SEDIMENTOLOGY AND RESERVOIR POTENTIAL OF THE LOWER EOCENE SAKESAR LIMESTONE OF DANDOT AREA, EASTERN SALT RANGE, DISTRICT CHAKWAL, PAKISTAN

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***ABSTRACT*:** *The sedimentology of the Lower Eocene Sakesar Limestone, Eastern Salt Range, District Chakwal, Pakistan was investigated to elaborate its microfacies, diagenetic settings and reservoir potential. The formation is widely distributed in the Salt Range and the Surghar Range and mainly composed of massive and nodular fractured limestone, with marls and chert in upper part. The lower contact with the Nammal Formation and the upper contact with the Chorgali Formation are conformable. A detailed study was conducted after collecting systematically more than 30 rock samples in vertical thickness of aprox.23.88m and studying selecting more than 20 thin sections. To investigate its sedimentology, microfacies package and diagenetic settings, the petrographic study of unstained and stained thin sections has been executed. Detailed field observations and laboratory investigations revealed that it contains microfacies forming Sk-MF-zones (-1, -2, -3, -4, -5, -6, -7, -8, -9). Zones comprised of mainly bioclastic wackestone, packstone, wackestone to packstone, packstone to grainstone and are showing cyclicity as these zones were repeating at certain stratigraphic levels. Research work demonstrates presence of various cement types and diagenetic process. The dolomitization has developed at different horizons as replacement. Microfacies analysis and diagenetic settings lead towards the conclusion that formation was deposited in shallow shelf environment with different digenetic environments having secondary porosity and high reservoir potential.*

Key words: Sakesar Limestone, Microfacies, Micritic Envelops, Bioclasts,

INTRODUCTION

The Lower Eocene succession in the Eastern Salt Range consists of the Nammal Formation and Sakesar Limestone (Fig.1). The term "Sakesar Limestone" has been introduced by Gee **[1]** after the peak Sakesar in the Salt Range (lat. 32°31'30" N; long. 71°56' E) designated its type locality. Principal reference section is Bhadrar village (lat. 32°41'N; long. 72°31'E) in the Eastern Salt Range, district of Jhelum, Punjab Province [2&3].

The Sakesar Limestone is consists of grey, nodular to massive bedded limestone which is cherty in the upper part. It is mainly fossiliferous and contains corals, mollusks and larger benthic foraminifera [4]. The Sakesar Limestone extends largely in the project area having thickness between 70 m to 150 m. The formation is thinning eastward in the Salt Range where it forms high peaks and prominent escarpments. Formation conformably overlies the Nammal Formation and overlain by the Chorgali Formation, in the north of Gandhala nala. While in the south, it is unconformably overlain by the Kamlial Formation of the Rawalpindi Group [5]. From sedimentological point of view, more than 12 beds of Sakesar Limestone are measured from Dandot area (Eastern Salt Range) which shows cyclic deposition [6 & 7].

From thin section studies, it shows nine types of microfacies [8]. The measured thickness of the Sakesar Limestone in the area is approx. 23.88m. The lithology of the formation comprises mainly of light to medium grey, nodular to massive, hard and jointed foraminiferal limestone with the considerable development of chert in the upper part, and grey subordinate marl in the lower part.

Microfacies Analysis of the Sakesar Limestone

With the help of thin sections studies, Tucker [9] following nine types of microfacies [10, 11 & 12] have been identified (Fig. 2 & 3).

Sk-MF-1 (0 – 3.92m)

Sk-MF-1 facie is classified as Bioclastic Wackestone [13]. The bioclasts are about 25 % and mainly of Discocyclina dispensa, Bryozoan, Miliolid, Assilina subspinosa, Mollusks, Nummulites atacicus, and broken shell fragments (Plate1 a, b, c). Micrite (carbonate mud) is about 40 %. Sparry and ferroan calcite cement is about 5 %. About 1% Fracture porosity has also been observed.

Sk-MF-2 (3.92–5.57m)

Sk-MF-2 facie is classified as Bioclastic Wackestone to Packstone. Bioclasts are about 30% and mainly consist of Alveolina sp., Nummulites atacicus, Assilina granulosa, Miliolid, Mollusks, Nummulites mamillatus, and other broken shell fragments (Plate 2 a, b, c). Micrite is about 20%. Sparry calcite cement is about 10%. 5 % ferroan calcite cement is also present.

Sk-MF- 3 (5.57–6.2m)

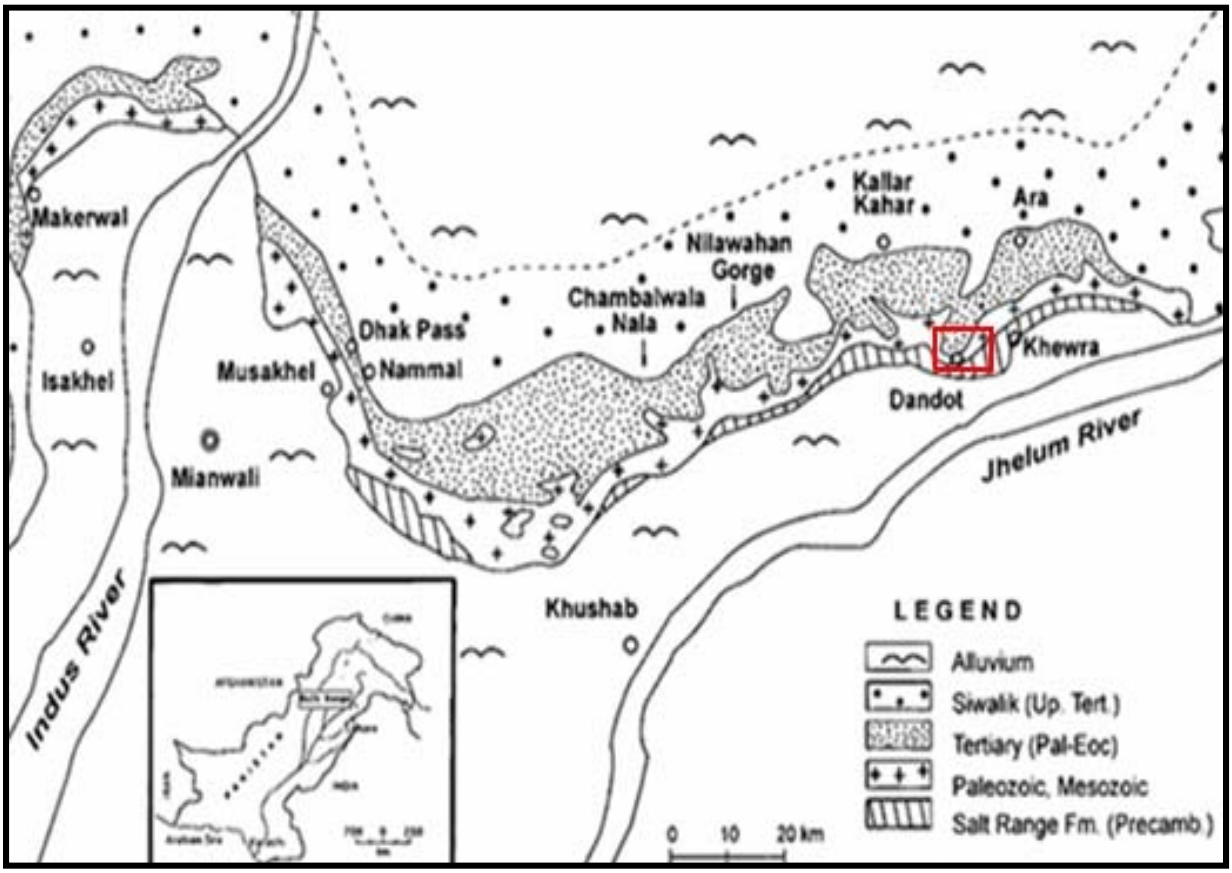

Fig. 1: Geological map of the Salt Range, Pakistan showing location of the Dandot area after [14].

Sk-MF-3 facie is classified as Bioclastic Packstone to Grainstone. The bioclasts are about 40% and mainly of Lockhartia conditi, Mollusks, Assilina sp., Assilina subspinosa, Nummulites atacicus, and other broken shell fragments (Plate 3 a, b). Micrite is about 10%. Sparry calcite cement is about 20%. About 5% of Ferroan calcite and isopach bladed cement has been observed. Subhedral to euheadral dolomite rhombs and fracture porosity is also present.

Sk-MF- 4 (6.2–10.5m)

Sk-MF-4 facie is classified as Bioclastic Packstone. The bioclasts are about 30% and mainly consist of Miliolid, Mollusks, Textularia, Dasycladacean green algae (Halimeda), Nummulites sp, and other broken shell fragments (Plate 4 a, b). Micrite (carbonate mud) is about 10%. High range of Fracture porosity is observed. Sparry calcite cement is about 15% with 3% of ferroan calcite cement.

Sk-MF- 5 (10.5–11.15m)

Sk-MF-5 facie is classified as Bioclastic Packstone to Grainstone. The bioclasts are about 45% and mainly of Assilina sp., Nummulites sp., and other broken shell fragments (Plate 5 a, b). Micrite is about 1%. Sparry calcite cement is about 20% and high range of ferroan calcite cement is present e.g.10%. About 25 % of Dolomite rhombs mainly subhedral to euhedral and secondary porosity is also observed.

Sk-MF- 6 (11.15–12.35m)

Sk-MF-6 facie is mainly classified as Bioclastic Wackestone. The bioclasts are about 15% and consist mainly of Marginopora sp., Nummulites globulus, and other broken shell fragments (Plate 6). Micrite is about 40%. Sparry calcite cement is about 20%. High range of Fracture porosity is also present.

Sk-MF- 7 (12.35–16.1m)

Sk-MF-7 facie is classified as Bioclastic Wackestone to Packstone. The bioclasts are about 35% and mainly consist of Nummulites globulus, Rugose coral, Mollusks, and other broken shell fragments (Plate 7 a, b). Micrite is about 40%. Fracture porosity is also present. Sparry calcite cement is about 20%. 5 % of Dolomite rhombs mainly subhedral are also present.

Sk-MF- 8 (16.1–16.9m)

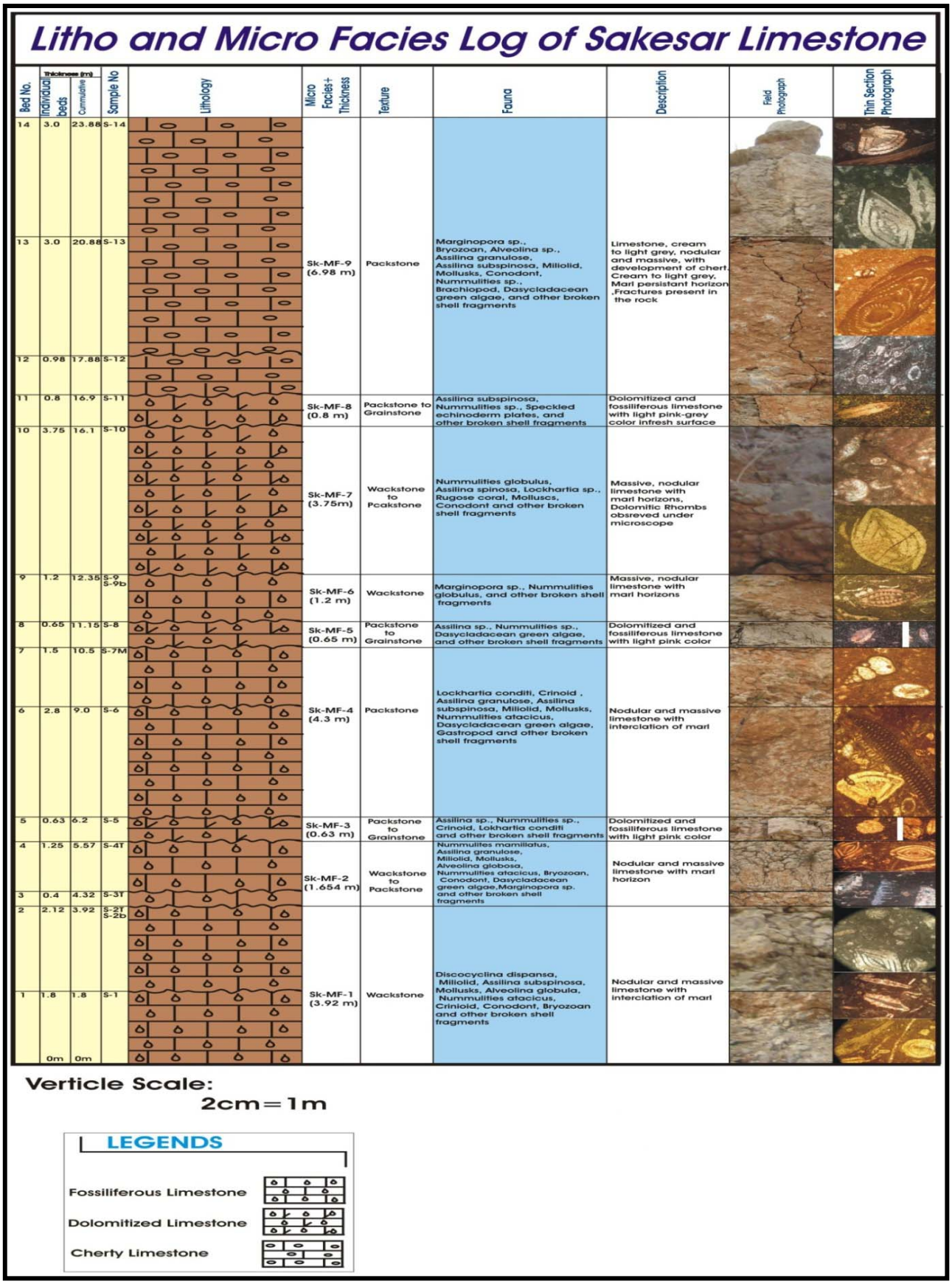
Litho and Micro Facies Log of Sakesar Limestone
Bed No.
Thickness (m)
Individual beds
Cummulative
Sample No
Lithology
Micro Facies+ Thickness
Texture
Fauna
Description
Field Photograph
Thin Section Photograph
14 3.0 23.88 S-14
13 3.0 20.88 S-13
12 0.98 17.88 S-12
11 0.8 16.9 S-11
10 3.75 16.1 S-10
9 1.2 12.35 S-9 S-9b
8 0.65 11.15 S-8
7 1.5 10.5 S-7M
6 2.8 9.0 S-6
5 0.63 6.2 S-5
4 1.25 5.57 S-4T
3 0.4 4.32 S-3T
2 2.12 3.92 S-2T S-2B
1 1.8 1.8 S-1
0m 0m
Sk-MF-9 (6.98 m)
Packstone
Marginopora sp., Bryozoan, Alveolina sp., Assilina granulose, Assilina subspinosa, Miliolid, Mollusks, Conodont, Nummulities sp., Brachiopod, Dasycladacean green algae, and other broken shell fragments
Limestone, cream to light grey, nodular and massive, with development of chert. Cream to light grey, Marl persistant horizon ,Fractures present in the rock
Sk-MF-8 (0.8 m)
Packstone to Grainstone
Assilina subspinosa, Nummulities sp., Speckled echinoderm plates, and other broken shell fragments
Dolomitized and fossiliferous limestone with light pink-grey color infresh surface
Sk-MF-7 (3.75m)
Wackstone to Pcakstone
Nummulities globulus, Assilina spinosa, Lockhartia sp., Rugose coral, Molluscs, Conodont and other broken shell fragments
Massive, nodular limestone with marl horizons, Dolomitic Rhombs obsreved under microscope
Sk-MF-6 (1.2 m)
Wackstone
Marginopora sp., Nummulities globulus, and other broken shell fragments
Massive, nodular limestone with marl horizons
Sk-MF-5 (0.65 m)
Packstone to Grainstone
Assilina sp., Nummulities sp., Dasycladacean green algae, and other broken shell fragments
Dolomitized and fossiliferous limestone with light pink color
Sk-MF-4 (4.3 m)
Packstone
Lockhartia conditi, Crinoid , Assilina granulose, Assilina subspinosa, Miliolid, Mollusks, Nummulities atacicus, Dasycladacean green algae, Gastropod and other broken shell fragments
Nodular and massive limestone with interclation of marl
Sk-MF-3 (0.63 m)
Packstone to Grainstone
Assilina sp., Nummulities sp., Crinoid, Lokhartia conditi and other broken shell fragments
Dolomitized and fossiliferous limestone with light pink color
Sk-MF-2 (1.654 m)
Wackstone to Packstone
Nummulites mamillatus, Assilina granulose, Miliolid, Mollusks, Alveolina globosa, Nummulities atacicus, Bryozoan, Conodont, Dasycladacean green algae,Marginopora sp. and other broken shell fragments
Nodular and massive limestone with marl horizon
Sk-MF-1 (3.92 m)
Wackstone
Discocyclina dispansa, Miliolid, Assilina subspinosa, Mollusks, Alveolina globula, Nummulities atacicus, Crinioid, Conodont, Bryozoan and other broken shell fragments
Nodular and massive limestone with interclation of marl
Verticle Scale:
2cm=1m
LEGENDS
Fossiliferous Limestone
Dolomitized Limestone
Cherty Limestone

Fig. 2- Litho- and Micro- Facies log of the lower Eocene, Sakesar Limestone Dandot area, District Chakwal, Pakistan.

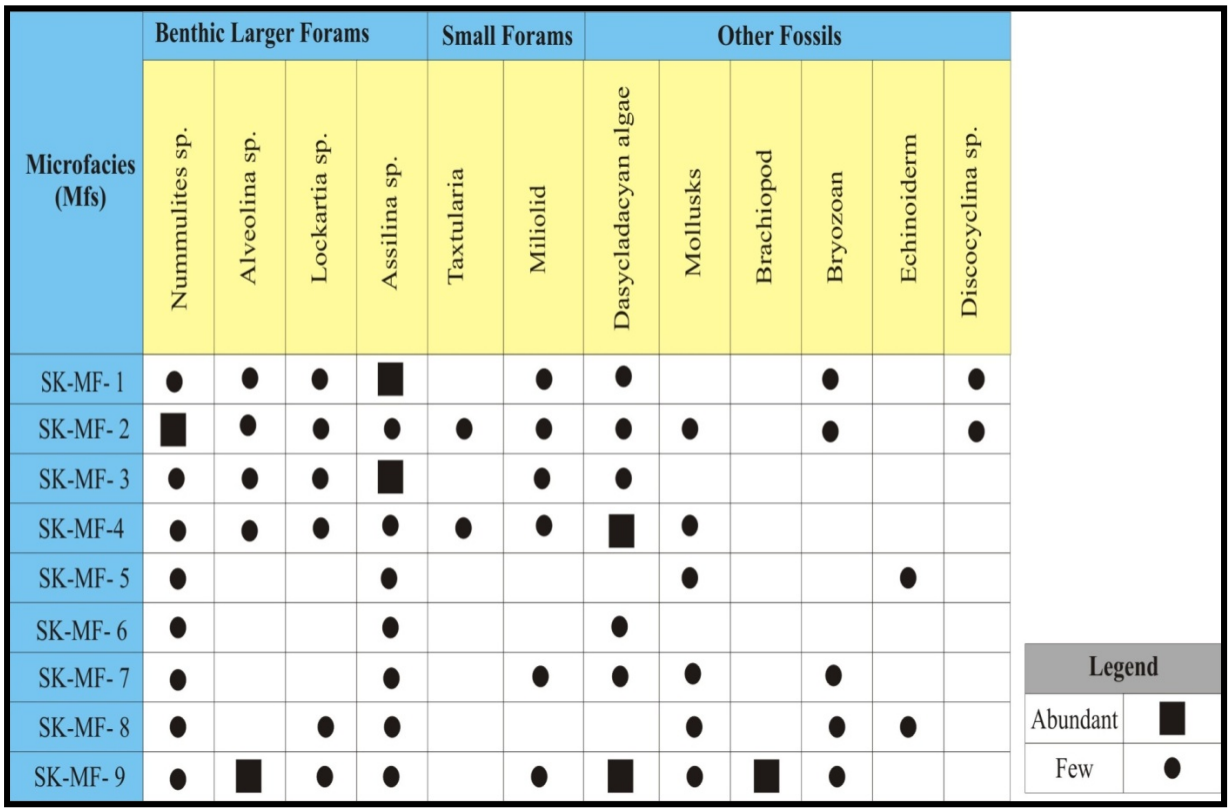

Fig. 3- Microfacies Based Range Chart of foraminiferas along with other fossils in Sakesar Limestone.

Plate1a: Discocyclina dispensa , Bryozoan , Miliolid , Sparry-calcite vein, Assilina sp., Mollusks, observed under Plane Polarized Light , stained part, magnification is 40x.

Plate1b: Assilina subspinosa, Miliolid, Ghost is also present. Observed under Cross Nicol, stained part, Magnification is 40x.

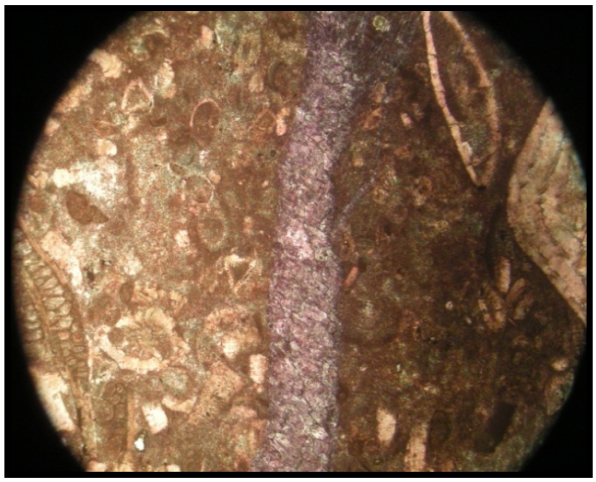

Plate1c: Ferroan calcite vein, Dasycladacean green algae, Mollusks, Assilina sp., Nummulites sp. Ghost is also present. Observed under Cross Nicol, stained part, Magnification is 40x.

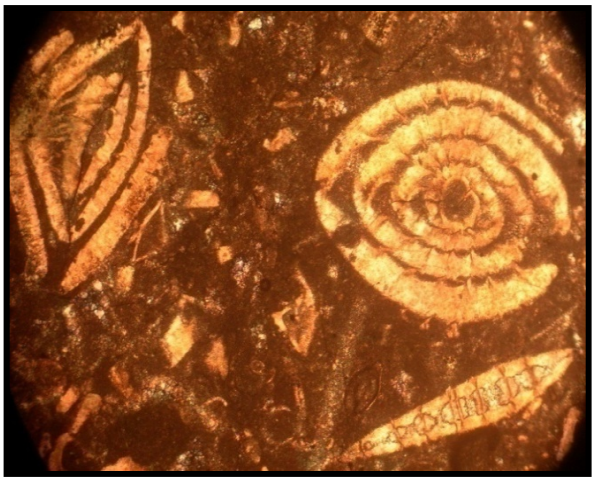

Plate 2c: Nummulites mamillatus, Assilina granulosa, Nummulites atacicus, Ghost is also present, observed under Cross Nicol, stained part, Magnification is 40x

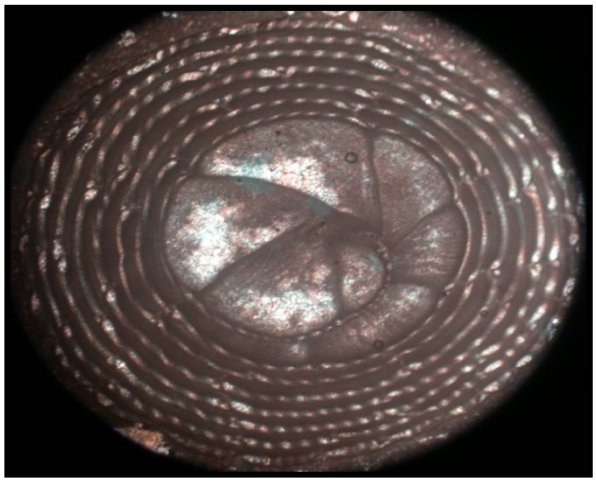

Plate 2a: Alveolina globosa axial section showing basal thick layer. Observed under Cross Nicol, stained part, Magnification is 40x.

Plate 3a: Assilina granulosa, Nummulites atacicus and rest are Assilina and Nummulites sp. showing sharp contacts, Ghost is also present. Observed under Plane Polarized Light, stained part, Magnification is 40x.

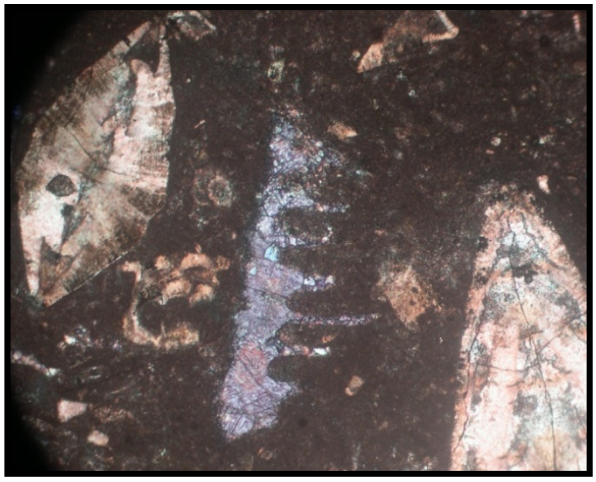

Plate 2b: Fragment in the middle fill by ferroan calcite cement, Assilina granulosa, Nummulites sp. Ghost is also present, observed under Cross Nicol, stained part, Magnification is 40x.

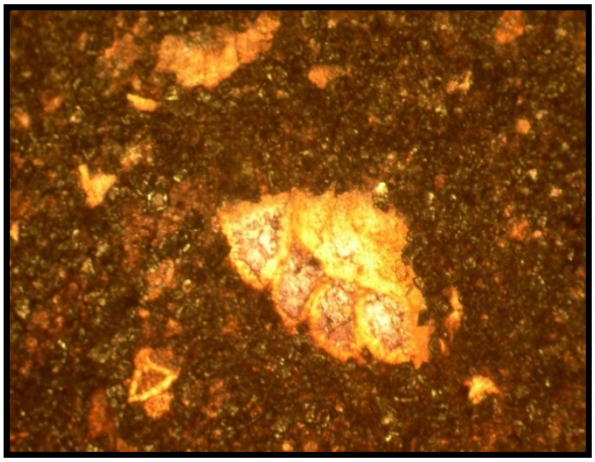

Plate 3b: Lockhartia conditi (filled by ferroan calcite cement but also Isopach bladed cement (yellow) is present around chambers), Dolomitic rhombs are subhedral to euhedral (zoning in rhombs and

calcite cement present showing dedolomitization). Ghost is also present, observed under PPL, stained part, Magnification is 40x.

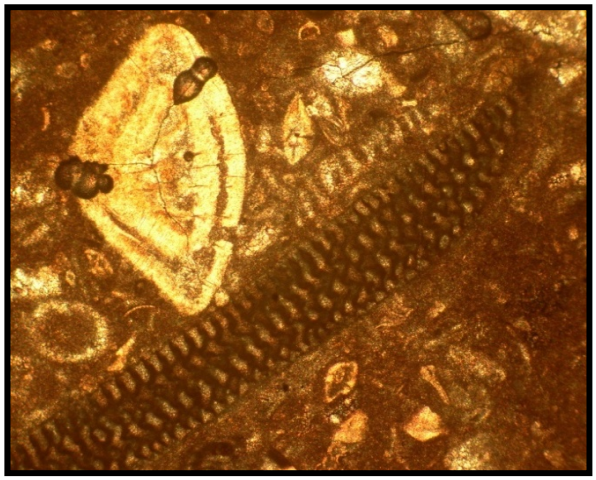

Plate 4a: Typical calc. green algae (Halimeda), Nummulites sp., Miliolid, Mollusks, and Ghost are also present, observed under Plane Polarized Light , stained part, Magnification is 40x.

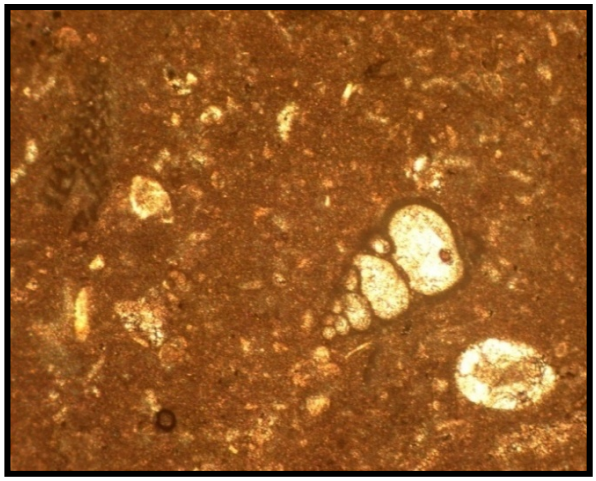

Plate 4b: Foraminifara, and possibly bioclast which is totally dissolved showing mould porosity, observed under Plane Polarized Light, stained part, Magnification is 40x.

Plate 5a: Assilina sp., Dolomite rhombs which are mostly subhedral to euhedral. Ghost is also present, observed under Plane Polarized Light, stained part, Magnification is 40x.

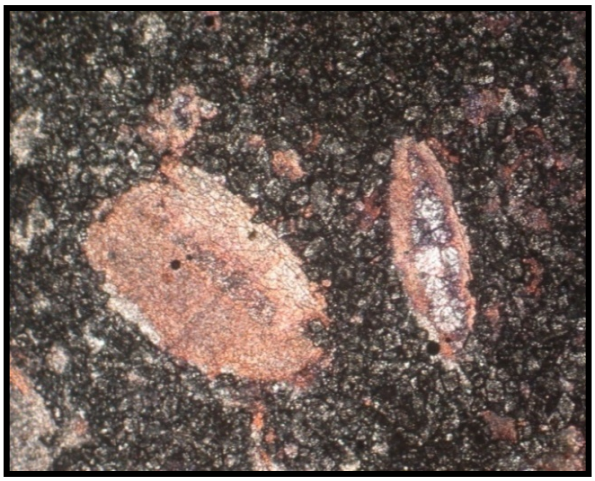

Plate 5b: Assilina sp., Nummulites sp., Dolomite rhombs which are mostly subhedral to euhedral. Moldic Porosity (partially filled by ferroan calcite cement). Ghost is also present, observed under Plane Polarized Light, stained part, Magnification is 40x.

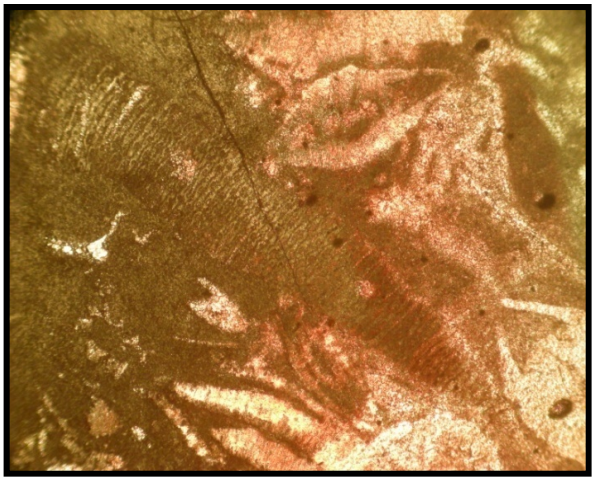

Plate 6: Marginopora sp., Assilina sp., Fracture porosity and ghost is present, observed under Plane Polarized Light, stained part, Magnification is 40x.

Plate 7a: Nummulites globulus, fracture porosity, and ghost is present, observed under Plane Polarized Light, unstained part, Magnification is 40x.

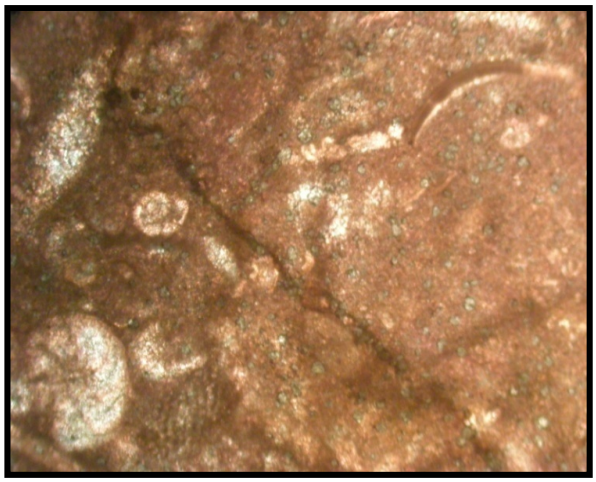

Plate 7b: Mollusks, Rugose coral, fracture porosity and dolomite rhombs and Ghost are present, observed under Plane Polarized Light, stained part, Magnification is 40x

Plate 8a: Assilina subspinosa. Sparry calcite cement, Ferroan calcite cement and Dolomite rhombs are present which are subhedral to euhedral, observed under Plane Polarized Light, stained part, Magnification is 40x.

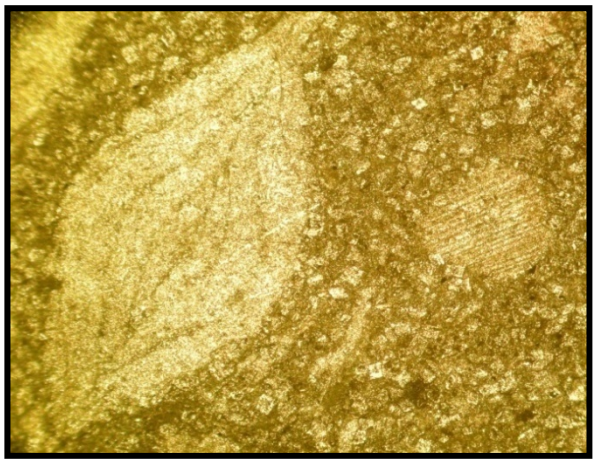

Plate 8b: Nummulites sp., Speckled echinoderm plate, Dolomite rhombs present which are subhedral to euhedral, observed under Plane Polarized Light, unstained part, Magnification is 40x.

Plate 9a: Marginopora sp. is an excellent example of a large foraminifer with planispiral coiling. It has small, early-formed chambers in the center and increasingly larger chambers toward the margins. Ghosts are also present, observed under Plane Polarized Light, unstained part, Magnification is 40x.

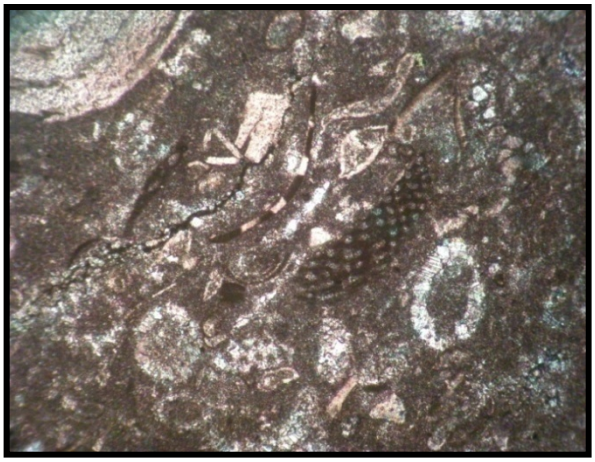

Plate 9b: Dasycladacean green algae, Mollusks, fracture porosity and Ghosts are present, observed under cross nicol, stained part, Magnification is 40x.

Plate 9c: Nummulites sp., Brachiopod, ferroan calcite vein, and ghosts are present, observed under Plane Polarized Light, stained part, Magnification is 40x

Sk-MF-8 facie is classified as Bioclastic Packstone to Grainstone. The bioclasts are about 30% and mainly consist of Assilina subspinosa, Nummulites sp., speckled echinoderm plates, and other broken shell fragments (Plate 8 a, b). Micrite is about 1%. Sparry calcite cement is about 25%. Dolomite rhombs which are subhedral to euhedral, 30% acts as grains.

Sk-MF- 9 (16.9–23.88m)

Sk-MF-9 facie is classified as Bioclastic Packstone. The bioclasts are about 30% and mainly consist of Brachiopod, Marginopora sp., Assilina sp., Mollusks, Nummulites globulus, Dasycladacean green algae, and other broken shell fragments (Plate 9 a, b, c).

Micrite is about 5%. Sparry calcite cement is about 25% while ferroan calcite cement is also present about 15%. Fracture porosity is also present.

Diagenetic Features of Sakesar Limestone

The petrographic analysis and the diagenetic settings of the Sakesar Limestone exposed at this section revealed the following diagenetic history [15 & 16].

Cement Types

Cements provide the stability and strength to the carbonate sediments. Cementation of carbonate sediments is an important diagenetic process as the well developed cement always resists physical and chemical compaction along with fracturing. Fibrous aragonite precipitates as early diagenetic cement while rest is precipitate as late diagenetic stage. Sakesar Limestone contains following three cement types as studied.

Micritic Envelopes

It is the first diagenetic phase which takes place in the marine diagenesis of limestones [17]. Micritic envelop develop around fauna which having aragonitic composition. Aragonite is a metastable carbonate mineral, easily dissolved in very early phase of diagenesis and is replaced by calcite. However in Sakesar limestone micritic envelopes present very rarely but at some places it is indicating this feature (Plate 4b).

Aragonite Dissolution

Aragonite dissolves in the second phase of faunal grains having the aragonitic composition and is precipitated as sparite. Internal structure of the skeletal grains may be totally destroyed or no relict structure is observed at all but the outline and morphology is preserved. In Sakesar Limestone this phase can easily be observed.

Sparry calcite cements (generally grains are whitish to reddish color). This cement type is mostly present partly or completely in the skeletal grains and some calcite veins. It is product of meteoric pheratic environment [2].

Ferroan calcite cements generally mauve to blue color. This cement type is mostly present partly or completely in the skeletal grains and some calcite veins. This type of cement shows deep environment of deposition.

Isopach bladed cements are also present. Mainly it covers ferroan calcite cement and its shape is like blade (Plate 1c, 2b, 3 b).

Mechanical Compaction

Next diagenetic event is mechanical compaction of the carbonate sediments. The inter grain and interstitial space reduces which results in the overall reduction of porosity of the rock. Component grains may break because of increased mechanical pressure for poorly cemented sediments. There is also possibility of production of fractures so, in result porosity and permeability may be enhanced of the rock (Plate 3a).

Fractures

In the measured section fractures are found at different horizons. Presence of fractures, veins and broken allochems show the imprints of both overburden pressure and tectonic stresses pre-and-post cementation phases [17]. Sakesar Limestone also show phase of fracturing along with stylolitization which are partially or completely filled by different phases of calcite and ferroan calcite (Plate 6, 7a, 7b).

Dolomitization

In the Sakesar Limestone, mainly two types of dolomitization are observed [18]. One is microdolomitization small and medium to fine size crystals and other is pervasive dolomitization occurs extensively and generally attacks the fabric of the rock, in the result mostly limestone is dolomitized (Plate 3b, 5a, 5b, 7b, 8a).

Dedolomitization

During diagenesis, the dolomite is replaced by calcite and along with some crystals of dolomite shows zoning (Plate 5a, 8a).

In this late stage of diagenetic phase the ferroan calcite cement develops (Plate 1c, 2b) [17].

CONCLUSION

The Sakesar Limestone at the studied section mainly composed of limestone with subordinate shale and marl, and very thick-bedded nodular limestone with chert nodules. Some dolomitized Limestone beds were present which shows fractures and stylolization with marl and shale components.

From the field observations and laboratory investigations (Stained and Unstained thin sections study) revealed that it contains microfacies mainly comprised of bioclastic packstone, wackestone, wackestone to packstone, packstone to grainstone and are showing cyclicity as these zones were repeating at certain stratigraphic levels.

The component grains of bioclastic microfacies mainly comprised of tests, shells and particles of: mollusks, brachiopods, echinoderms, bryozoans, corals and algae. The diagenetic settings produced variety of features like, micritization, cements from early marine to late diagenetic cements, fractures, compaction, dolomitization and dissolution fabric. The Formation's diagenetic settings point towards its high reservoir potential.

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