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# BIOSTRATIGRAPHIC IMPLICATIONS OF THE DISCOVERY OF LATE BATHONIAN INDONESIAN AMMONITE *MACROCEPHALITES* CF. *MANTATARANUS* BOEHM [M] FROM THE CORE OF JARA DOME, KACHCHH, WESTERN INDIA

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## ABSTRACT

The age of the basal sediments at Jara (Kachchh, Western India) has been a matter of debate due to the absence of time diagnostic fossils (notably of ammonites and nannofossils). Previous nannofossil records from these basal beds indicate an Early Callovian age, whereas ammonite records (largely noted in passing), point to either a Latest Bathonian or an Earliest Callovian interval. Now, for the first time, from the core (basal marl and marlstone intercalations) of the Jara Dome, discovery of a typical Latest Bathonian Indonesian ammonite *Macrocephalites* cf. *mantataranus* Boehm [M] is recorded. A similar find is now also documented from coeval Latest Bathonian strata (the Sponge beds) of the Jumara Dome, ~12 km east of Jara. Previous nannofossil assemblage data from Jara is also critically reviewed with updated biochronology and it suggests that the nannofossils assemblage is not exclusively Early Callovian age, as has been suggested but is of late Middle Callovian age (late part of the Middle Callovian Tethyan Gracilis Zone). Additionally, based on morphological similarity, coeval stratigraphic distribution and statistical analyses, the present study reaffirms the close affinity of the Indonesian *M. mantataranus* Boehm [M] with the Kachchh Bathonian zonal index *Macrocephalites triangularis* Spath [M].

**Keywords**: Latest Bathonian, Kachchh, ammonite, nannofossil, western India

## INTRODUCTION

Jara is a domal outcrop with a 210 m thick succession exposed in the northwestern fringe of the Kachchh Mainland, western India (Fig. 1a; 23°43'00"N: 68°57'52"E to 23°45'00"N: 65°00'00"E) where the delineation of the Bathonian-Callovian boundary has remained elusive in spite of the fact that the basal sediments (ash gray marl-limestone alternations in the core of the dome) bear striking lithological resemblance with the adjacent well-dated Late Bathonian Sponge beds of the Patcham Formation exposed at the Jumara Dome (Callomon, 1993; Jain and Pandey, 2000) (Fig. 2). Jumara is barely ~12 km east of Jara (Fig. 1a). However, unlike at Jumara (Fig. 2), stratigraphically controlled ammonite records from the basal sediments at Jara have only been noted in passing (Cariou and Krishna, 1988; Bhaumik *et al*., 1993; Krishna and Ojha, 2000), resulting in conflicting ages that have ranged from Early Callovian to Late Bathonian (Prasad, 1998; Cariou and Krishna, 1988; Bhaumik *et al*., 1993). Even the nannofossil record has been equally ambiguous in age demarcation (Rai, 2003).

This paper reviews both ammonite and nannofossil records from the basal sediments of the Jara dome and, for the first time, records and illustrates a typical latest

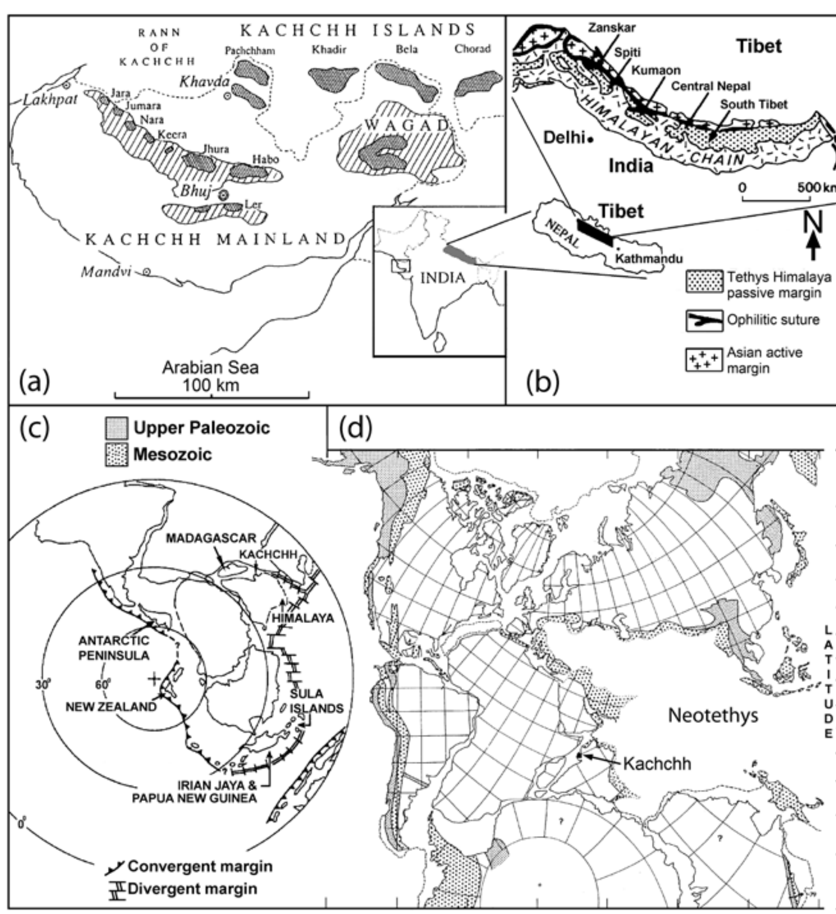



Fig. 1. Jurassic localities. (a): Kachchh Middle Jurassic localities of the Mainland and Island belt. (b): Jurassic localities of the High Himalayas. (c): Jurassic tectonic configuration of mentioned ammonite-bearing regions mentioned in the text. (d): Position of Kachchh in context of Neotethys.

Late Bathonian Indonesian ammonite *Macrocephalites* cf. *mantataranus* Boehm [M] from the basal ash gray marl-limestone alternations (2 m from the base) and conclusively dates the core sediments at Jara as Late Bathonian (Fig. 2c). Thus, this find of a typical Bathonian ammonite from the core of the Jara Dome, not only enables a wider stratigraphic correlation within the Kachchh Basin but also with Nepal and Indonesia (see Fig. 1).

## BIOSTRATIGRAPHY OF BASAL SEDIMENTS AT JARA

### The ammonite record

At Jara, in the basal beds, six units have been identified (A to D) (Prasad and Kanjilal, 1985). The lowest, Unit A, is a 30 m thick unit composed of "shales with hard, thin, calcareous and ferrugenous bands" of Early Callovian age (Prasad and Kanjilal, 1985). Later, the basal 15 m of this unit were placed in a new "Gypsiferous Shale Member" by Kanjilal and Prasad (1992) yielding macrocephalitids, reineckeiids and corals. From these basal sediments, Cariou and Krishna (1988) noted in passing the presence of *Bullatimorphites* (*Kheraiceras*) *cosmopolitum* and *Macrocephalites dimerus* along with loose fragments of typical Bathonian ammonite *Macrocephalites triangularis*. Based on this faunal association, they suggested the presence of Bathonian Patcham Formation at Jara. Later, from the same basal beds (the "cream colored limestone"; bed 1 of Bhaumik *et al*., 1993) *Macrocephalites formosus* was added to the faunal list (Bhaumik *et al*., 1993). Prasad (1998) in his biostratigraphic review of the Jara dome, assigned these basal beds to his Earliest Callovian "Madagascariensis Subzone", which formed the lower part of his larger Early Callovian "Formosus Assemblage Zone". *M. formosus* [M] has now been recorded from typical Late Bathonian sediments from the adjoining Jaisalmer Basin (Kuldhar Member) associated with *M. madagascariensis* [M], *M. lamellosus* [m] along with the typical Bathonian association of *Sivajiceras congener* [M] and *Macrocephalites triangularis* [M] (Jain 2007, 2008, 2012, 2013, 2014). In Kachchh, *M. formosus* has a long range (Prasad, 1988; Jain and Pandey, 2000; Jain, 2012).

Hence, so far, at Jara, the ammonite records are inconclusive in their age assignment, only suggesting that the basal sediments straddle the Bathonian-Callovian boundary.

### The nannofossil record

Recently, based on nannofossil data, collected from a single sample of "hard calcareous shale" from the "basal part of the Jara Dome", Rai (2003) correlated the assemblage with the

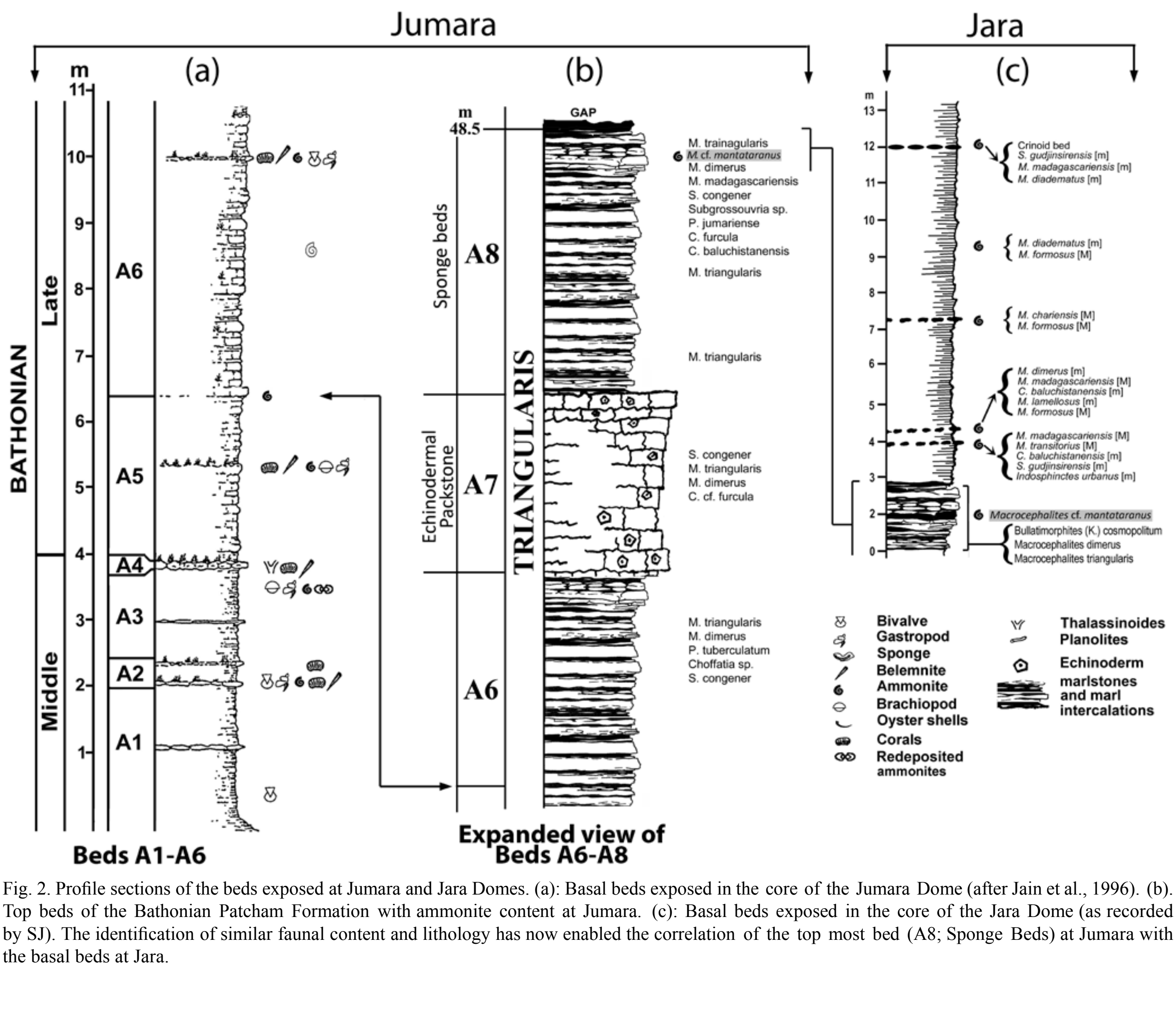


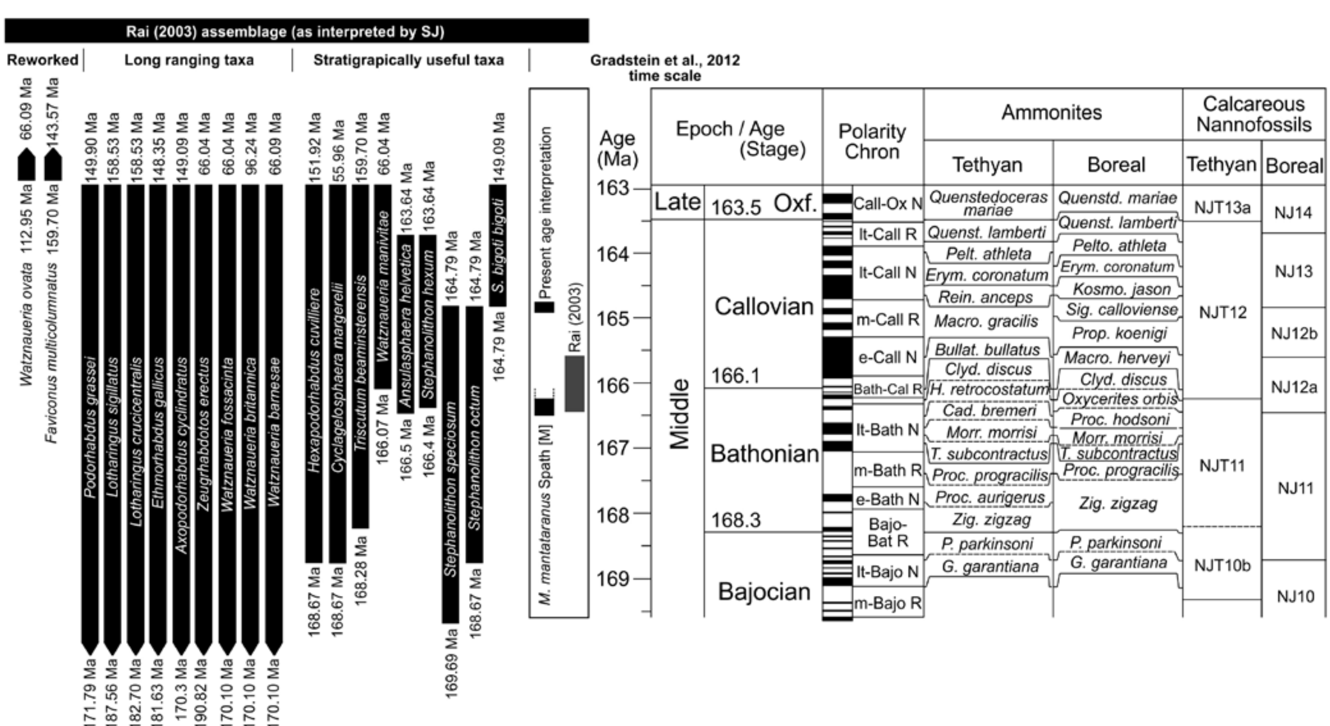

Fig. 2. Profile sections of the beds exposed at Jumara and Jara Domes. (a): Basal beds exposed in the core of the Jumara Dome (after Jain et al., 1996). (b). Top beds of the Bathonian Patcham Formation with ammonite content at Jumara. (c): Basal beds exposed in the core of the Jara Dome (as recorded by SJ). The identification of similar faunal content and lithology has now enabled the correlation of the top most bed (A8; Sponge Beds) at Jumara with the basal beds at Jara.

Nannofossil Zone NJ12 (Table 1) but dated the sample as latest Early Callovian. Curiously, however, Rai (2003, p. 283) noted that the nannofossil assemblage also extends down into the Late Bathonian Tethyan Retrocostatum Zone (= Subboreal Orbis Zone, see also Mangold and Rioult, 1997; Gradstein *et al*., 2012; Nannofossil Zone NJ12a) (Table 1). Strictly speaking, the Nannofossil Zone NJ12 is split into two (Table 1), the lower (NJ12a) spans from the early Late Bathonian Retrocostatum Zone to the bottom of the Earliest Callovian Bullatus Zone and the upper (NJ12b) up to the top of the Gracilis Zone (latest Middle Callovian; Table 1). Besides this age discrepancy, there are other intriguing aspects of this unique nannofossil assemblage from Jara as recorded by Rai (2003) (see also Table 1). These are:

a. The occurrence of *Stephanolithion bigotti bigotti* with *Stephanolithion speciosum speciosum* has not yet been recorded from the same horizon (De Kaenel, *et al*., 1996; Gradstein, *et al*., 2012; Bown and Cooper, 1998 in Bown, 1998) and globally, the last occurrence (LO) of *S. speciosum speciosum* is below the first occurrence (FO) of *S. bigotti bigotti* (De Kaenel, *et al*., 1996; Bown and Cooper, 1998 in Bown, 1998; see also Jain, 2008). *S. bigotti bigotti* and *S. speciosum* only occur together in the earliest part of the NJ13 Zone (= the latest Middle Callovian Calloviense Zone; Table 1; see Ogg and Hinnov in Gradstein *et al*., 2012). *S. bigotti bigotti* is a very long ranging form, spanning from the base of NJ13 to the top of NJ17a (Middle Tithonian; Gradstein, *et al*., 2012).
b. The presence of *Faviconus multicolumnatus* (159.70 to 143.57 Ma) and *Watznaueria ovata* (112.95 to 66.09 Ma) have their first appearance in Middle Oxfordian and Early Cretaceous, respectively. Thus, it appears that the assemblage recorded by Rai (2003) is reworked. Reworking has been previously noted at Jara at these basal levels (Rai, 2006; Rai and Jain, 2012, 2013).
c. *Stephanolithion hexum*, another co-occurring species, is also a long ranging taxon with diachronous last (LO) and first occurrences (FO) (see Rai and Jain, 2013). Its FO spans from the Retrocostatum to the Discus Zones (Bown and Cooper, 1998; see also Rai and Jain, 2013) and its LO has been reported both from latest Early Callovian (end of the Gracilis Zone) to the Latest Callovian Lamberti Zone (Table 1) (De Kaenel *et al*., 1996; Gradstein *et al*., 2012; see also Jain, 2008; Rai and Jain, 2013).
d. *Ansulasphaera helvetica* makes its FO in the early Late Bathonian Retrocostatum Zone and its LO in the mid-Late Callovian Lamberti Zone (Table 1; see also Jain, 2008).
e. Interestingly, the "hard calcareous shale" (2.8 m above the base of the core sediments; Fig. 2) from where the nannofossil assemblage came (Rai, 2003), overlies the white to ash gray marlstones and marl intercalations from where the Jara ammonite was recorded (2 m above the base of the core sediments; Fig. 2).
f. Hence, it is perilous to assign an age to all of a unit when only part of it has been investigated (Rai, 2003). This has previously led to erroneous age demarcation in the adjoining Jaisalmer Basin, also (Rai and Garg, 2007; see also Jain, 2008, 2012).

Thus, the nannofossil assemblage from the basal sediments at Jara suggests that the strata most likely straddles the NJ12b-NJ13 boundary (late part of the Middle Callovian Tethyan Gracilis Zone; see Table 1), but certainly is not exclusively Early Callovian as suggested (Rai, 2003). Also, note that the Early Callovian age for the common presence of *Ansulasphaera helvetica* in the adjoining Jaisalmer Basin (Kuldhar section) (Rai and Garg, 2007), is now conclusively

**Table 1. Correlation between Bathonian-Callovian ammonite and nannofossil zonation and the distribution of nannofossil assemblage from Jara of Rai (2003). Interpretation by SJ and time scale after Gradstein *et al*. (2012).**



dated as Latest Bathonian, based on the co-occurrence of typical Late Bathonian ammonites (Jain, 2007, 2008. 2012) (for nannofossil age discussion see also de Kaenel *et al*., 1996).

In this context, interestingly, at Kuldhar (in beds K1-K4 of Kalia and Roy, 1989; = beds 1-4 of Jain, 2007, 2008, 2012; beds not studied by Rai and Garg, 2007), the Early Callovian marker species *Stephanolithion bigotti* is absent. This can be expected, as these basal beds (beds 1-4 of Jain, 2007) have yielded the typical Bathonian association of *Sivajiceras congener* [M] and *Macrocephalites triangularis* [M] (Jain, 2007, 2012). Additionally, *Hexapodorhabdus cuvillieri*, whose FO straddles the Middle to Late Bathonian boundary, marks its occurrence in bed K3 (bed 4 of Jain 2007), below the Bathonian-Callovian boundary which is drawn between beds 4 and 5 (Jain, 2007). The Kuldhar section example illustrates excellent correspondence between a well-constrained ammonite record (Jain, 2007, 2012) and a better interpreted nannofossil data (Jain, 2008), though not noted for the Jara record (Rai, 2003).

Additionally, based on recent species data (Bown, 1998), there appears to be continuous variation in the length of the rim spines and so the subspecies *Stephanolithion speciosum octum* (distinguished by longer rim spines) is considered a variant of *S. speciosum* here. Similarly *Stephanolithion bigotii* subspecies *bigotii* (with six, sometimes 7-8 long rim spines and a central area spanned by diagonal cross bars) is considered under *S. bigotii*. *Calolithus martalae* is synonymised under *Watznaueria fossacincta* (Black, 1971) (Bown, 1998).

In conclusion, collection of more stratigraphically controlled nannofossil data or discoveries of more age diagnostic taxa is needed which will produce a more precise biochronostratigraphic control for these important basal sediments at Jara. But, as a cautionary note, it must also be emphasized here that globally during the Jurassic, and more so for the Bathonian-Callovian boundary interval, most nannofossil occurrences (FO and LO) are diachronous (see De Kaenel *et al*., 1996; Rai and Jain 2013).

## DISCUSSION

This find of a typical Late Bathonian Indonesian *Macrocephalites mantataranus* Boehm [M] suggests the presence of definite Bathonian sediments at the core of the Jara Dome. Lithologically, also, the basal sediments at Jara (white to ash gray marlstones and marl intercalation = fine grained carbonates) are similar to the topmost unit of the Bathonian Patcham Formation, bed A8, 18 m thick, of Jain and Pandey (2000) in the nearby Jumara Dome (Fig. 3). These marker carbonates are pervasive across the basin (Fürsich *et al*., 2001) yielding typical Late Bathonian taxa (Callomon, 1993; Krishna and Ojha, 2000; Jain and Pandey, 2000). It is hard to imagine that an 18 m thick unit (bed A8), so well exposed at Jumara, would be completely missing at Jara, where vast lateral extensions of beds within the basin are frequent, enabling their identification as marker beds (Fürsich *et al*., 2001).

However, in spite of the uniformity of lithology and moderate faunal similarity at coeval stratigraphic levels at Jara and Jumara, the latter exhibits a somewhat different and more diverse fauna, including abundant sponges (Mehl and Fürsich, 1997), not yet recorded from Jara. Another interesting fact between the two outcrops is the distribution of the macrocephalitid fauna (Fig. 4). Fauna from both domes demonstrate that although the zonal indices such as *M. triangularis*, *M. madagascariensis*, etc. are generally recorded across the domes (and within the basin), their dominance, however, varies considerably from dome to dome, even if the domal outcrops are in such close proximity (Fig. 4). This lateral faunal variation has often led to the erection of varied faunal zones/subzones even within the same lithological unit occurring at coeval stratigraphic levels (Prasad, 1988; Callomon, 1993; Krishna and Ojha, 1996, 2000; Jain and Pandey, 2000).

Hence, identification of assemblages and integration with other faunal elements (e.g. nannofossils, as done here) along with lithological correlation will not only enable better local and regional correlation, but is also required for precise biostratigraphic interpretation.

## SYSTEMATIC PALAEONTOLOGY

*Genus* ***Macrocephalites*** Zittel, 1884

(Type species: *Macrocephalites macrocephalus* Schlotheim, 1813)

*Macrocephalites* cf. *mantataranus* Boehm, 1912 [M]

(Pl. I, fig. a-d; Pl. II, figs. a-c, Figs. 5-8, Tables 2-3)

*Macrocephalites mantataranus* Boehm [M] - Westermann and Callomon, 1988, p. 59, pl. 10, figs. 1-5, text-figs. 11, 18. - Cariou and Enay, 1999, p. 710, figs. 6.5-7, 7.1. - Roy *et al*., 2007, p. 640, figs. 8.10-8.13.

*Macrocephalites triangularis* Spath [M] – Jain, 1996, pl. 9, figs. 1a-c. (for detailed synonymy on *M. mantataranus* Boehm [M], see Westermann and Callomon, 1988, p. 59).

*Material*: 2 specimens. One fully septate specimen from Jara (see Plate I; BGD collection; repository at the Paleontology

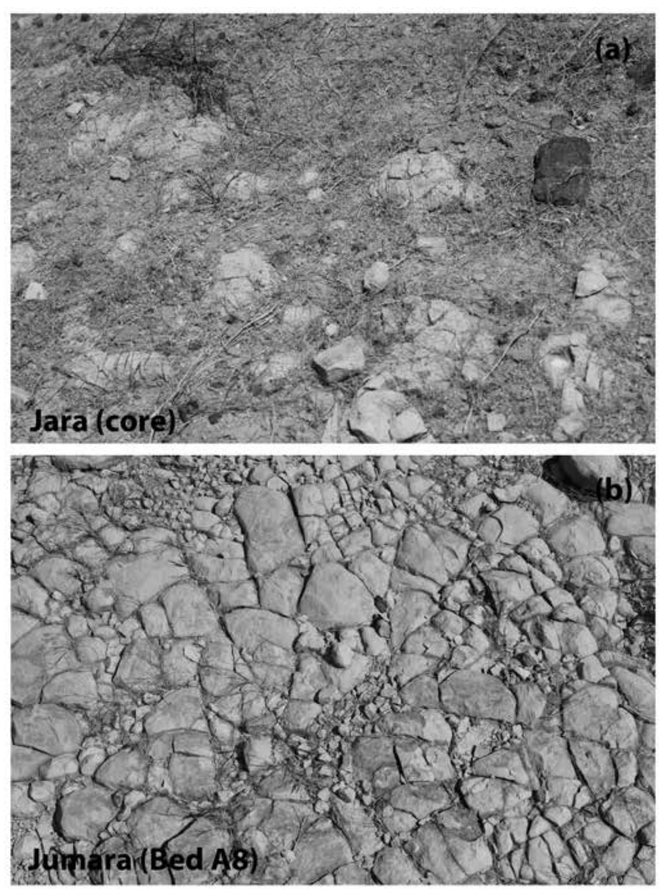



Fig. 3. Bathonian exposures at Jara (a) and Jumara (b) (after SJ). Note the characteristic nodular nature of carbonate rocks, being well exposed at Jumara (Sponge Beds; bed A8).

Research Laboratory, School of Petroleum Technology, Pt. Deendayal Petroleum University, Gujarat, India). One fully septate specimen from Jumara (see Pl. II; Figs. a-c; SJ collection; part of Jain, 1996 dissertation, repository at the Department of Geology, University of Rajasthan, Jaipur, India).

*Horizons*: Jara: From the basal marlstone, 2 m from the base in the core (Specimen no. BGD/JA/05/04). Jumara: From the top most unit of Bed A8 (Sponge Bed) at Jumara Dome (Specimen no. Ju/22/8c; part of Jain, 1996 dissertation)

*Dimensions*: see Appendix 1

*Description of phragmocone*: Shell is small, moderately involute and compressed. The Jara specimen is septate at 94 mm (Pl. I), whereas the Jumara specimen shows suture line even at 110 mm shell diameter (Pl. II, figs. a-c). Ornamentation is fine and dense. Sharp primaries arise from the upper half of the vertical umbilical wall, thence, they are slightly concave (rursiradiate) at the inner flank and form an adapical arch at the umbilical region. They bifurcate at mid-flank into two to three rectiradiate secondaries with a single intercalatory. The secondaries are strong and sharp and cross the venter straight. Flanks converge gently towards a rounded venter at the phragmocone stage into a somewhat broadly rounded venter at the body chamber. Maximum inflation of the shell is near the umbilical margin. Umbilical wall is vertical and is delimited by a sharp umbilical margin. Smoothening of the umbilical region begins at ~70 mm of shell diameter. By ~90 mm, the last few sutures are closer together than the previous ones accompanied by slight uncoiling of the umbilical seam indicating that the Jara specimen is an adult. Whorl section is variable ranging from subquadratic to broadly arched to subtriangular (somewhat tapering at the venter) at the end of the phragmocone or beginning of the body chamber (Fig. 5). Suture line is frilled with characteristic retracted lobes (Fig. 6; Jara specimen). Assuming that most macrocephalitids have ¾ whorl as body chamber (Westermann and Callomon 1988), the maximum reconstructed shell diameter for the Jara specimen is estimated to be between 150-160 mm and for the Jumara specimen, 180-190 mm.

*Remarks*: The retracted lobes of the suture line and presence of sharp umbilical edge distinguishes the present specimens from any of the illustrated Kachchh forms described so far. Interestingly, both retracted lobes of the suture line and presence of sharp umbilical edge are unique to Indonesian macrocephalitids (Westermann and Callomon 1988). Additionally, the present specimens with their umbilical smoothening, dimensional proportions (U/D and T/H ratios) and suture line match well the Late Bathonian Indonesian *Macrocephalites mantataranus* Boehm [M] (Westermann and Callomon 1988, pl. 10, fig. 2a-b) recorded from Assemblage XII of New Guinea and assigned to the Late Bathonian *M. apertus-mantataranus* Assemblage Zone (Sukamto and Westermann 1996; Westermann and Callomon, 1988) (Fig. 4).

The Jara specimen strongly resembles specimens from Central Nepal (Cariou and Enay, 1999, p. 21, Fig. 6.5a-b; sp. no. Dd28) recorded from their Q2 unit (bed 10). This Nepalese specimen also came from the Latest Bathonian Apertus Zone (Cariou and Enay, 1999). A comparison between the present specimens and *M. mantataranus* Boehm [M] (data from Thierry, 1978; Westermann and Callomon, 1988; Cariou and Enay, 1999; Roy et al.,2007), places the present specimens well within the range of *M. mantataranus* Boehm [M]. Roy *et al.*'s Jumara specimen matches well with the present specimens in whorl thickness, morphological characters and in its pattern of ribbing, though, the Jara specimen is much more evolute at comparable diameters (Fig. 7a).

Among the Kachchh macrocephalitins, the present specimens, in their compressed and fine ribbed pattern, closely resemble the endemic Bathonian *Macrocephalites triangularis* Spath [M]. However, *M. triangularis* is a large involute compressed macroconchiate form (Pl. II, figs. d-f) with denser and sharper ribbing, a typical triangular whorl section throughout shell growth and strongly converging flanks, besides lacking the characteristic sharp umbilical edge, and the retracted nature of the suture line. However, macroconch growth curves

**Table 2. Result of the Analysis of Variance (ANOVA) between *Macrocephalites mantataranus* Boehm [M] and *M. triangularis* Spath [M]. Df: Degrees of freedom; P: Probability value (Interpretation by SJ).**

| Source | Sum-of-Squares | Df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| Coiling ratio (U/D) | 0.007 | 1 | 0.007 | 4.394 | 0.039 |
| Error | 0.113 | 76 | 0.001 | | |
| Whorl thickness (T/H) | 0.038 | 1 | 0.038 | 2.289 | 0.134 |
| Error | 1.266 | 76 | 0.017 | | |

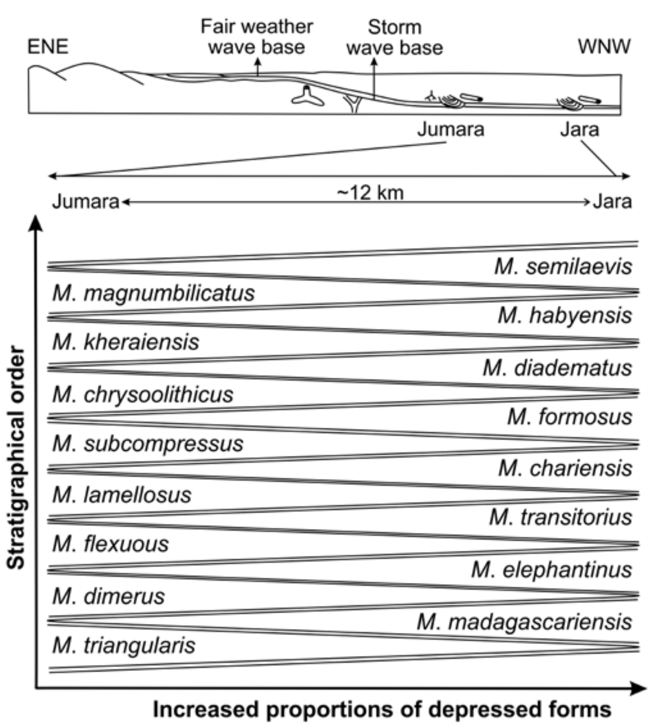



Fig. 4. Lateral distribution of the macrocephalitid fauna between Jumara and Jara Domes (after SJ). Note that the species abundance varies considerably between the two domal outcrops. For example, the presence of Late Bathonian *Macrocephalites triangularis* Spath is considerably more at Jumara than at Jara. All species arranged vertically occur stratigraphically also, i.e. from bottom to top, Bathonian to Early Callovian. *M. dimerus* and *M. madagascariensis* make their first appearance within the Late Bathonian sediments of Jumara and then commonly occur in earliest Callovian sediments (see Jain, 1996; Jain and Pandey, 2000). Except *M. flexuous*, *M. chariensis*, *M. subcompressus*, *M. kheraiensis* and *M. habyensis*, all other species form nominal zones or subzones in Kachchh (see Jain and Pandey, 2000).

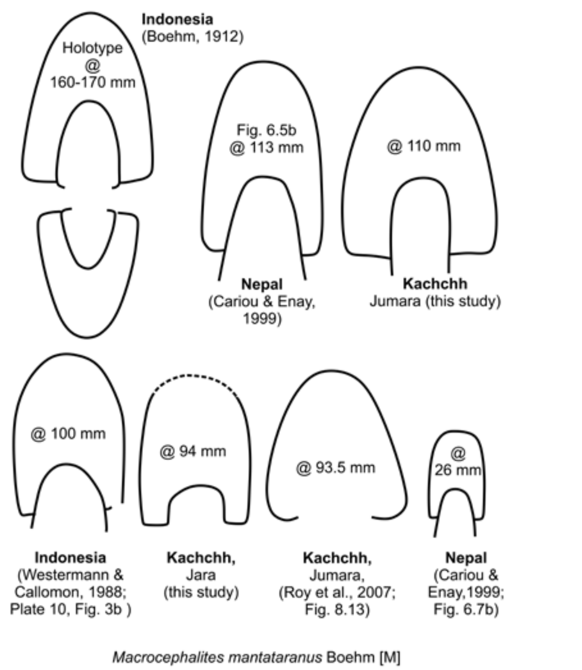



Fig. 5. Whorl sections of *Macrocephalites mantataranus* Boehm [M]. Note the large variability in whorl sections ranging from subquadratic to subtriangular (image after SJ).


Fig. 6. The suture line of *Macrocephalites* cf. *mantataranus* Boehm [M] from Jara. Bar represents 1 cm (image after BGD).

and single plots for relative umbilical diameter (coiling ratio; U/D) versus whorl thickness (T/H) of *M. mantataranus* and *M. triangularis* indicate overlapping ranges, with *M. triangularis* having a more restricted range, being more compressed and involute (Fig. 8). A simple regression plot between coiling ratio versus whorl thickness for these two species also yields different slopes (*M. mantataranus*: $y = 1.3434x + 0.6154$; $R^2 = 0.3106$ and *M. triangularis*: $y = 1.0228x + 0.6363$; $R^2 = 0.0738$). The analysis of variance (ANOVA) on the same dataset (N = 76) yielded significant values for coiling ratio ($p<0.05$) but not for whorl thickness, indicating significantly differing patterns of coiling for these two species (Table 2).

Thus, based on closely similar adult morphological characters and coeval stratigraphic occurrence, the closeness of *M. triangularis* with *M. mantataranus* is reaffirmed (Westermann and Callomon 1988) (Fig. 8). But, more stratigraphically controlled finds are needed to confirm the suggestion that *M. triangularis* evolved from *M. mantataranus* (Krishna and Cariou, 1993; Roy *et al*., 2007). The latter suggestion is rejected for now.

The present specimens in their compressed nature and smoothening of the umbilical region compare well with the latest Early Callovian *Macrocephalites semilaevis* (Waagen) [M]. However, besides being much more densely ribbed, *M. semilaevis* has fine rectiradiate primaries that divide much higher in the flank. Additionally, the whorl section of *M. semilaevis* is acutely rounded instead of the subquadratic to broadly rounded in the present specimens.

The present specimen in its compressed nature closely resembles Latest Bathonian-earliest Middle Callovian *Macrocephalites subcompressus* Waagen [m] (see Jain and Pandey, 2000; Jain, 2014). However, *M. subcompressus* has a more tabulate morphology, crested prorsiradiate ribbing pattern with a pronounced forward ventral sulcus.

*Remarks on Age*: In Indonesia, the Late Bathonian *M. apertus-mantataranus* Association has yielded *M. mantataranus* [M], *M.* cf. *madagascariensis* [M], *Oxycerites* cf. *sulaensis* [M] and *Oxycerites* (*Alcidellus*) gr. *tenuistriatus* [M] along with the Andean species of *Xenocephalites* cf. *neuquensis* (Westermann and Callomon, 1988). *O.* (*A.*) *tenuistriatus* is very widely distributed in the European Late Bathonian, and has recently been recorded in Spain (Sandoval, 1983), Mexico (Sandoval *et al*., 1990) and in the Andean region (from Late Bathonian sediments of Chacay Melehué, Argentina; Parent, 1998). Thus, based on the common presence of *O.* (*A.*) *tenuistriatus* and *X. neuquensis* from Late Bathonian European and Andean sediments, the *M. mantataranus* containing *M. apertus-mantataranus* Association was comfortably dated as Late Bathonian (Westermann and Callomon, 1988).

Closer home, in Central Nepal, *M. mantataranus* [M] occurs in association with *M. apertus*, *M. bifurcatus* [M], *M. intermedius* [M], *Homoeoplanulites* (*Parachoffatia*) aff. *evoluta* [M] and *Oxycerites sulaensis* [M] assigned to Latest Bathonian age and correlated with the Indonesian Apertus Zone (Cariou and Enay, 1999). Interestingly, the overlying bed (bed 11 of unit Q2) has yielded Bathonian *M. triangularis* in association with *M. chrysoolithicus*, *Choffatia* cf. *madani* and *Oxycerites sulaensis*, but was placed in an age bracket between Late Bathonian and Early Callovian (Cariou and Enay, 1999). However, based on the widespread and exclusive occurrence of *M. triangularis* [of both M and m] within Bathonian sediments (Westermann and Callomon, 1988; Callomon, 1993; Jain and Pandey, 2000; Krishna and Ojha, 2000; Jain, 2007, 2008, 2012, 2013, 2014), a Late Bathonian age for bed 11 of unit Q2 is a most likely possibility.

## CONCLUSIONS

Based on the record of *M. mantataranus*, and the common association of Late Bathonian fauna and similar lithology of beds at Jara and Jumara, the core of the Jara Dome is

### EXPLANATION OF PLATE I

***Macrocephalites*** cf. ***mantataranus*** Boehm [M], fully septate specimen from the basal marlstone, 2 m from the base in the core of the Jara Dome, BGD collection, sp. no. BGD/YSP/JA/05/04. (a): Lateral view. (b): Opposite lateral view. (c): Ventral view. (d): Apertural view. Bar measures 1 cm.

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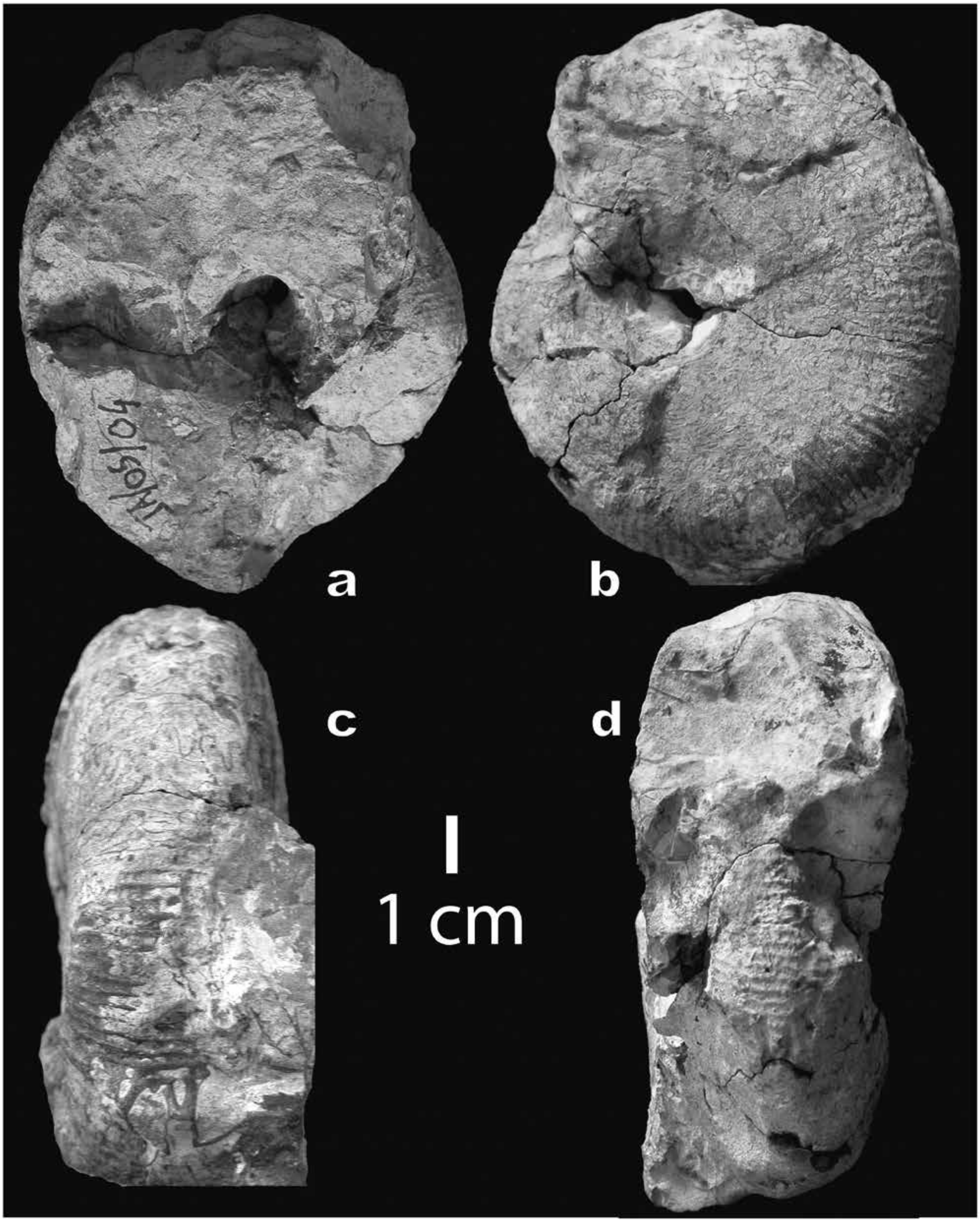
**Plate I**



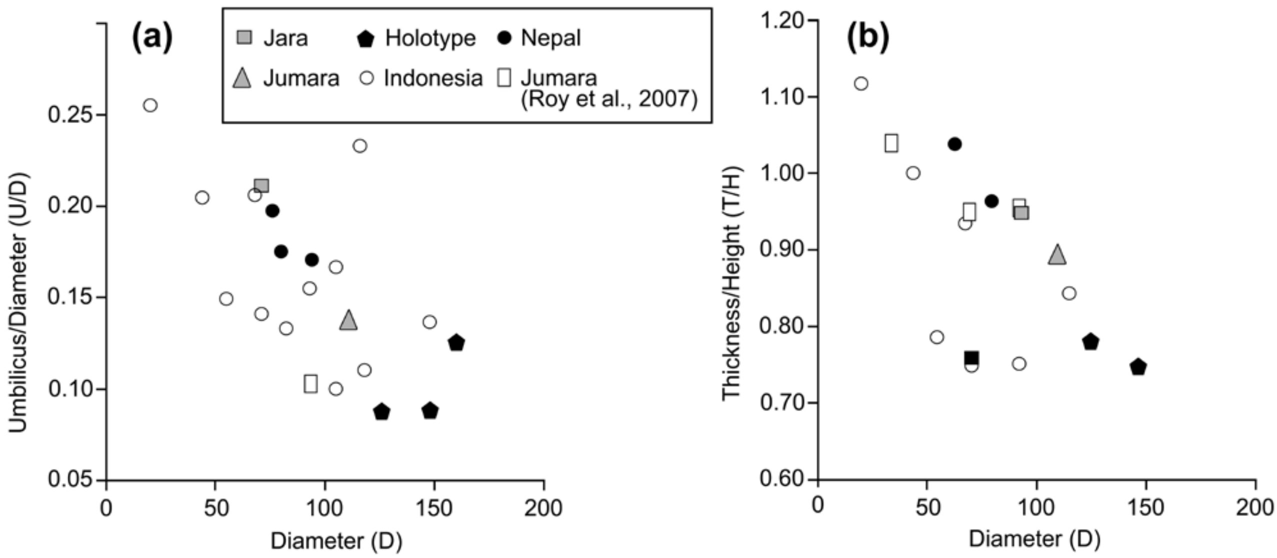



Fig. 7. Macroconch growth curves of *Macrocephalites mantataranus* Boehm [M]. (a): coiling ratio (relative umbilical diameter versus diameter) and (b): whorl section (relative whorl thickness versus diameter).

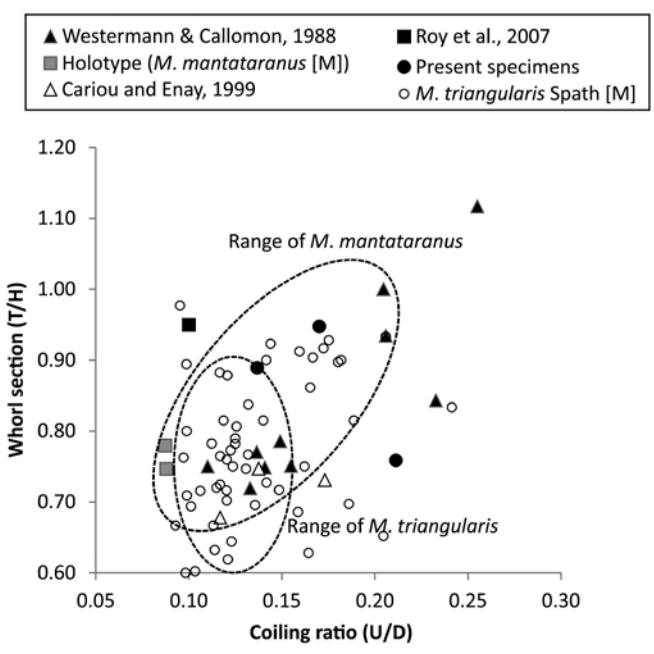



Fig. 8. Macroconch growth curves and single plots for relative umbilical diameter (coiling) versus whorl section of *Macrocephalites mantataranus* Boehm and *M. triangularis* Spath. The *M. triangularis* data are after several authors (Spath, 1927-33; Cariou and Enay, 1999; Roy et al., 2007; Singh et al., 1979; Pandey, 1982; Ojha, 1995; Jain, 1996; Datta et al., 1996). Note the overlapping range of *M. mantataranus* and *M. triangularis* and the restricted range of the latter, being more compressed and involute (after SJ).

assigned a definite Late Bathonian age. Contextually, based on similar and well documented lateral extensions of beds within the Kachchh Basin, we suggest that the 18 m thick bed (Sponge Beds = the ash gray marl-limestone alternations) exposed at Jumara would continue to be present westwards at Jara (the basal 2 meters of the core section), which is barely 12 km west. Additionally, the find of a typical Late Bathonian ammonite from the core of the Jara Dome, also enables to suggest a wider stratigraphic correlation within the Kachchh Basin and faunastically with the outcrops of Nepal and Indonesia. Review of recorded nannofossil assemblage data based on new literature also suggests that the nannofossil assemblage is not exclusively Early Callovian but that the basal beds at Jara actually belong to a late Middle Callovian age (late part of the Middle Callovian Tethyan Gracilis Zone). Presence of reworking is noted.

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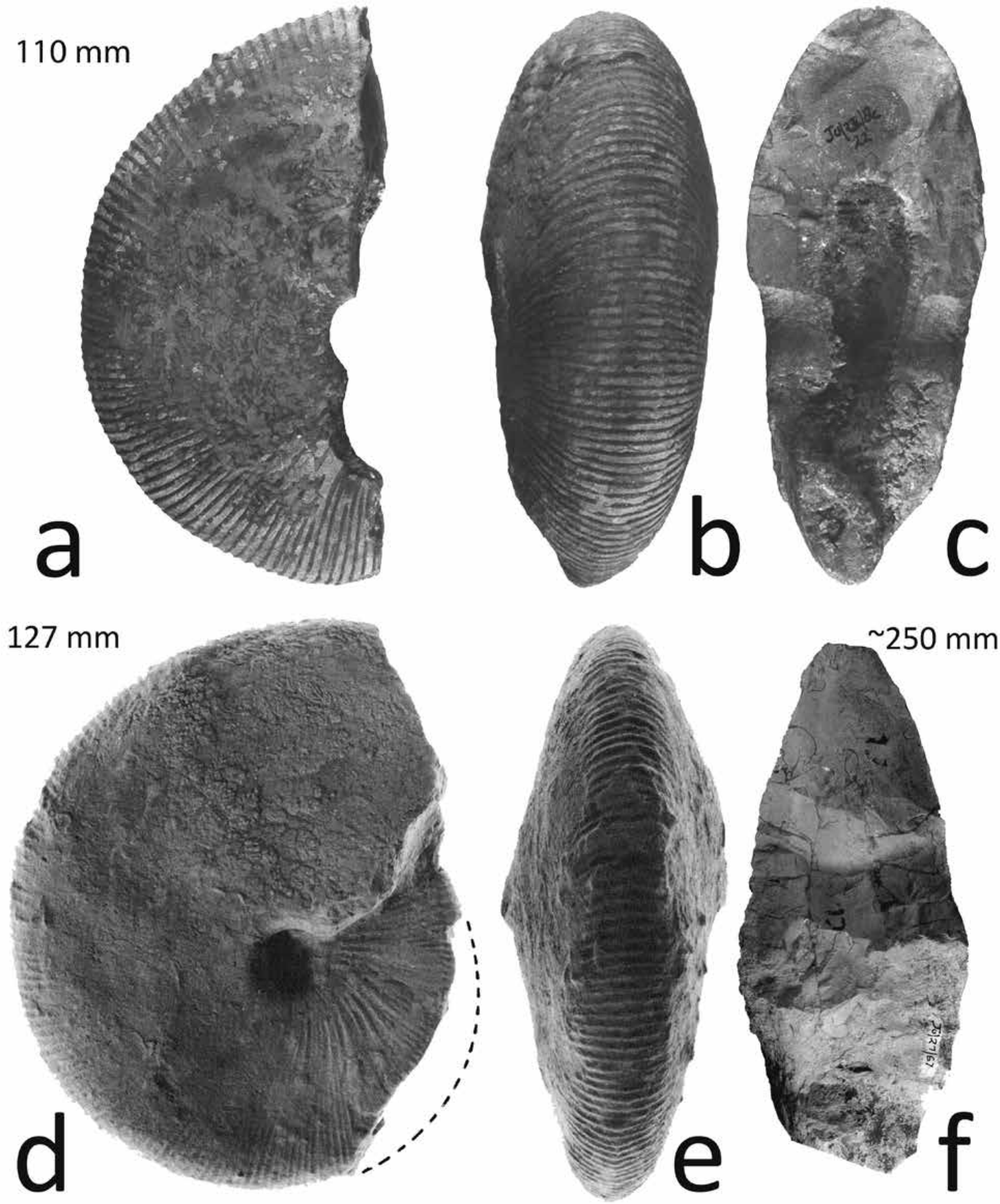
## EXPLANATION OF PLATE II

(a-c): ***Macrocephalites*** cf. ***mantataranus*** Boehm [M], fully septate specimen from bed A8 (Sponge Beds) at Jumara (Jain, 1996; SJ thesis collection). (d-f): ***Macrocephalites triangularis*** Spath [M]. (d-e): Plaster cast of the Holotype of ***M. triangularis*** Spath [M] (from Krishna and Westermann, 1987; BMNH C224o2). (f): A fully septate fragment of ***M. triangularis*** Spath [M] from an early Middle Bathonian bed A4 at Jumara (see Fig. 2a for bed occurrence; see also Jain, 2013).

**Plate II**



**Appendix 1 Measurements of *Macrocephalites mantataranus* Boehm [M] and the Holotype of *M. triangularis* Spath [M] (as discussed in the text).**

| Species name | Locality | Specimen no. | Measured at | D | H | T | U | U/D | T/H |
|---|---|---|---|---|---|---|---|---|---|
| *M.* cf. *mantantaranus* Boehm [M] | Jara (this study) | BGD/YSP/ JA/05/04 | at | 71 | 29 | 22 | 15 | 0.21 | 0.76 |
| | | | at | 94 | 38 | 36 | 16 | 0.17 | 0.95 |
| | Jumara (this study) | Ju/22/8c | at | 110 | 52 | 46 | 15 | 0.14 | 0.89 |
| *M. mantantaranus* Boehm [M] | Jumara (Roy *et al*., 2007) | JUM/M/1 | phragmocone | 93.5 | 51.1 | 48.5 | 9.6 | 0.10 | 0.95 |
| | | | inner whorl | 70 | 38.5 | 40 | | | 0.95 |
| | | | inner whorl | 34 | 15 | 21 | | | 1.04 |
| | Indonesia (Westermann and Callomon, 1988) | Holotype | aperture | 160 | | | 20 | 0.13 | |
| | | | body chamber | 148 | 79 | 59 | 13 | 0.09 | 0.75 |
| | | | | 126 | 68 | 53 | 11 | 0.09 | 0.78 |
| | | IMC 438a [M] | end phragmocone | 105 | | | 10.5 | 0.10 | |
| | | | aperture | 116 | 51 | 43 | 27 | 0.23 | 0.84 |
| | | | end phragmocone | 68 | 33.5 | 31.3 | 14 | 0.21 | 0.93 |
| | | | - | 44 | 19.5 | 19.5 | 9 | 0.20 | 1.00 |
| | | | - | 20 | 9.4 | 10.5 | 5.1 | 0.26 | 1.12 |
| | | IMC 438b [M] | body chamber | 105 | | 39 | 17.5 | 0.17 | |
| | | | end phragmocone | 93 | 47 | 35.3 | 14.4 | 0.15 | 0.75 |
| | | | - | 71 | 35 | 26.2 | 10 | 0.14 | 0.75 |
| | | | - | 55 | 28 | 22 | 8.2 | 0.15 | 0.79 |
| | | IMC 438 [M] | aperture | 148 | 66.2 | | 20.2 | 0.14 | |
| | | | body chamber | 118 | 60 | | 13 | 0.11 | |
| | | | end phragmocone | 82 | 43.1 | | 10.9 | 0.13 | |
| | Nepal (Cariou and Enay, 1999) | Dd 21 | phragmocone | 76 | 32 | | 15 | 0.20 | |
| | | loge | phragmocone | 63.2 | 29.4 | 30.5 | | | 1.04 |
| | | Dd 32 | - | 80 | 32.4 | 31.2 | 14 | 0.18 | 0.96 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *M. triangularis* Spath [M] | Jumara (Holotype; BMNH C22402) | phragmocone | 127 | 66 | 49 | 12.7 | 0.10 | 0.74 |

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