



## MOLLUSCAN BIOSTRATIGRAPHY OF THE PALAEOGENE SEDIMENTS AROUND LAKHPAT, KACHCHH, GUJARAT, INDIA

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### ABSTRACT

The highly fossiliferous strata of Palaeogene age comprise mainly limestones and shales in the basal part, which are exposed in Lakhpat Fort (23°50'N: 68°47'E) and adjoining area. Faunally, these are very rich in foraminifers, followed by molluscs and echinoids. The present work is the first attempt to build the biostratigraphy on molluscan data. Lithostratigraphically, these strata belong to the Harudi, the Fulra Limestone Formations of middle Eocene and the Maniyara Fort Formation of the Oligocene. On the basis of molluscs, five biozones are established in addition to earlier known Coral zone. These zones are correlatable with the larger foraminiferal zones of earlier workers. The study also infers presence of upper Eocene strata in the area on the basis of molluscan evidence.

**Keywords:** Palaeogene, Lakhpat, Biostratigraphy, Molluscs, Upper Eocene.

### INTRODUCTION

The strata in and around Lakhpat Fort are composed mainly of limestones with subordinate shales. These lithostratigraphically belong to the upper part of the Harudi Formation (middle Eocene), the Fulra Limestone Formation (middle Eocene) and the Maniyara Fort Formation (Oligocene) (Biswas and Raju, 1973). Chronostratigraphically, these are classified into the Babian Stage (=Harudi and Fulra Limestone Formations) and the Ramanian Stage (=Maniyara Fort Formation) (Biswas, 1992). The lowermost rocks of the Harudi Formation are characterized by shales with thin bands of limestone and mainly laterite. The strata are exposed in a depression just south of Lakhpat Fort. *Nummulites obtusus* is the zonal fossil. The shales are succeeded by highly fossiliferous white coloured limestones of the Fulra Limestone Formation. The limestones are full of *Nummulites*, *Discocyclus* and the upper part is especially dominated by *Fasciolites*. The main foraminiferal taxa are *Nummulites exponense* and *Discocyclus sowerbyi* succeeded by *Fasciolites elliptica*.

Concerning the megafossils, the rocks of the Harudi Formation contain only the oysters dominated by the genus *Ostrea* and its allies. In overlying Fulra Limestone Formation besides oysters, *Chlamys* and *Spondylus* also make their appearance. In addition, gastropods also occur and the most characteristic one is a giant gastropod viz. *Turbinella bulbiformis* J. de C. Sowerby, an index taxon of middle Eocene. In the uppermost part of the Fulra Limestone Formation, above the bed of *Fasciolites elliptica*, the small-sized bivalves and gastropods are quite common. In authors' opinion, the bed containing them may range up to Upper Eocene. Mukhopadhyay and Shome (1996) opined that the rocks of the Harudi Formation were deposited in tidal flat environment followed by littoral semi-reef environment, whereas the Fulra Limestone Formation started with lagoonal environment and ended with littoral-shelf environment. The Fulra Limestone Formation is succeeded by dirty white to pale brown limestone of the Maniyara Fort Formation outcropping just outside the Lakhpat Fort in the northern side at the edge of the Great Rann of Kachchh. The lower part of the formation is abounded with *Nummulites* and *Chlamys*. Further up there is no variation in

lithology but faunal change is conspicuous. The succeeding strata are mainly coral bearing and marked by absence of foraminifers and molluscs. The uppermost beds of the Maniyara Fort Formation are characterized by presence of molluscs but devoid of foraminifers. Molluscs are also comparatively rare. Overall, the strata are striking east-west with a very gentle northward dip of around 5°.

In the present work, the geological-cum-foraminiferal zonal map, prepared by Sen Gupta (1964) as well as by Sengupta and Nielsen (2009), is being adopted in modified form, because all the six zones are mappable units and have distinct foraminiferal assemblages (Fig.1). Following their work, the strata are divisible into six units instead of three or two based on lithostratigraphy or chronostratigraphy respectively. In the studied area, the collection of megafossils has been done by taking traverses along and across the strike of each bed. Altogether, around 600 individuals of molluscs have been collected and worked out systematically resulting into 48 taxa of bivalves and 29 of gastropods. On the basis of these taxa, a biostratigraphical scale has been erected for the Palaeogene sediments of the area around Lakhpat. The unique feature of each molluscan zone is the non repetition of the most of the earlier taxa amounting to distinct assemblages. Therefore, each zone is well defined.

The area of Lakhpat is well known to geologists through the memoir of Wynne (1872). Earlier, the molluscs were worked out by Sowerby (1840a) and Vredenburg (1925, 1928).

From the Kachchh region, various workers have reported molluscs from time to time, e.g. *Venericardia* sp. from lower part of the Naredi Formation (Tandon, 1962), *Venericardia vredenburgi*, *Turritella (Stirocolpum)* cf. *pakistanica*, *Motvris* sp. *Turbinella (Chemnitzia) soriensis*, *Rissoina* sp., and *Cancellaria* sp. from upper part of the Naredi Formation (Tandon, 1962), as also *Conus* sp., *Natica obscura*, *Corbula harpa*, *Corbula lyrata*, *Venus* sp., *Nuculana baboensis*, *Trigonia trigonalis* and *Venericardia* sp. by Chatterji and Mathur (1962-64), and likewise *Mytilus* sp. (Biswas, 1965). Compiled checklist of all these species is given by Mathur (1988) without any illustration and description.

From the younger strata, *Pecten laevicostata* Sowerby, *Cytherea (Callista) pseudo-umbonella* Vredenburg, *Ostrea*

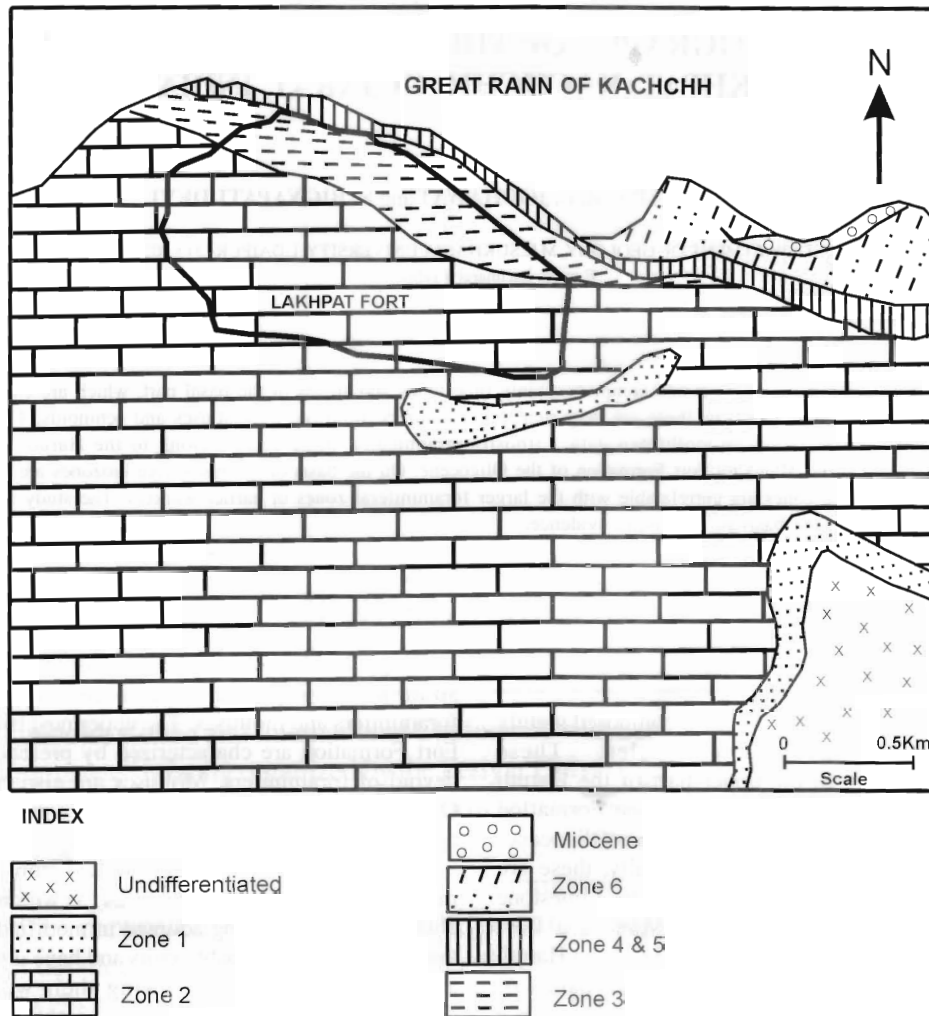


Fig. 1. Palaeogene molluscan zones around Lakhpat (Modified after Sen Gupta, 1964).

*angulata* Sowerby (bivalves), *Cerithium* sp., *Lunatia* sp. (gastropods), *Echinolampus kachensis* Duncan and Sladen, *Clypeaster (Guebhardanthus) faloriensis* Duncan and Sladan (echinoids) of Oligocene age and *Turbinella bulbiformis* Sowerby of the middle Eocene have been listed by Sen Gupta (1964).

### LITHOLOGY OF VARIOUS ZONES

Lithology of various foraminiferal zones envisaged by Sen Gupta (1964) along with index foraminifer taxa and characteristic molluscs of present work is given below:-

**Zone 1:** Limestone of this zone directly overlies the laterites derived from the Deccan Traps. Limestones are reddish and lateritized and contain thin bands of white to reddish clay or shale with minor bands of gypsum. This zone is 3.5-5.0m thick. Foraminifer-wise it is characterized by *Nummulites obtusus* and *Nummulites acutus*. In the present work, this zone is named after characteristic *Gryphaeostrea lakhpatensis*, a bivalve which is very common.

**Zone 2:** The contact between zone 1 and zone 2 is unconformable but not exposed anywhere. This zone is thick and most widespread. Thickness is about 45m. Overall, limestones are white in colour and characterized by *Nummulites exponense* and *Discocyclina sowerbyi*. Herein, the zone is named after a giant gastropod viz. *Turbinella bulbiformis* an

index taxon of middle Eocene. Both zones 1 and 2 are of middle Eocene age. Among bivalves, a large oyster, namely *Pycnodonte (Pycnodonte) kachhensis* n. sp characterizes both the zones.

**Zone 3:** The lithology is similar to zone 1 except that the rocks are slightly light coloured. The thickness of this zone varies from 1.5-4.6m. It mainly outcrops just inside the northern wall of Lakhpat Fort. In the lower part, besides *Nummulites exponense* of zone 2, it is characterized by *Fasciolites elliptica*, *Dictyoconooides cooki* and *Nummulites bagenlensis* and in the upper part by distinct assemblages of molluscs. The zone has been named after commonly occurring characteristic taxa, viz. *Microcyprina fortensis* and *Corbula (Bicorbula) subexarata lituus*.

**Zone 4:** It outcrops at the edge of the Great Rann of Kachchh just outside the northern wall of Lakhpat Fort. Its maximum thickness is around 9m. with an average of 4.5m. A depositional hiatus is envisaged between zone 3 and zone 4 by earlier workers. The limestone of this zone is dirty white to brown in colour containing appreciable amount of sand and belongs to the Ramanian Stage of the Maniyara Fort Formation of Oligocene. *Nummulites fichteli* is an index form of the zone. Echinoids have made their appearance in this zone. Molluscs are quite common and the zone is named after *Ostrea (Ostrea) protoimbricata*, which is the most abundant and characteristic

taxon amongst all.

**Zone 5:** This zone along with the overlying zone 6 is quite thin, and together their thickness is about 3m. Lithology is similar to that of zone 4. Its outcrops are in the form of small mounds and are characterized by hermatypic corals like *Montastrea tertiaria* (Duncan), *Diploastrea eocenica* Duncan and *Stylocoenia vicaryi* Haime of Oligocene time. It is devoid of molluscs as also foraminifers.

**Zone 6:** It is the uppermost zone of the Maniyara Fort Formation consisting of dense fine-grained earthy limestone. Limestone is somewhat dolomitized and recrystallized at places. Like zone 5, it is also devoid of foraminifers. Molluscs are present but very sparse and ill preserved. Herein, the zone is named after *Conus (Lithoconus) ineditus* and *Glossus (Aralocardia) kachhensis*.

## BIOSTRATIGRAPHY

A checklist of the molluscan taxa (48 bivalve and 29 gastropod taxa) in different zones is given in Table 1. On the basis of molluscan community, six biozones comparable with the foraminiferal zones are established. A table of currently established all the biozones with their foraminiferal counterparts is given below (Table 2). All the molluscan zones so established in present work are discussed sequentially as follows:

### Zone 1 *Gryphaeostrea lakhpatensis* zone

This zone contains only bivalves which belong to oysters. Altogether, nine forms are recorded. These include: *Gryphaeostrea lakhpatensis* n. sp., *Pycnodonte (Pycnodonte) kachchhensis* n. sp., *Gryphaeostrea brongniarti* (Bronn), *Gryphaeostrea* sp. juv. *brongniarti* (Bronn), *Ostrea (Ostrea) cf. protoimbricata* Vredenburg, *Ostrea (Ostrea) velata* S.V.Wood, *Ostrea (Ostrea) cf. rouaulti* Mallada, *Cubitostrea angulata* J.de C.Sowerby and *Flemingostrea* sp. Leaving aside forms new to science and unidentified ones which cannot be used for dating the rocks, *Gryphaeostrea brongniarti* is a long-ranging species known from Eocene to Miocene. *Ostrea (Ostrea) protoimbricata* is said to be of Oligocene; however, here a comparable form in the present material is not important. *Ostrea (Ostrea) velata* is an Eocene and Oligocene form from Europe. *Cubitostrea angulata* made its appearance from middle Eocene and continued up to Oligocene. *Ostrea (Ostrea) cf. rouaulti* Mallada ranges from Palaeocene to middle Eocene. Therefore, the zone in question is definitely of middle Eocene, precisely Lutetian. It is in agreement with the inference drawn from the foraminiferal occurrences. Lately, Khosla and Pant (1988) also established an ostracode zone *Acanthocythereis bhujensis* of Lutetian age. The zone is named after *Gryphaeostrea lakhpatensis* n. sp., a most abundant and characteristic form.

Main lithology of this zone is shales with bands of reddish limestone. Among bivalves, only oysters occur. On the whole, oysters live on rocky bottom under brackish water to shallow marine conditions in warm tropical waters with a depth less than 60m. On the other hand, *Gryphaeostrea* thrives at a depth around 30m. Foraminifers with thick tests namely *Nummulites obtusus* and *N. acutus* also occur. Taking into consideration all these, it seems that the environment of deposition was warm water at shallow depth under oxidizing conditions. It seems to be a protected shelf as shales are dominant with depth around 30m.

### Zone 2 *Turbinella bulbiformis* zone

Gastropods have made their appearance in this zone.

Besides oyster genera, *Chlamys* and *Spondylus*, too, are present in this zone. The molluscan taxa include *Chlamys (Chlamys) multistriata* Deshayes, *Spondylus (Spondylus) subequivalvis* Eames, *Crassostrea angusta* Deshayes, *Ostrea (Ostrea) aff. edulis* Linne', *Pycnodonte (Pycnodonte) kachchhensis* n. sp. and *Gryphaeostrea brongniarti* (Bronn) (all bivalves). The latter also occurs in the zone 1. Besides these, five taxa of gastropods also occur namely, *Fissurella* sp., *Campanile habiana* n. sp., *Turbinella bulbiformis* J.de C. Sowerby, *Turbinella* sp. and *Conus (Leptoconus) safaedensis* Eames. Of these, *Turbinella bulbiformis* J. de C. Sowerby is a typical index species of the Kirthar Series of Pakistan. *Conus (Leptoconus) safaedensis* Eames ranges from Ypresian to early Lutetian. *Ostrea (Ostrea) protoimbricata* Vredenburg is mainly the Oligocene species and here a comparative form is being recorded. On the other hand, *Ostrea (Ostrea) aff. edulis* Linné still thrives in modern seas and our reported form shows some affinity to it. On the other hand, *Chlamys (Chlamys) multistriata* Deshayes and *Crassostrea angusta* Deshayes are the Eocene taxa. Further, *Spondylus (Spondylus) subequivalvis* Eames is restricted to middle Eocene. In view of the above, this zone is assigned the middle Eocene age. It may be mentioned that Singh (1980) has also recorded the late middle Eocene calcareous nannoplankton from this zone.

The white limestone of this zone is full of foraminifers containing *Nummulites*, *Discocyclina*, *Fasciolites* which are characteristic of tropical warm water environment with a bathymetry from 20 to 50 metres. The lower part of this zone is in the form of fossiliferous micrite followed by biomicroparite. This limestone reflects its deposition in well-oxygenated (shallow and wave-agitated) waters. Among bivalves, in addition to oysters, *Chlamys* and *Spondylus* have made their appearance. Gastropods are represented by *Fissurella*, *Campanile*, *Conus* and *Turbinella*. The last one is a giant form. This molluscan community also indicates a very shallow warm water, open shelf environment with a depth range from 30 to 50 m.

### Zone 3 *Microcyprina fortensis* - *Corbula (Bicorbula) subexarata lituus* zone

This zone is restricted to the upper part of the Fulra Limestone Formation. There is an appreciable change in foraminiferal biota, but these are confined to the lower part of the zone. Molluscs from zone 2 do not extend into this zone and totally a new assemblage appears. However, a solitary bivalve species and a few forms of gastropods continue in the ascending zone 4. Among foraminifers, *Nummulites exponense* of zone 2 disappears and is replaced by *Nummulites beumonti*, *Fasciolites elliptica*, *Dicytoconoides cooki* and *Nummulites bagelensis*. Of course, *Discocyclina sowerbyi* of the lower zone still continues. On the basis of foraminifers, all the earlier workers have assigned this zone to middle Eocene. Based on molluscan species, authors feel that it may range from uppermost middle Eocene to at least lower part of upper Eocene. Not only this, it may be even younger because of presence of some upper Eocene forms.

The bivalve taxa of this zone are - *Mytilus (Mytilus) nummuliticus* d' Archiac and Haime (lower-middle Eocene), *Spondylus (Spondylus) radula* Lamarck (Eocene), *Venericardia (Venericardia) soriensis* Eames (Middle Eocene), *Trachycardium (Trachycardium) juv. sp. cotteri* (Cox) (lower-middle Eocene), *Nemocardium (Discors) bunburyi* d' Archiac and Haime (lower-middle Eocene), *Macoma (Macoma) aff.*

Table-1: Zone-wise distribution of bivalves and gastropods.

Sl. No.	Species Name	Zones					
		1	2	3	4	5	6
1	<i>Gryphaeostrea</i> sp.juv. <i>brongiarti</i> (Bronn)	+					
2	<i>Gryphaeostrea lakhpatensis</i> n. sp.	+					
3	<i>Ostrea (Ostrea) velata</i> S.V. Wood	+					
4	<i>Ostrea (Ostrea) cf. rouaulti</i> Mallada	+					
5	<i>Flemingostrea</i> sp.	+					
6	<i>Pycnodonte (Pycnodonte) kachhensis</i> n. sp.	+	+				
7	<i>Gryphaeostrea brongiarti</i> (Bronn)	+	+				
8	<i>Ostrea (Ostrea) cf. protoimbricata</i> Vredenburg	+	+				
9	<i>Cubitostrea angulata</i> J.de C. Sowerby	+			+		
10	<i>Chlamys (Chlamys) multistriata</i> Deshayes		+				
11	<i>Spondylus (Spondylus) cf. subequivalvis</i> Eames		+				
12	<i>Crassostrea angusta</i> Deshayes		+				
13	<i>Ostrea (Ostrea) aff. edulis</i> Linne'		+				
14	<i>Fissurella</i> sp.		+				
15	<i>Campanile babiana</i> n. sp.		+				
16	<i>Turbinella bulbiformis</i> J. de C. Sowerby		+				
17	<i>Turbinella</i> sp.		+				
18	<i>Conus (Leptoconus) safaedensis</i> Eames		+				
19	<i>Mytilus (Mytilus) nummuliticus</i> d'Archiac and Haime			+			
20	<i>Amusium pleuronectes</i> (Linne')			+			
21	<i>Spondylus (Spondylus) tallavignesi</i> d'Archiac and Haime			+			
22	<i>Spondylus (Spondylus) radula</i> Lamarck			+			
23	<i>Venericardia (Venericardia) soriensis</i> Eames			+			
24	<i>Trachycardium (Trachycardium) sp. juv. cotteri</i> (Cox)			+			
25	<i>Nemocardium (Discors) cf. hunburyi</i> d'Archiac and Haime			+			
26	<i>Macoma (Macoma) aff. calcarea</i> Gmelin			+			
27	<i>Apolymetis tarkhobiensis</i> Eames			+			
28	<i>Semele mekranica</i> Vredenburg			+			
29	<i>Microcyprina fortensis</i> n. sp.			+			
30	<i>Trapezium (Trapezium) cf. oblongum</i> (Linne')			+			
31	<i>Glossus (Aralocardia) fulraensis</i> n. sp.			+			
32	<i>Callista (Costacallista) punjabensis</i> Eames			+			
33	<i>Corbula (Bicorbula) subexarata</i> d'Archiac and Haime			+			
34	<i>Corbula (Bicorbula) subexarata</i> d'Archiac and Haime var. <i>lituus</i> Cotter			+			
35	<i>Diplodonta (Diplodonta) incerta</i> d'Archiac and Haime			+	+		+
36	<i>Turritella narica</i> Vredenburg			+			
37	<i>Torinia buddha</i> (Noetling)			+			
38	<i>Seila stracheyi</i> (d'Archiac and Haime)			+			
39	<i>Campanile brookmani</i> Cox			+			
40	<i>Terebellum fusiformorpse</i> de Gregorio			+			
41	<i>Seraphs cf. sopitum</i> (Solander)			+	+		
42	<i>Ectinochilus cf. canalis</i> (Lamarck)			+			
43	<i>Natica obscura</i> J. de C. Sowerby			+	+		
44	<i>Globularia brevispira</i> (Leymerie)			+			
45	<i>Crommium rouaulti</i> (d'Archiac and Haime)			+			

46	<i>Cassidia mamillaris</i> Grateloup var. <i>nummulitiphila</i> Sacco	+	+	+
47	<i>Conus (Lithoconus)</i> aff. <i>kyudowonensis</i> Vredenburg	+		
48	<i>Comus</i> sp. indet	+		
49	<i>Chlamys (Chlamys)</i> sp.		+	
50	<i>Chlamys (Aequipecten) jeddemi</i> Vredenburg		+	
51	<i>Chlamys (Aequipecten) prototranquebaricus</i> Vredenburg		+	
52	<i>Chlamys (Aequipecten) quilonensis</i> Dey		+	
53	<i>Spondylus (Spondylus) rouaulti</i> d'Archiac		+	
54	<i>Spondylus (Spondylus)</i> aff. <i>truncatus</i> (Lamarck)		+	
55	<i>Hyotissa hyotis</i> (Linne')		+	
56	<i>Ostrea (Ostrea) protoimbricata</i> Vredenburg		+	
57	<i>Ostrea (Ostrea) pseudodigitalina</i> Fuchs		+	
58	<i>Lopha (Lopha) folium</i> (Linne')		+	
59	<i>Fragum (Fragum)</i> aff. <i>fragum</i> (Linne')		+	
60	<i>Lutraria (Lutraria)</i> cf. <i>phillipinarum</i> Reeve		+	
61	<i>Arctica planata</i> (J.de C. Sowerby)		+	
62	<i>Callista (Callista) pseudoumbonella</i> Vredenburg		+	
63	<i>Periglypta puerpera</i> (Linne') var. <i>aglaurae</i> Brongniart		+	+
64	<i>Callista (Callista) yawensis</i> Cotter		+	+
65	<i>Clathrus gajensis</i> Vredenburg		+	
66	<i>Crisposcala decaspirata</i> Jain MS		+	
67	<i>Xenophora gajensis</i> Jain MS		+	
68	<i>Xenophora</i> sp.		+	
69	<i>Ampullospira</i> sp.		+	
70	<i>Clavilithes cossmanni</i> Vredenburg		+	
71	<i>Volutospina augustae</i> Vredenburg		+	
72	<i>Marginella</i> cf. <i>glabella</i> Linne'		+	
73	<i>Unitas narica</i> Vredenburg		+	
74	<i>Cochlis</i> sp.		+	+
75	<i>Glossus (Cytherocardia) cytheroides</i> (Mayer)			+
76	<i>Callista (Callista) pseudoumbonella</i> Vredenburg var. <i>globosa</i> n. var.			+
77	<i>Conus (Lithoconus) ineditus</i> Michelotti			+

*calcareia* Gmelin, *Apolymetis tarkhobiensis* Eames (lower Eocene), *Microcyprina fortensis* n. sp., *Trapezium (Trapezium)* cf. *oblongum* (Linne'), *Glossus (Aralocardia) fulraensis* sp. nov., *Callista (Costacallista) punjabensis* Eames (middle Eocene), *Corbula (Bicorbula) subexarata* d'Archiac and Haime (Eocene), *Corbula (Bicorbula) subexarata* d'Archiac and Haime var. *lituus* Cotter (upper Eocene), *Diplodonta (Diplodonta) incerta* d'Archiac (upper Eocene-Oligocene), *Amusium pleuronectes* (Linne') (lower Miocene-Recent),

*Spondylus (Spondylus) tallavignesi* d'Archiac (Miocene), *Semele mekranica* Vredenburg (Pliocene) and Gastropods - *Seila stracheyi* (d'Archiac and Haime) (upper Eocene), *Campanile brookmani* Cox (Eocene), *Terebellum fusiformopse* de Gregorio (Eocene), *Ectinochilus canalis* (Lamarck) (middle Eocene), *Crommium rouaulti* (d'Archiac and Haime) (upper Palaeocene-Eocene), *Globularia brevispira* (Leymerie) (middle Eocene), *Cassidea mamillaris* Grateloupe var. *nummulitiphila* Sacco (upper Eocene-Oligocene), *Seraphs sopitum* (Solander)

Zone	Sen Gupta (1964)	Present work
Zone 6	Unnamed zone	<i>Conus (Lithoconus) ineditus</i>
Zone 5	Corals	Corals
Zone 4	<i>Nummulites fichteli</i>	<i>Ostrea (Ostrea) protoimbricata</i>
Zone 3	<i>Fasciolites elliptica</i> in part	<i>Microcyprina fortensis</i> - <i>Corbula (Bicorbula) subexarata lituus</i>
Zone 2	<i>Nummulites exponense</i> - <i>Discocyclusina sowerbyi</i>	<i>Turbinella bulbiformis</i>
Zone 1	<i>Nummulites obtusus</i>	<i>Gryphaeostrea lakhpatensis</i>

(upper Eocene - Oligocene), *Natica obscura* J. de C. Sowerby (Oligocene-Miocene), *Conus (Lithoconus)* aff. *kyudowonensis* Vredenburg, *Turritella narica* Vredenburg (Oligocene), *Torinia Buddha* (Noetling) (Oligocene) and *Conus* sp. indet.

In this zone, leaving aside the forms left in open nomenclature, including those with affinity and comparable ones, the remaining taxa are mainly of middle and upper Eocene. There are few forms making their exit in upper Eocene as well as being restricted to upper Eocene. There are others which are not surviving after middle Eocene. Taking into consideration this fact, the zone may be assigned to middle and upper Eocene. In addition, Biswas (1992, p.17) has mentioned that in the Kachhh region Upper Eocene strata on mainland are present in the Berwali stream, in the form of discontinuous patches which are not mappable. Similar conditions are also observed in the area of Lakhpat Fort, where above the *Fasciulites elliptica* bed, a thin horizon of molluscs is present in the form of scattered mounds striking east-west and the presence of upper Eocene strata cannot be ruled out. Therefore, the age of middle and upper Eocene is justified.

Lithology and foraminifer-wise, there is no change from zone 2. Oysters are almost absent and a good number of shallow infaunal bivalves and shallow epifaunal gastropods occur. Based on molluscan community, the bathymetry may vary from 20m (*Mytilus*) to slightly more than 50m (*Turritella*). It was a warm water, open shelf with gently sloping soft substratum.

#### Zone 4 *Ostrea (Ostrea) protoimbricata* zone

As compared to the preceding zone, it is very rich in molluscan population mainly dominated by representatives of *Ostrea* and *Chlamys*. Out of 19 forms of bivalves recorded from this zone except *Diplodonta (Diplodonta) incerta*, others do not extend to higher strata. Gastropods are represented by 13 forms of which four are common to the lower zone. The list includes following forms:

Bivalves - *Ostrea (Ostrea) protoimbricata* Vredenburg (Oligocene), *Cubitostrea angulata* J. de C. Sowerby (Oligocene-Miocene), *Periglypta puerpera* Linne var. *aglaurae* Brongniart (Oligocene), *Diplodonta (Diplodonta) incerta* d'Archiac (upper Eocene-Oligocene), *Arctica planata* J. de C Sowerby (lower Eocene-lower Oligocene), *Chlamys (Chlamys) sp.*, *Chlamys (Aequipecten) feddeni* Vredenburg (Oligocene - lower Miocene), *Chlamys (Aequipecten) prototranquebaricus* Vredenburg (Oligocene-lower Miocene), *Chlamys (Aequipecten) cf. quilonensis* Dey, *Spondylus (Spondylus) rouaulti* d' Archiac (upper Palaeocene - Miocene), *Spondylus (Spondylus) aff. truncatus* (Lamarck), *Hytissa hyotis* (Linne') (Lower Miocene - Recent), *Ostrea (Ostrea) pseudodigitalina*

Fuchs (Miocene - Pliocene), *Lopha (Lopha) folium* (Linne') (Miocene - Recent), *Fragum (Fragum) aff. fragum* Linne, *Lutraria (Lutraria) cf. philippinarum* Reeve (Miocene - Pliocene), *Callista (Callista) pseudoumbonella* Vredenburg (Oligocene - Pliocene), *Callista (Callista) yawensis* Cotter (upper Eocene).

Gastropods - *Unitas narica* Vredenburg (Oligocene), *Turritella narica* Vredenburg (Oligocene), *Seraph cf. sopitum* Solander (upper Eocene - Oligocene), *Cassidea mamillaris* Grateloup var. *nummulitiphila* Sacco (upper Eocene - Oligocene) continuing from Lower zone, *Clavilithes cossmanni* Vredenburg (upper Eocene), *Clatharus gajensis* Vredenburg (Miocene), *Crisposcala decaspirata* Jain MS (lower Miocene), *Xenophora gajensis* Jain MS (lower Miocene), *Xenophora sp.*, *Cochlis sp.*, *Ampullospira sp.*, *Marginella cf. glabella* Linné, *Natica obscura* J. de C. Sowerby (Oligocene - lower Miocene).

This zone is Oligocene in age as typical foraminifers, e.g. *Nummulites fichteli*, characterize it. As genera like *Anadara* and *Timoclea* which indicate the Miocene age, do not appear in this zone, it is referable to Oligocene.

Lithologically, this zone appears to be biosparite with 80% of fossil fragments belonging to bivalves, gastropods, bryozoans and foraminifers. It seems to represent shallow neritic conditions. Among foraminifers, it is characterized by reticulate *Nummulites*, *Asterigerina*, which suggest deposition in warm water conditions at depths less than 40 metres.

Irregular echinoids (*Echinolampus* and *Brennia*) typical of soft substratum in shallow shelf region are also encountered in this zone. Medium-sized *Chlamys* and *Ostrea* occur in abundance. These indicate shallow and warm water conditions with water depths ranging from littoral to inner neritic. Because of oysters, presence of hard substratum here and there cannot be ruled out.

#### Zone 5 Coral zone

This zone is devoid of molluscs as well as foraminifers and contains only corals of Oligocene age.

As this zone is characterized by corals only, the environment of deposition was very shallow, open shelf characterized by high-energy conditions.

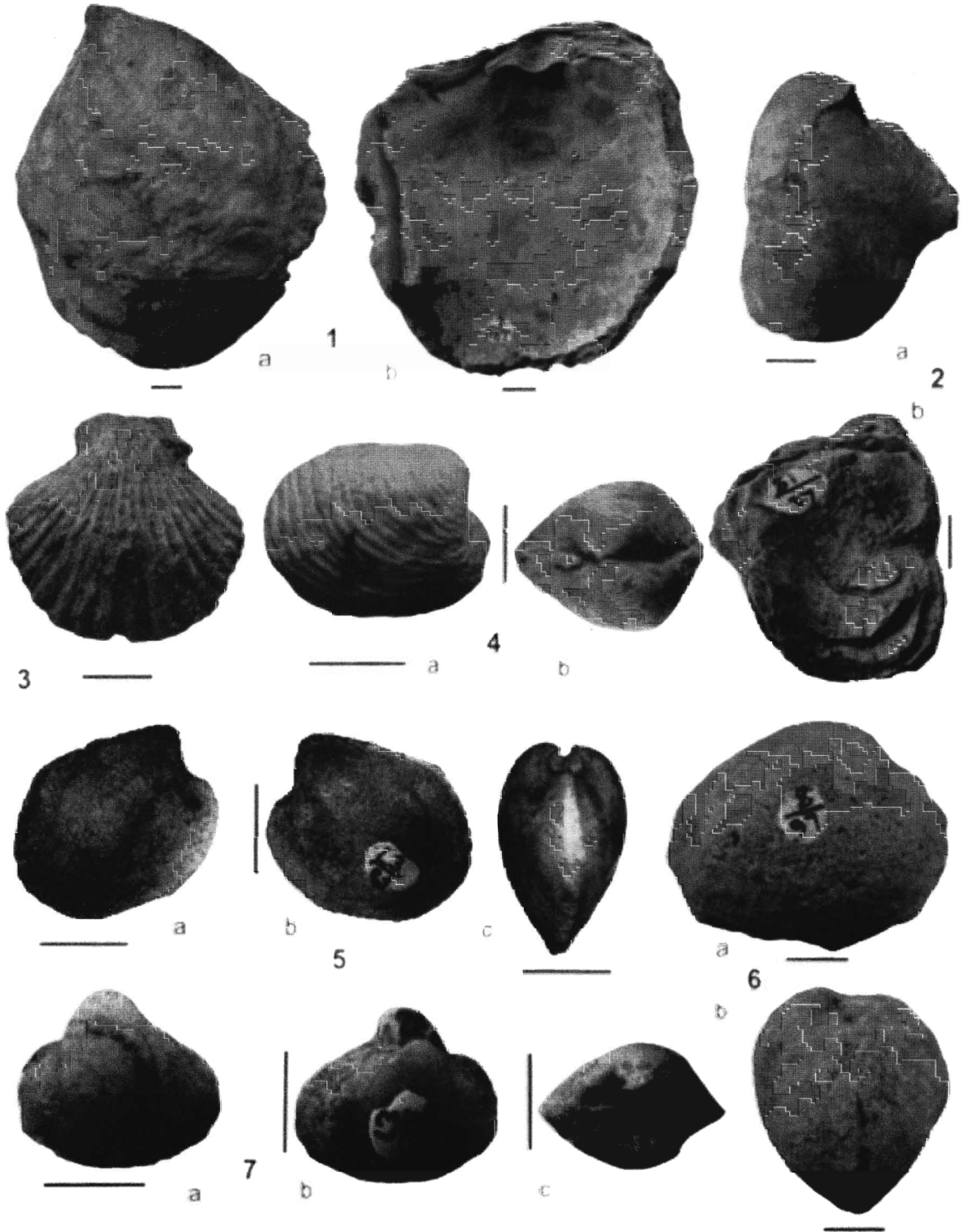
#### Zone 6 *Conus (Lithoconus) ineditus* zone

It is the uppermost zone devoid of foraminifers and molluscs are comparatively less represented. Most of the forms continue from zone 4, namely *Chlamys (Chlamys) sp.*, *Diplodonta (Diplodonta) incerta* d'Archiac (upper Eocene - Oligocene), *Periglypta puerpera* Linne var. *aglaurae* Brongniart (Oligocene), *Callista (Callista) yawensis* Cotter (upper Eocene), *Cochlis sp.*, *Cassidia mamillaris* Grateloup

## EXPLANATION OF PLATE I

(Bar scale 10 mm)

- |   |                                                                                                                                                           |   |                                                                                                                                                                               |
|---|-----------------------------------------------------------------------------------------------------------------------------------------------------------|---|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | a,b. <i>Pycnodonte (Pycnodonte) kachchhensis</i> n. sp. Holotype. Zone-2 (No.L2U/1)<br>(a) Exterior of left valve and (b) Interior of left valve (× 0.65) | 5 | a,b,c. <i>Microcyprina fortensis</i> n. sp. Holotype. Zone-3 (No.L3/29)<br>(a) Exterior of right valve (b) Exterior of left valve and (c) Lateral view (× 1.5)                |
| 2 | a,b. <i>Gryphaostrea lakhpatensis</i> n. sp. Holotype. Zone-1 (No.L1/18)<br>(a) Exterior of left valve and (b) Exterior of right valve (x1)               | 6 | a,b. <i>Callista (Callista) pseudoumbonella</i> Vredenburg var. <i>globosa</i> n. var. Holotype. Zone-6 (No.L6/8)<br>(a) Exterior of right valve and (b) Lateral view (×1.15) |
| 3 | <i>Chlamys (Aequipecten) feddeni</i> Vredenburg. Zone-4 (No.L4/908)<br>Exterior of right valve (×1.25)                                                    | 7 | a,b,c. <i>Corbula (Bicorbula) subexarata</i> var. <i>lituus</i> . Zone-3 (No.L3/31)<br>(a) Exterior of left valve (b) Exterior of right valve and (c) Dorsal view (×1.85)     |
| 4 | a,b. <i>Glossus (Aralocardia) fulraensis</i> n. sp. Holotype. Zone-3 (No. L3/5)<br>(a) Exterior of right valve and (b) Dorsal view (×1.70)                |   |                                                                                                                                                                               |





var. *nummulitiphila* Sacco (upper Eocene-Oligocene). Only three forms make their first appearance in this zone. These include two bivalves: *Glossus* (*Cytherocardia*) *cytheroides* Mayer (Miocene), *Callista* (*Callista*) *pseudombonella* Vredenburg (Miocene-Pliocene), with a new variety *globosa* and one gastropods viz. *Conus* (*Lithoconus*) *ineditus* Micheloti which is Oligocene in age.

In the absence of *Nummulites*, comparatively much less number of molluscs, and presence of few corals, a shallow marine (littoral to inner neritic) conditions are inferred. This is further evidenced by presence of limestone of arenaceous type.

### SYSTEMATIC DESCRIPTION

All the measurements are in millimeters and figures in parenthesis are the percentage of ratio with respect to length.

Class **Bivalvia** Linne', 1758

Subclass **Pteriomorphia** Beurlen, 1944

Order **Pterioida** Newell, 1965

Suborder **Ostreina** Ferussac, 1822

Superfamily **Ostreacea** Rafinesque, 1815

Family **Gryphaeidae** Vyalov, 1936

Subfamily **Pycnodonteinae** Stenzel, 1959

Genus **Pycnodonte** Fischer De

Waldheim, 1835

Subgenus **Pycnodonte** s.str.

*Pycnodonte* (*Pycnodonte*) *kachchhensis* n. sp.

(Pl. I, figs. 1 a, b)

*Material*: Numerous specimens, overall preservation good.

*Derivation of name*: The species *Pycnodonte* (*Pycnodonte*) *kachchhensis* n. sp. is named after the place of occurrence of the species, i.e. Kachchh (Gujarat).

*Locality and Horizon*: Lakhpat Fort, zones 1 and 2

*Diagnosis*: Very thick vertical left valve, almost straight to slightly convex hinge line, shallow and triangular resilifer, semicircular muscles scar in rounded depression and small almost orbicular flat and thick right valve.

*Description*: Shell medium to large sized with much variable outline. Left valve vertically ovate, sub rounded to sub triangular. It has very large attachment area which is varying from individual to individual. Due to this phenomenon outline is also variable. Umbo may be small, just touching the hinge line or may be prominent and salient depending upon the attachment area. Valve is ornamented by variable concentric puckers. The maximum convexity depending on attachment area may be along the mid line running from umbo to the ventral margin or may be slightly posterior to the mid line. In such cases posterior flank is steeply inclined. Chomata is in form of radial oblique lines adjacent to the hinge line are present. Right valve is almost orbicular in outline, flat and thick. It is characterized by well marked chomata below the hinge line at triangular resilifer and a platform type of margin to the inner side of the edge about a centimetre in width. Surface of the valve is characterized by prominent concentric welts. Umbo rather indistinct. The diagnostic characters of the shell are very thick left valve, almost straight to slightly convex hinge line with triangular and shallow resilifer and semi circular muscle scar in a rounded depression.

Dimensions:	Length	Height	Inflation
L2U/1 (Holotype)	96.00	101.50(105.72)	46.50(48.43) LV
L2U/2	82.50	88.50 (107.27)	43.20(52.36) LV
L2U/6	81.60	92.00(112.74)	44.50(54.53) LV

*Remarks*: *Ostrea* (*Crenostrea*) *wuellerstorti* Zittel (in Marwick, 1931) from the upper Oligocene of New Zealand seems to be the nearest species in having almost similar configuration and chomata, muscle scar and ornamentation but the attachment area is very small. To some extent, it also approaches *Gryphaea* (*Gryphaea*) *pseudovesicularis* Gumpel, 1861 in concentric ornamentation on left valve but differs in its slightly oblique ovate triangular outline and in having very thin right valve which bears radial threads. In nature of muscle scar and hinge line, it is very much nearer to *Gigantostrea* *gigantica* Solander (in Brander, 1766) of upper Eocene age, however, that has almost orbicular outline, much inequilateral symmetry and has very small attachment area.

Subfamily **Exogyrinae** Vyalov, 1936

Genus **Gryphaeostrea** Conrad, 1865

*Gryphaeostrea* *lakhpatensis* n. sp.

(Pl. I, figs. 2 a, b)

*Material*: Numerous specimens.

*Derivation of name*: The species is named after the village of Lakhpat, its place of occurrence.

*Locality and Horizon*: Lakhpat Fort, zone 1

*Diagnosis*: Small to medium size with a variable outline of left valve from bilobate-ovate to bilobate- triangular, presence of shallow to deep, narrow almost vertical sulcus in posterior region, slightly ophistogyrous umbones, small shallow concave ovate resilifers, very deep rounded muscles scar and small slightly concave triangularly ovate right valve with concentric folds and widely space narrow radial grooves.

*Description*: Shell is small to medium sized. Shape varies from bilobate-ovate to bilobate- triangular. Left valve is much more convex, tall and narrow. Height is about 112- 138 % of length. It is regularly curved attaining its maximum convexity about one-third to two-fifth of height along a sharp rounded ridge. From this ridge, posterior flank is steeply inclined and the anterior flank is regularly convex. To the posterior side a shallow to deep narrow almost vertical sulcus separates wing like posterior flange forming posterior extremity. Umbo is small, not so prominent and slightly opisthogyrous.

The surface of the left valve appears to be smooth except for widely spaced irregular concentric folds traversed by indistinct radials. Attachment area is small and almost 90° to the valve surface adjacent to umbo. Hinge line rather straight and gently inclined towards the posterior. Resilifer in left valve is shallow, concave, small and ovate. Muscle scar very deep, rounded almost below the resilifer and situated to posterior at about mid height. Right valve is small, slightly concave and triangularly ovate. Its umbo is small and ill defined. Valve is sculptured with well marked concentric folds and widely spaced narrow radial grooves. It is slightly smaller and lid like.

Dimensions:	Length	Height	Inflation
L1/18 (Holotype)	42.40	48.50(114.38)	25.50(60.14) BV
L1/17	42.20	53.80(127.48)	27.40(64.92) BV
L1/27	39.50	44.60(112.91)	24.70(62.53) BV

*Remarks*: The recorded species is very much similar to *Gryphaeostrea* *globosa* J. de C. Sowerby (1840 a) in overall configuration; however, the latter is very large, much thick and has distinct spirally coiled umbo, centrally placed muscle scar and devoid of nodes along the ridge. In outline, shape, nature of posterior flange and curvature, it resembles *Gryphaea* *bilobata* J. de C. Sowerby (1840 b) from Middle Jurassic of



England. Compared to it, the present form differs in having well marked radial grooves over the right valve and in the presence of nodes over the vertical ridge.

In overall configuration, it is like middle and upper Eocene species of Central Asia and Europe, namely *Sokolowia bushi* (Grewingk) (Stenzel, 1971) which is distinguishable from the recorded species by the presence of distinct radials over the left valve and in the absence of radial grooves in the right valve.

In nature of rounded ridge, posterior flange and right valve ornamentation, the reported taxon is approaching *Gryphaea eversa* (Melleville, 1843) from the lower Eocene of France, which has narrow, oval right valve instead of triangularly ovate, as also broadly rounded ridge without any node.

Superfamily **Arcticacea** Newton, 1891

Family **Arcticidae** Newton, 1891

Genus **Microcyprina** Cossmann, 1921

*Microcyprina fortensis* n. sp.

(Pl. I, figs. 5 a, b, c)

**Material:** Fourteen specimens, preservation good.

**Derivation of name:** It is named after the Lakhpat fort where this species is confined to zone 3.

**Locality and Horizon:** Lakhpat Fort, zone 3

**Diagnosis:** Small much inequilateral, smooth and cordiform to sub-quadrangular shell, moderate inflation with maximum at about dorsal third, slightly posterior to umbo, anterior third umbonal position, presence of faint carina from umbo to postero-ventral corner, small and gently curved hinge with typical dentition of A1, 2a, 2b.

**Description:** Shell is small, equivalve, much inequilateral, cordiform to sub-quadrangular and smooth. Height is slightly less than the length and moderately inflated. The maximum inflation is at about dorsal third of the height, slightly posterior to umbo. From this point towards anterior, posterior and ventral direction valve surface is moderately sloping whereas to the dorsal side gently sloping. Umbo is small, well defined, slightly salient, distinctly prosogyrous, pointed and situated at about anterior third to anterior fourth of the shell length. Postero-dorsal margin is gently sloping and almost straight merging with broadly curved posterior margin in a rounded obtuse angle. Posterior margin is merging with feeble to moderately arched ventral one with an angulation. From umbo to this angulation a faint carina runs. Adjacent to umbo, the dorsal margin is small, slightly concave and merges with moderately rounded and slightly oblique inward anterior one which in turn joining the ventral margin at even curve or at an ill define angulation. Hinge small and gently curved. Lunule and escheteon are absent. Dentition is as for genus, i.e. presence of A1, 2a 2b. Of these, latter two are distinct. Other internal features are not observable.

**Dimensions:**

Sp.No.	Length	Height	Inflation
L3/29 (Holotype)	23.20	21.50(92.6)	15.00(64.6)
L3/16	26.12	24.50(93.7)	16.62(63.62)
L3/63	19.20	18.00(93.7)	12.00(66.6)
L3/39	18.50	17.20(92.9)	11.60(62.7)
L3/55	17.60	16.70(94.8)	11.50(65.3)

**Remarks:** The recorded species is approaching *Microcyprina newvillei* (Cossmann) (Keen and Casey, 1969) from the Eocene of France in nature of hinge and bearing ill

defined ridge from umbo to the postero-ventral corner, but is quite distinct in having ovate-triangular outline with truncated posterior margin.

No other closely comparable form could be recorded.

Subclass **Heterodonta** Neumayr, 884

Order **Veneroida** H.Adams and Adams, 1856

Superfamily **Glossacea** Gray, 1847

Family **Glossidae** Gray, 1847

Genus **Glossus** Poli, 1795

Subgenus **Aralocardia** Vyalov, 1937

*Glossus (Aralocardia) fulraensis* n. sp.

(Pl. I, figs. 4 a,b)

**Material:** Two specimens.

**Derivation of name:** The species is named after the Fulra Limestone Formation in which it occurs.

**Locality and Horizon:** Lakhpat Fort, zone 3

**Diagnosis:** Transversely elongate outline, with height about 3/4<sup>th</sup> of the length, strong inflation almost equal to height, there by cylindrical shape, distinctly coil prosogyrous and terminal umbones, presence of gently incline ridge umbo to postero-ventral corner and sculpture in form of equally space strong concentric undulation.

**Description:** External cast of small size, equivalve, much inequilateral, strongly inflated, transversely elongate with height about 3/4<sup>th</sup> of the shell length. Inflation almost equal to the height thus shell attaining a cylindrical shape with narrow dorsal profile. Maximum inflation is just below the umbo. Postero-dorsal margin is small about half the length, almost straight and very gently sloping to merge in an uninterrupted much obtuse curve with long, steeply outward, oblique and almost truncated posterior one. Anterior margin is moderately small, openly curved and meeting slightly concave and very small antero-dorsal one. Ventral margin is asymmetrical, feebly arched, posterior segment about 1/3<sup>rd</sup> of the length and regularly rounded, whereas 2/3<sup>rd</sup> anterior segment slightly convex and rises rapidly to meet anterior margin without any angulation. Umbones are coiled distinctly prosogyrous, prominent and almost terminal. From umbo to the postero-ventral corner, feebly convex, gently inclined, distinct ridge runs which is becoming slightly broader and faint towards the postero-ventral corner. The maximum inflation corresponds to this ridge. To the anterior and posterior side of the ridge, valve surface is steeply inclined. Hinge is very small and convex. Shell surface ornamented by equally spaced strong concentric undulations almost parallel to the margins and intersecting the postero-dorsal margin at moderate angle. Interior is not known.

**Dimensions:**

Sp.No.	Length	Height	Inflation
L3/5 (Holotype)	23.20	19.20(82.75)	16.00(68.96)
L3/65	19.60	15.00(76.53)	15.20(77.55)

**Remarks:** Authors have not come across any closely comparable form in the available literature and the genotype *Glossus (Aralocardia) multicostatus* (Nyst) (Stenzel, 1971) from the Oligocene of Germany is cordiform, bears spirally coiled umbones and has strong concentrics restricted to umbonal region, hence, a distinct species.

Superfamily **Veneracea** Rafinesque, 1815

Family **Veneridae** Rafinesque, 1815

Subfamily **Pitarinae** Stewart, 1930

Genus **Callista** Poli, 1791

Subgenus **Callista** s.str.

*Callista (Callista) pseudoumbonella* Vredenburg var.  
*globosa* n. var.  
(Pl. I, figs. 6 a, b)

**Material:** One complete specimen

**Derivation of name:** Its strong inflation isolates it from the type species and is named after this character.

**Locality and Horizon:** Lakhpat Fort, Lakhpat zone 6

**Diagnosis:** In shape very much similar to typical form of *Callista (Callista) pseudoumbonella* Vredenburg, except for its strong inflation of 70%.

**Description:** Shell is medium sized, transversely subovate, equivalve, sufficiently inequilateral and globose. The height is about 3/4<sup>th</sup> of the shell length and the inflation is in the central region slightly posterior to the umbone. Anterior, posterior margins are broadly curved, slightly less than the height and merging with gently arched ventral margin in even curve. Umbones are distinct, prosogyrous, broadly inflated situated at about anterior third of shell length. Umbonal region is almost flat and about 90° to the valve surface. Dorsal margin is very gently convex. Hinge is almost straight and about 4/5<sup>th</sup> of shell length. Interior not known.

Dimensions:	Length	Height	Inflation
L6/8 (Holotype)	44.50	34.30(77.07)	31.50(70.78)

**Remarks:** In overall configuration, it is very much similar to the individuals of *Callista (Callista) pseudoumbonella* Vredenburg (1928), leaving aside its strong inflation which is around 70% instead of 62%; therefore, it has been erected as a new variety. Moreover, it comes from a lower horizon, i.e. Oligocene instead of Miocene. Vredenburg (1928), while erecting *pseudoumbonella* as a new species, has mentioned that the forms older than this may be regarded as a variety *kachhensis* and younger ones as variety *persica*. However, in the absence of any photograph of the type specimens related to this variety, it is described here as a new variety under the name *globosa*.

**Class** *Gastropoda* Cuvier, 1797

**Subclass** *Prosobranchia* Miln ards, 1848

**Order** *Mesogastropoda* Thiele, 1925

**Superfamily** *Cerithiacea* Fleming, 1822

**Family** *Cerithiidae* Fleming, 1822

**Subfamily** *Cerithiinae* Fleming, 1822

**Genus** *Campanile* Bayle in Fischer, 1884

*Campanile babiliana* n. sp.

(Pl. II, fig. 3)

**Material:** Lone specimen.

**Derivation of name:** The name is derived from its occurrence in the Babian Stage of middle Eocene age.

**Locality and horizon:** Lakhpat Fort, Lakhpat zone 2

**Diagnosis:** Smooth conch, narrow apical angle of 25°, many whorls, sculptures in form of grooves and flat whorls.

**Description:** Conch is regularly conical, narrow with an apical angle of 25°. Number of whorls seems to be many but not available due to breaking away of conch adapically. Each spire whorl has a diameter about three and half times to the height. Whorl surface of each one is almost plane except for very feeble convexity adapically. Sutures are much narrow, in form of grooves and dipping very gently. Each spire whorl is the characterized by four flat spiral bands. Of these, anterior- and posteriormost bands are equally wide and the band adjacent to the anterior one is slightly less wide, whereas the band anterior to the posteriormost is much narrow, less than half of the width of the others. Columella well formed and bears prominent columellar fold. It does not appear that the last whorl is fully preserved; however, the available whorl is bluntly angular to the anterior and moderately convex. Base appears to be smooth and reveals the presence of spiral bands crossed by fine growth lamellae which are oblique, slightly concave and procline. It seems that the base bears three very shallow and narrow grooves. The anterior extremity of the columella is twisted and projected beyond the aperture which is large and almost oval. Because of broken nature, it is difficult to decipher all the characters of labrum. It seems that the outer lip is entire, though giving a slight hint of the presence of anterior channel. Parietal lip bears a prominent fold which is obliquely inclined towards anterior. This results into two concavities, of which apertural one is three times broader than the apical one.

Dimensions:	Diameter	Height
L2U/17 (Holotype)	42.50	60.20(141.6)

**Remarks:** In majority of the forms of genus *Campanile*, the later whorls usually bear rows of nodes below the suture but this is not the case in the recorded species. In the nature of coiling, and the absence of nodes, the species described here approaches *Campanile brookmani* Cox (1930) from Samana Range but the present one is distinguishable by its very narrow apical angle, i.e. 25° instead of 35°. In addition to it, the whorl surface is almost plane or very feebly convex instead of being concave. Further, in the Samana range species the suture lies between raised rims of successive whorls, whereas in the Kachhh species it is in the form of an indentation between the flat surfaces of the successive whorls. Though the lone recorded specimen is in the form of fragment, it is erected as a new species because of its smooth conch which is a rare phenomenon.

## CONCLUSIONS

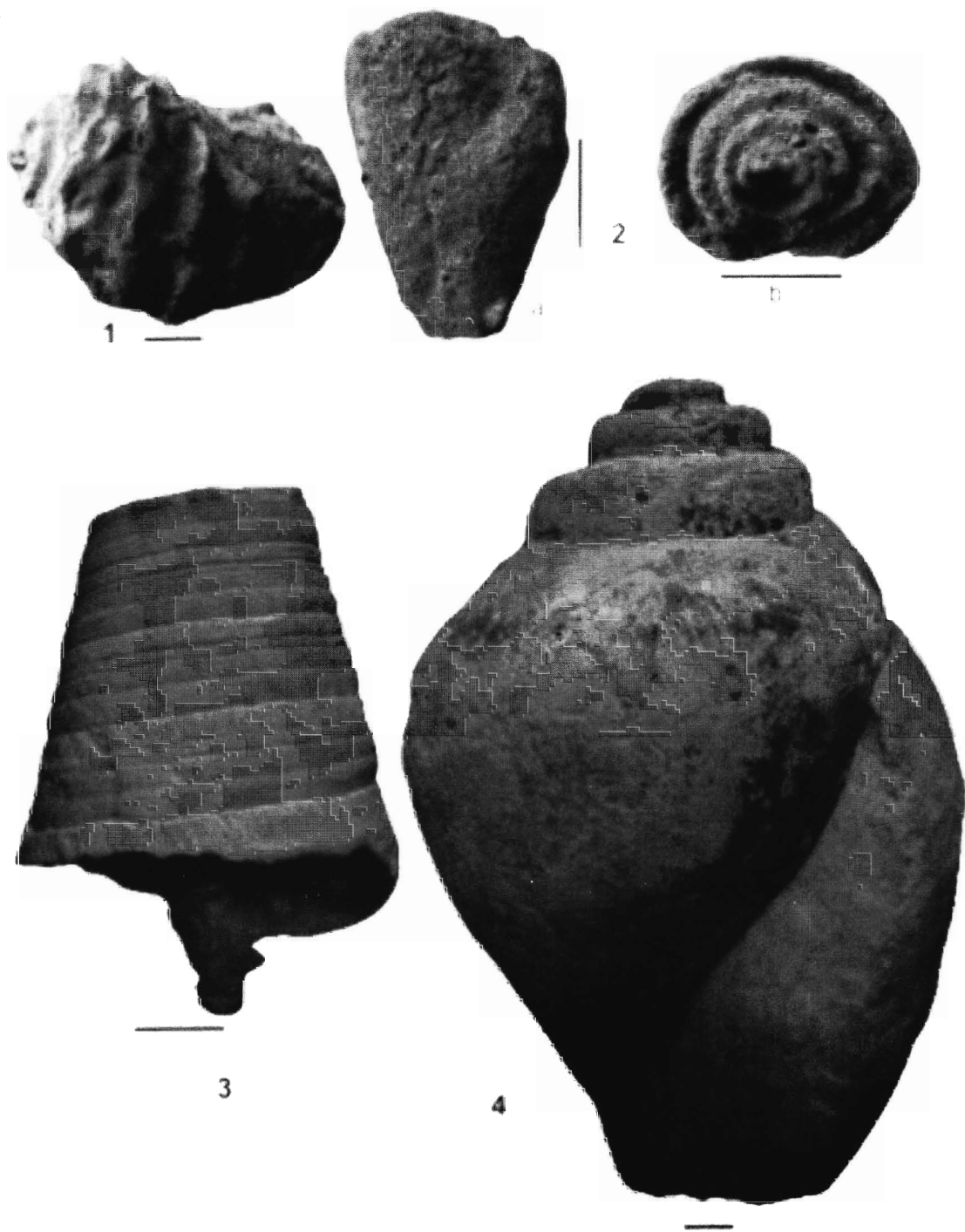
1. Overall 77 taxa (48 bivalves and 29 gastropods) are identified in the material collected from the Palaeogene strata (middle Eocene-lower Oligocene) of Lakhpat.
2. Six molluscan zones correlatable with foraminiferal zones, are established.
3. All the molluscan zonal assemblages are quite different

## EXPLANATION OF PLATE II

(Bar scale 10 mm)

1. *Ostrea (Ostrea) protoimbricata* Vredenburg  
Zone 4 (No.L4/175)  
Exterior of left valve (×1.2)
2. a,b. *Conus (Lithoconus) inaditus* Micheloti  
Zone 6 (No.L6/24)

- (a) External view and (b) Top view (× 1.5)
3. *Campanile babiliana* n. sp. Holotype  
Zone-2 (No.L2U/17) (× 1.5)
4. *Turbinella bulbiformis* J.de C. Sowerby  
Zone-2 (No.L2U/B-19) (×0.5)



from each other.

4. Based on molluscan assemblage, presence of upper Eocene strata is inferred.
5. The molluscan assemblages ranging from middle to upper Eocene are found in the uppermost part of the Fulra Limestone Formation in zone 3.

## REPOSITORY

All specimens of the present collection of fossil molluscs (described and photographed) have been deposited in the Department of Geology, M. L. Sukhadia University, Udaipur-313 002.

## ACKNOWLEDGEMENTS

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