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PARATAXONOMIC CLASSIFICATION OF LATE CRETACEOUS DINOSAUR EGGSHELLS FROM INDIA

ASHU KHOSLA AND ASHOK SAHNI
CENTRE OF ADVANCED STUDY IN GEOLOGY, PANJAB UNIVERSITY, CHANDIGARH - 160 014. INDIA

ABSTRACT

The Late Cretaceous eggs and eggshell fragments of India have been parataxonomally described and classified as follows: seven new oospecies (*Megaloolithus cylindricus, M. jabalpurensis, M. mohabeyi, M. baghensis, M. dholiyaensis, M. walpurensis and M. padiyalensis*) are of tubospherulitic morphotype and have been assigned to the oogenus *Megaloolithus* of the oofamily Megaloolithidae. The eighth new oospecies (*Subtiliolithus kachchhensis*) of ornithoid-ratite morphotype has been assigned to the oogenus *Subtiliolithus* of the oofamily Subtiliolithidae.

In the absence of identifiable embryonic remains in the *Megaloolithus* oospecies, these eggs have been correlated to the taxa of Sauropoda based mostly on the titanosaurid bones found in the associated strata. *Subtiliolithus* may represent an avian eggshell or eggshell of a small theropod dinosaur.

INTRODUCTION

During the last twelve years, considerable progress has been made in recording diverse dinosaur eggshell types from various localities in India (Mohabey, 1984; Mohabey & Mathur, 1989; Vianey-Liaud *et al.*,1987; Srivastava *et al.*, 1986; Sahni, 1993; Bajpai *et al.*,1993; Sahni *et al.*,1994). In the initial stages, when relatively few types had been described, the nomenclature used was mostly informal. Terms such as Type A and B (Srivastava *et al.*,1986); Type I and Type II (Mohabey, 1984; Mohabey and Mathur, 1989) and more recently ?TST-I to TST-III (Sahni, 1993; Sahni *et al.*, 1994) were used. Such an informal system now needs to be revised in the light that many new types have been recorded including the four documented herein.

The problem of finding a suitable method for classifying dinosaur eggs is particularly vexatious when (as is often the case) the eggshells cannot be related to the parent dinosaur. In those instances, where identifiable embryos are contained within the eggs, for example, in *Maiasauria* (Horner and Gorman, 1990) the correlation of the eggshells to a particular dinosaur taxon can be made with confidence. However, in the absence of contained embryos all other identifications remain tentative. More commonly, eggshells have been correlated to a particular family or taxon on the basis of associated bones for instance, as in the case of Late Cretaceous sauropod *Hypselosaurus priscus* from France (Erben *et al.*, 1979). Such association between skeletal elements and eggshell fragments have also been used in India for relating specific eggshell types to specific families: for example, the variously labelled dinosaur eggs and eggshell fragments from Balasinor, Dohad, Jabalpur etc. (consisting of large spherical eggs 120-200 mm in diameter) have been assigned to "titanosaurids," (Sahni *et al.*,1994).

The parataxonomic classification obviates the necessity of correlating an eggshell morphotype to a particular taxon. Fossil eggs infact have been treated as trace fossils and classified as such without using the taxonomic name of an animal (Sarjeant and Kennedy 1973; Vialov, 1972). Fossil eggshells are classified by their structure (basic type of eggshell organization, morphotypes, pore systems etc.) in a parataxonomic system (oofamilies, oogenera and oospecies).

Zhao and his colleagues (Zhao, 1975; Zhao and Ding, 1976; Zhao 1979 a,b; Zhao and Li, 1988; Zhao, 1993; Zhao and Li, 1993 and Zhao, 1994) have established a parataxonomic scheme for classifying Chinese dinosaur eggs and eggshell material into eight families namely Elongatoolithidae, Megaloolithidae, Hypsilophodontidae, Ovaloolithidae, Spheroolithidae, Dendroolithidae, Faveoloolithidae and Dictyoolithidae.

Kurzanov and Mikhailov (1989) and Mikhailov (1992) improved the system of classification by treating eggshells as a biocrystalline structure and have established five basic types of eggshell organization namely geckonoid, testudoid, crocodiloid, ornithoid and dinosauroid. Mikhailov (1991) recognized three groups of shell unit structures and textures in the eggshells of dinosaurs: (1) spherulitic type-in which five morphotypes are recognized namely tubospherulitic, prolatospherulitic, angustispherulitic, filispherulitic and dendrospherulitic; (2) spherulitic-prismatic type - prismatic morphotype (3) ornithoid type- ratite morphotype.

Mikhailov (1991) classified eggs and eggshells of dinosauroid basic types into five distinct families namely Megaloolithidae, Faveoloolithidae, Dendroolithidae, Spheroolithidae and Ovaloolithidae. He put eggshells of ornithoid basic type into three distinct families namely Elongatoolithidae, Laevisoolithidae and Subtiliolithidae.

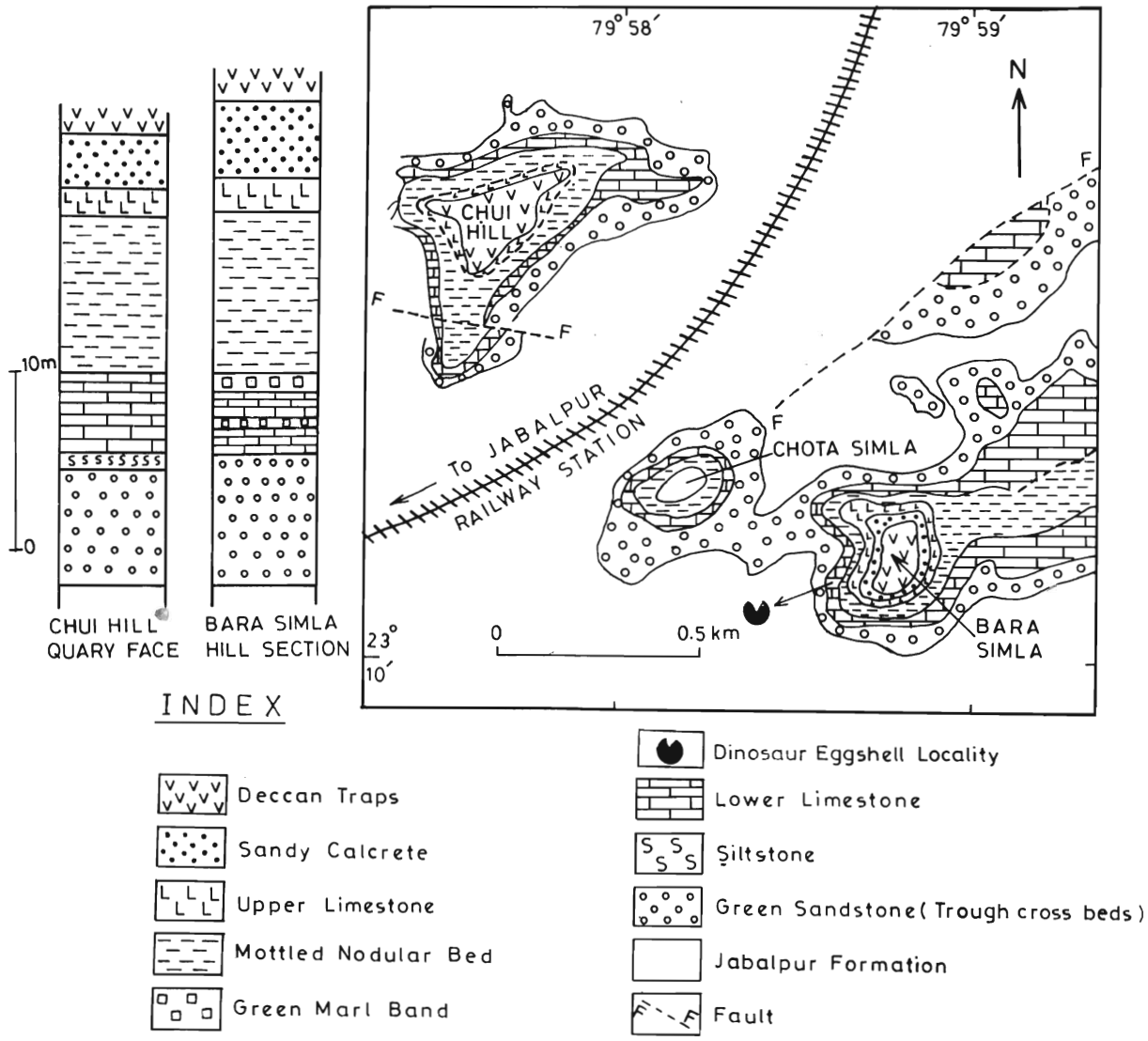

Fig 1. Geological map of the Jabalpur Cantonment area (modified after Matley, 1921) and lithostratigraphic sections showing dinosaur eggshell horizon.

More recently, Hirsch and Quinn, (1990) and Hirsch, (1994 a,b) have done extensive work on structural classification of fossil eggshells. According to Hirsch (1994a), the structural classification combined with an extended parataxonomic classification of year has produced a workable scheme in which to describe and classify fossil eggs and eggshells world-wide. Hirsch (1994a) classified fossil eggshells of gecko, turtle, crocodile and birds into four basic types of histostructure: geckonoid, testudoid, crocodiloid and ornithoid. He also gave a structural classification for dinosaurian eggshells. Based on the general histostructure and the ultrastructure, he grouped ten distinct dinosaur eggshell morphotypes to their specific basic type. Hirsch (1994b) based on associated embryos erected a new family Prismatoolithidae under dinosauroid-prismatic basic type for the eggs and eggshells of protoceratopsids and hypsilophodontids. He also assigned an ornithoid basic type for the fossil eggshells of neognathe birds. He further classified five different pore systems, their patterns and external ornamentation of the shell surface. This new classification system is better dealt in Hirsch (1994a, Table 11.1) which led him to correlate parataxonomic families to structural morphotypes and basic types of eggshell organization.

The need for following a parataxonomic classification for Indian dinosaur eggs and eggshell types is very apparent and this paper addresses this aspect in some detail. The emphasis in the application of parataxonomic schemes is based on the description of new oospecies and their comparison with previously known forms. The known Indian dinosaurian eggshell types are grouped into various parataxonomic families based on the following structures: 1. *Ultrastructure* (or texture of eg-

gshell), refers to the fine organisation of calcareous material as a sequence and composition of horizontal ultrastructural zones (zone of tabular or squamatic, crystalline aggregates) in combination with the organic network or layers of the eggshell. 2. *Microstructure* (general histology) refers to the histomorphology of the calcareous material of the shell units (organic core, eisospherite, basal cap, mammillae, wedges and prisms, or continuous shell layer, etc.) and the arrangement of the pore system (pore canals, etc.). 3. *Macrostructure* (general morphology) encompasses size and shape of egg, eggshell thickness, pore pattern and sculpture of the outer shell surface.

Most of the dinosaurian eggshell types described in this paper have a basic dinosauroid eggshell organization (Mikhailov, 1991) excluding one of the ornithoid type (Hirsch and Quinn, 1990; Mikhailov, 1991). Seven new oospecies definitely are of tubospherulitic morphotype. The eighth oospecies represents the ratite morphotype (Hirsch and Quinn, 1990; Mikhailov, 1991). A map of the type localities of the holotype material is given in the figs. 1;2A,B;3A,B;4.

Abbreviations - Aff.-Affinities; *M- Megaloolithus*; PLM-Polarizing Light Microscope; SEM-Scanning Electron Microscope; VPL/KH, Vertebrate Palaeontology Laboratory, Khosla.

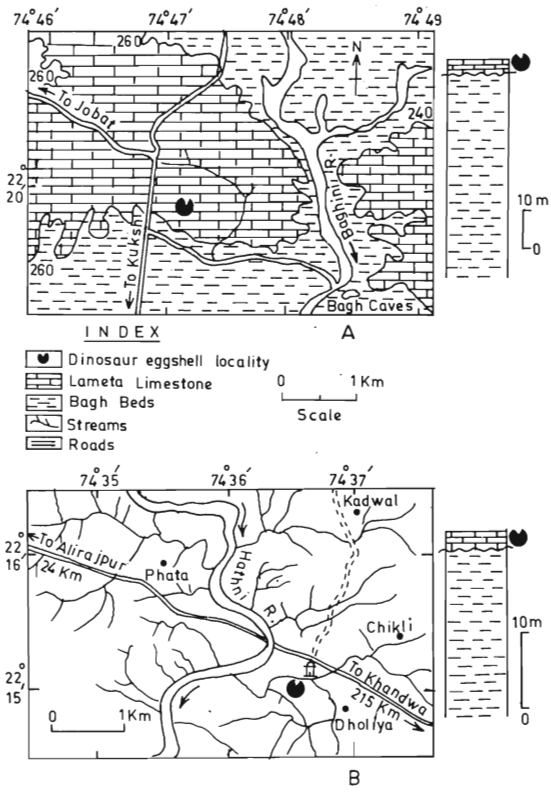

Fig 2. A. Geological map of the Bagh Cave area and lithostratigraphic section showing dinosaur eggshell horizon. B. Map and lithostratigraphic section showing location of dinosaur eggshells collected at Dholiya.

SYSTEMATIC DESCRIPTION

Oofamily ***Megaloolithidae*** Zhao, 1979

Oogenus ***Megaloolithus*** Vianey-Liaud *et al.*, 1994

Emended diagnosis (modified after Vianey-Liaud *et al.*, 1994) : Dinosauroid-spherulitic basic type; tubospherulitic morphotype; tubocanaliculate pore system; compactituberculate sculpturing; spherical to subspherical eggs varying in diameter from 120-200 mm, eggshell thickness 1.0 -3.5 mm.

Megaloolithus cylindricus n. oosp.

(Pl. I, figs. 1-6; fig. 5)

Holotype and type locality : VPL/KH 201 (Chui Hill, Fig. 1) Jabalpur, Madhya Pradesh.

Type Horizon : Sandy carbonate (= limestone) bed; Late Cretaceous Lameta Formation.

Examined material and locality : 30 eggshell fragments from Chui Hill (VPL/KH 201) and thirty eggshell fragments from Pat Baba Mandir (VPL/KH 212, 213), Jabalpur, Madhya Pradesh; over fifty eggshell fragments from Dholiya (VPL/KH 101, 102), District Dhar, Madhya Pradesh; five eggshell fragments from Walpur, District Jhabua, Madhya Pradesh and ten eggshell fragments from Khempur (VPL/KH 151), District Kheda, Gujarat.

Etymology : The name *cylindricus* is derived after the cylindrical shape of spheroliths.

Diagnosis : Spherical eggs 120 - 200 mm in diameter; eggshell thick (1.7-3.5 mm); mostly discrete nodes seen; tall spheroliths cylindrical in shape distinct from adjacent ones; average height to width ratio 4:1; pores subcircular; basal caps medium sized (0.2-0.5 mm in diameter).

Description : The eggshells are fragmentary in nature. The eggshell thickness varies from 1.7 - 3.5 mm. The outer surface exhibits nodose ornamentation. The nodes are circular to subcircular in shape and are well separated from each other. The nodal diameter ranges from 0.4 to 1.4 mm, with most about 0.8-1.0 mm. The spheroliths present in this group are long, slender, elongate, compressed and cylindrical in shape. They do not show any interlocking or fusion. Each spherolith ends into a single node. The margins of the spheroliths are straight and vertical. The height of the spheroliths tend to be uniform in this oospecies which led to the same nodal relief. The average height and width of spheroliths

are 2.24 mm and 0.56 mm respectively. The height/width ratio is 4:1. Highly arched growth lines originating from the lateral boundaries of spherolith are restricted to the individual spherolith. Vertical to subvertical radiating growth lines originating from the core of the basal caps are usually prominent. In tangential sections, pores are subcircular in shape. In radial sections, the pore canals are long, narrow, straight and run throughout the thickness of the eggshell. The basal caps are subcircular and tightly packed. They are of medium size (0.2 - 0.5 mm in diameter), generally distinct from each other.

Discussion : The eggshell structure of this type was first reported from Upper Cretaceous of France (Thaler, 1965; Erben, 1970 and designated as Penner Type - 1 in Vianey-Liaud *et al*; 1987). *Megaloolithus cylindricus* is closely similar in external sculpturing of the eggshells, spherolith shape, pore pattern to Type 4 of Williams *et al.*,(1984) and to *Megaloolithus siruguei* (Vianey - Liaud *et al.*,1994) known from the Middle Rognacian (Maastrichtian), La Bégude Formation under the Rognac Limestone. The only distinction is that in general Indian eggshells are somewhat thicker than their French counterparts.

In India, spherical eggs of 120-160 mm in diameter had previously been reported from Rahioli, Kevadiya and Khempur in Kheda district, Gujarat representing Type "B" of Srivastava *et al.* (1986). Similar spherical eggs with variable diameter had also been reported from Paori (180 mm), Dholidhanti (120-200 mm) and Mirakheri (160-180 mm) in Panchmahal District, Gujarat (Mohabey and Mathur, 1989). Egg clutches and eggshell fragments had also been reported from Pavna (Mohabey, 1990), Jabalpur and Hathni River Section (Kukshi) as ? Titanosaurid Type-I (Tripathi, 1986; Sahni, 1993, Sahni *et al.*, 1994).

Megaloolithus jabalpurensis n. oosp.

(Pl. I, fig. 7; Pl. II, figs. 1-4; fig. 5)

Holotype and type locality : VPL/KH 250 (Bara Simla Hill, fig. 1), Jabalpur, Madhya Pradesh.

Type Horizon : Sandy carbonate (= limestone) bed; Late Cretaceous Lameta Formation.

Examined material and locality : Over two hundred and fifty eggshell fragments from Bara Simla Hill (VPL/KH 250-252), Jabalpur; fifty eggshell fragments from Dholiya (VPL/KH 351); two from Bagh Cave Section (VPL/KH 401) and three from Padiyal, District Dhar, Madhya Pradesh.

Etymology : The name *jabalpurensis* is derived after the city of Jabalpur.

Diagnosis : Spherical eggs 140-160 mm in diameter; eggshell thickness ranges from 1.0-2.3 mm; average node diameter about 0.47 mm with diameter ranging from 0.35-0.60 mm; spheroliths of variable width and shape; average height to width ratio 2.45:1 ; pore circular to elongate in shape; basal caps smaller (0.1 - 0.5 mm in diameter) than in *Megaloolithus cylindricus*.

Description : The eggshells are 1.0-2.3 mm in thickness. Nodose ornamentation is well displayed in almost all the eggshell fragments. The nodes are subcircular in shape. The nodes have variable diameter between 0.35 mm - 0.60 mm, with an average of about 0.47 mm. The spheroliths are short, broad and conical in shape. The average height and width of spheroliths are 1.67mm and 0.68mm. The height/width ratio is 2.45:1. The growth lines moderately arched upwards and follow the contour of the external profile. Small spheroliths also occur in between the larger spheroliths. In tangential sections, the pores are circular to elongate in shape and are present along the contact between the nodes. The pore canals are narrow, inclined and subvertical. The basal caps are subcircular, tighty packed and smaller than those of *Megaloolithus cylindricus* about 0.1 - 0.5 mm in diameter.

Discussion : The eggshell structure of the oospecies *Megaloolithus jabalpurensis* is similar to Penner Type 3, described from Upper Rognacian (Maastrichtian) of Aix-en- Provence Basin, France (Penner, 1985). The eggshells of the same type had also been reported as Type 3.1 by Williams *et al.* (1984). More recently, Grigorescu (1993); Grigorescu *et al.* (1994) has also reported similar eggs (120-160 mm in diameter), eggshells from Late Maastrichtian, Hateg Basin (Romania). Romania eggshell thickness ranges from 2.1 - 2.7 mm (average eggshell thickness 2.3 - 2.4 mm) which is almost identical to *Megaloolithus jabalpurensis*. Vianey-Liaud *et al.*, (1994) has described the oospecies *Megaloolithus mammilare* from the Upper Rognacian (Maastrichtian) of Rousset-Erben Formation near La Bégude (Aix- en-Provence, Basin) above the Rognac Limestone, France. The eggshells are almost identical in external sculpture and shape of the spheroliths to the Indian dinosaur eggshell oospecies *Megaloolithus jabalpurensis*. The only distinction is that in general Indian eggshells are somewhat thicker than the French counterparts.

In India, the eggs belonging to this morphotype initially were reported from Jabalpur and Hathni River Section (Kukshi) as ? Titanosaurid Type-II (Tripathi, 1986; Sahni, 1993; Sahni *et al.*,1994). Eggshells collected at Dholiya are much thicker (2.3 mm) as compared to those from Jabalpur and Kukshi which are 1.0 - 1.5 mm in thickness (Sahni *et al.*,1994) but are otherwise similar. A similar type represented by spherical eggs with

diameter ranging from 140-160 mm had previously been reported from Waniawao (Panchmahal District, Mohabey and Mathur, 1989).

Megaloolithus mohabeyi n. oosp.

(Pl. I, fig. 8; fig. 5)

Holotype and type locality : VPL/KH 233 (Dholiya), District Dhar, Madhya Pradesh.

Type Horizon : Sandy carbonate (= limestone) bed; Late Cretaceous Lameta Formation.

Examined material and locality : Three eggshell fragments from Dholiya (Hathni River Section, VPL/KH 233), District Dhar, Madhya Pradesh.

Etymology : The species *mohabeyi* is named in honour of Dr. D.M. Mohabey, Nagpur, GSI, India.

Diagnosis : Spherical eggs 160 mm to 190 mm in diameter; eggshells 1.8 mm in thickness; spherolith long and fused to adjacent ones; height to width ratio is 3.06:1; basal caps broad or semicircular (0.14 - 0.21 mm in diameter).

Description : The eggshells are about 1.8 - 1.9 mm in thickness. The eggshell fragments exhibit well developed nodose ornamentation. The nodes are circular to polygonal in shape. The spheroliths are long and exhibit highly arched nodal roofs. The "fanning" of the spheroliths extends upto 2/3-3/4 of the eggshell thickness. The spheroliths are commonly of single node type, fused to their neighbours and rarely multinodal. The average height and width of spheroliths are 1.87 mm and 0.61 mm. The height/width ratio is 3.06:1 Highly arched, crescent shaped, well pronounced convex growth lines are present and their convexity increases externally. The growth lines continue into adjacent spheroliths with a marked concavity parelleling the valley between adjacent nodes. Small spheroliths are fused with large ones and their growth lines exhibits convex to undulating orientation. The pores are elliptical in shape. The pore canals are short, inclined and of irregular type. The pores in the specimens presently available are filled with sparry calcite. Minute acicular and radiating striations are restricted to the core in basal caps. Basal caps are broad or semicirculr in shape (0.14 - 0.21 mm in diameter).

Discussion : The eggshell microstructure of this type is similar to 'Type-IV' structural type described by Mohabey, 1991 from Balasinor and Rojhav. Nests contain partially preserved, crushed and fragmented eggs in clutches. The eggs from Phenasani Lake and Waniawao Quarry appear to be spherical in shape. The diameter of the eggs varies between 160 to 190 mm (Mohabey, 1991). *Megaloolithus mohabeyi* differs sufficiently from *M. jabalpurensis* to warrant separation of another oospecies. For example, spheroliths are higher and narrower, they are fused not discrete, the nodes are more distinct. Pore canals are short, inclined and irregular. The growth lines are more highly convex as compared to those of *Megaloolithus jabalpurensis*. In spherolith shape, pore and growth line pattern, *M. mohabeyi* is somewhat similar to *M.* aff. *siruguei* and aff. *M. petralta* (Fig. 11.6 D in Vianey - Liaud *et al.* 1994) known from Upper Rognacian (Maastrichtian) Rousset Erben Formation, France.

Megaloolithus baghensis n. oosp.

(Pl. II, figs. 5-8; Pl. III, fig. 1; fig. 5)

Holotype and type locality : VPL/KH 551 (Bagh Cave Section, fig. 2A), District Dhar, Madhya Pradesh.

Type Horizon : Sandy carbonate (=limestone) bed; Late Cretaceous Lameta Formation.

Examined material and locality : Four eggshell fragments from Bagh Cave Section (VPL/KH 550, 551) and numerous other uncatalogued specimens; seven eggshell fragments from Pisdura (VPL/KH 555,556), District Chandrapur, Maharashtra; about thirty eggshell fragments from Balasinor Quarry in Kheda, Gujarat; two from Anjar (Kachchh, VPL/KH 560), Gujarat and two from Lametaghat, Jabalpur, Madhya Pradesh.

Etymology : The name *baghensis* is derived after Bagh town near which the "Buddhist" Bagh Caves are located.

Diagnosis : Spherical eggs 140-200 mm in diameter; eggshell 1.0-1.70 mm thick; nodose ornamentation, coalesced and discrete nodes; average node diameter about 0.60 mm; fan-shaped spheroliths distinct or even partially fused; height to width ratio 2.32:1; pores subcircular to elliptical; swollen-ended, variably-spaced basal caps (0.2- 0.3 mm in diameter).

Description : The eggshells are 1.0 - 1.70 mm thick and are fragmentary in nature . The external ornamentation consists of coalesced as well as discrete nodes showing nodose ornamentation. The nodes are subcircular in shape. The diameter of the nodes varies from 0.40 mm to 0.80 mm with an average diameter of about 0.60 mm. The node size is variable so radial sections show variability in nodal relief. The spheroliths are distinct or sometimes even partially fused. The individual spheroliths are fan-shaped or conical and relatively widely separated in the inner part near the basal caps. While the fused spheroliths looks much compressed and narrow when it is a part of multiple node and their lateral boundaries are traceable only in the inner third to half of shell thickness. The average height and width of spheroliths are 1.37 mm and 0.59 mm. The height/width ratio is 2.32:1. The growth lines are moderatly arched beneath the nodes and enter into adjacent spherolith with concavity and at sometime continue throughout

the thickness of the eggshells as observed at Pisdura and Balasinor Quarry in Kheda. Some of the eggshell fragments observed at Bagh Caves show faintly developed or nearly absent growth lines. The pores on the outer surface are subcircular to elliptical in shape. The pore canals are short, narrow and curved. Spheroliths terminate into variably spaced swollen-ended basal caps (0.2 - 0.3 mm in diameter) which is a characteristic feature of this oospecies.

Discussion : The eggshell microstructure is similar in shape and size to type No. 3.2 described from Upper Rognacian (Maastrichtian) Aix-en-Provenance of France (Williams *et al.*,1984). This eggshell type was initially described from Pisdura by Jain and Sahni (1985) and Anjar (Kachchh, Sahni *et al.*, 1994). The present described type has also been described from Balasinor Quarry associated with spherical eggs (140 - 200 mm in diameter) and described as Kheda, "Type-A", Srivastava *et al.*,1986; Nagpur (Takli Formation, Vianey-Liaud *et al.*,1987) and previously designated as ? Titanosaurid Type - III (Sahni *et al.*,1994).

Megaloolithus dholiyaensis n. oosp.

(Pl. III, figs. 2,3; fig. 5)

Holotype and type locality : VPL/KH 451 (Dholiya, fig. 2B), District Dhar, Madhya Pradesh.

Type Horizon : Sandy carbonate (=limestone) bed; Late Cretaceous, Lameta Formation.

Examined material and locality : Over thirty eggshell fragments from Dholiya (VPL/KH 451), District Dhar, Madhya Pradesh.

Etymology : The name *dholiyaensis* is derived after the village Dholiya, District Dhar, Madhya Pradesh.

Diagnosis : No eggs known; fragmentary eggshells; eggshell thickness ranges from 1.47 mm - 1.75 mm, nodose ornamentation; much common cylindrical and fan-shaped spheroliths present in the same eggshell type; average height to width ratio is 2.94:1; fusion may occur between adjacent spheroliths, and fusion between 3 or 4 basal caps is frequently observed and ends into a single multinode; pore canal straight; subcircular and conical basal caps isolated or coalescing and of variable diameter from 0.15 - 0.30 mm.

Description : Eggshell belonging to the fifth structural type are 1.47 - 1.75 mm thick. The nodes are not very distinct on the outer surface but wherever seen are faintly developed and generally exhibits nodose ornamentation. The node size is same in all of the observed eggshells which has led to the same nodal relief on the outer surface. This type shows admixture of cylindrical and fan-shaped spheroliths. Cylinder-shaped spheroliths are much common and may be distinct or fused to their neighbours exhibiting shallow gently curving growth lines. The growth lines display a convex to slight undulatory path while entering into the adjacent spherolith. Some of the spheroliths show fusion between three or four thin, slender basal caps ending into a single multinode exhibiting horizontal to subhorizontal growth lines. In this type the spheroliths are mostly of multinodose type and less commonly of single node type. The lateral margins of spherolith are generally straight and nearly conical type. The average height and width of spheroliths are 1.59 mm and 0.54 mm. The height/width ratio is 2.94:1. In radial thin sections the upper part of nodes and growth lines are not much arched as compared to other *Megaloolithus* types. The pore canals are narrow, long and vertical to subvertical in distribution and run parallel to the walls of the spherolith. Sub-circular and conical isolated or coalesced basal caps (0.15- 0.30 mm in diameter) can be noticed. Widely spaced interstices occur in isolated and closely spaced between fused spheroliths.

Discussion : The eggshell microstructure of oospecies *Megaloolithus dholiyaensis* shows close resemblance to Type 1 of Williams *et al.*, (1984) and Penner Type (1983,1985). In the presently described eggshell type the outer surface, spherolith shape and growth line pattern are almost identical to the oospecies *Cairanoolithus dughii* and *Cairanoolithus* oospecies indet. (Vianey-Liaud *et al.*, 1994) known from La Cairanne (Aix Basin) and Villeveyrac Basin of Lower Rognacian (Upper Maastrichtian) age, France. Fan shaped spheroliths are less common seen in both of the Indian and French eggshell material. In one instance of *Cairanoolithus* oospecies indet. (Fig. 11.20 A in Vianey-Liaud *et al.*,1994) fan shaped spheroliths are present in between the fused cylindrical shape spheroliths. The pore canal pattern observed in the *M. dholiyaensis* is almost straight along the spherolith margins but in *Cairanoolithus dughii* (Fig. 11.17 A-C in Vianey-Liaud *et al.*, 1994) slight variation is seen in pore canal pattern. The pore canals are short and straight. Another difference is that the French eggshells are much thicker (1.57-2.41 mm) as compared to the Indian eggshells (1.47 - 1.75 mm). Vianey-Liaud *et al.*, (1994) also described the outer surface of eggshells as not completely smooth in contrast to the 'smooth' appearance described by previous workers (Williams *et al.*, 1984; Penner, 1983, 1985).

Morphologically, *Megaloolithus dholiyaensis* also shows close similarities to *Dughioolithus roussetensis* (Vianey- Liaud *et al.*,1994) described from Rousset Village of Middle Rognacian (Maastrichtian) age, France. Both the types have almost similar eggshell thickness, pore canal, growth line pattern and have discrete, fused spheroliths. In *Dughioolithus roussetensis* all the

spheroliths are fan shaped and not even a single cylindrical shape spherolith is noticed. In *Megaloolithus dholiyaensis* the top of nodes are not much arched and basal caps are subcircular and conical in shape while in *Dughioolithus roussetensis* the nodal surface appears smooth and basal caps are conical in shape. In one of radial thin sections of *Dughioolithus roussetensis* (Fig. 11.18B in Vianey-Liaud *et al.*, 1994) the growth lines are seen to be continuous throughout the thickness of the eggshell. In *M. dholiyaensis*, growth lines are continuous only in fused and multinodal spheroliths. Morphologically, oospecies *Megaloolithus dholiyaensis* shows close affinities towards *Cairanoolithus dughii* inspite of the nearly identical shell thickness of *Dughioolithus roussetensis*.

Megaloolithus walpurensis n. oosp.

(Pl. IV, figs. 1-4; fig. 5)

Holotype and type locality : VPL/KH 570; (Walpur, fig. 3A), District Jhabua, Madhya Pradesh.

Type Horizon : Sandy carbonate (=limestone) bed; Late Cretaceous, Lameta Formation.

Examined material and locality : Three eggshell fragments from Walpur (VPL/KH 570), District Jhabua, Madhya Pradesh.

Etymology : The name *walpurensis* is derived after the village Walpur, District Jhabua, Madhya Pradesh.

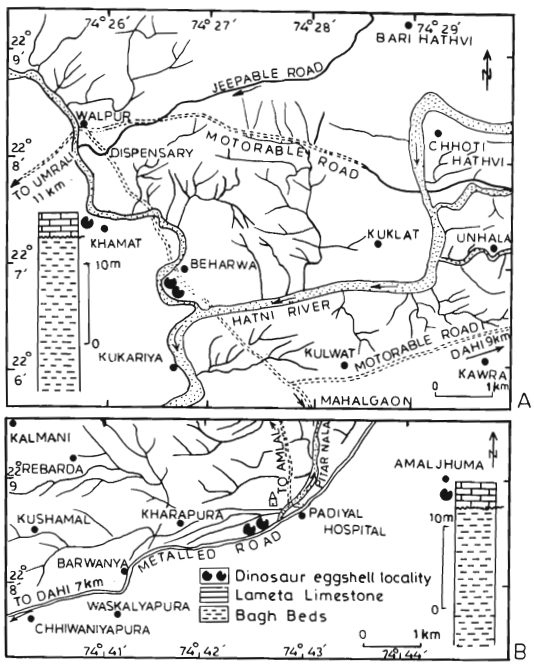

Fig. 3. A. Map and lithostratigraphic section showing location of dinosaur eggshells collected at Walpur. B. Map and lithostratigraphic section showing location of dinosaur eggshells collected at Padiyal.

Diagnosis : No eggs known; fragmented eggshells; eggshell quite thick (3.5-3.6 mm); spheroliths irregularly fan-shaped and at some places show fusion towards the outer surface; average height to width ratio 2.9:1; pore canals thin, slender with slit- like openings; basal caps conical to subcircular in shape (0.25- 0.30 mm in diameter).

Description : Presently, very few eggshell fragments are known and they are embedded radially in a hard nodular calcrete so it is very difficult to comment on their external ornamentation. The eggshells have a great thickness ranging from 3.5-3.6 mm possessing extraordinary large, irregular, fan-shaped spheroliths. The spheroliths are less- sharply separated from each other. The spheroliths interlock laterally and show fusion at some places towards the outer surface of the eggshell. Small spheroliths grow in between the larger spheroliths (varying in height 1/6 to 1/3) due to irregular spacing of nucleation centres. The spheroliths are diagenetically altered by silica towards the middle of spherolith and the spaces left in between the spherolith are filled with sparry calcite. The average height and width of spheroliths are 3.55 mm and 1.23 mm respectively, with height/width ratio of nearly 2.9:1. Radial sections show fine crystals radiating from centre of basal caps while the upper part of spheroliths show moderately arched growth lines. Rhombohedral calcite cleavage results in a herringbone pattern. The pore canals originate in between the fused spherolith and are narrow thin, slender with slit-like openings. The pore canals are entirely filled with sparry calcite. The basal caps are well developed conical and subcircular in shape, widely spaced and range from 0.25 mm - 0.30 mm in diameter.

Discussion : This is a new variation of the tubospherulitic morphotype which has not been described earlier in India. Presently, no complete egg has yet been recorded and additional material is required to confirm the identity of this type.

Megaloolithus padiyalensis n. oosp.

(Pl. IV, figs. 5,6; fig. 5)

Holotype and type locality : VPL/KH 590 (Padiyal), District Dhar, Madhya Pradesh (fig. 3B).

Type Horizon : Sandy carbonate (=limestone) bed; Late Cretaceous, Lameta Formation.

Examined material and locality : Four eggshell fragments and several other uncatalogued specimens collected from Padiyal VPL/KH 590, 591 (near Police Thana Dahi) District Dhar, Madhya Pradesh.

Etymology : The name *padiyalensis* is derived after village Padiyal, District Dhar, Madhya Pradesh.

Diagnosis : No eggs known; fragmented eggshells; eggshell of moderate thickness (1.12-1.68 mm); nodose ornamentation; spheroliths small, slender, irregular; average height to width ratio 3.95:1; pore canals small and large; closely packed basal caps circular to semicircular shape (.07-.21 mm in diameter).

Description : The eggshells are fragmentary in nature. The eggshell thickness ranges between 1.12 mm - 1.68 mm. The external ornamentation is nodose type. This oospecies possesses relatively small, moderately slender, rather irregular, spheroliths of various lengths and widths. The average height and width of spheroliths are 1.58mm and 0.40mm. The height/width ratio is 3.95:1. The spheroliths are surrounded by numerous small and large pore canals running irregularly along the spherolith margins. The upper part of spheroliths exhibit moderately arched growth lines and a herringbone pattern in the presently studied specimens. The spherolith terminates internally into thin, slender, closely packed conical to semicircular shaped basal caps (.07-.021 mm in diameter).

Discussion : This is a new variation of the tubospherulitic morphotype and has not been observed previously.

Oofamily **Subtiliolithidae** Mikhailov, 1991

Oogenus ***Subtiliolithus*** Mikhailov, 1991

Diagnosis (after Mikhailov, 1991) : Ornithoid basic type; ratite morphotype; angusticanaliculate pore system; strongly developed mammillary layer (1/2 -1/3 of eggshell thickness); smooth outer surface or microsculpture (tubercles); very thin eggshells (0.3 - 0.4 mm).

Subtiliolithus kachchhensis n. oosp.

(Pl. III, figs. 4-7; fig. 5)

Holotype and type locality : VPL/KH 580 (Anjar, fig. 4), District Kachchh, Gujarat.

Type Horizon : Dark grey splintery shale containing stringers of chert (third intertrappean level) and of Late Cretaceous.

Examined material and locality : Over three hundred and fifty eggshell fragments collected from Deccan intertrappean beds at a locality about 1.5 km SE of village Viri near Anjar (VPL/KH 580-583), District Kachchh, Gujarat.

Etymology : The name *kachchhensis* is derived after district Kachchh, Gujarat.

Diagnosis : No eggs known, extremely thin eggshells (0.35- 0.45 mm); two-layered; mammillary layer thick comprising 1/2-1/3 of the total shell thickness; outer spongy layer poorly defined; outer surface with irregularly spaced nodes or tubercles; rarely seen pore canal system; distinct, slender mammillary cones; mammillae tightly packed (0.03-0.05 mm in diameter).

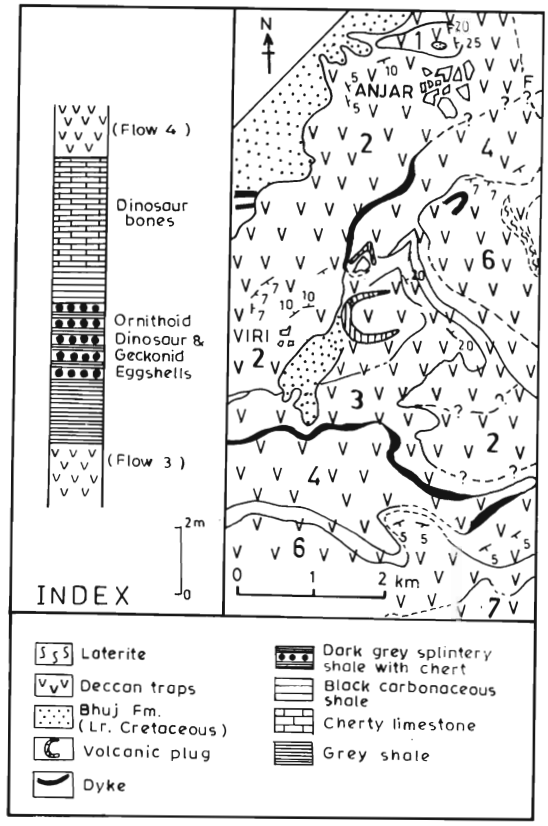

Fig 4. Geological map of the Anjar area and lithostratigraphic section at the collecting locality (map modified after Ghevariyaa, 1988; Bajpai et al., 1993).

Description : The presently described eggshell material is fragmentary in nature. The eggshells are extremely thin and slight variation has been noticed in the eggshells belonging to this type. The thickness of the eggshells ranges between 0.35-0.45 mm. The outer surface is generally smooth while some specimens are characterized with irregularly spaced nodes or microtubercles with no distinct ornamentation.

There is clear differentiation between outer spongy layer and inner mammillary layer. The outer spongy layer is continuous, however some faintly developed columnar structures can be observed. Pore canals are rare. The mammillary layer is exceptionally well-preserved and varies in thickness from 1/2-1/3 of the total shell thickness. As a result, the shell units are distinct in the mammillary zone. In radial sections, slender mammillary cones with radiating crystallites are well observed. The mammillae are tightly packed and are circular to polygonal in shape with no or little intermammillary space. The diameter of the mammillae ranges between 0.03-0.05 mm. Some of them are cratered in-

dicating possible resorption of the calcite by the growing embryo, no large scale dissolution has been observed.

Discussion : Ghevariya and Srikarni (1990) had earlier mentioned the occurrence of complete 'Ornithischian eggs and egg clutches' from the Late Cretaceous intertrappean sequences near Anjar, Kachchh but no detailed description has been published by them. More recently, eggshell fragments have also been reported from the same locality (Bajpai *et al.*,1993; Sahni *et al.*, 1994) in a more detailed manner. The latter authors have not attributed the material to any particular family but have compared them with two ornithoid families namely, Laevisoolithidae and Subtiliolithidae described from Nemegt Formation of Mongolia (Mikhailov, 1991). The Kachchh eggshell material look closer to the family subtiiolithidae, based on microscopic structure, thickness and pore canal system.

DISCUSSION

Morphostructural studies of dinosaur eggs and eggshell fragments belonging to different groups have been carried out in a detailed manner in order to know microstructural variations within a single egg and between adjacent eggs in the same nest. To achieve this objective, sections were made from different regions of the same eggs, from the eggs of the same nest and eggs in adjacent nest. It has been concluded that the eggshell morphostructure appears to be uniform within a single egg, between adjacent eggs in the same nest and between eggs of adjacent nests which can be differentiated on megascopic and microstructural grounds (Sahni and Khosla, 1994). .mt8

The systematic parataxonomic description of the Indian eggshell is aimed mainly at making comparative analysis of dinosaurian and related eggshell morphotype easier and more meaningful. Another goal in such classifications is the correspondence of eggshell morphotypes to animal taxa based on cranial and skeletal remains. Taphonomical biases play a prominent role in the preservation of different element of a vertebrate animal hence make it more difficult to assess species correspondence between disparate elements. At the present seven of the eggshell types described here have been correlated to a single genus *Megaloolithus* representing seven new oospecies with affinities to sauropod dinosaurs. Describing eggshell it is desirable to have the shape, size and general geometric characteristics of a complete fossilized egg. In the Indian Lameta localities nests or fairly complete eggs have been discovered (Mohabey, 1984; Mohabey and Mathur, 1989). These complete eggs belongs to four of the above described seven new oospecies of tubospherulitic morphotype which is correlated to sauropods. These oospecies are: *Megaloolithus cylindricus* sp. nov., *Megaloolithus jabalpurensis* n. sp., *Megaloolithus mohabeyi* n. sp. and *Megaloolithus baghensis* n. sp. For eggshell types for which egg dimensions are not known because of their fragmentary nature the assignment to the family Megaloolithidae is based on features like external ornamentation, shell thickness, single layered etc.

On the other hand, though numerous species were erected for Late Cretaceous dinosaurian material from India (Matley 1923; Huene and Matley, 1933; Chakravarthy, 1933). Most of these were based on incomplete material for example isolated teeth, vertebrae, limb bone elements and in some rare cases cranial fragments. The taxonomic picture of species diversity for Indian Late Cretaceous sauropods is in a state of flux. Though, it is admittedly difficult to give a precise account of specific diversiy, it is estimated that about five or six species of sauropod taxa are known from the Lameta Formation belonging to the family Titanosauridae (Huene and Matley, 1933) which is listed below (modified after Huene and Matley, 1933; Berman and Jain, 1982; Buffetaut, 1987).

Titanosaurus indicus

Titanosaurus blanfordi

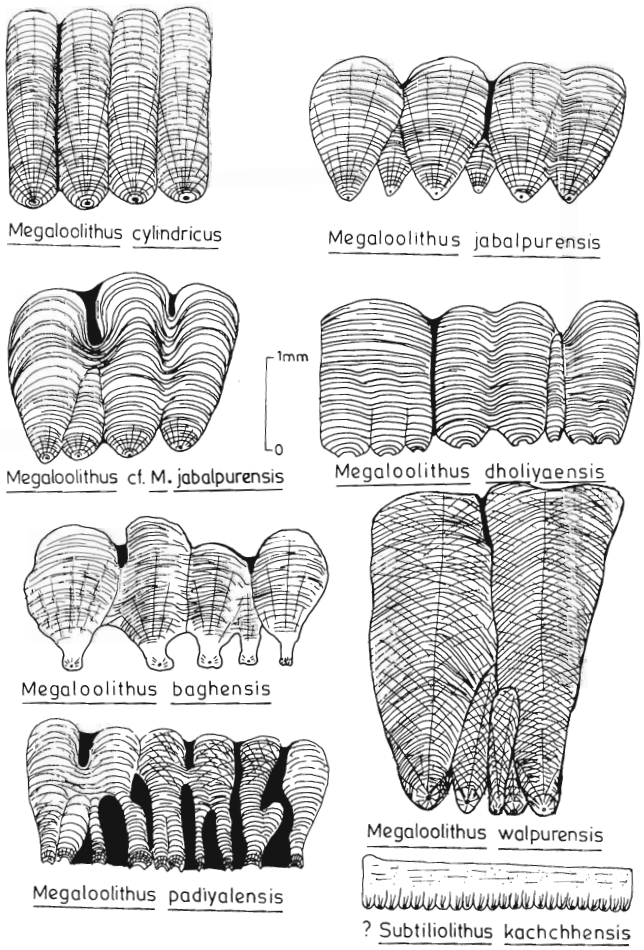

Fig 5. Schematic drawings of radial sections of Late Cretaceous dinosaurian eggshell morphotypes.

Titanosaurus sp.

Antarctosaurus septentrionalis

Laplatosaurus madgascarensis

At present, the assumed sauropod eggshell morphotype diversity is in general agreement with the specific diversity based on skeletal material. The presence of ornithischians is yet to be established in the Late Cretaceous Lameta Formation with certainity. The taxonomic assignment of the previous described ornithischian dinosaurs collected from Jabalpur like *Brachypodosaurus gravis* (Matley 1923); *Lametasaurus indicus* (Huene and Matley, 1933) and *Dravidosaurus blanfordi* from South India (Yadagiri and Ayyasami, 1979) is under controversy (Chakravarthy, 1935; Buffetaut, 1987).

The ornithoid-ratite eggshell morphotype is easily distinguishable but no distinction can be made at present, whether the parent was a small theropod dinosaur or a bird. In this paper seven new oospecies with tubospherulitic morphotype and one new oospecies with ornithoid-ratite morphotype have been recognized. Stylistic drawings (fig. 5) show their different structures. The scientific validity for the classificatory scheme presented here can be tested on the basis of present specimens and future work.

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EXPLANATION OF PLATES

Plate I

1-3. Radial views of *Megaloolithus cylindricus* n. oosp. PLM, Chui Hill (VPL/KH 201), Jabalpur; Dholiya (VPL/KH 101), District Dhar; Pat Baba Mandir (VPL/KH 212), Jabalpur, Madhya Pradesh; single spheroliths.

4. Radial view of *Megaloolithus cylindricus* n. oosp. SEM, Khempur (VPL/KH 151); several discrete spheroliths with circular to subcircular nodes on the outer surface.

5. Single basal cap of *Megaloolithus cylindricus* n. oosp. SEM, Pat Baba Mandir (VPL/KH 213) Jabalpur.

6. Tangential thin section of outer surface of *Megaloolithus cylindricus* n. oosp., PLM, Dholiya (VPL/KH 102) District Dhar, Madhya Pradesh.

7. Radial view of *Megaloolithus jabalpurensis* n. oosp., PLM, Dholiya (VPL/KH 351) District Dhar, Madhya Pradesh.

8. Radial view of *Megaloolithus mohabeyi* PLM, Dholiya (VPL/KH 233); District Dhar, Madhya Pradesh; highly arched growth lines with small pore canals. Bar length equals 500 µm for figures 1-4; 100 µm ffigure 5, 500 µm for figures 6-8. Abbreviations: Pc, pore canal (Figs. 4,6,7).

Plate II

1. Radial view of *Megaloolithus jabalpurensis* n. oosp., crossed nicols, Bara Simla Hill (VPL/KH 250), Jabalpur showing small and large fan shaped spheroliths.
2. Tangential thin section of outer surface of *Megaloolithus jabalpurensis*.
3. Inner surface of eggshell (*Megaloolithus jabalpurensis* n. oosp.), SEM, Bara Simla Hill (VPL/KH 252), Jabalpur showing tightly packed basal caps.
4. Radial view of *Megaloolithus jabalpurensis* n. oosp. PLM, Bagh Caves (VPL/KH 401), District Dhar, Madhya Pradesh showing micritization and silcritization of spherolith.

5-6. Radial view of *Megaloolithus baghensis* n. oosp., PLM, Bagh Caves (VPL/KH 551, 550 District Dhar). Discrete and a single spherolith showing moderately arched growth lines ending into prominent well-separated basal caps.

7-8. Outer surface of eggshell (*Megaloolithus baghensis* n. oosp.), SEM, Pisdura (VPL/KH 555, District Chandrapur, Maharashtra and Anjar (VPL/KH 560 District Kachchh, Gujarat). Discrete and fused nodes with subcircular to elliptical pores. Bar length equals 500 μm for figures 1,2; 4-8; 100 μm for figure 3. Abbreviations: P, pore; Si, silcritization; Mi, micritization

Plate III

1. Radial view of *Megaloolithus baghensis* n. oosp. PLM, Pisdura (VPL/KH 556) District Chandrapur, Maharasthra showing large and small fused spheroliths with moderately arched growth lines confluent to those of adjacent spherolith.
2. Radial view of *Megaloolithus dholiyaensis* n. oosp., PLM, Dholiya (VPL/KH 451) District Dhar, Madhya Pradesh showing fusion between spheroliths exhibiting shallow arched growth lines; fusion between 3 or 4 basal caps is also seen exhibiting ending into a single multinode.
3. Enlarged view of Figure 2 showing a part of fused spheroliths ending into a multinode with horizontal to subhorizontal growth lines.

4-5. Radial view of *Subtiliolithus kachchhensis* n. oosp., PLM, Anjar (VPL/KH 580) District Kachchh, Gujarat. Two layered eggshell showing well defined mammillary layer and faintly spongy layer. While figure 5 (VPL/KH 581) shows enlarged mammillary layer, PLM with small mammillary caps.

6. Inner surface of eggshell (*Subtiliolithus kachchhensis*), SEM, Anjar (VPL/KH 582), District Kachchh, Gujarat showing tightly packed mammillae. 7. Outer surface of eggshell (*Subtiliolithus kachchhensis*), SEM, Anjar (VPL/KH 583) District Kachchh, Gujarat showing irregularly spaced tubercles or nodes. Barlength equals 500 μm for figures 1-5,7; 100 μm for figure 6.

Abbreviations : Ml, mammillary layer; N, nodes or microtubercles

Plate IV

1,3,4 Radial views of *Megaloolithus walpurensis* n. oosp., PLM, Walpur (VPL/KH 570), District Jhabua, Madhya Pradesh. Extremely thick eggshells with large and small spheroliths. Small pore canals and spaces left in between the spheroliths are filled with sparry calcite.

2. Enlarged view of figure 1 showing semicircular basal cap with dense growth lines.
5. Radial view of *Megaloolithus padiyalensis* n. oosp., PLM, Padiyal (VPL/KH 590), District Dhar, Madhya Pradesh showing thin slender, fused spheroliths moderately arched growth lines and irregularly arranged numerous pore canals.
6. Radial view of *Megaloolithus padiyalensis* n. oosp., PLM, Padiyal (VPL/KH 591), District Dhar, Madhya Pradesh; note large and small fused spheroliths with irregularly arranged pore canals running throughout the thickness of the eggshell. Bar length equals 500 μm for all figures.

Abbreviations: Mk, basal knobs; Pc, pore canal; Sp, sparry calcite.

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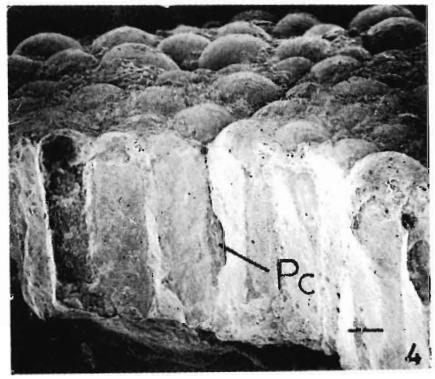

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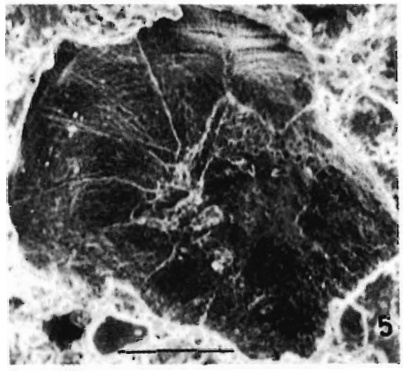

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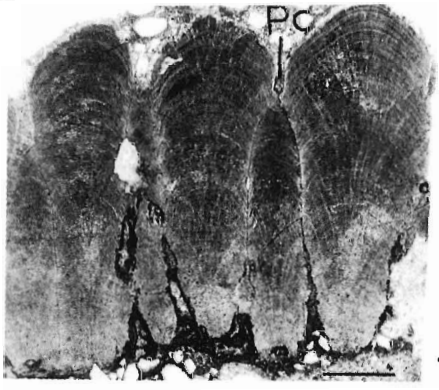

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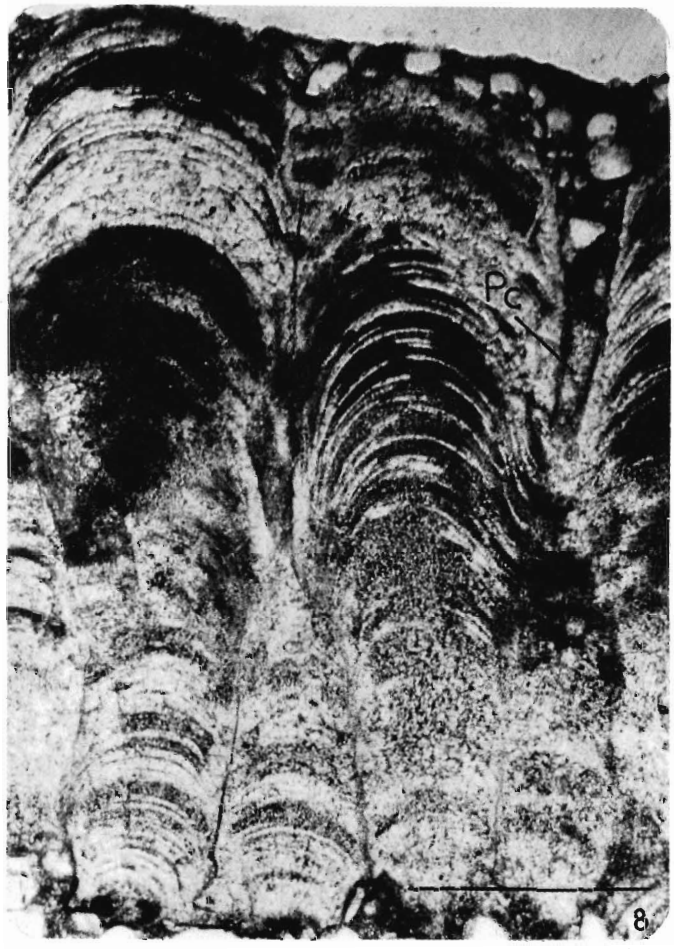

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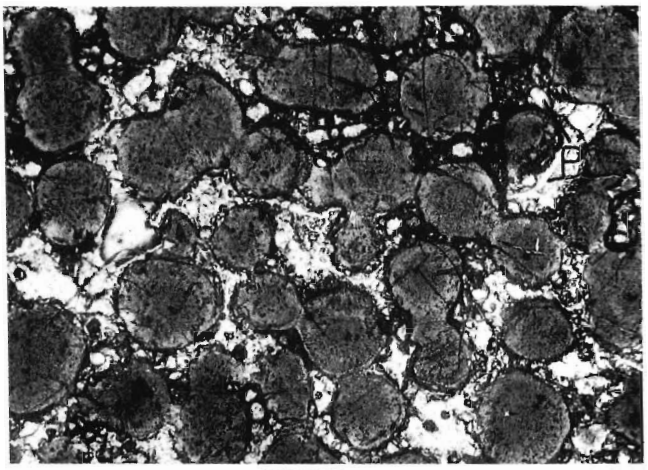

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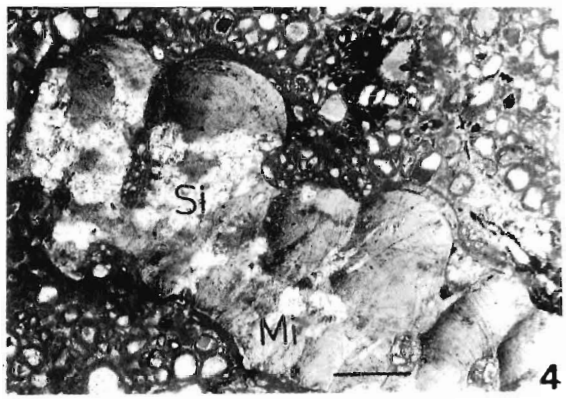

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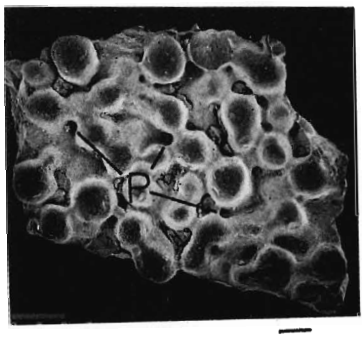

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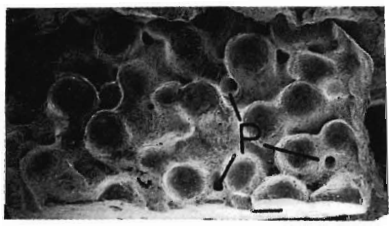

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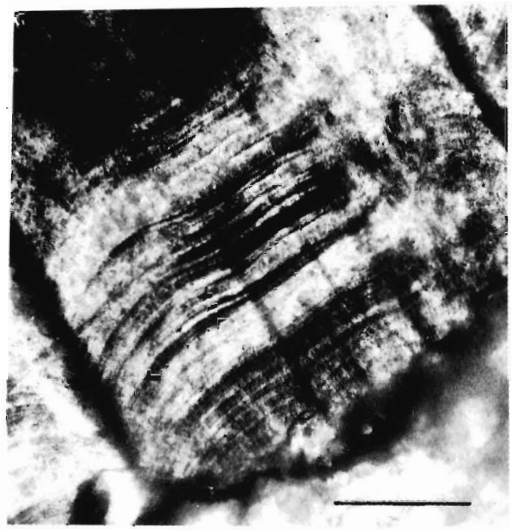

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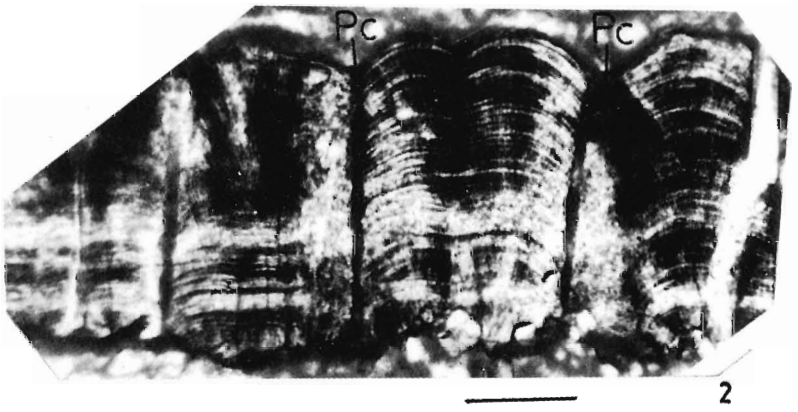

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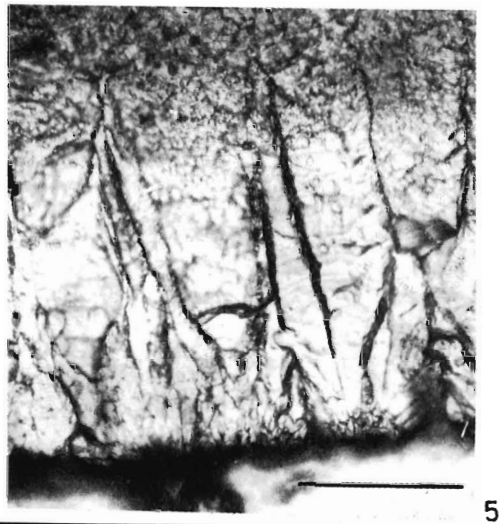

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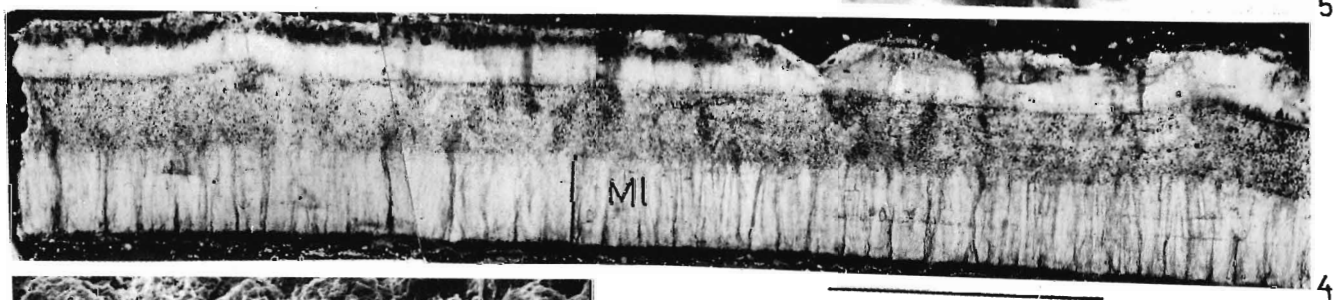

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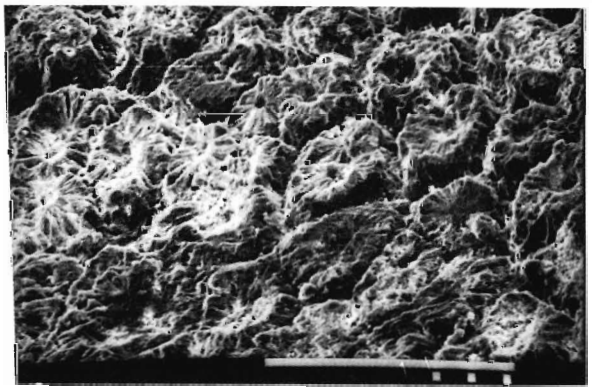

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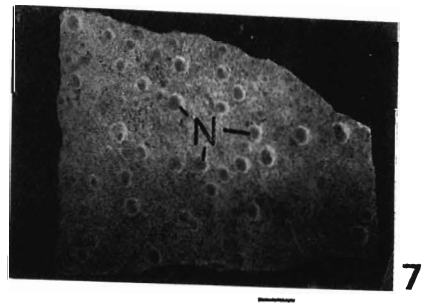

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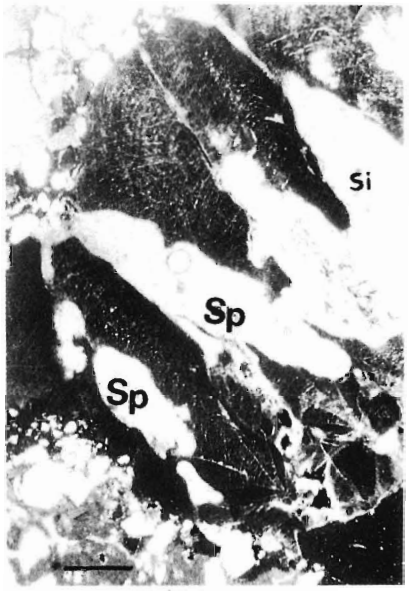

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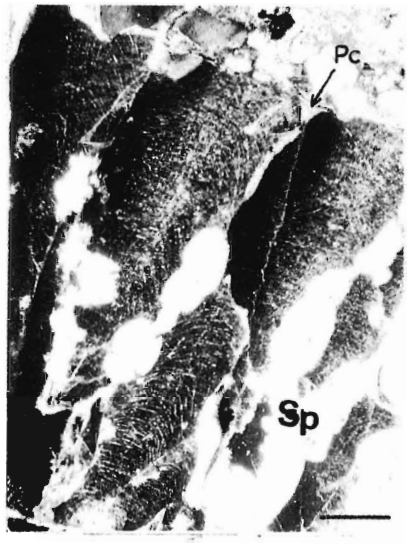

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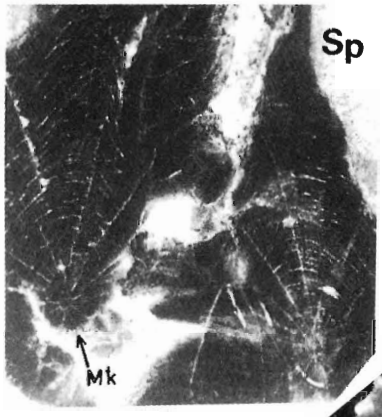

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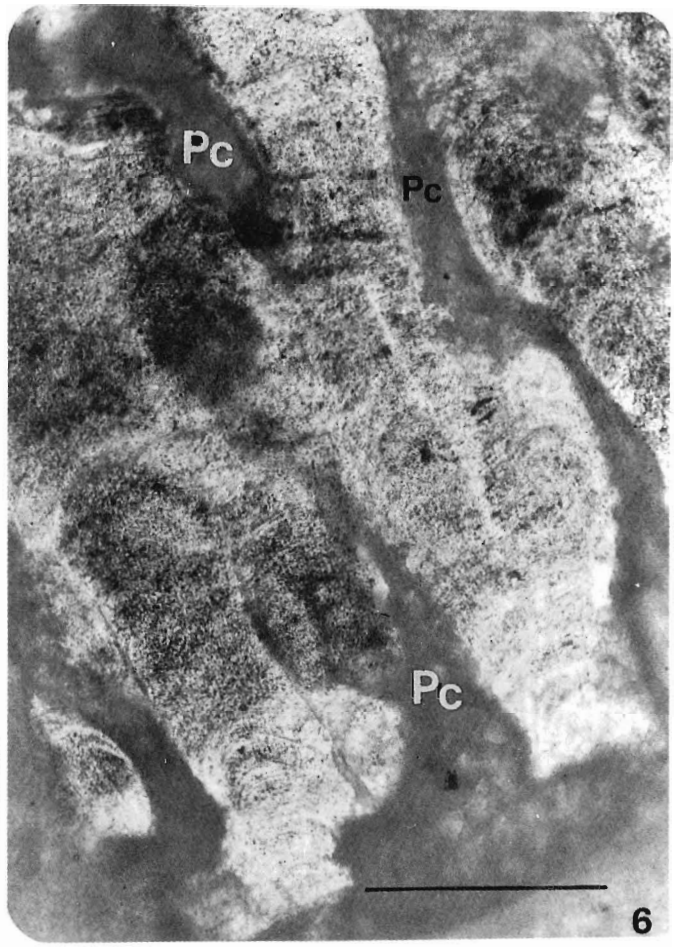

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KHOSLA AND SAHNI