

Microfacies and diagenetic fabric of the Chorgali Formation in Bhuchal Kalan, Kallar Kahar, Salt Range, Pakistan

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Abstract

The Chorgali Formation of Eocene age is composed of planar to nodular bedded limestone with shale intercalations, which is exposed in the Bhuchal Kalan, Kallar Kahar of the eastern Salt Range. In this study, a 16.5 m thick stratigraphic section is measured, logged and sampled with a total of 30 samples in two sections (about 1km apart). Four microfacies are recognized from field and petrographic studies and are: 1) Mud-Wackestone Microfacies, 2) Larger Foraminifera Wacke-Packstone Microfacies, 3) Mixed Bioclastic Wacke-Packstone Microfacies and 4) Shale Lithofacies. These microfacies re-occurred vertically in stratigraphic section. The depositional texture and faunal association suggested that the microfacies represents deposition on a low energy carbonate shelf. The analysis further showed that the Chorgali Formation was also subjected to various diagenetic changes, mainly showing the compaction, aragonite to calcite transformation, tectonically induced fracturing and calcite veins passing from marine diagenesis to meteoric diagenesis through burial diagenesis.

Keywords: Chorgali Formation; Eocene; Carbonate shelf; Salt Range; Pakistan.

1. Introduction

The study area falls within Kallar Kahar, situated in eastern Salt Range. The Salt Range is east and west trending fold and thrust belt, it can be located as to its north is Potwar Plateau and to its south is SRT (Salt Range Thrust), the eastern limit is bounded by Jhelum River and west by Indus River (Fig. 1). The study area is easily accessible throughout the year along the Khushab-Chakwal Road. The Chorgali Formation has been investigated at two locations: one lies at lat. 32° 40' 41.5" N long. 72° 36' 53.9" E (1km south of Bhuchal Kalan town) and the second at lat. 32° 41' 02.7" N long. 72° 37' 21.1" E (within the Bhuchal Kalan town) along the Khushab-Chakwal Road. The stratigraphic succession of the Salt Range ranges from Pre-Cambrian to Eocene (Fatmi, 1973; Fatmi et al., 1984) (Fig. 3). These stratigraphic successions can be traced at various localities in the Salt Range. The Chorgali Formation of Eocene age at Bhuchal Kalan is one of them.

The Chorgali Formation is studied at different localities within Pakistan (Shah, 2009). In the present study area, earlier, Gill (1953) carried out detailed studies on the facies and fauna in the Bhadrar beds of the Salt Range and correlated the lithological units exposed in lower Indus Basin and Kohat-Potwar Basin on the basis of their fauna. Gill (1953), Iqbal (1969), Fatmi (1973), Shah (1977), and Baqri et al. (1997) assigned early Eocene age to

the Bhadrar beds on the basis of the fauna encountered. The latest work, which is unpublished (a PhD dissertation) is that of Mujtaba (2001) on the depositional and diagenetic environments of the Chorgali Formation. In this study he discussed in detail about facies distribution and reservoir potential of the Chorgali Formation within Salt Range and Potwar Plateau (supported by isotopic analysis) from number of sections (subsurface and surface). However, in light of the above literature it is understood that the work regarding Chorgali Formation in terms of facies and diagenesis within the Salt Range is unpublished. Further, the Chorgali Formation within the eastern Salt Range can be found in bits and pieces. Here, the outcrop level of the Chorgali Formation is confusing without its upper and lower contact being exposed in most of the places. Hence, the clarity can come through if we analyze more outcrops of the said formation. Thus, the present study is aimed to identify various allochemical constituents along with identification of microfacies and their interpretation to construct a schematic depositional model for the Chorgali Formation exposed in Bhuchal Kalan area of Kallar Kahar that will add to the understanding of the Chorgali Formation in eastern Salt Range.

2. Materials and methods

The Chorgali Formation (Eocene) comprised of planar to nodular bedded limestone with shale interbeds as exposed in the Bhuchal Kalan area of

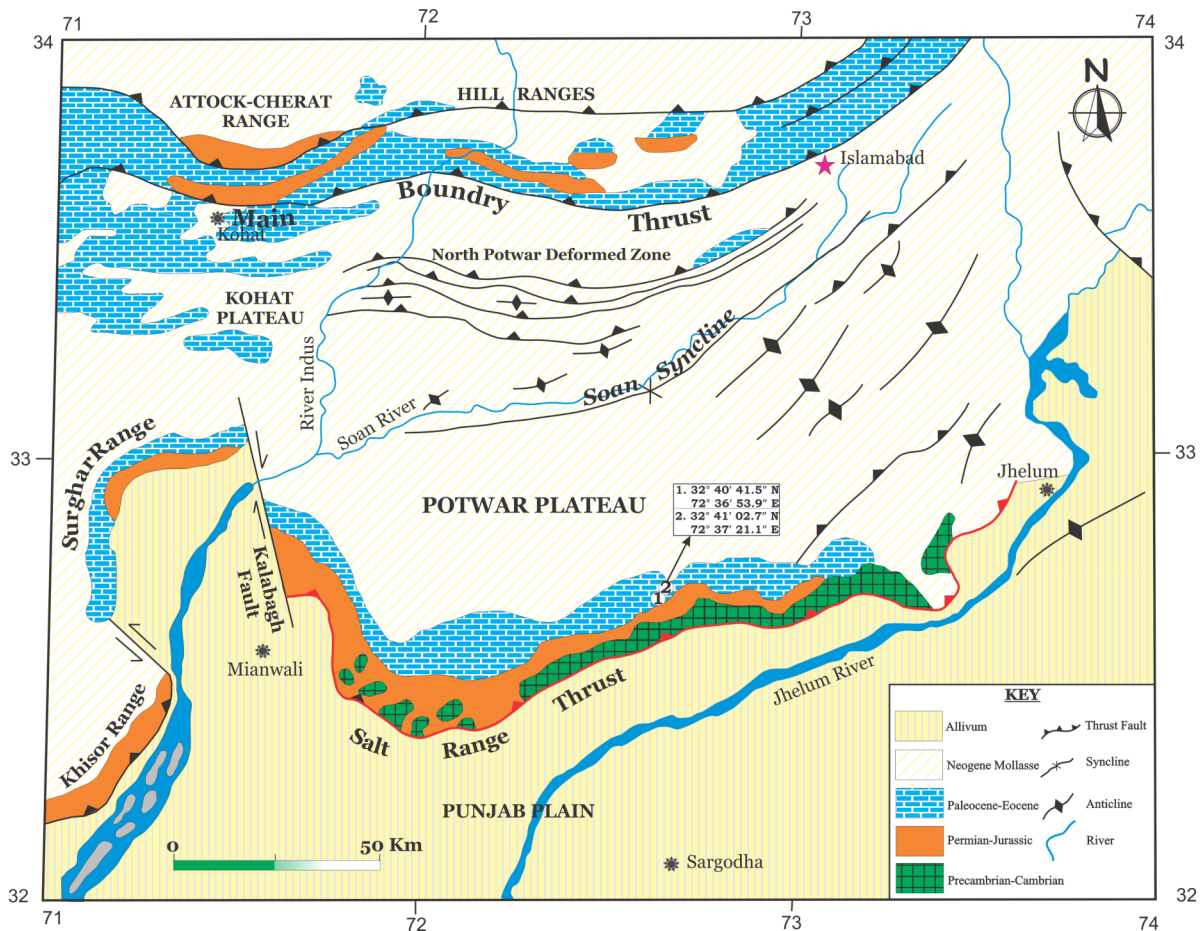


Fig. 1. Location Map, with respect to Potwar Plateau (after Kazmi and Rana, 1982; Jaswal et al., 1997), studied locations are represented by 1 and 2.

Kallar Kahar in Potwar Plateau, Salt Range. The upper and lower contact of the Chorgali Formation in the area is not exposed. As a part of this study, a 16.5 m thick stratigraphic section is measured, logged and sampled at two sections (1km apart) as shown in Figure 2. A total of 30 samples have been collected for further petrographic analysis, samples were prepared for petrography using the established thin sectioning techniques (Flügel, 2004). The microfacies along with the diagenetic analysis were carried out using digital camera fitted Nikon Petrographic Microscope at the Department of Geology, University of Peshawar. The classification scheme of Dunham (1962) is used in this study. The microfacies identified were compared with the Standard Microfacies of Flügel (1982) and Wilson (1975). The depositional model presented is based on the interpreted microfacies.

3. Results

3.1. Facies analysis

Based on field and petrographic analysis four microfacies were identified. These microfacies are as follows: (1) Mud-Wackestone Microfacies, (2)

Larger Foraminifera Wacke-Packstone Microfacies, (3) Mixed Bioclastic Wacke-Packstone Microfacies and (4) Shale Lithofacies.

3.1.1. Mud-wackestone microfacies

The Mud-Wackestone microfacies is comprised of light grey, medium bedded limestone interbedded with shale. Shale beds show variable thickness of 5-10cm. The total thickness of the mud-wackestone microfacies is 1.5m. It has been repeated 4 times vertically in the section (Table 1). The microfacies is mud-supported and has approximately 10% skeletal/biogenic grains (Dunham, 1962) classified as mud-wackestone. Biogenic grains are of Nummulites, Lockhartia, echinoderms, pelecypods and algae. The average relative abundance of the biogenic grains is: Nummulites (4%), Lockhartia (3%), echinoderms (1%), pelecypods (1%) and algae (1%). Mud-Wackestone Microfacies can be shown in Plate 1A and 1B.

3.1.2. Larger foraminiferal wacke-packstone microfacies

The rock consisting of the microfacies is

Age	Formation	Thickness	Lithological Log	Sample No	Forams	Reduction spot	Description	Photographs																										
Eocene	Chorgali Formation	17.00		30																														
		16.00		29																														
		15.00		28-25						» Shale horizon with brownish patches.																								
		14.00		24																														
		13.00		23																														
		12.00		22																														
		11.00		21																														
		10.00		20																														
		9.00		19						Light grey limestone with calcitic patches																								
		8.00		18						Yellowish grey shale																								
		7.00		17						» Grey limestone with milky patches																								
		6.00		16						Light grey shale having burrow mottling																								
		5.00		15																														
		4.00		14																														
		3.00		13						» Grey limestone containing pelecypods and calcite patches.																								
		2.00		12						Creamy yellow to light grey limestone containing forams.																								
		1.00		11																														
				10						Grey to yellowish limestone containing forams.																								
				9						» Creamy to reddish brown shale having reduction spot.																								
				8																														
				7																														
				6																														
				5						» Grey limestone with yellowish patches containing large forams.																								
				4						Limestone containing larger forams, gastropods. Shale/Marl interbedded.																								
				3																														
				2						Forams bearing grey limestone.																								
				1						» Reddish brown shale with reduction spots, recessive profile																								

Fig. 2. Graphic log, description and photographs of the measured section of Chorgali Formation in Bhuchal Kalan area, Kallar Kahar, Salt Range, Pakistan.

comprised of light grey, thin to medium bedded, nodular limestone with abundant foraminifera, gastropods and brachiopods. Thin shale horizons characterized by greenish colour with purplish tint are also present at regular intervals in the basal portion. The Larger Foraminiferal Wacke-Packstone represents a total thickness of 10m and is repeated 3 times in the section (Table 1). The microfacies contain more than 10% of skeletal/biogenic grains. The allochemical constituents are Nummulites, Alveolina along with other larger foraminifera, pelecypods and echinoderms in the microfacies. Different species of Nummulites, Assilina, Alveolina and Lockhartia have been identified. The average relative abundance of the benthic foraminifera is 50-60%, with subordinate echinoderms and pelecypods. The microfacies is comprised of lime mud as matrix varying from 20 to 80 % with Grains: Matrix ratio varying from 4:1 to 1:4. The average percentage of allochems is as follows: Nummulites (9%), Alveolinids (7%), Assilina (6%), Lockhartia (4%), echinoderms (1%), and pelecypods (1%). Larger Foraminifera Wacke-Packstone Microfacies can be shown in Plate 2A and 2B.

3.1.3. Mixed bioclastic wacke-packstone microfacies

The rock consisting of this microfacies is comprised of medium bedded limestone, yellowish at weathered surface and light grey at fresh surface. Fossil percentage is very low in the outcrop. Upper portion is represented by a 1m bed of greenish shale. This microfacies has a total thickness of 5m (Table 1), appears at 5.2m from base and is repeated 4 times in the section. The skeletal/biogenic grains are more than 10% in this microfacies. The microfacies contains shell fragments as well as well-preserved of Lockhartia and the other bioclasts, include echinoderms and pelecypods. The Grain: Matrix varies from 4:1 to 7:3. The average relative abundance of the various allochems is: Nummulites (5%), Lockhartia (4%), echinoderms (6%), pelecypods (2%) and biodebris (40%). Mixed Bioclastic Wacke-Packstone Microfacies can be shown in Plate 3A and 3B.

3.1.4. Shale lithofacies

This lithofacies comprised of shale beds (Plate 4A and 4B; in both the measured sections) and is characterized by the brownish colour on the fresh surface. This lithofacies shows some bioturbation that is present in the form of vertical burrows.

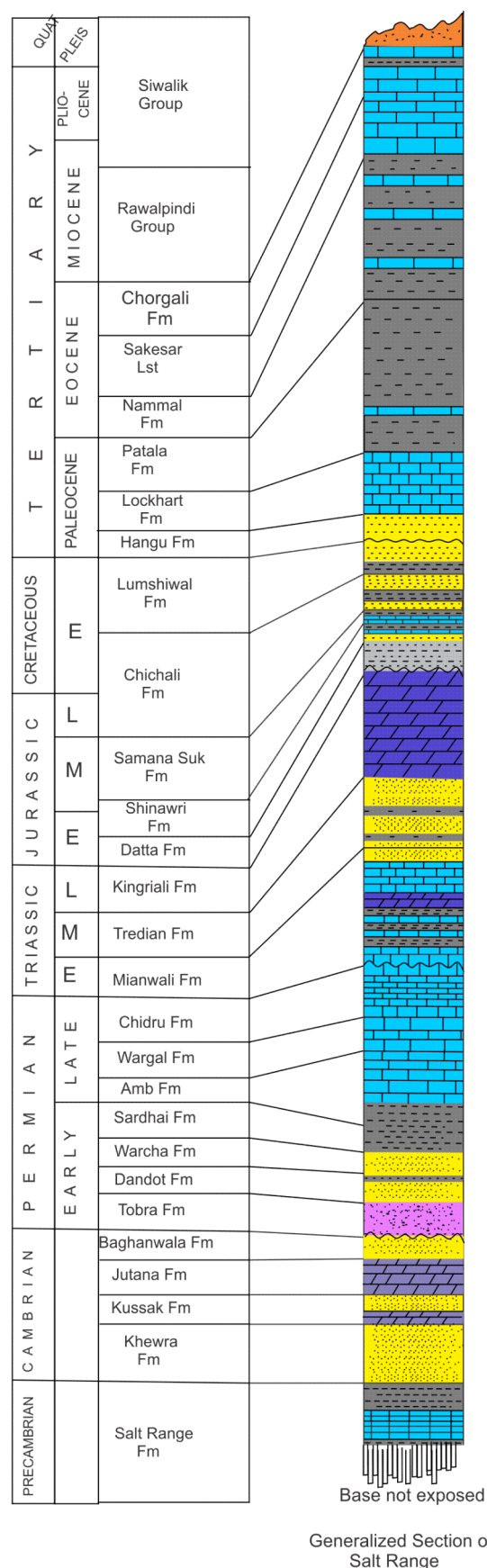


Fig. 3. The stratigraphic succession within the Salt Range (Fatmi 1973 and Fatmi et al., 1984; Fm: Formation).

Table 1. Vertical distribution of textural elements in the measured section of Chorgali Fomation in Bhuchal Kalan area, Kallar Kahar, Salt Range, Pakistan.

Sample No.	Bioclasts							Bioclasts	Matrix	Grain : Matrix	Microfacies
	Foraminifera				Other						
	Nummulites	Assilina	Alveolina	Lockartia	Echinoderms	Pelecypods	Bio-clasts				
30							10	10	90	1:9	
29							20	20	80	1:4	
28				2			8	10	90	1:9	
27				5	10	2	53	70	30	7:3	
26				10			40	50	50	1:1	
25				10			60	70	30	7:3	
24							20	20	80	1:4	
23	10						50	50	50	1:1	
22				2			48	60	40	1:5.1	
21				5	2		3	10	90	1:9	
20							20	20	80	1:4	
19							40	40	60	1:2.5	
18							20	20	80	1:4	
17							10	10	90	1:9	
16	15		10	10			35	70	30	7:3	
15	15	5					30	50	50	1:1	
14	10			10			10	30	70	3:7	
13	10						10	20	80	1:4	
12	10	1			1	1	7	20	80	1:4	
11	4	1			1	1	3	10	90	1:9	
10	10	1			1	1	7	20	80	1:4	
9							60	60	40	1.5:1	
8	25	1		5		1	38	70	30	7:3	
7	40	1					29	70	30	7:3	
6	10	5		1			44	60	40	1.5:1	
5	10	40		10			10	70	30	7:3	
4	10	40	15			1	14	80	20	4:1	
3	5	10		5	1		29	50	50	1:1	
2	10						10	20	80	1:4	
1	20		5	10			45	80	20	4:1	

Index

Mud
Wackestone Microfacies

Larger Foraminifera
Wacke Packstone Microfacies

Mixed Bioclastic
Wacke Packstone Microfacies

3.2. Diagenetic fabric analysis

Diagenesis is a set of various processes which affect the sediments after deposition, on one hand it lithifies the rock with subsequent cementation and on the other hand, it encompasses the dissolution which results in karst topography (Tucker and Wright, 1990). The diagenetic fabric within Chorgali Formation are:

3.2.1. Compaction

The compaction is of two types: a) Physical Compaction, b) Chemical Compaction.

In-situ brecciation of allochemical constituents is typically associated with physical compaction caused breakage of tests which were associated with relatively shallow burial (Tucker and Wright, 1990). In the Chorgali Formation this process is shown in (Plate 5A and 5B). The process of chemical compaction is marked by stylolites. In the studied formation a number of pressure dissolution feature are recorded. These includes: i) Stylolitic fabric; most stylolites are diagenetic features initiated during the early burial stage and ending upon the complete elimination of pore space by drusy mosaic carbonate. Tectonically produced

stylolites are considered to be the result of pressure solution and recrystallization due to physical factors rather than the chemical factors (Park and Schot, 1968). Low amplitude stylolites having iron oxide residue are observed in the Chorgali Formation (Plate 6A); ii) Solution seams; solution seams are isolated or swarms, like parting, characterized by thin seams, often with accumulations of insoluble residue. The insoluble residue is comprised of iron oxide and quartz grains (Plate 6B); iii) Stylolaminated fabric; the stylolaminated fabric is characterized by a set of closely spaced, low amplitude stylolites separated by seams of iron oxide residue. This type of fabric is the result of continuous dissolution of the limestone in the formation (Plate 7A).

3.2.2. Aragonite to calcite transformation

The Chorgali Formation majority displays wacke to packstone textural type with an appreciable amount of lime mud matrix. The microfacies contain larger benthic foraminifera and mollusk skeletal fragment with the original mineralogy of aragonite and high Mg calcite (HMC). These minerals owing to their metastable state, are converted to low Mg calcite (LMC) through time (Plate 7B)

3.2.3. Nature and origin of calcite filled microfractures

Major microfractures in the limestone are attributed to the brittle failure induced by tectonic deformation (Sibson et al., 1975). The Carbonate saturated fluids passing through the fractures seals the fracture by precipitating calcite forming dense networks of calcite-filled fractures, referred to as veins. These veins or microfractures range in size from millimeter to centimeters. A wide variety of calcite veins and veinlets are present in the Chorgali Formation. These includes single (Plate 8A) to multiple intersecting (Plate 8B), large to small veins displaying a wide range of thickness from few millimeter to several centimeter.

Plate 1

- A: Photomicrograph of Mud-Wackestone Microfacies showing Nummulite (N; PPL, Sample No. 11).
- B: Photomicrograph of Mud-Wackestone Microfacies with Algae (A) and skeletal debris (Sd; PPL, Sample No. 21).

Plate 2

- A: Photomicrograph of Larger Foraminifera Wacke-Packstone Microfacies showing Alveolina (Al) and Nummulite (N; PPL, Sample No. 16).
- B: Photomicrograph of Larger Foraminifera Wacke-Packstone Microfacies showing Lockhartia (L) and Assilina (As; PPL, Sample No. 5).

Plate 3

- A: Photomicrograph of Mixed Bioclastic Wacke-Packstone Microfacies showing fragments of echinoderm (E) and Lockhartia (L; PPL, Sample No. 25).
- B: Photomicrograph of Mixed Bioclastic Wacke-Packstone Microfacies showing echinoid (E) spine (PPL, Sample No. 27).

Plate 4

- A: Outcrop view of the Shale Microfacies of the measured section of Chorgali Formation (second location; for scale interbedded shale is taken measured as 0.4m).
- B: Outcrop view of the Shale Microfacies of the measure section of Chorgali Formation (first location; pointer is used as a scale).

Plate 5

- A: Photomicrograph of an echinoderm fragments showing breakage of grains due to compaction (PPL, Sample No. 27).
- B: Photomicrograph showing alignment of Lockhartia and skeletal fragments indicating compaction (?); (PPL, Sample No. 27).

Plate 6

- A: Photomicrograph of low amplitude stylolite marked by truncation of Nummulites shell fragments (PPL, Sample No. 16)
- B: Photomicrograph of bifurcating stylolitic swarms lined with iron oxide residue (PPL Sample No. 27).

Plate 7

- A: Close-up view of low amplitude stylolitic swarm (PPL, Sample No. 5).
- B: Photomicrograph showing transformation of aragonitic shells into low Mg calcite (LMC) marked by coarse, inequicrystalline fabric (PPL Sample No. 19).

Plate 8

- A: Photomicrograph of a fracture filled by coarse sparry mosaic of calcite crystals (PPL Sample No. 17).
- B: Photomicrograph of a bifurcating fracture associated with stylolitic swarm (PPL Sample No. 21).

4. Discussion

4.1. Depositional environments

The Mud-Wackestone Microfacies is characterized by lime mud, lack of diversity of organisms and restricted fauna, which suggests that microfacies is interpreted to have been deposited in a restricted environment on the inner shelf. The microfacies is similar to Standard Microfacies (SMF) 19 of Wilson (1975) and Flügel (1982). Fossils are rare except ostracods, some foraminifera, gastropods and a few algae. The microfacies represent partially restricted inner shelf lagoon.

The Larger Foraminifera Wacke-Packstone Microfacies is characterized by the presence of lime mud with varying proportions of larger benthic foraminifera represented by Lockhartia, Nummulites, Alveolinids and Assilina, according to

Plate 1

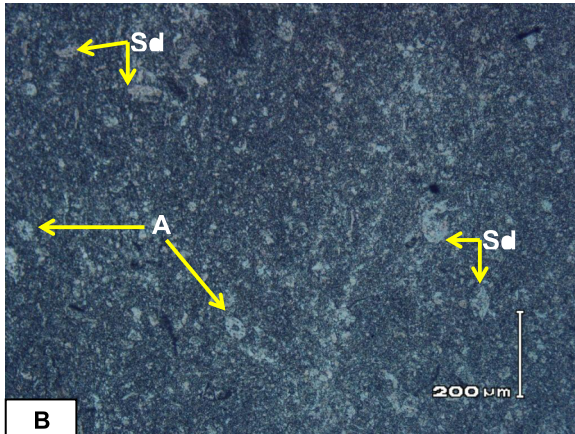
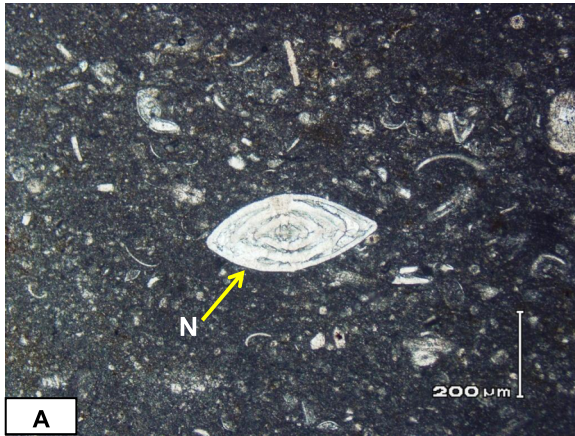


Plate 2

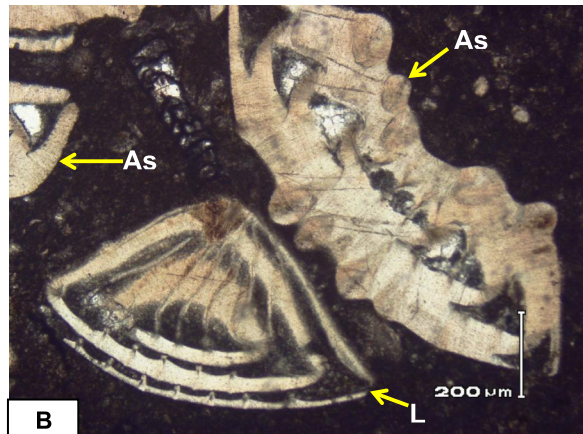
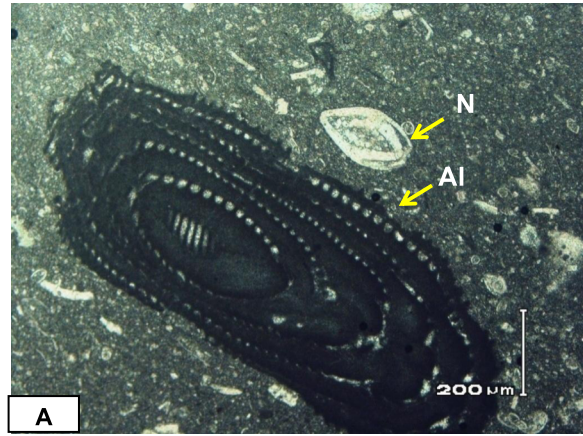


Plate 3

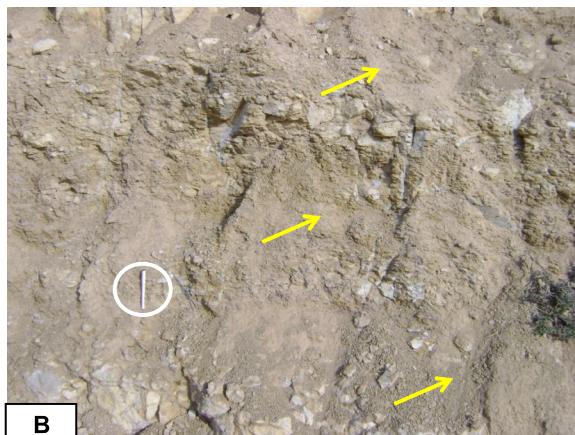


Plate 4

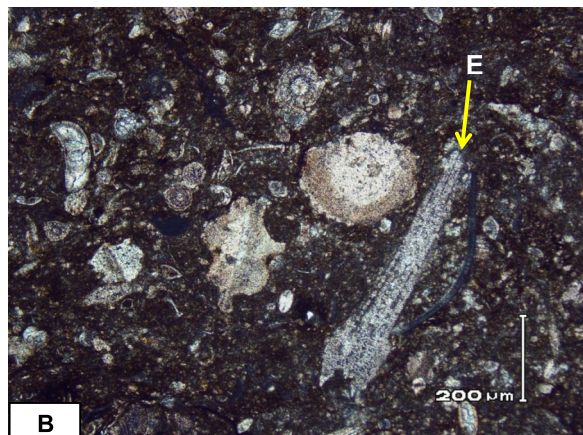
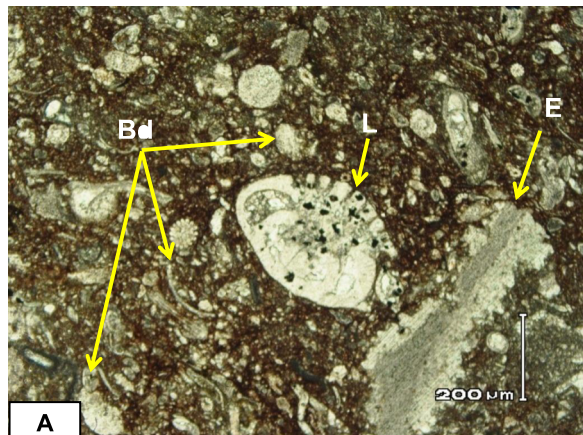


Plate 5

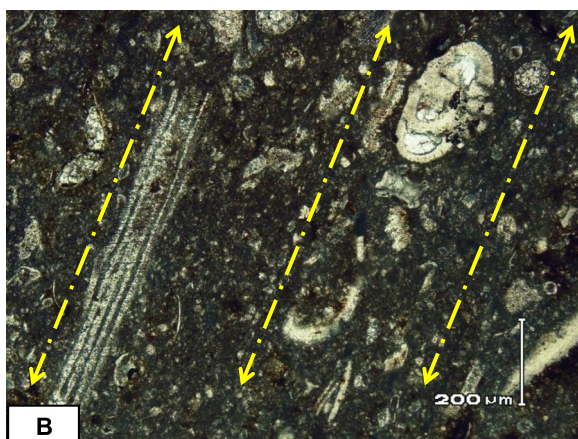
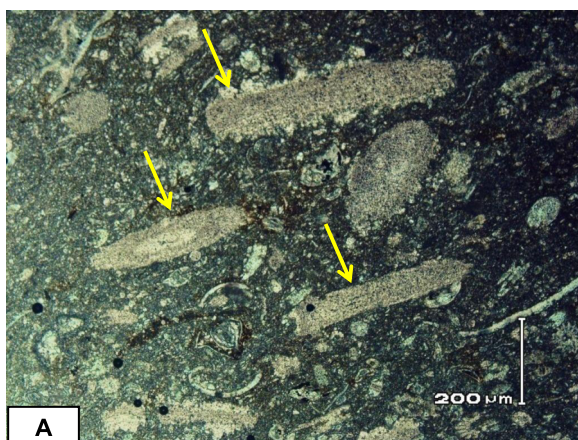


Plate 6



Plate 7

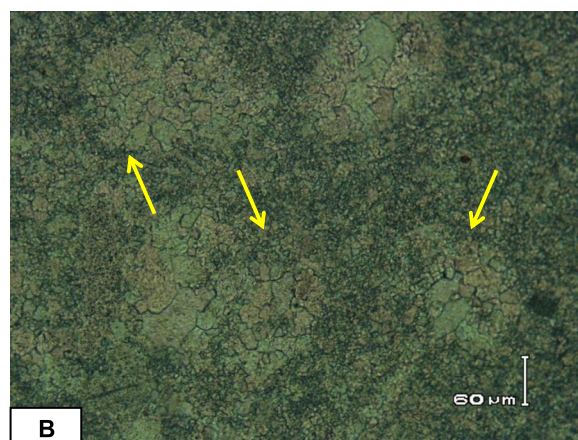
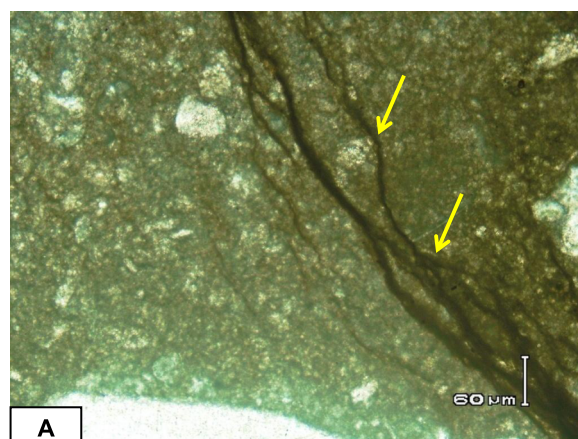
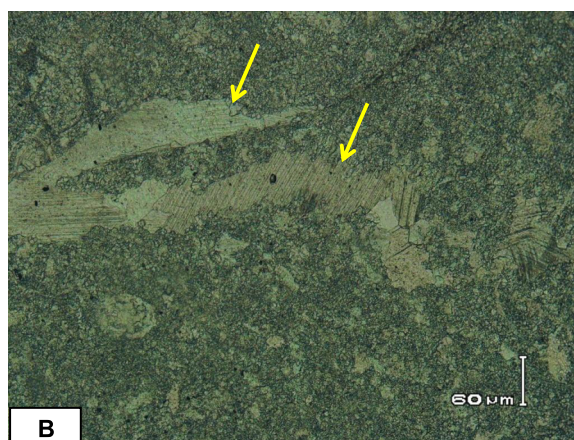
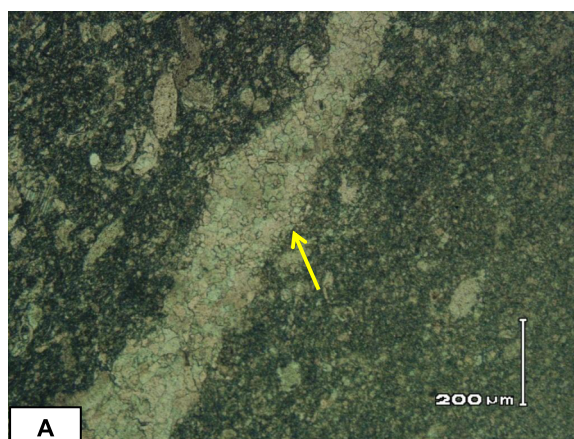


Plate 8



which the microfacies is interpreted to have been deposited in shallow, subtidal (below wave base) conditions on the middle shelf with no reworking. The microfacies is similar to SMF 8 of Wilson (1975) and Flügel (1982).

The Mixed Bioclastic Wacke-Packstone Microfacies is characterized by the presence of lime mud, with assemblage of mixed bioclasts including Nummulites, Lockhartia, echinoderms and pelecypods. Lime mud indicate low energy conditions of deposition while mixed bioclasts represent open marine, normal salinity, below wave base conditions of deposition. Based on textural characteristics and faunal content the microfacies are interpreted to represent deposition in middle shelf to outer shelf with open circulation at or just below the fair-weather wave base. The microfacies is similar to SMF 9 of Wilson (1975) and Flügel (1982).

The Shale Lithofacies is characterized by clay having vertical burrows. Wilson (1975) and Flügel (1972, 1982) interpreted such microfacies as planar or variously dome-shaped laminated mudstone composed of fine or coarse grained laminae sometimes exhibiting microbial or algal structures, very common in the intertidal zone, but also in supratidal and shallow subtidal environments. According to them this microfacies is equivalent to SMF 20. Thus, the Shale Lithofacies along with its association with other microfacies (which overlies and underlies it) is interpreted to be deposited in shallow subtidal environment.

The depositional texture and faunal association suggests that all the microfacies represents deposition on a low energy carbonate shelf (Fig. 5); the microfacies are repeated within the formation, reflecting the fluctuation of sea level, which can be shown as in Figure 5.

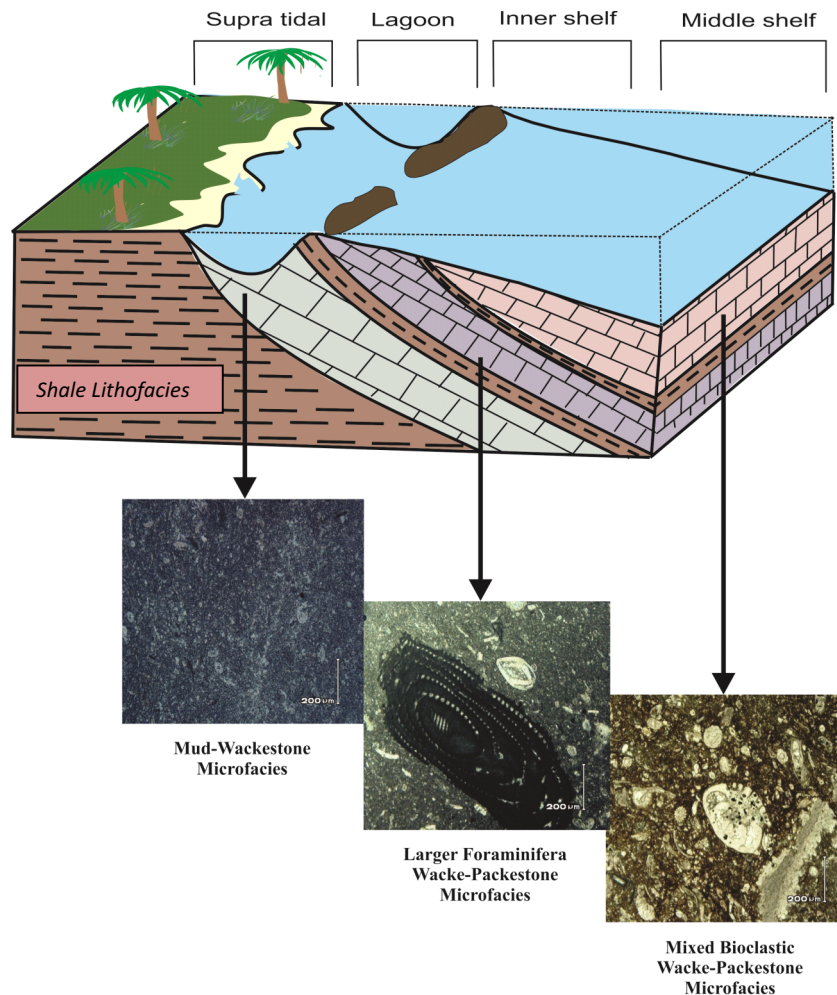


Fig. 4. Schematic depositional model of the upper part of Chorgali Formation, based on the interpretation of the Microfacies.

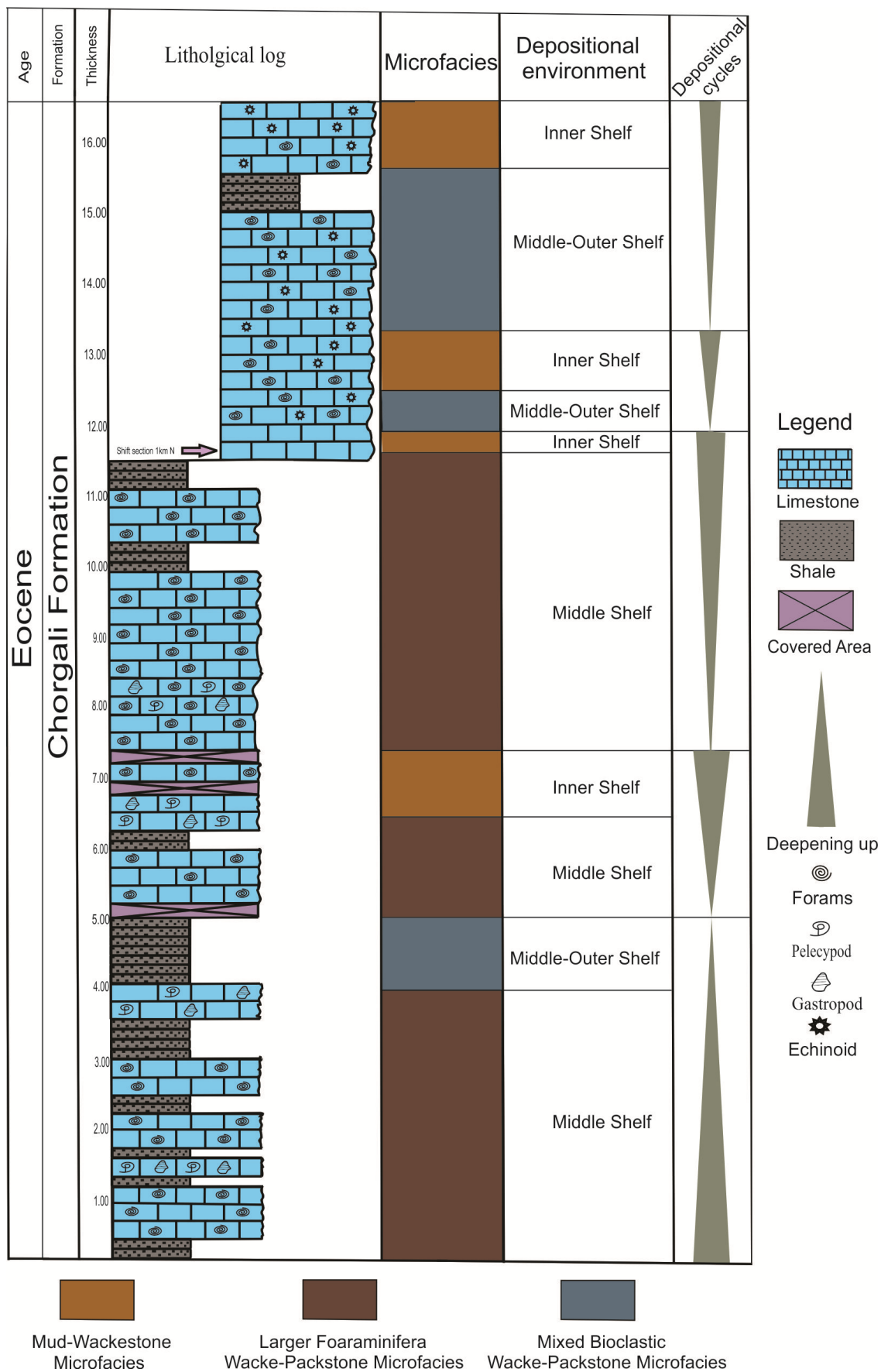


Fig. 5. Summary diagram showing vertical distribution of microfacies, depositional environments and depositional cycles.

4.2. Diagenetic history

The diagenetic fabric observed within Chorgali Formation indicates that the Formation is subjected to various post deposition processes, the diagenesis starts as soon as the rock get deposited and passes from marine diagenesis into burial to meteoric diagenesis (Bathurst, 1966, 1975; Scholle and Ulmer-Scholle, 2003). The Chorgali Formation shows all three diagenetic environments; aragonite to calcite transformation, suggesting the marine diagenetic environment. The burial diagenesis can be shown by various stylolites and its associated seams, then in later stage the tectonic effect causes the fractures and its uplift to the surface for the meteoric diagenesis.

5. Conclusions

The Chorgali Formation is predominantly light to dark grey, planar to nodular bedding limestone with thin beds of shale. The Chorgali Formation is characterized by a variety of faunal assemblages. These include larger benthic foraminifera, mollusks, ostracodes and echinoderms. As a part of this study, four microfacies are identified in the Chorgali Formation. These microfacies are: a) Mud-Wackestone Microfacies, interpreted to have been deposited in a restricted environment of the inner shelf. b) Larger Foraminifera Wacke-Packstone Microfacies, interpreted to have been deposited under a shallow, subtidal (below wave base) conditions on the middle shelf. c) Mixed Bioclastic Wacke-Packstone Microfacies, interpreted to have been deposited in a slightly deeper shelf. d) Shale Lithofacies interpreted to have been deposited on the shallow open lagoonal setting upto mid shelf. On the basis of microfacies diagnostic criteria, the Chorgali Formation is interpreted to represent deposition on a low energy carbonate shelf. The presence of several diagenetic features indicate that the Chorgali Formation in the study area has been subjected to various post depositional alterations including compaction, aragonite to calcite transformation, tectonically induced fracturing and development of calcite veins passing from marine diagenesis to meteoric diagenesis through burial diagenesis.

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