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# Mineralogy, Origin and Diagenesis of Golden Oolitic Limestones of Jhurio Formation (Middle Jurassic) Kachchh Mainland, Gujarat, Western India

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**Abstract:** The Jhurio Formation, is a carbonate-siliciclastic succession deposited during Bathonian in Kachchh sedimentary basin. The petrographic analysis indicate presence of three types of ooids, tangential, radial and micritic with subordinate superficial and composite ooids. The diagenetic cements include isopachous fringe cement, equant calcite cement, mosaic sparry calcite cement and syntaxial rim cement. XRD-analysis of ooids, mud intraclasts and groundmass of oolitic limestones indicate that the low magnesian calcite and goethite are the predominant minerals. Both pettrographic studies and XRD-analysis indicate that the original mineralogy was dominated by aragonite and the golden coloured coating over the ooids is goethite. Based on different cement textures, four diagenetic environments could be identified, marine phreatic, meteoric phreatic, meteroic vadose and burial diagenetic and a plausible depositional and diagenetic model is proposed.

***Keywords:*** *Golden Oolitic Limestones, Ooids, Goethite, Marine Phreatic, Meteoric Vadose, Etc.*

## Introduction:

Since the pioneering study by Sorby [1], it has been recognised that coatings of oolitic allochems exhibit a variety of fabrics and composition in modern and ancient marine and non-marine units (Wilkinson et al., 1984). Modern marine cortices are almost exclusively aragonite with constituent acicular crystallites oriented parallel to grain exteriors (Wilkinson et al.,[2] ), while ancient cortices are of low magnesian calcites with radial and equant or sparry fabrics (Wilkinson et al., [2]; Tucker and Wright, [3] ).

The origin of oolitic ironstones of the world has been discussed by many workers (Young, [4]; Macquaker et al., [5]; Donaldson et al., [6], Taylor et al., [7] ). Ooidal ironstones have a distinctive mineralogical composition of iron silicates (berthierine and chamosite), iron carbonate (siderite), iron oxide (haematite) and iron hydroxide (goethite) (Young [4] and Macquaker et al., [5] ). The fabric data (Mackensie and Pigot, [8]; Sandberg, [9] ) and trace element data (Kahle, [10]; Brand and Veizer, [11] ) of calcarous ooids are available for the detailed comparative studies. Many researchers proposed that ooidal ironstone mark the key stratal surfaces in sedimentary successions, formation at sequence boundaries (Macquaker and Taylor, [12].

The Jhurio Formation is a Middle Jurassic marine carbonate-siliciclastic succession deposited in a pericratonic embayed basin of Kachchh on the west coast of India. This succession is characterised by their condensed stratigraphic horizons and rich fossil content. The work carried out so far in the Jurassic exposures of Kachchh, are mainly on stratigraphic, palaeontologic and sedimentologic aspects (Biswas, [13], [14], [15], [16]; Singh, [17]; Pandey and Dave, [18] ). But the petrography and original mineralogy of golden coloured calcareous ooids and the depositional and diagenetic environment of golden oolitic limestones, are not so far studied in detail.

Present study, therefore, focusses on the petrography and original mineralogy of golden oolitic limestones of Middle Jurassic of Kachchh in its type section and based on the data, a depositional and diagenetic model is proposed.

## Geology and Stratigraphy:

The Kachchh sedimentary basin (68$^{O}$ 00′ 00″ E to 71$^{O}$ 30′ 00″ E) filled up with 5000 to 8000 ft. of Mesozoic sediments and 1800 ft. of Tertiary sediments are covered by Recent sediments. The Tertiary sediments are covered by sediments of Rann and Banni. The Mesozoic sediments deposited during Middle Jurassic to Lower Cretaceous are exposed in six highlands, Kachchh “Mainland” near depocentre, Pachham Island in northern part of the basin and Eastern Kachchh which includes Khadir, Bela and Chorar islands and Wagad, near the eastern provinces. he basin framework, palaeo-environment and depositional history of the Mesozoic sediments of Kachchh Basin has been described in details by Biswas [15].

Biswas [14] has classified the Jurassic succession exposed in Kachchh Mainland into four formations, namely, Jhurio, Jumara, Jhuran and Bhuj Formations respectively. In the type section in Jhura Dome (Fig.1), Jhurio Formation exposes thick sequence of limestones and shales with bands of golden oolites which forms the lower part of the Mainland stratigraphy. The Jhurio Formation dates back to Bathonian times (Callomon, [19]; Khadkikar, [20]). Jhura dome, the present study area, comprises the Jhurio Formation and overlained by part of Jumara Formation. Jhura dome, situated NW of Bhuj, is roughly elliptical in shape and the longer axis trending E-W, extends approximately upto 38 kms. The stratigraphic succession of the Jhurio Formation in its type section (Biswas, [17]) is shown in Table-1. The sedimentary structures include cross-bedding of various types like ripple marks, hardgrounds, concretions and soft sediment deformation.

**Materials and Methods:**

The rock successions were collected across the stratigraphic boundary from the Jhurio Formation near Badi nala and around 60 sedimentary rock samples are thin-sectioned to study the petrography under the microscope. The ooids, groundmass and mud intraclasts of golden oolitic grainstone samples collected from different stratigraphic levels in the Jhurio Formation were analysed separately using the Philips X-ray Diffractometer in order to understand the mineralogy of the ooids as to whether these are oolitic ironstones comparable to that noticed in other parts of the world or oolitic calcareous ironstones as seen in the Jurassic of England (Milot, [21].

The ooids were separated from the oolitic grainstones by soft hammering and the individual ooids picked up manually with the help of hand-lens. The idea of collecting the ooids with the help of magnet (Millot, [21] ) was completely unsuccessful. About 380 to 400 ooids were collected from different stratigraphic levels from the Jhurio Formation at Jhura dome. These ooids were washed and air-dried to avoid impurities. The ooids are observed under the binocular microscope to study the size and shape of the individual ones. These ooids were powdered and passed through the sieves of 200 mesh size. The powdered samples are analysed with x-ray diffractometer to identify the mineralogy. Apart from ooids, the fine grained groundmass and the mud intraclasts were collected powedered and passed through 200 mesh size. The X-ray diffraction studies were carried out on these powdered samples in two separate methods: in the first method the powdered samples are exposed to X-ray from 20 to 50 $^{O}$ C 2θ at 1.2 $^{O}$ 2θ/min and in the second method, slow scan is carried out on these powdered samples from 3 to 20$^{O}$C 2θ at 0.5$^{O}$2θ/min and the mineralogy is determined from the corresponding X-ray diffractograms.

**Results:**

**Petrographic Studies:**

A remarkable variety of coated grains occurs and many classifications including Peryt’s [22], have distinguished two broad categories of coated grains; one is of chemically formed (especially ooid) and the second one is, biogenically formed (oncoids). The main coated grains of Jhurio Formation are ooids and there are few oncoids also present. The ooids sometime grade into pisoids on top portion of each oolitic limestone beds.

The golden oolitic limestones of Jhurio Formation exposed in its type area, Jhura dome, well preserved and show textural maturity. The colour of the ooids is golden yellow to yellowish brown. The individual size of the ooid varies from 0.2 to 2 mm. Basically there are three types of ooids observed: (i) tangential calcitised ooids with concentric layers, (ii) radial ooids, showing rounded to well rounded forms with radiating calcite crystals, while the concentric remnant layers of original mineralogy has been preserved and (iii) micritic ooids, showing neomorphosed equant mincrite which mostly grade into microspar. The nuclei of the ooids are mainly peloids (micritised fossils) and sometimes quartz. The other varieties of ooids comprise the superficial ooids, composite ooids and pisoids, which are very few. All the ooids described above are coated with iron oxide. This iron oxide layering appears as smooth shining golden coating in hand specimens, The characteristic layering is observed not only over the calcareous ooids, but also over the micritised fossil grains of varying sizes and mud intraclasts. The two or more ooids, which are broken due to reworking and cemented together with carbonate cement, is also coated with iron oxide matter forming a composite ooid.

The microfacies studies indicate that the oolites belongs to two types of microfacies: (i) Oolitic grainstone (Photomicrographs 2 and 4) and (ii) Oolitic bioclastic wackestone – packstone micro- facies (Photomicrograph–1). In Oolitic grainstones the ooids are packed tightly and the percentage of ooids range from 30 – 40% and sometimes upto 50%. The ooids are mostly tangential ooids and superficial ooids with subordinate amounts of radial ooids and micritic ooids and, few composite ooids. The nuclei of the ooids are usually micritised fossil grains mainly echinoids, crinoids, brachiopod and molluscan shell fragments and ostracod carapaces. The cement types include isopachous fringe cement over the ooids and mosaic sparry calcite cement in intergranular spaces.

In oolitic bioclatic wackestone-packstone microfacies the ooids are manily observed as patches and pockets and in some as bands. The microfacies type is characterised by various fossil faunas such as large bivalves, brachiopod shells, echinoids, crinoids, formaninifers and ostracod carapaces. The percentage of ooids vary from 10 to 15%.

**Mineralogical Investigation:**

XRD-analysis results indicate that the present mineralogy is of low magnesian calcite (LMC) and the coating over the ooids, golden coat, is of goethitic (Go) in composition. The other minerals present include quartz (Qz), siderite (Sid), and stipnomelane (Stip). From the XRD-data (Fig 2 & 3) it is understood that the ooids, fine-grained ground mass and the mud intraclasts show the same mineralogical composition. The petrographic studies also support the calcitised mineralogy of the ooidal grains.

All the samples analysed reveal that the predominant peak is at 2.98 Å which is of LMC (relative intensity 100) and other peaks of LMC observed at 2.27 Å, 2.08 Å, 1.90 Å and 1.86 Å (Fig. 2 & 3). The Fig. 2a and 2b represents the X-ray diffractograms of calcareous iron ooids and Fig. 3a shows the X-ray diffractogram of representative sample of iron coated mud intraclast and the Fig. 3b represents the X-ray diffractogram of representative sample of graoundmass (cement material) of calcareous iron oolitic grainstones. The low magnesian calcitic mineralogy of the ooids, intraclasts and the groundmass are well documented. Characteristic peaks are also seen at 4.13 Å, 2.67 Å, 2.43 Å, 2.18 Å. This represents the presents of goethite in the ooids and as well as in groundmass and mud intraclasts. The presence of goethite in the ooids explains the mineralogy of the golden yellow to yellowish brown layering over the ooidsand over the mud intraclasts and the yellowish brown to dark brown colour of the groundmass. The goethite coating over the calcareous ooids later oxidised to form the golden yellow colour to ooids and the mud intraclasts and also on the bioclasts. This oxidation process can be correlated with low water depth during the high stand and followed by the regression of the Tethys sea.

**Discussion:**

**Depositional Environment:**

The petrographic analysis and mineralogical investigation shows that the oolitic liemtones of Jhurio Formation deposited in a shallow marine environment. The textural features revealed by the petrographic analusis underline the shallow marine mixed energy environment. The equal abundance of true ooids and the superficial ooids indicate a low to moderate energy condition of the depositional realm. The physical and biological aspects of the Jhurio Formation indicate littoral to infra-littoral environment (Biswas, [14] ).

In Kachchh sedimentary basin, ooids are formed as aragonite grains in warm transgressive Tethys sea and oolitisation increased when the transgression reached near high stand. The water depth was comparatively very low. Less than 20m, and the process took place over shallow marine carbonate mounds. The carbonate build up decreased the water depth brining shoaling conditions to the depositional environment. The to and from movement of the carboante particles and other rock fragments carried by the waves provided the responsible mechanism for the thin concentric layering of aragonite over the micritised fossil grains and quartz grains which moved over the small gentle carbonate mounds. The introduction of iron into the shallow water marine environment of Kachchh basin occurred simultaneous with the high stand of Tethys sea. This has coated as layering over the calcareous ooids. The smoothness of the golden coating is an indication of slow precipitation of iron oxidde matter over the calcareous ooids and over all the available grains in a very muddy still water environment. The subsequent evaporation and aerial exposures brings coating of iron oxide matter and its oxidation to form goethite over the framework elements and in the groundmassof the oolitic facies. The subaerial exposure and subsequent weathering lead to the golden yellow colour to be turned to yellowish brown to dark brown. This is the proposed depositional and diagenetic model for the Golden oolitic limestones of Kachchh Mainland.

The source of iron observed in limestones throughout the world has been attributed conventionally to pedogenic breakdown of iron rich continental parent rocks and subsequent transportation to ocean water through fluvial channels. According to Khadkikar [20] iron is contributed at the mid-oceanic ridges through hot spirng fluids. Thus it seems plausible that the Kachchh ironstones sequestered iron from Fe-rich ocean waters during phases of Event hydrothermal plumes. The older Bathonian Golden Oolite, which extends in to the lower Callovian in Keera dome, shows greater enrichment relative to the younger Dhosa Oolite of Oxfordian age.

**Diagenesis:**

The carbonate diagenetic environments and their products are well documented in Tucker [23] and Tucker and Wright [3]. The processes of diagenesis of oolitic limestones of Middle Jurassic of Kachchh include five processes: cementation, microbial micritisation, dissolution, neomorphism and compaction (including pressure dissolution). The types of diagenetic cements identified signify the four different processes of diagenetic environments: marine-phreatic, marine-vadose, meteoric phreatic and meteoric vadose. These diagenetic fabrics can be important indicators of both of the depositional environments of the sediment and of the chemistry of a variety of fluids, which have been flushed through the sediment during burial.

Diagenetic cements are mainly isopachous fringe cement, equant calcite cement, mosaic sparry calcite cement and syntaxial calcite rim cement. The isopachous cement is a first generation and other three types are second generation cement types. The isopachous fringe cement of aragonite mineralogy is formed over the aragonitic ooids and other coated carbonate framework elements in the shallow marine phreatic environment. The equant calcite cements formed in some micritised oolitic grainstones at shallow burial during the deposition of overlying pelagic limestones, are produced by the neomorphic processes. The mosaic coarse sparry calcite cement is basically formed in meteoric phreatic environment occurred during the high stand and the regressive phase which followed it. The syntaxial calcite rim cements formed over mainly echinoidal and crinoidal grains and most ooids in micritised oolitic grainstones. The processes of syntaxial cementation occurred in the later deep burial diagenetic phase especially initiated by burial in the marine-phreatic environment continued till the deposition of entire Jhurio and overlaying Jumara Formations during the major transgressive phase. The porosity types observed in the microfacies types are secondary porosity and oomouldic porosity (Photomicrographs 2 and 4).

From the XRD-data, along with the petrological observations, it is understood that the original mineralogy of the ooids was aragonite. Few samples analysed for major and trace element studies indicate the same. The Sr content in the Golden Oolitic limestones is around 250 – 300 ppm. The modern aragonitic ooids show Sr content about 8000 – 10,000 ppm. This indicate that the diagenetic stabilisation of these originally aragonitic limestones into sparritised calcite with the introduction of fresh water. The aragonitic ooids originated in the shallow agitated water were bound together by the aragonitic mud formed by the microbial micritisation of fossils of aragonitic and high magnesian calcitic composition. These metastable aragonitic ooids later neomorphosed to low magnesian calcite and consequently the mineralogy of the groundmass also recrystallised in to low magnesian calcite.

**Conclusion:**

The results of petrographic studies and XRD analysis indicate that the original mineralogy of the golden oolitic limestones of Jhurio Formation in its type section at Jhura dome was aragonite. The subsequent diagenesis stabilisation through meteoritic and burial diagenetic processes led to the solution of metastable aragonite mineral and reprecipitation of low magnesian calcite. The characteristic golden colour is identified as goethite coating over almost all the grains in the oolitic limestones.

The occurrence of Fe oolitic limestones is not norm in the Jurassic succession of Kachchh Basin. The climate changed from tropical wet to temperate dry climate from Bathonian to Oxfordian. Thus iron may not be derived necessarily due to weathering of continental ferromagnesian rich rocks (Khadkikar, [20]). It is proposed that these horizons represents distinct short-lived episodes of magmatic activity at the mid-oceanic ridges. The Bathonian golden oolites represent the first stage of rupturing, resulting in the genesis of mid-oceanic ridge system between Greater India and Africa (Khadkikar, [20]). The similar oolitic facies (Bajocian oolites) have been also observed off the western part of Sechelles Plateau (Perlmutter et al., [24]).

The stratigraphic position, depositional environment and diagenetic signatures implies that the oolitic grainstone facies are important indicators of low or fall in sea level. The regressive features such as the hardground surfaces, secondary meteroric diagenetic cementation and cyclically stacked position alternate with bedded pelagic limestones indicate that Kachchh basin was an unstable active sedimentary basin. The stratigraphic position of oolitic grainstones might proved to be an important stratigraphic trap as hydrocarbon reservoir rock through much detailed studies in the future.

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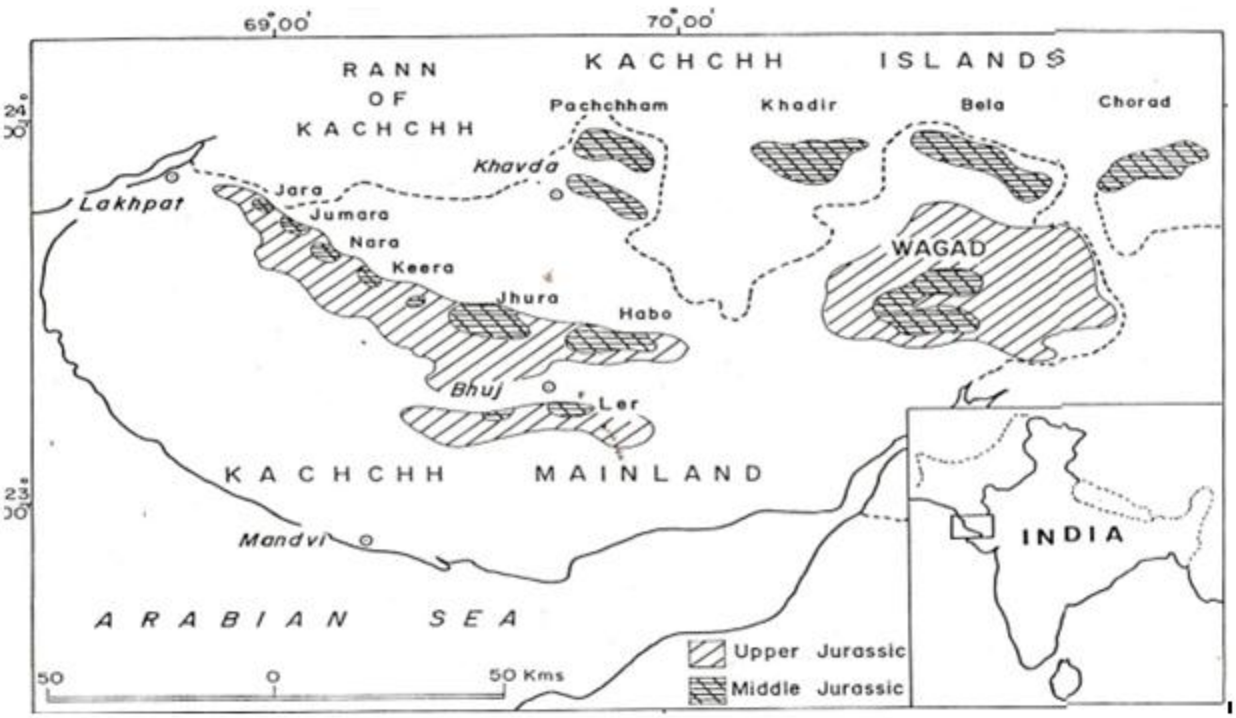
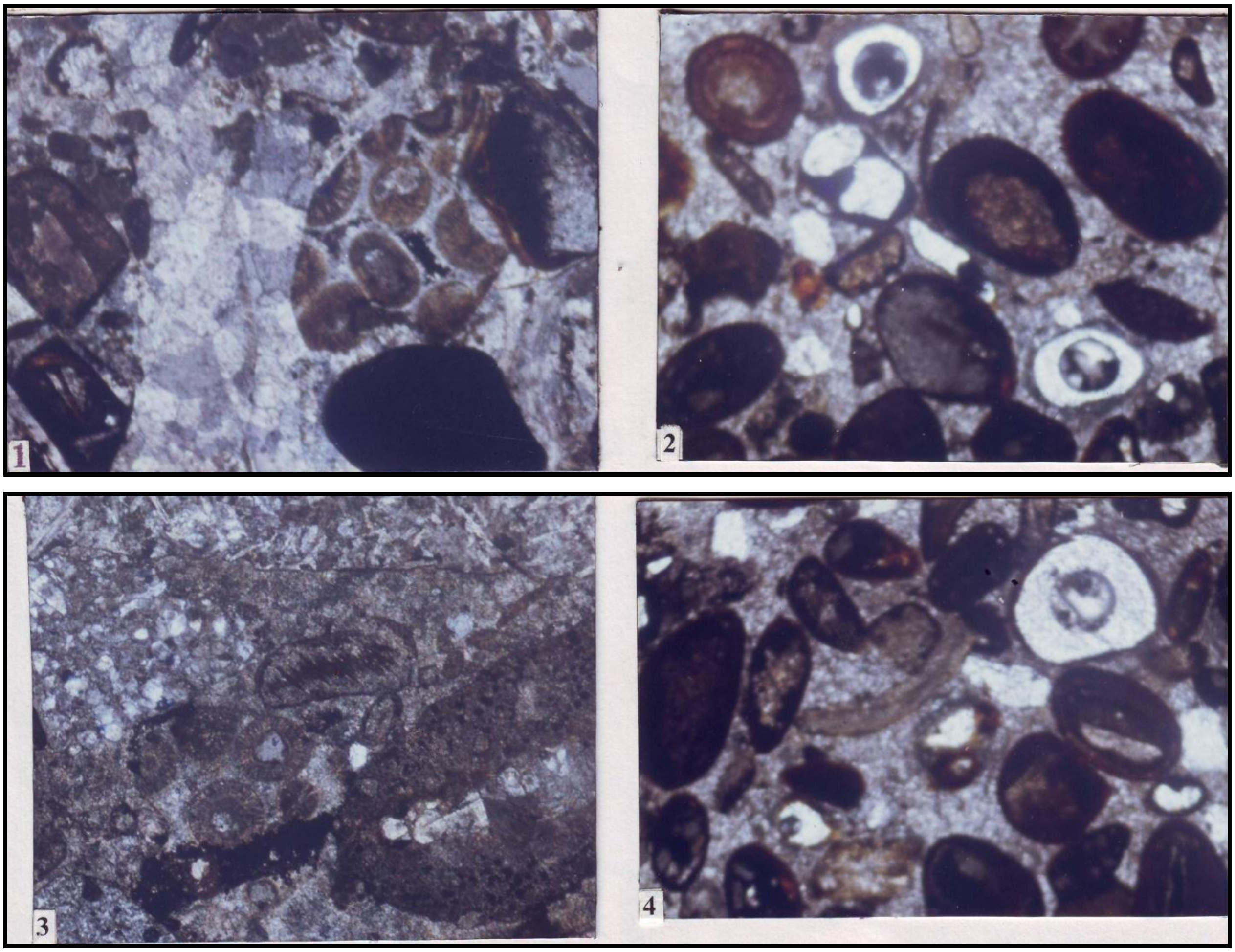



***Figure 1:*** *Geological Map of Kachchh Mainland*

**Table- 1. Lithostratigraphic succession of Jhurio Formation (Biswas, 1977)**

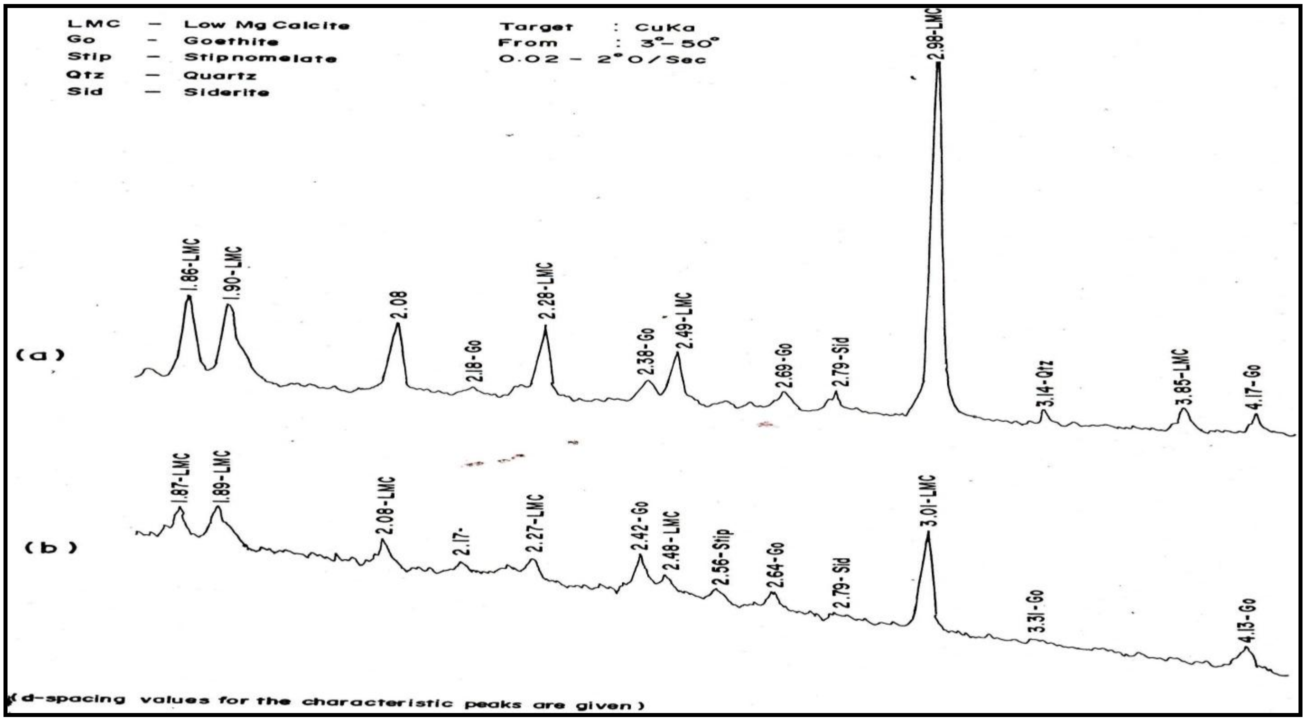
| AGE | Formation | Member | | Lithological Description | Environment |
|---|---|---|---|---|---|
| Callovo-Oxfordian Jumara Fm | | | | | |
| Bathonian to Callovian | JHURIO (300 m) | Upper (80 m) | G | Thinly bedded, yellowish-brown & white limestone interbedded with white calcareous shales | Littoral Wave zone-Intertidal |
| | | | F | Thin bedded yellowish limestone with thin bands of limestone pebble conglomerate & Golden oolite limestone | |
| | | Middle (140 m) | E | Brownish gray thin bedded limestone interbedded with Golden oolitic limestone beds | Littoral (Peritidal) to Sub-littoral |
| | | | D | Gray calcareous shale | |
| | | | C | Golden Oolitic limestone weathering into brick red | |
| | | Lower (80 m) | B | Gray calcareous shale | Littoral to Sub-littoral |
| | | | A | Interbeedd, yellowish brown & gray limestone with local golden oolites and shales | |
| Base not exposed | | | | | |

**Photomicrographs:**

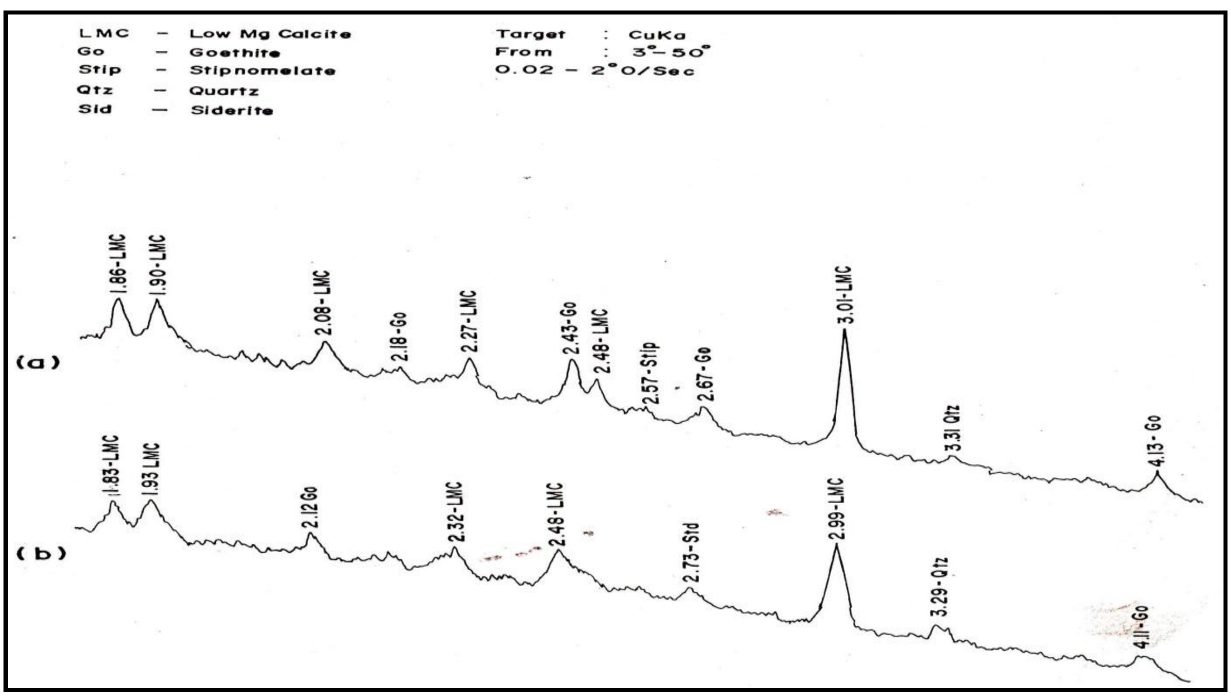



***1.*** *Microfacies showing Calcareous Ooids with Equant Calcite Cement at the Centre. Also seen Calcite Sparitised Bioclast with Coarse Blocky Sparite Cement (Magnification 24X).*
***2.*** *Normally Packed Oolitic Grainstone Microfacies with Calcareous Ooids Coated with Iron Oxide Matter Shows First Generation Cement as Micritic Rinds. Ture Ooids Coated with Iron Spheroidal Shape Radiating Calcite Crystals also seen. Coarse Granualr Mosaic Cement formed due to Meteoric Diagenesis and also Evidences of Oomouldic Porosity indicating the Original Aragonitic Mineralogy (Magnification 24X).*
***3.*** *The Reworked Oolite with Ooids showing Radial Calcitic Crystal Pattern. Ooids are with Radiating Calcite Crystals and might Redeposited in the Site of Deposition (Magnification 24X).*
***4.*** *The Oolitic Grainstone showing the Regressive features of the Microfacies. The Ooids are seen with Microsparite to Sparite Cement and Oomouldic Porosity develeopment due to Diagenetic Stabilisation of the Allochems with Meteoric Water during Regressive Phase (Magnification 40X).*

**X-Ray Diffractomgrams:**




*d- Spacing Values for the Characteristic Peaks are given.*
***Figure 2:*** *X-Ray Diffractograms of Representative Samples of Iron Coated Ooids of Oolitic Grainstone Facies of Jhuri Formation, Kachchh Mainland*




*d- Spacing Values For The Characteristic Peaks Are Given.*
***Figure 3:*** *X-Ray Diffractograms of Representative Samples of Iron Coated A) Mud Intraclasts, B) Groundmass, of Oolitic Grainstone Facies of Jhurio Formation, Kachchh Mainland.*