Microfacies Analysis of Kuldhar Limestone, Jaisalmer Formation (Callovian-Oxfordian), Western Rajasthan, India

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ABSTRACT. The Jaisalmer basin experienced sedimentation since late Proterozoic-Early Cambrian with intervening hiatuses. During Mesozoic, sedimentation started with the deposition of Lathi Formation (Lias to Bathonian) and were followed by deposition of Jaisalmer Formation (Callovian to Oxfordian). Jaisalmer Formation, a carbonate sequence with basal siliciclastics is subdivided into five members. The studied Kuldhar member consists of fossiliferous limestones, pelletal limestones and claystones.

The depositional environments were recognised on the basis of microfacies identification and interpretation. The presence of wackestone-Packstones rich in micrite represents deposition in lagoon to restricted warm shelf. The interbedded grainstones and ooidal bioclastic packstones were deposited in a shallow agitated water above wave base. Presence of homogenous microbioclastics and iron rich argillaceous micrite suggest open shelf deposits below wave base to slightly deeper conditions.

Introduction
The Jaisalmer basin, 30,000 km$^2$ in area, is the largest of several sedimentary basins, which comprise the vast and well differentiated west Rajasthan shelf (Fig. 1). The shelf forms the northwestern slope of the western Indian shield and extending westward from the Aravalli range, across the Thar desert upto the mobile belt of Indus Basin in Pakistan. The Jaisalmer Formation forms a major part of the Jurassic sequence. Rocks of Kuldhar Member are exposed around Jaisalmer town of western Rajasthan and extends in northeast-southwest direction between latitude 26º45’ and 27º10’N and longitude 70º45’ and 71º10’E.
TABLE 1. Mesozoic and Cenozoic stratigraphy of the Jaisalmer Basin, Western Rajasthan, India (After, Misra et al., 1993).

<table>
<thead>
<tr>
<th>Formation</th>
<th>Lithology</th>
<th>Age</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simmar</td>
<td>Sand, Sandstone, Limestone</td>
<td>Middle to Upper Eocene</td>
<td>710</td>
</tr>
<tr>
<td>Bandh</td>
<td>Shale, Limestone</td>
<td>Paleocene to Lower Eocene</td>
<td>200</td>
</tr>
<tr>
<td>Khulda</td>
<td>Shale, Limestone, Sandstone, Marl, Limestone, Shale</td>
<td>Aptian to Cenomanian</td>
<td>400</td>
</tr>
<tr>
<td>Saro</td>
<td>Argillaceous Limestone</td>
<td>Turonian to Coniacian</td>
<td>670</td>
</tr>
<tr>
<td>Parth</td>
<td>Sandstone and Shale</td>
<td>Aptian to Cenomanian</td>
<td>350</td>
</tr>
<tr>
<td>Garu</td>
<td>Avesaceous Limestones and Calcareous Sandstones</td>
<td>Aptian</td>
<td>565</td>
</tr>
<tr>
<td>Halaur</td>
<td>Sandstone, Shale, Lignite</td>
<td>Neocomian</td>
<td>200</td>
</tr>
<tr>
<td>Parwar</td>
<td>Sandstone, Shale</td>
<td>Kimmeridgian to Hettangian</td>
<td>670</td>
</tr>
<tr>
<td>Baisakli / Bhedagar</td>
<td>Sandstone, Limestone</td>
<td>Callovian to Oxfordian</td>
<td>710</td>
</tr>
</tbody>
</table>

**Litho-log**

- **UNCONFORMITY**
- **PRE MESOZOC**
- **Lathli**
- **Sandstones, Shale, Lignite**

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**Note:** The table and diagram provide a detailed stratigraphic overview of the Jaisalmer Basin, highlighting the various formations and their ages, along with their lithological characteristics.
Fig. 1. Geological map of the study area.
The tectonic evolution of western Rajasthan can be divided into four distinct phases. The first phase encompasses the interval from Precambrian to Triassic and corresponds to Pre-Indian plate movement. The second phase commenced in Triassic onward when the precursor activities such as doming and incipient rifting, which led to the incipient breaking of the Indian plate form the southern continent started taking place. The third phase relates to the final rifting and drifting and the fourth phase to the collision of Indian plate with Asian plate from Eocene onwards (Ghosh, 1952 and Veevers, 1989).

The Jaisalmer basin experienced sedimentation since Late Proterozoic-Early Cambrian to Quaternary with intervening hiatuses (Misra et al., 1993). During the middle Jurassic, after considerable clastic influx, carbonate deposition was widespread on an extensive stable shelf comprising several cycles of carbonate sedimentation. The Jaisalmer Formation is sub-divided into five members, viz. the Basal, the Joyan, the Fort, the Badabagh and the Kuldhar members, in the ascending order (Mahender and Banerji, 1989).

The Jaisalmer basin has been studied by various workers, specially for regional geology and basin configuration (Pareek, 1984), basin evolution (Datta, 1983 and Biswas et al., 1993), stratigraphy (Mishra et al., 1993) (Table 1), biostratigraphy (Chidambaram, 1991), sedimentological aspects (Mahender and Banerji, 1989 & 1990) and hydrocarbon potential (Dhannawat and Mukherjee, 1996 and Tripathi et al., 1998).

This study was carried out for interpreting the depositional conditions of the carbonates of the Kuldhar Member.

**Methods and Materials**

The study is based on the measurement of lithostratigraphic sections and examination of thirty thin sections for microfacies analysis. Thin sections were stained with Alazarin Red S. The percentages of allochems, micrite and spar were estimated by counting 300-400 point counts from each thin section. On the basis of percentages of various constituents, seven types of microfacies were identified.

The lithostratigraphic section of the Kuldhar Member (Fig. 2 & 3) was measured in a river cutting near Kuldhar village. Sedimentary structures present include wavy bedding, cross-bedding and ripple marks (Fig. 4).

The studied Kuldhar sequence (Kuldhar Member) consists of poorly fossiliferous limestones, fossiliferous limestones, pelletal limestones and claystones. The limestones mainly comprise coarse, whole and broken shells, peloids, common to superficial ooids and intraclasts, set mostly in micrite.
**FIG. 2.** Measured stratigraphic section of the Kuldhar Member.

<table>
<thead>
<tr>
<th>ROCK TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0m</td>
<td>Packstones - wackestones with abundant whole fossils. Some ooids, peloids and intraclasts. Irregular and wavy bedding. Bioturbation common.</td>
</tr>
<tr>
<td>1.5m</td>
<td>Weathered, grey and earthy cloured massive clay. Irregular and nodular bedding.</td>
</tr>
<tr>
<td>1.0m</td>
<td>Packstones &amp; wackestones with abundant pellets and fossil fragments. Ooids common &amp; some intraclasts. Whole fossils abundant towards top. Irregular and wavy bedding.</td>
</tr>
<tr>
<td>2.5m</td>
<td>Coarse bioclastic packstones - grainstones with occasional interbeds of wackestones. Fossil fragments abundant. Some whole fossils. Terrigenous material, ooids and peloids common. Wavy bedding and large scale cross-bedding. Trough type common than the planar type. Micro-cross -laminations.</td>
</tr>
</tbody>
</table>
Bioclasts include mainly shell with some whole remains of brachiopods, echinoderms, molluscs (belemnites, ammonites and pelecypods), foraminifers and occasional bryozoans. 'Oolicasts' and 'pellcasts' cavities left behind after removal of ooids and peloids are observed. Shell cavities have been filled with pelmicrite. Branched and horizontal burrows have been filled with micrite.

**Description of Microfacies**

Dunham (1962) and Folk (1962) schemes were followed for the classification of the studied limestones. Flugul (1982) method was used for identification, nomenclature and description of carbonate microfacies.

**Bioclastic Wackestone**

This microfacies occurs in thin, wavy bedded fossiliferous limestones inter-bedded with cross-bedded poorly fossiliferous arenaceous limestones in the lower part of Kuldhar Member.
The microfacies mainly consist of micrite (45%) and bioclasts (43%). The other textural constituents include ooids (6%), dolomites (3%), terrigenous admixture (2%), intraclasts and peloids (1%) (Fig. 5).

Micrite matrix is ferruginous and argillaceous. Bioclasts include molluscs, mostly gastropods, brachiopods, echinoderms, bryozoans, ostracods and foraminifers and traces of algal encrustations. The bioclasts are poorly sorted, show sharp to ragged boundaries and are moderately compacted. Shell cavities in gastropods are filled with dark coloured, ferruginous micrite.

Ooids include superficial and true ooids and occasionally composite ooids. Dolomite occurs as small isolated patches, terrigenous admixture includes quartz, feldspars, iron and clay minerals.

**Ooidal Bioclastic Packstone**

This microfacies occurs in irregular and nodular bedded limestones in Kuldhar Member. It consists of mainly micrite (35%), ooids (34%) and bioclasts (21%). The other components include peloids (6%), intraclasts, grapestone lumps, and terrigenous (4%) admixture (Fig. 6).

The micrite matrix appears ferruginous and has recrystallized to pseudospar at some places. Superficial ooids are abundant but true ooids and composite ooids are also present.

The bioclasts are predominantly fragmented, but whole fossils occasionally occur. They include molluscs (pelecypods, gastropods, and belemnites) (Fig. 7), echinoderms, brachiopods, foraminifers, serpulid worms, calcispheres, and traces of ostracods, and few unidentified bioclasts. This microfacies show moderate to poor sorting.
Ooids present are mainly normal ooids with more than three laminae and have high sphericity. These ooids normally show tangential microstructure. Few superficial ooids are also present and seems to be micritic ooids. Compaction diagenesis is evidence in this microfacies by high packing density and inter-penetrative contacts.

Peloids are well rounded and well sorted. They show the typical bioclastic shape and 'ghost' of original wall microstructure suggesting their derivation by micritization of bioclasts.

The intraclasts are made up of pelletal grainstone, ooidal bioclastic packstone, ooidal wackestone and bioclastic wackestone. Terreginous admixture includes quartz grains.
**Pelletal Packstone**

This microfacies occurs in nodular-bedded limestones in the middle part of Kuldhar Member. It contains mainly bioclasts (40%) faecal pellets (34%) and micrite spar (25%). Other constituents are superficial ooids, intraclasts, and terrigenous material (1%). The rock shows nodular structure in thin section in form of bedding parallel discontinuity microstructure resulted due to fissure fillings (Fig. 8).

![Fig. 8. Photomicrograph showing pelletal packstone in the Kuldhar Member.](image)

Bioclasts are poorly sorted and include molluscs, bryozoans, echinoderms, brachiopods, foraminifers, ostracods, minor amounts of calcispheres and tintinnines and some unidentified bioclasts. Whole fossils mostly belong to gastropods. Ooids are mostly superficial possessing nuclei of faecal pellets, and altered unidentifiable bioclasts also occur. Stylolites of black colour are common.

**Crinoidal Packstone**

This microfacies occurs in irregularly bedded fossiliferous limestones of the middle part of the Kuldhar Member. Its major constituents are crinoids (48%), other bioclasts (14%), peloids (14%), recrystallized micrite (22%), terrigenous admixture and traces of ooids and intraclasts (2%). The other bioclasts include brachiopods, molluscs, bryozoans, ostracods & foraminifers, calcispheres and tintinnines.

Peloids are ovoid and superficial. Intraclasts of ferruginous silty lime mudstone and ferruginous bioclastic wackestone. Micrite matrix is generally recrystallized. Terrigenous admixture includes silt size quartz and feldspar grains.
Molluscan Packstone

This microfacies is confined to bioturbated, irregular bedded limestones of the upper part of the Kuldhar Member. It consists of dominant bioclasts (45%) and micrite (38%), other minor constituents include ooids and intraclasts (6%), peloids and terrigenous admixture (5%) (Fig. 9).

Bioclasts include whole fossils of belemnites (Fig. 7), fragments of brachiopods, echinoderms, corals, algae and foraminifers. Most bioclasts have well preserved wall microstructure. The shell cavities in belemnites have been filled with ferruginous bioclastic wackestone. Abundant elongated borings and some elliptical borings are also present in the belemnite shells. The borings have been filled with the same micrite as present outside. Algae occur as dark coloured encrustations on bioclasts.

Micrite matrix is dark brown, ferruginous and appears homogenous. Both superficial and true ooids are present along with intraclasts of ooidal wackestone, bioclastic wackestone/packstone and pelletal wackestone. Terrigenous admixtures are largely quartz grains.

Sandy Packstone-Grainstone

This microfacies occurs in cross-bedded arenaceous limestones of the lower part of the Kuldhar Member. The dominant constituent is terrigenous admixture (34%). Other constituents include sparry calcite (17%), micrite, bioclasts, peloids, ooids, dolomite and intraclasts (49%) (Fig. 10).

Bioclasts include fragments of brachiopods, molluscs, (gastropods, pelecypods), echinoderms, foraminifers and traces of ostracods and bryozoans. The bioclasts are moderately sorted and well rounded with sharp boundaries, whilst
peloids are well rounded and well sorted. Dolomite occurs in small patches of finely crystalline to mostly medium crystalline rhombs. Sparsely distributed intraclasts of pelletal bioclastic packstone and ferruginous silty wakestone.

**Fig. 10.** Photomicrograph showing sandy packstone/grainstone in the Kuldhar Member.

Micrite matrix and sparry calcite cement are present in almost equal amounts. Terrigenous admixture includes mainly quartz grains with minor amount of chert, tourmaline, biotite and muscovite.

**Bioclastic Grainstone**

This microfacies occurs in cross-bedded limestones of the lower part of the Kuldhar Member. The microfacies comprises bioclasts (37%), sparry calcite (28%), ooids (12%), peloids (7%), intraclasts and terrigenous admixture (8%) (Fig. 11).

**Fig. 11.** Photomicrograph showing bioclastic grainstone in the Kuldhar Member.
Bioclasts consist of mostly fragments of mollusc (pelecypods and gastropods), other bioclasts include fragments of brachiopods, echinoderms and very small amount of bryozoans and foraminifers. The shell cavities have been filled with dark coloured micrite. Sparry calcite cement occurs as thin isopachous rims.

Ooids include both superficial and true types but the former are common. Composite ooids are occasionally present. Terrigenous admixture is high and includes sand and silt size quartz and feldspars.

**Depositional Environments**

1. The basal part of the Kuldhar Member consists of interbedded terrigenous bioclastic packstone-grainstone, coarse coated bioclastic grainstone and bioclastic wackestone. The interbedding of terrigenous grainstones, poorly washed biosparite and bioclast-rich wackestones suggests that these sediments were deposited under variable energy conditions ranging from shelf and lagoon to platform with open circulation. Presence of homogenous iron-rich argillaceous micrite suggests intermixing of microfacies elements in shallow water and their redeposition below wave base or in back waters.

2. The overlying lithology is rich in ooids, sand and bioclast admixture. The ooids are well sorted, spherical and are well formed with mainly tangential microtexture. This microfacies indicates high energy environment found in beach/coastal zone wherein siliciclastics and abraded bioclasts were incorporated during reworking and winnowing.

3. The ooidal packstone is followed by bioclastic pelletal packstone and recrystallized crinoidal packstone, thus suggesting deposition in shallow warm water with moderate water circulation normally found in shelf-lagoon complex or sometimes in open marine conditions below wave base.

4. The bioturbated packstones-wackestones, with abundant whole fossils and bioclasts including ammonites and belemnites, represents deposition in open shallow marine conditions.

5. Similarity, repetition and overlapping of microfacies in the Kuldhar sequence suggest gradual deepening during transgression followed by shallowing in regression resulted into local changes in environmental condition. The overall change in wave base level has resulted into mixing of faunal bioclasts, terrigenous material and other microfacies elements, which may have formed in a shelf lagoon.

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تحليل السحنة الدقيقة لحجر جير كولدار، مكون جايلسمار
(كولفو-أكسفورد) راجستان الغربية، الهند

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المستخلص. استمر الترسيب بحوض جايلسمار منذ البروتوبوزو- الكامبري المبكر مع بعض فترات التوقف. ثم بدأ الترسيب أثناء حقب الحياة الأوسط لمكون لافي (لياس- باثوني) الذي يتبعه مكون جايلسمار (كولفو-أكسفورد) حيث يتألف من تتبع من صخور الحجر الجيري تعلو صخورًا فاتحة سيليكاتية قسم إلى خمسة أعضاء. ويتكون أحد أعضائه (كولدار) المعنى بالدراسة الحالية من حجر جيري حفري وحجر جيري عقدي بالإضافة إلى حجر الصلصال. هذا وقد تم تحديد بيئة ترسيب عضو كولدار استنادًا إلى تعرف خصائص السحات الدقيقة المكونة لوحداته الصخرية. حيث حل وجود نسج الواكي ستون والباكستون في ورقة من الوحل الجيري على ترسيب في بيئة مدرجة بين لاغوئنية إلى رفيعة دافئة، بينما حل وجود النسج الجيبي المحتوى على سريرس وحات صخري على ترسيب في بيئة ضحلة ومياه مضطربة تعمل مستوى قاع الموجة. كما حل وجود الحبات الهيكلية المنجانس مع فرشاة أرضية طينية غنية بالخليط على ترسيب في بيئة تتراوح بين رفية مفتوحة ومياه هادئة أسفل قاع الموجة إلى أعمق من ذلك.