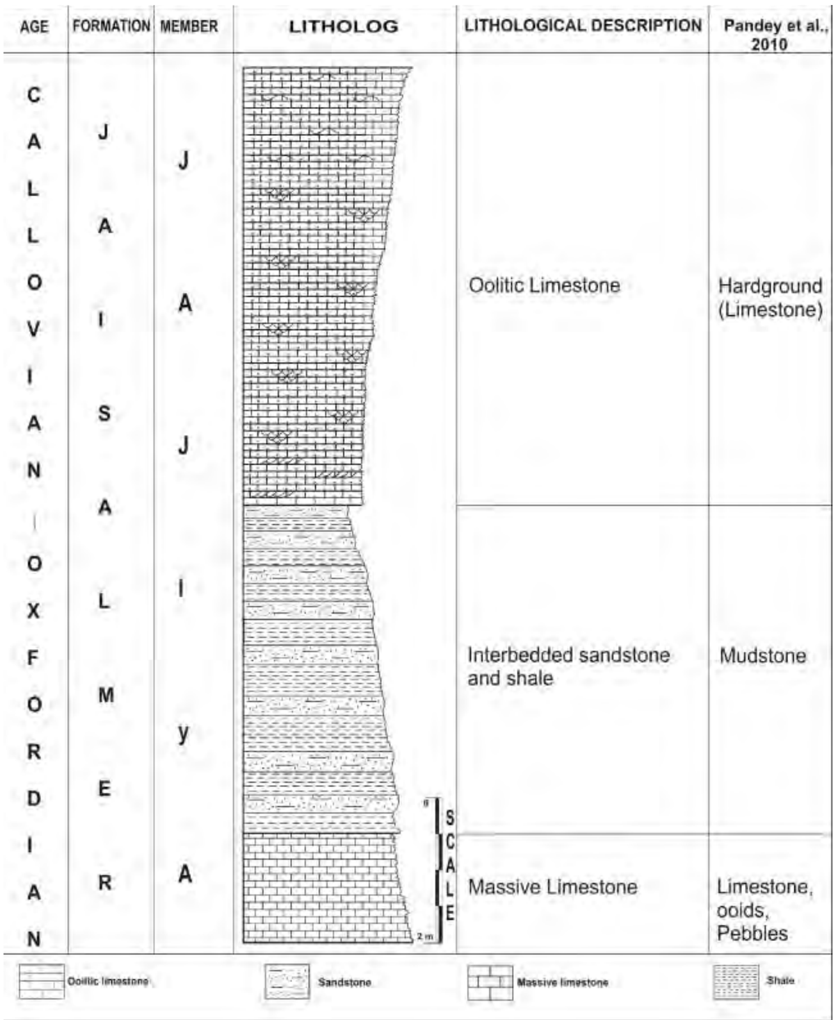

Fig. 2: Lithological succession of Jajiya Member, Jaisalmer Formation

plagioclase in order of abundance. Majority of feldspar are altered variety but some fresh feldspar is also present. Both muscovite and biotite occur as tiny to large elongated flakes with frayed ends. Mica grains usually show the effect of compaction and alteration. Rock fragments include siltstone, chert, phyllite and schist. Heavy minerals include opaque, zircon, tourmaline, epidote, rutile and garnet.

5. Diagenesis

Mechanical compaction has played a dominant role in shaping up the Jajiya Member sediments, however there are evidence of chemical compaction as well (Plate I-A,B). Two phases of early compaction are observed. Evidence of the first phase includes deformation of bioclasts without any bending and the micritic groundmass has caused the compaction.

to very well sorted having angular to well rounded grains of low to high sphericity. Bioclasts include mainly shell with whole remains of brachiopods, echinoderms, molluscs (belemnites, ammonites and pelecypods), foraminifera and occasional bryozoans. Oolicasts and pellcasts cavities left behind after removal of ooids and peloids are observed. Shell cavities have been filled with pelmicrite.

The detrital content of the studied sandstone is mainly composed of several varieties of quartz followed by feldspar, mica, rock fragments and heavy minerals. Quartz varieties are recorded: common quartz, recrystallized metamorphic quartz and stretched metamorphic quartz. Two varieties of feldspar are recognized which include microcline and

Five types of early diagenetic cement have been identified in the studied limestone. The early diagenetic cement includes blocky, bladed, microcrystalline calcite, sparry calcite and rim cements (Plate I-C,D). Bladed cement is of the first generation and it is formed by the recrystallized bladed aragonite cement. Bladed cement occur in the form of bundles of calcite crystals embedded in micrite. The blocky cement completely fills the intergranular pores. It sometimes occur as intergranular cements occupying in the center of the pores. In some cases the blocky cement is characterized by ferrous calcite vein (blue in colour) which represents the final phase of cementation and probably formed in the deep phreatic burial environment.

Syntaxtial rim cement is observed on echinoderm tests and coated grains. The overgrowth shows strongly preferred orientation in optical continuity with the echinoderm nucleus. Coating of micrite on the larger calcite grains and in the outer cores of the echinoderm tests obliterates the development of syntaxial rim cement. Textural evidence suggests that overgrowth is contemporaneous with early marine cement and the two show interference effects reflecting a competitive growth. Evidence in this study suggests early marine origin for syntaxial overgrowth which was apparently composed of Mg calcite (McGill and Walker, 1982). Carbonates characterized by extensive early marine cement represent high energy environment. The study demonstrates the presence of microcrystalline and sparry calcite cements. The former primarily represent the cements from internal chambers and other openings within individual or colonial organism revealing the interparticle porosity loses. It is observed that the fossil fragments have been replaced by micrite and later on micrite itself precipitated over the host boundaries as overgrowth. The sparry calcite cement is distinguished from the former cement type by its clarily and coarser grain size.

Micritization is seen in the form of envelope of completely micritized grains as well as the total groundmass and is evident in the studied limestone (Fig. 3E). A micritic envelop is formed if precipitation in the boring is accompanied by bacterial decomoposition of organic matter (Bathurst, 1975). Under favourable condition the boring processes continue leaving behind only lump without any record of the original grain. Micritization is generally an early marine processes where up to 20% of skeletal grains may be micritized (Sherman, 1999). However micritized grains also form due to syndepositional recrystallization of skeletal carbonate to equent micritic fabrics (Macintyre and Reid, 1998).

Aggrading bioclast neomorphism is evident in the form of irregular patches of neomorphic calcite microspar found within micritic matrix (Fig. 3F). Patchy distribution of neomorphic fabrics along with the fabric selective calcite mosaic is consistent with neomorphism in meteoric vadose zone (Sherman *et al*. 1999). The micritic intraclast have been replaced internally by calcite clearly indicating the replacement of micritic grains by larger calcite crystal mosaic. In such cases much of the original structure of the allochems has remained preserved even after replacement by neomorphic calcite.

In the studied limestone, both primary and secondary porosity is present while secondary porosity is more common. Primary porosity occurs in the form of intergranular and intragranular porosity. Secondary porosity has evolved through biological breakdown of the carbonate minerals. Evidence of dissolution of aragonite and persistence of low Mg-calcite matrix suggests evolution of secondary porosity in these carbonates. Dissolution appears to have been the main mechanism responsible for the formation of secondary porosity in these rocks producing a variety of distinctive textures.

Various types of grain to grain contacts were point-counted with a view to estimating pore space reduction as a result of compaction. In our study floating grain are dominant followed by point and long contacts. Dominance of point and long contacts indicates that the sand grains did not suffer much pressure solution (Fig. 4A). The contact index values for sandstone are very low (average of 0.9%). This is mainly because of very high percentage of grains which have no grain contact, and hence are floating grains. The high percentage of floating and point contacts with low contact index values are mainly in sandstone with pervasive development of calcite and iron oxide cement, which are probably precipitated at a very early stage. The early stage of cementation resisted large scale mechanical and chemical compaction, which normally take place after deposition and concomitant burial under the overlying sediments. Less mechanical compaction and high content of intergranular cement may be related to high grain strength, good sorting and early cementation. The above features are indicative of compaction and pressure due to shallow burial/or early cementation.

Three types of cement are identified in Jajiya Member sandstones. The iron cement is present as a dark brown-black coating on a detrital quartz and

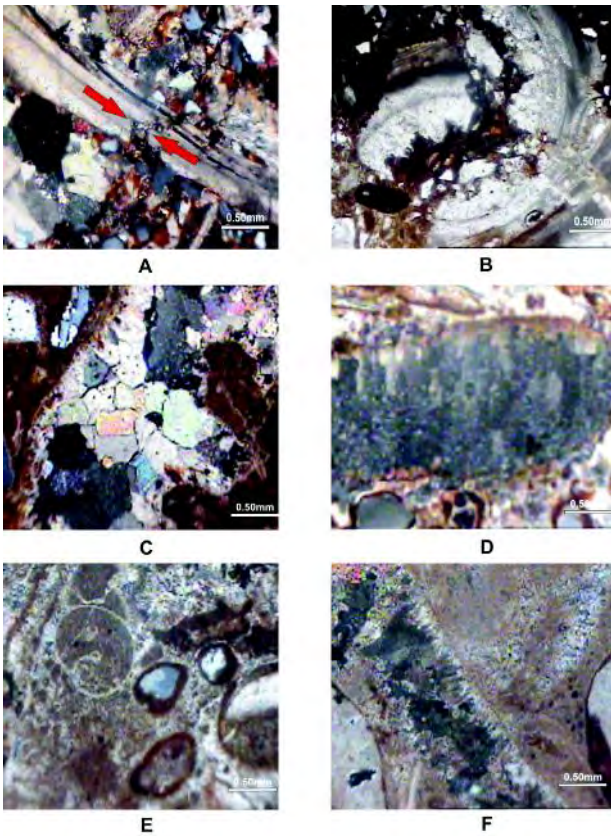

Fig. 3: Photomicrographs showing, A=Mechanical compaction, B=Chemical compaction, C=Blocky cement, D=Bladed cement, E=Micritization and F=Neomorphism

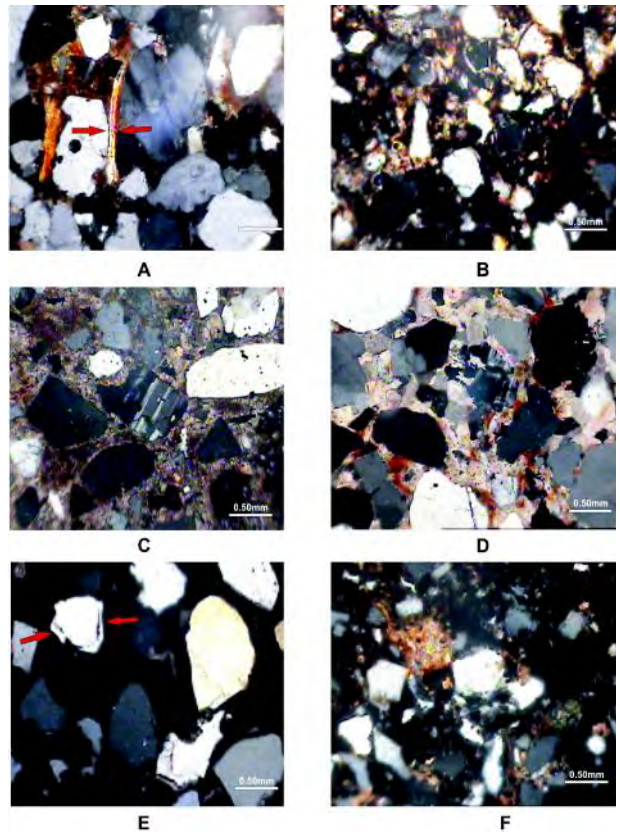

Fig. 4: Photomicrographs showing, A=Mechanical compaction, B=Detrital grains corroded by iron cement, C,D=Detrital grains corroded by carbonate cement followed by Fe-calcite cements, E=Quartz overgrowth and F=Silty to clayey matrix

feldspar grains. Iron oxide also occurs along the cleavage traces of altered and leached feldspar grains. Different stages of alteration and leaching are observed and some empty voids lined with iron oxide represent completely leached feldspar. Thin dark brown grain coating of iron oxide may have formed outside the depositional basin, were regenerated during burial (Walker, 1974). The pervasive porefilling cement of iron oxide is very dark brown coloured to opaque haematite. The cement has corroded the detrital grains extensively. In some instance, the clastic grains have lost their grain morphology and are present now in the form of protrusions, embayments and notches (Fig. 4B). The iron oxide also replaces calcite cement.

Carbonate cement occurs in the form of sparry calcite and microcrystalline calcite cement .The calcite cemented sandstones are high minus-cement porosity and corrosion of detrital grain. Apart from quartz, the feldspar too are subjected to corrosion along grain boundary and cleavage planes (Fig. 4C, D). In some thin sections characterized by Fe-calcite cement, the corroded quartz grains exhibit calcite cement in filling. This evidence suggests the presence of syndepositional calcite cement, which was later replaced by Fe-calcite cement during late burial. This type of cementation occurs by exchange of interstitial marine pore water either by meteoric water or by pore water expelled from the underlying sediments. Precipitation of microcrystalline calcite cement probably took place at shallow depth above water table by the process of concretion which is evident from open framework entrapped iron oxide cement. It suggests that the depositional setting may have been intermittently exposed, allowing onset of pedogenic process that induced calcite cement precipitation. Later, during burial, the micrites were replaced by sparry calcite in meteoric hydrologic regime along the interface zone of accretion and saturation.

Quartz overgrowths are scarce in Jajiya Member sandstones. Only occasionally the sandstone show local development of large overgrowth (Plate II-E) Locally cryptocryatalline quartz seems are found instead of homotaxial overgrowth in the studied sandstones, lack of any significant pressure solution, scarcity of illite and only local replacement of quartz by calcite cement rules out sources of replacement of quartz and feldspar or pressure solution/alteration of smectite to illite. The silica forming overgrowth was probably derived from associated shales-siltstones by dissolution of quartz grain and/or from compaction water. Silty to clayey matrix is present in the studied sandstones. Detrital silt, chert and fine grained muscovite and clay materials are present in the form of matrix (Fig. 4F). Most of the matrix material is syndepositional, hence represents porefilling. The matrix 'therefore' influences diagenetic processes by supplying chemical entities and bulk properties, such as porosity and permeability by pore occlusion.

6. Conclusions

(a) Mechanical and chemical compaction taking place under phreatic marine and fresh water diagenetic environments have largely controlled the porosity in these carbonates. Two phase of early mechanical compaction was followed by a phase of chemical compaction in these carbonates. Chemical compaction has played a vital role in shaping these carbonates. Our study reports five types of cements including bladed, blocky, syntaxial rim cements, microcrystalline and sparry calcite cements. Evidence suggests that bladed cement has formed in early marine phreatic environment. Bladed and syntaxial rim cements have formed in deep burial phreatic and early marine freshwater phreatic diagenetic environments. Micritization was restricted to the lagoonal environment. Secondary porosity has developed in the form of fractures and pressure solution cavities. Evidence of aggrading neomorphism is documented in the form of coarse sparry calcite cement in both bioclastic bars and oolitic bar-to-bank system.

(b) Three processes are commonly important in modifying the studied sandstone of Jajiya Member; mechanical compaction, chemical compaction and cementation. The relative percentage of various grain contacts suggests that sandstone show early cementation and consequently little compaction effects. The original depositional packing of sandstone is largely preserved. Mechanical compaction was operative during early stage of diagenesis and in a limited way causing rotation and adjustment of grains and formation of point and long contacts. Among the various cements, calcite is the earliest followed by iron oxide, while silica cementation occurred probably at a late stage. Another burial diagenetic event was alteration of feldspar and dissolution. The feldspar grains show different stages of alteration. Dissolution and loss of feldspar reflected shallow weathering zone. The silica forming overgrowth was probably derived from associated shales-siltstones by dissolution of quartz grains and/or from compaction water. Precipitation of calcite took place in the meteoric hydrologic regime. Iron oxide formed last in the sequence due to weathering and pedogenic processes. The development of secondary porosity is mainly due to microfracture in grains, dissolution pores in iron oxide and calcite cements and intragranular dissolution of micropores in feldspars.

7. Acknowledgements

The authors gratefully acknowledge the help received from the Chairman, Department of Geology, Aligarh Muslim University, Aligarh in completing this work.

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