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Immigration of the genus *Macrocephalites* Spath and the Bathonian biostratigraphy of the Kachchh basin (Western India, South Tethys)

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Abstract

The Bathonian occurrences of Indonesian *Macrocephalites* from the Kachchh basin (Western India) (and correspondingly the immigration of the genus into the basin) is evaluated in context of improved biostratigraphy and new ammonite data vis-à-vis European and Submediterranean records. The Indonesian Middle Bathonian macrocephalitids [*Macrocephalites bifurcatus* transient *intermedius* (Spath) (M), *M. bifurcatus* transient cf. *intermedius* (Spath) (M), *M. bifurcatus* transient aff. *bifurcatus* Boehm (m) and *M.* cf. *etheridgei* Spath (m)], have largely been recorded from a single dome, Jumara (from the basal Yellow bed, bed A4), with additional singular occurrences of *M.* cf. *etheridgei* Spath (m) from the adjoining Nara and Jhura domes (Kachchh). In Jumara, the Indonesian macrocephalitids are associated with *Micromphalites* (*Clydomphalites*) *clydocromphalus* Arkell (M), *Procerites* (*Gracilisphinctes*) *arkelli* Collignon (M), *P.* (*G.*) *intermedius* Jain (m), *P. hians* (Waagen) (M), *Wagnericeras* sp. (m), *Parapatoceras distans* (Baugier and Sauzé) (M), *Sivajiceras congener* (Waagen) (M and m), *Macrocephalites triangularis* Spath (M and m), *Epimorphoceras decorum* (Waagen) (M), and *Reineckeia* sp. A and B (M). This fauna is correlated with the European early Middle Bathonian Progracilis Zone. Both Jumara and the adjoining Jara domes have also yielded characteristic Indonesian Late Bathonian macrocephalitids – *M.* cf. *keeuwensis* Boehm (M and m), *M. keeuwensis* var. aff. forma *flexuosa* Boehm (m) and *M.* cf. *mantataranus* Boehm (M). In light of improved high–resolution stratigraphy, the Kachchh Bathonian fauna is evaluated and an improved biostratigraphy of the basin is proposed.

Key words: *Macrocephalites*, Bathonian, Middle Jurassic, Kachchh, South Tethys

1. Introduction

The Middle Jurassic (Bathonian–Callovian) genus *Macrocephalites* Zittel has global correlation potential (Westermann & Callomon 1988; Krishna & Westermann 1987; Krishna & Cariou 1993; Seyed-Emami et al. 2014; Mönnig 2014; Jain 2014, 2019a, 2019b). Its earliest occurrence comes from two regions, (a) from the stratigraphically well–constrained Tethyan localities of Kachchh (Krishna & Westermann 1987; Jain 2014) and (b) from the relatively loosely–constrained localities of Indonesia (Sula Islands and Papua New Guinea: Boehm 1912; Westermann & Callomon 1988). However, recently a singular record of *Macrocephalites* cf. *etheridgei* Spath (m) has also been noted from Somalia but the biostratigraphy is not well–constrained due to previous unlocalized sampling (Stefanini 1925; Jain 2019b). Hence, with updated stratigraphy, a better understanding of the occurrences of the Kachchh macrocephalitid fauna is fundamental in enabling global correlations and paleobiogeography.

Globally, the Late Bathonian records of genus *Macrocephalites* Zittel are as pervasive (Dietl 1981; Dietl & Callomon 1988; Cariou et al. 1988; Westermann & Callomon 1988; Callomon et al. 1989; Callomon 1993; Krishna & Cariou 1993; Jain 1996, 2008, 2014; Mönnig 1995, 2014; Page & Melendez 2000; Jain & Pandey 2000; Seyed-Emami et al. 2014) as the rarity of their Middle Bathonian reports (Westermann & Callomon 1988; Jain 1996, 2002, 2014, 2019b; Jain & Pandey 2000; Roy et al. 2007).

Recently, a prolific Middle Bathonian (Arkelli Zone) assemblage was recorded from the core of the Jumara Dome (Kachchh basin; bed A4, Yellow Bed, the basal part of the Jumara Coral Limestone Member; Figs 1, 2) containing *Micromphalites* (*Clydomphalites*) *clydocromphalus* Arkell (M), *Procerites* (*Gracilisphinctes*) *arkelli* Collignon (M and m; M = Macroconch, m = microconch), *P.* (*G.*) aff. *arkelli* Collignon (M), *P.* (*G.*) *intermedius* Jain (m), *Procerites hians* (Waagen) (M), *Procerites* (*Siemiradzkia*) cf. *verciacensis* (m) (=*Wagnericeras* sp. (m); present interpretation; see also Mangold 1971), *Parapatoceras distans* (Baugier and Sauzé) (M), *Sivajiceras congener* (Waagen) (M and m), *Macrocephalites triangularis* Spath

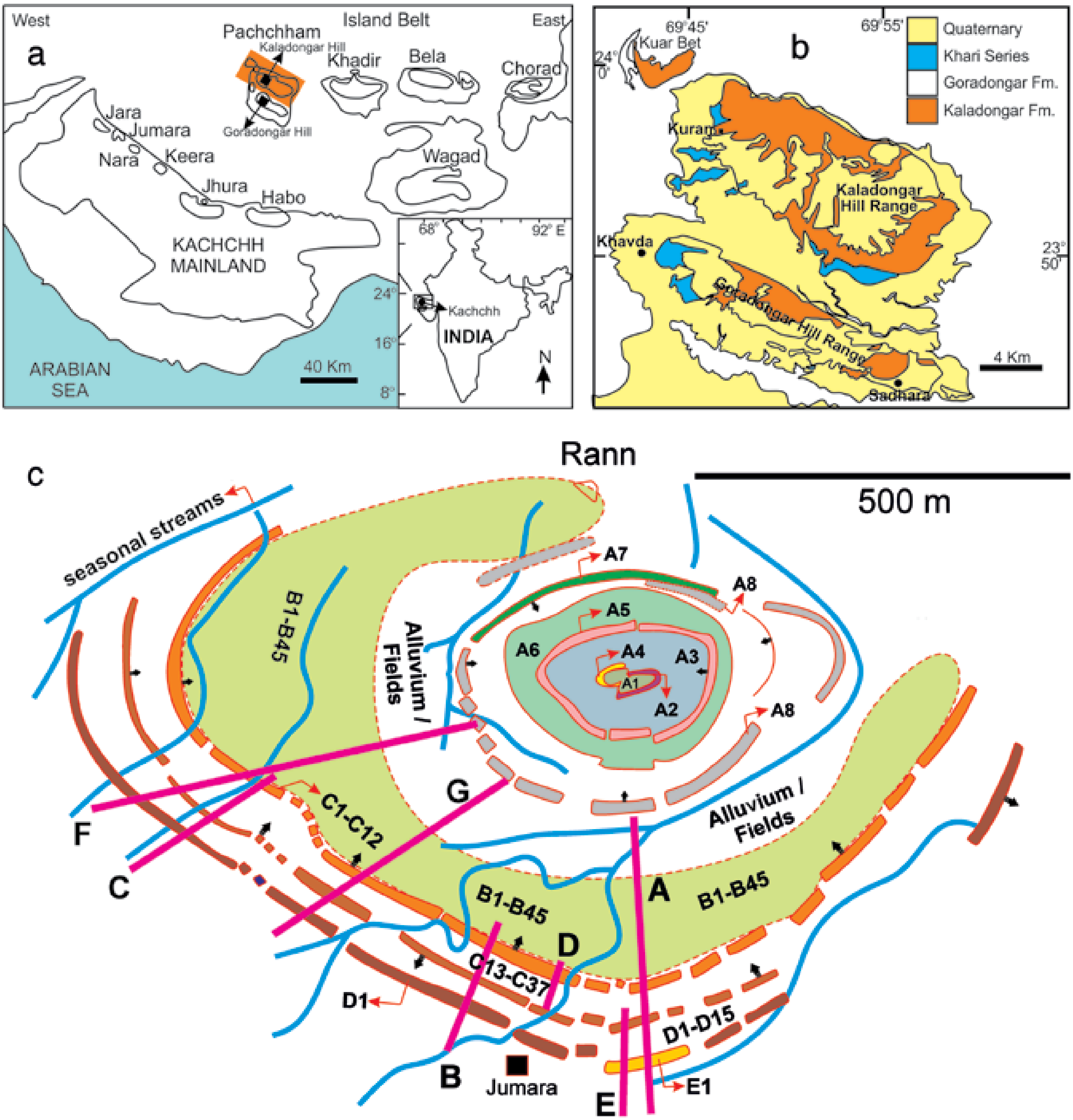


Figure 1: (a) Domal outcrops of the Kachchh basin (between latitudes 22°30′N and 24°30′N and longitudes 68°E and 72°E) discussed in the text. **(b)** Geological map of the Pachchham Island and localities mentioned in the text. The oldest beds of the basin are exposed at Kuar Bet (b) within the Dingi Hill Member (see Fig. 2) where Pliensbachian–Toarcian nannofossils have been recorded (Rai & Jain 2013) marking the first marine transgression for the basin. (c) Map of Jumara Domes showing Bathonian (A1–A8; this study), Callovian (B-1-B45, C-C37 and D1-D5), and Early-Middle Oxfordian (E) beds.

(M and m), *Reineckeia* sp. A and B (M), *Macrocephalites* cf. *etheridgei* Spath (m), *M. bifurcatus* transient aff. *bifurcatus* Boehm (m), *M. bifurcatus* transient *intermedius* (Spath) (M and m), *M. bifurcatus* transient cf. *intermedius* (Spath) (M), *Procymatoceras* sp., and *Eutrephoceras* sp. (M) (Figs 3–11; see also Fig. 12 for assemblage distribution) (Jain 1996, 2002, 2014, 2018). A juvenile specimen of *Micromphalites* (*Clydomphalites*) sp. and two more specimens of *Wagnericeras* sp. (m) are now added to this list (and illustrated later in the paper). Roy et al. (2007) also recorded the Middle Bathonian Indonesian ammonite *M.* cf. *etheridgei* (m) from the nearby locality of Jhura (see Figs 10a, 13d; see Jain 2014 for details), occurring 65 m below the Yellow Bed (bed A4) of the Jumara Dome and another singular record from a coeval strata from Nara (Figs 1, 10b–c, 13a). Recently, based on magnetostratigraphic analysis from Jumara, Mamilla et al. (2016) came to an even earlier age of Early Bathonian for the same Yellow bed (bed

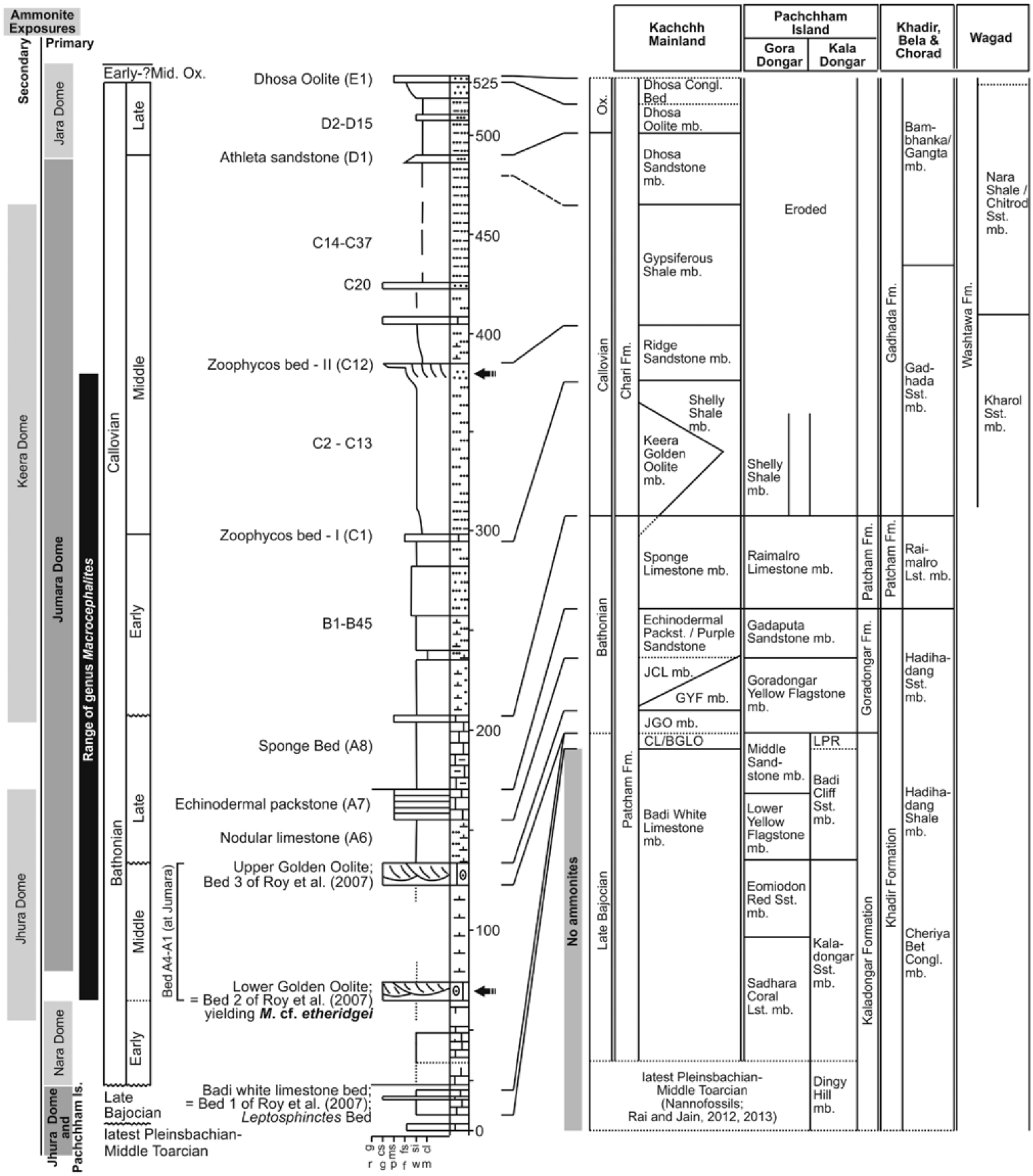


Figure 2: Pliensbachian–Oxfordian stratigraphy of the Kachchh basin. Beds from the Jumara Dome are correlated with the established Members. The *Leptosphinctes*-bearing Pebbly Rudstone Bed forms the top unit of the Babia Cliff Member. Abbreviations – Mb.: Member; Fm.: Formation.

A4) and correlated the bed with the standard magnetostratigraphic zone M41 (based on the timescale of Gradstein et al. 2012) (Fig. 14).

In this context, the calcareous nannofossil record extracted from the microconch specimen of *Macrocephalites triangularis* Spath from the Yellow Bed (bed A4) by Rai in Jain et al. (2013) is very interesting. They recorded the following nannofossil assemblage of *Axopodorhabdus cylindratus, Cyclagelosphaera margerelii, Calyculus* sp., *Diazomatolithus lehmanii, Discorhabdus criotus, Ethmorhabdus gallicus, Carinolithus magharensis*, *L. crucicentralis, Lotharingius haufii, L. sigillatus, L. velatus, Octopodorhabdus deccusatus, Staurolithites* sp., *Watznaueria barnesae, W. britannica, W. manivitae* and *Zeugorhabdotus erectus*. Rai (in Jain et al. 2013) used the presence of *Watznaueria manivitae* (FAD in Early Bajocian) and *Carinolithus magharensis* (LAD in Middle Bathoni-

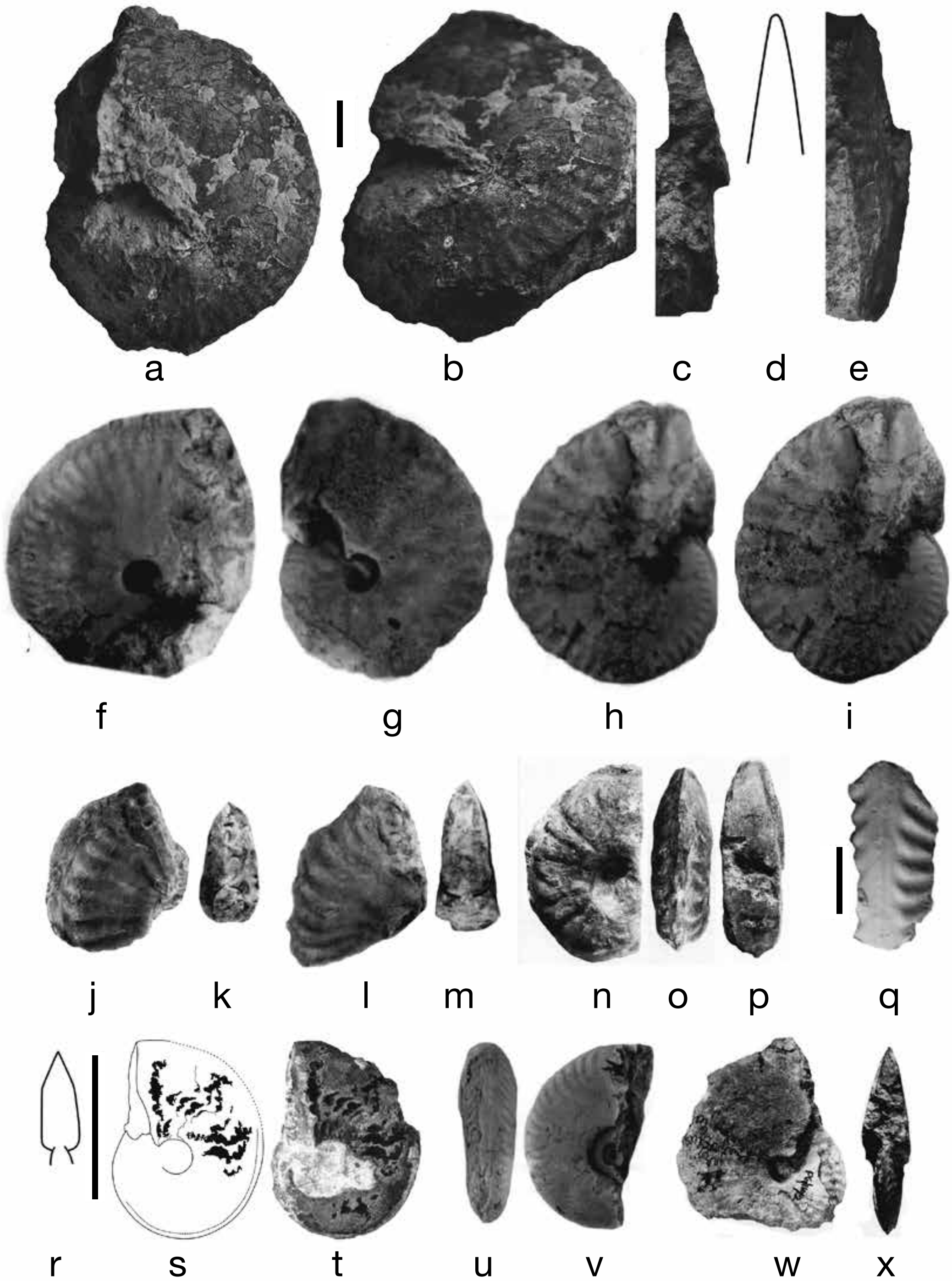


Figure 3: Middle Bathonian *Micromphalites-Clydoniceras* Assemblage. **(a–e)** *Micromphalites* (*Clydomphalites*) *clydocromphalus* Arkell (Macroconch), specimen no. SJ/Ju/14/A4/1, diameter: 58.4 mm, septate, Yellow Bed (bed A4), Jumara, **(a)** lateral view, **(b)** lateral view at an angle to highlight ribbing pattern, **(c)** apertural view, **(d)** Whorl–section reconstructed from (c), **(e)** ventral view showing the narrow keel. **(f–i)** *Micromphalites* (*Clydomphalites*) cf. *clydocromphalus* Arkell (Macroconch) (refigured from Pandey & Callomon 1995: pl. 1, figs 2, 3, septate specimens), north–east of Khari, Goradongar (Pachchham Island), **(f)** specimen no. PG/240/8, lateral view, diameter: 50 mm. **(g–i)** specimen no. PG/172/l5a, diameter: 41 mm. **(g)** lateral view, **(h)** opposite lateral view **(i)** at an angle to show the ribbing pattern. **(j–m)** *Micromphalites* (*Clydomphalites*) sp. indet. (refigured from Pandey & Callomon 1995: pl. 1, figs 4, 5, septate specimens), **(j, k)** specimen no. PG/129/4, north–east of Khari, Goradongar (Pachchham Island), **(j)** lateral view, **(k)** apertural view. **(l, m)** specimen no. PG/239/10, north–east of Sadhara, Goradongar (Pachchham Island), **(l)** lateral view, **(m)** apertural view. **(n–p)** *Micromphalites hourcqui* Collignon (M) (refigured from Jaitly & Singh 1984: fig. 1, septate specimen), specimen no. PK/122/57, South of Jatara Talav, Kaladongar, Pachchham, Island, diameter = 56 mm, **(n)** lateral view, **(o)** ventral view, **(p)** apertural view. **(q)** *Micromphalites* sp. indet. (refigured from Pandey & Pathak 2015: pl. 2, fig. 10), specimen no. NR 15/106/13, bed 15, Nara Dome, fragment of a ?body chamber. **(r–t)** ?*Micromphalites* (*Clydomphalites*) sp. indet., septate specimen, Yellow Bed (bed A4), specimen no. SJ/Ju/1999/A4/8, Jumara Dome, diameter: 16mm, **(r)** whorl–section, **(s, t)** lateral views, note the keel in (t). **(u, v)** *Clydoniceras* sp. indet. (refigured from Pandey & Callomon 1995: pl. 1, fig. 1, septate specimen), specimen no. PG/172/25b, north–east of Sadhara, Goradongar (Pachchham Island), diameter=12.9 mm, **(u)** ventral view, **(v)** lateral view. w–x: *Clydoniceras* sp. (refigured from Singh et al. 1983: fig. 1, septate specimen), **(w)** lateral view, **(x)** apertural view, specimen no. PG/110/2, north–west of Sadhara, Goradongar (Pachchham Island), diameter: 93.5 mm. Bars represent 1 cm. M = Macroconh, m = Microconch.

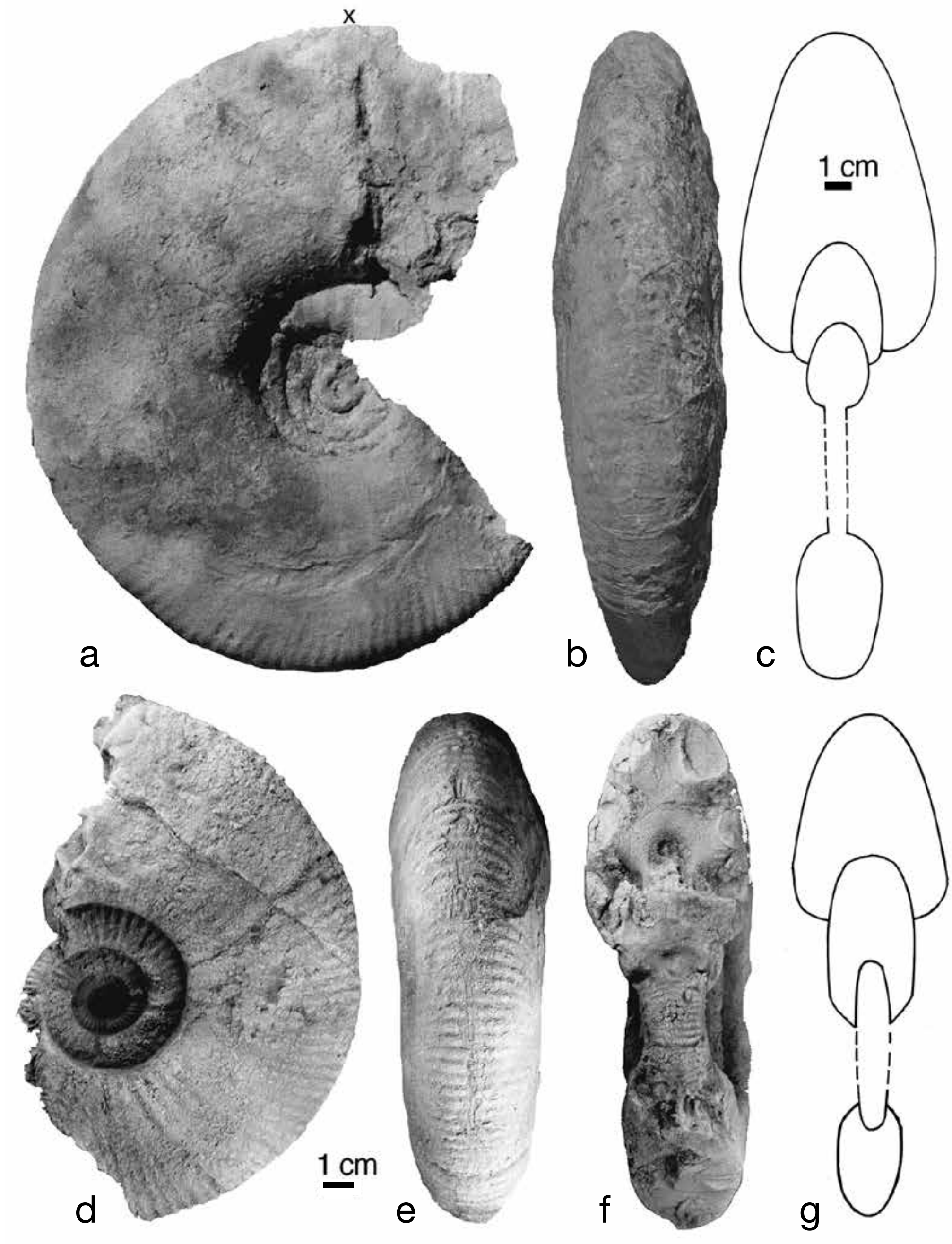


Figure 4: *Procerites* (*Gracilisphinctes*) *arkelli* Collignon, 1958 (Macroconch). **(a–c)** specimen no. Ju/27/59, **(a)** lateral view, **(b)** ventral view, **(c)** whorl section. **(d–g)** specimen no. Ju/27/60, septate specimen, **(d)** lateral view, **(e)** apertural view, **(f)** ventral view, **(g)** whorl section. All specimens are from the Yellow Bed (bed A4), Jumara. Cross (x) marks the beginning of body chamber.

an) to bracket the age of the Yellow Bed between Early Bajocian and Middle Bathonian. Although they recoded *W. barnesiae* whose FAD marks the Early Bathonian (NJ11), but somehow, they overlooked it. Here, the data is re–accessed, and considering the FAD of *W. barnesiae* (168.2 Ma) and LAD of *Carinolithus magharensis* (167.2 Ma), the age of the Yellow Bed (bed A4) lies between Early to early Middle Bathonian (168.2–167.2 Ma) (Fig. 14) (see also Bown 1998). *Calyculus* is reworked (the range of genus is between 190.82–168.28 Ma; Pliensbachian–earliest Bathonian) and *Diazomatolithus lehmanii* is leaked (the range of the species is 152.06–122.98 Ma; Tithonian–Aptian) (Bown 1998).

In this contribution the Bathonian ammonite faunal content and biozonation for the Kachchh basin are evaluated, aided by improved higher stratigraphic resolution and the additional record of three specimens of *Wagnericeras* sp. (m) [two from this study and one previously identified as *Procerites* (*Siemiradzkia*) cf. *verciacensis* (m) by Jain et al., 1996] from the same horizon, the Yellow bed at Jumara (Fig. 1a, c). Old and new ammonite data from four Bathonian localities of Nara, Jumara, Jhura and Jara (Fig. 1) are evaluated and summarized below. Besides the data from the Kachchh Mainland (Nara, Jumara, Jhura and Jara; Fig. 1a), the Bajocian–Bathonian ammonite records also come from the island belt of

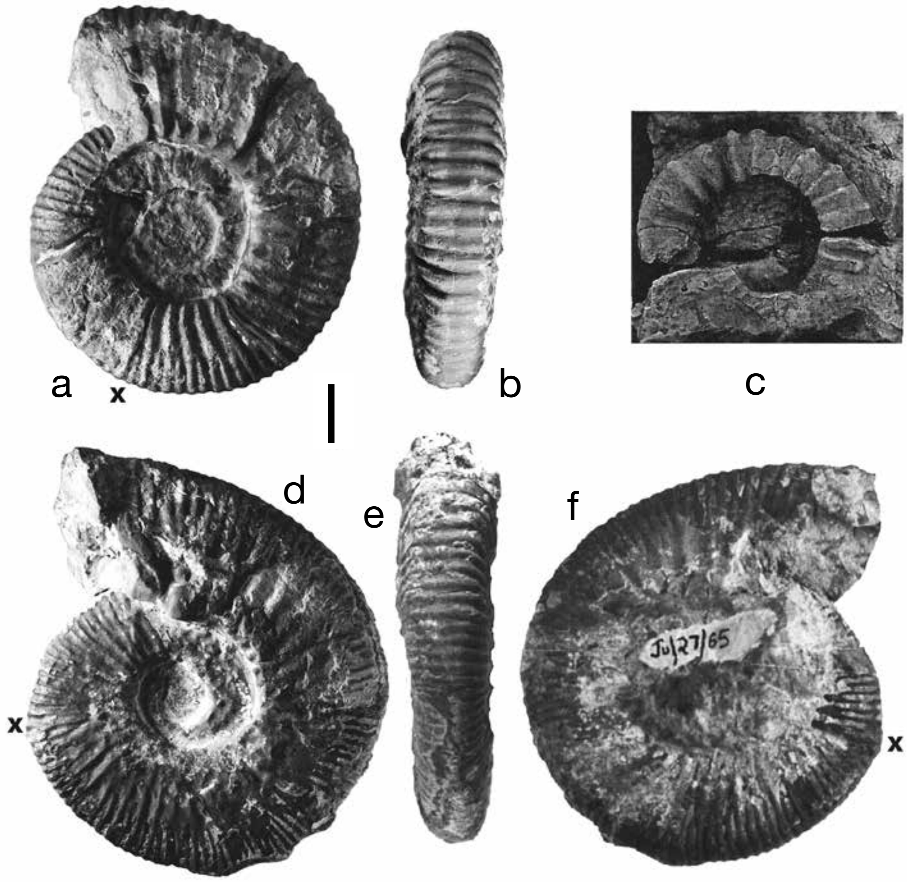


Figure 5: *Procerites* (*Gracilisphinctes*) *arkelli* Collignon (microconch), **(a, b)** specimen no. Ju/27/61, **(a)** lateral view, **(b)** ventral view, diameter=63.7 mm. **(c)** *Parapatoceras distans* Baugier and Sauzé (M), natural size. **(d–f)** *Procerites* (*Gracilisphinctes*) *intermedius* Jain (Microconch), specimen no. Ju/27/65, **(d)** lateral view, **(e)** ventral view, **(f)** opposite lateral view, diameter = 75.4 mm. All specimens are from the Yellow Bed (bed A4), Jumara. Cross (x) marks the beginning of body chamber. Bar represents 1cm.

Pachchham (Fig. 1b). The latter records have been dealt with in Pandey and Callomon (1995) and Jain (2014) and will not be discussed here again, except very briefly mentioning the faunal content, in context of this contribution.

2. Remarks on sporadic records and major ammonite–bearing localities

The ammonite reports from the Kachchh basin are largely characterized by fragmented records that suffer from ambiguous stratigraphy and imprecise sampling horizons (see Jain 2014 for a review). Hence, to better understand the basin-wide ammonite biozonation, a relook at ammonite records from major ammonite–bearing localities is imperative (Figs 1a, 2). This is needed not just to integrate the disjointed records but also to refine and update and remove any remaining ambiguity in basin-wide biostratigraphy. The major Bathonian ammonite–bearing localities include Pachchham Island, Nara, Jumara, Jhura and Jara (Figs 1, 2).

2.1 Pachchham Island

The Bajocian is marked by the presence of a single age–diagnostic moderately preserved specimen of *Leptosphinctes* (Fig. 15a–c) recorded from the Pachchham Island (Fig. 1b) from the topmost unit (*Leptosphinctes* Bed) of the Pebbly Rudstone Bed of the Babia Cliff Sandstone Member (Fig. 2). *Leptosphinctes* characterizes the early Late Bajocian Niortense Zone (Pavia et al. 2013; Galácz 2017; pers. comm. V. Dietze, 2019) (Fig. 14).

The overlying Goradongar Yellow Flagstone Member (GYF; Fig. 2) has yielded ammonites (topmost part) from two closely spaced levels; the lower 1.5 m thick unit yielded *Bullatimorphites* (s. s.) (Fig. 15d–g) and *Clydoniceras triangularis* Pandey and Agrawal (1984) and the overlying 6.5 m thick unit yielded *Procerites* (*Gracilisphinctes*) *arkelli*, *Procerites* (*G.*) cf. *schloenbachi* (Grossouvre), *Micromphalites* (*Clydomphalites*) cf. *clydocromphalus*, *M.* (*Clydomphalites*) sp. indet. and *Clydoniceras* sp. (Pandey & Callomon 1995). Additionally, Jaitly & Singh (1984) recorded *Micromphalites hourcqi* Collignon (Fig. 3n–p) from a coeval stratum from another Pachchham Island locality, Kaladongar (Fig. 1b). On lithostrati-

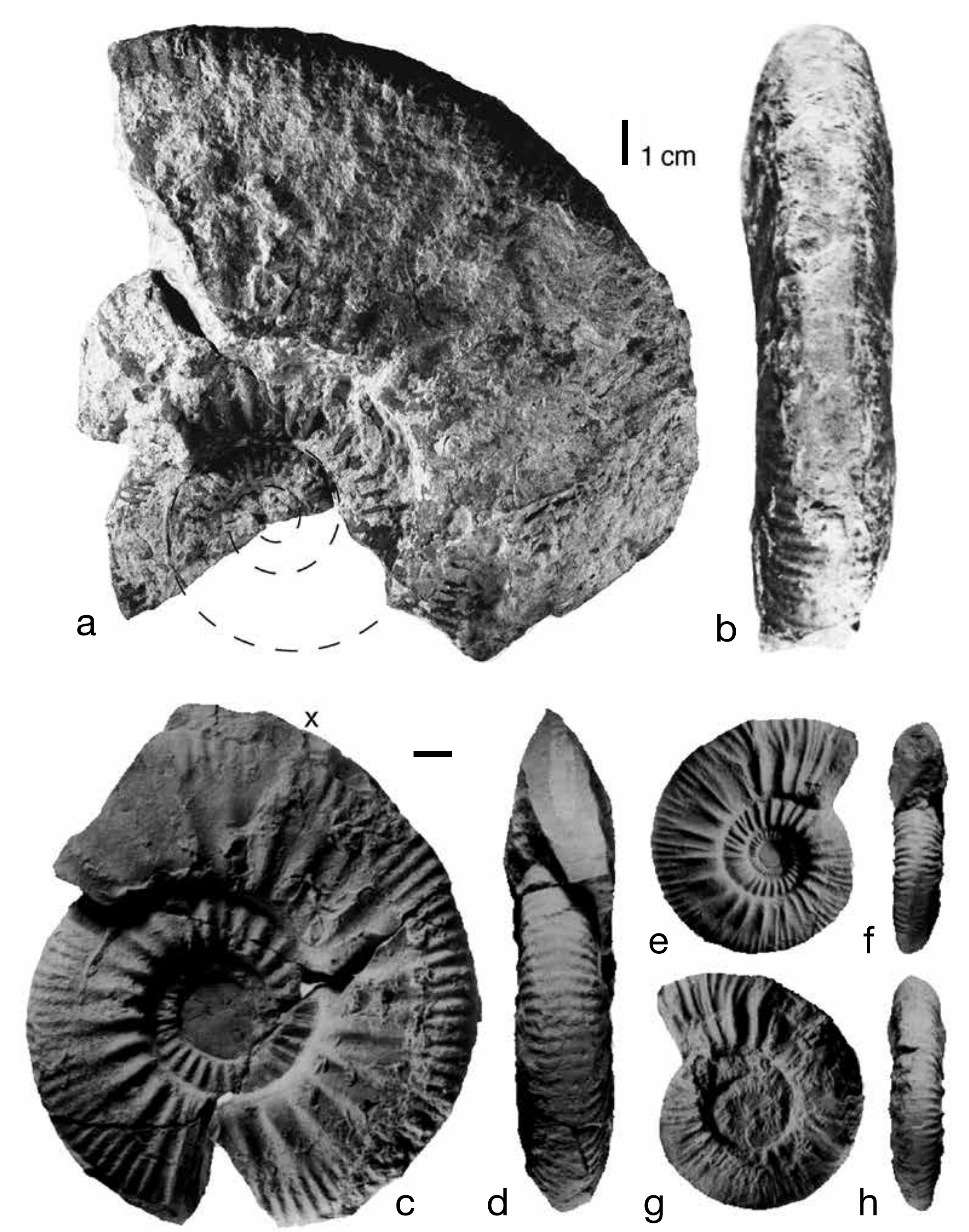


Figure 6: *Procerites hians* (Waagen) (Macroconch), **(a, b)** specimen no. Ju/27/5, **(a)** lateral view, **(b)** ventral view, Yellow Bed (bed A4), Jumara. **(c–h)** *Sivajiceras congener* (Waagen) (M and m), refigured from Callomon (1993: figs 23, 24) from the "Upper Patcham limestone of Jumara" (= the base of Sponge Beds, bed A8; see Fig. 22 for sampling level). **(c, d)** Macroconch refigured from Callomon 1993: figs. 23, 24.1, phragmocone with beginning of body chamber, **(c)** lateral view, **(d)** ventral view. **(e–h)** Microconch; **(e, f)** from the same level as the Macroconch (c–d), refigured from Callomon 1993: fig. 24.2a, b. Callomon (1993) considered both *P*. *hians* (Waagen) and *S. congener* (Waagen) as conspecific, representing two extreme variants of a widely variable biological species. However, it must be noted that *P*. *hians* which co–occurs with *S*. *congener* is a much larger form. The Holotype of the former is still septate at 215 mm with an estimated shell diameter of ~300 mm, whereas the latter is septate only up to 125 mm with an estimated shell diameter of ~200 mm. In the latter (*S. congener*), at the body chamber (~190 mm), the primaries become thick, bullae–like and bifurcate relatively higher on the flank. Both primaries and secondaries continue until the end of the adult body chamber without any sign of rib attenuation. But, in *P*. *hians*, ribbing becomes progressively weak at the body chamber, so much so that, in larger forms, even secondaries disappear from the ventral region. Cross (x) marks the beginning of body chamber. Bars represent 1cm.

graphic grounds, the Goradongar Yellow Flagstone Member has been correlated with the Yellow Bed of Jumara (Jain et al. 1996; Jain 2014; Fürsich et al. 2001, 2013) and the *arkelli*–bearing strata with the European early Middle Bathonian Progracilis Zone (Pandey & Callomon 1995; Jain 2014) (Figs 2, 12).

2.2 Nara Dome

At Nara, Roy et al. (2007) recorded three horizons for their Middle Bathonian Etheridgei Zone (their tab. 2 on p. 633), starting from below, *Gracilisphinctes* cf. *arkelli*, *Prohecticoceras manjalense* and *Kamptoke-*

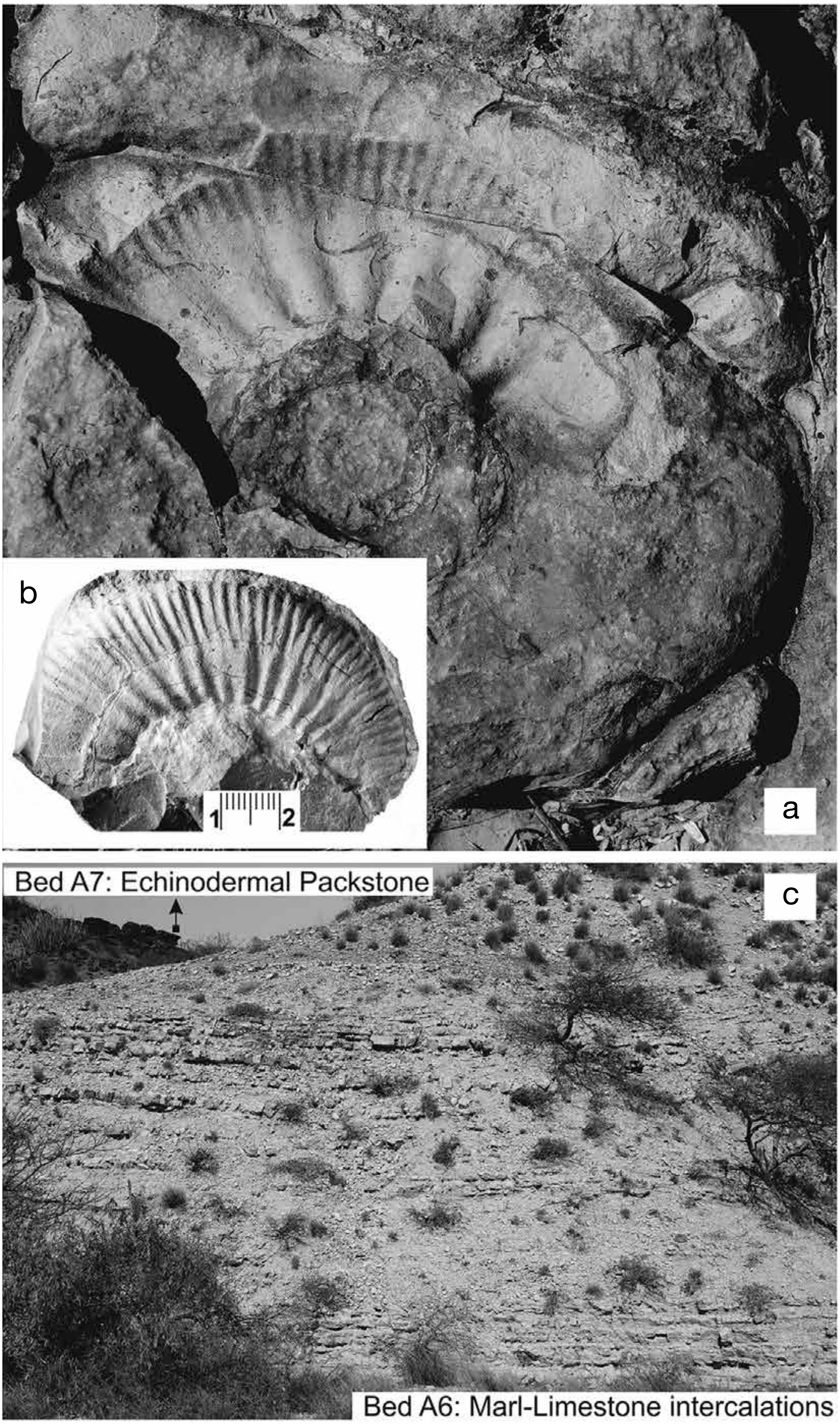


Figure 7: *Sivajiceras congener* (Waagen) (Macroconch and miroconch) from the top of bed 6, part of body chamber, Jumara. **(a)** Macroconch, lateral view and in situ (Field photograph), **(b)** Microconch, specimen no. Ju/24/187. **(c)** Marl-Limestone intercalations in bed A6; altogether, there are about 28 such <1 m thick marl-limestone intercalations. Bar represents 1 cm.

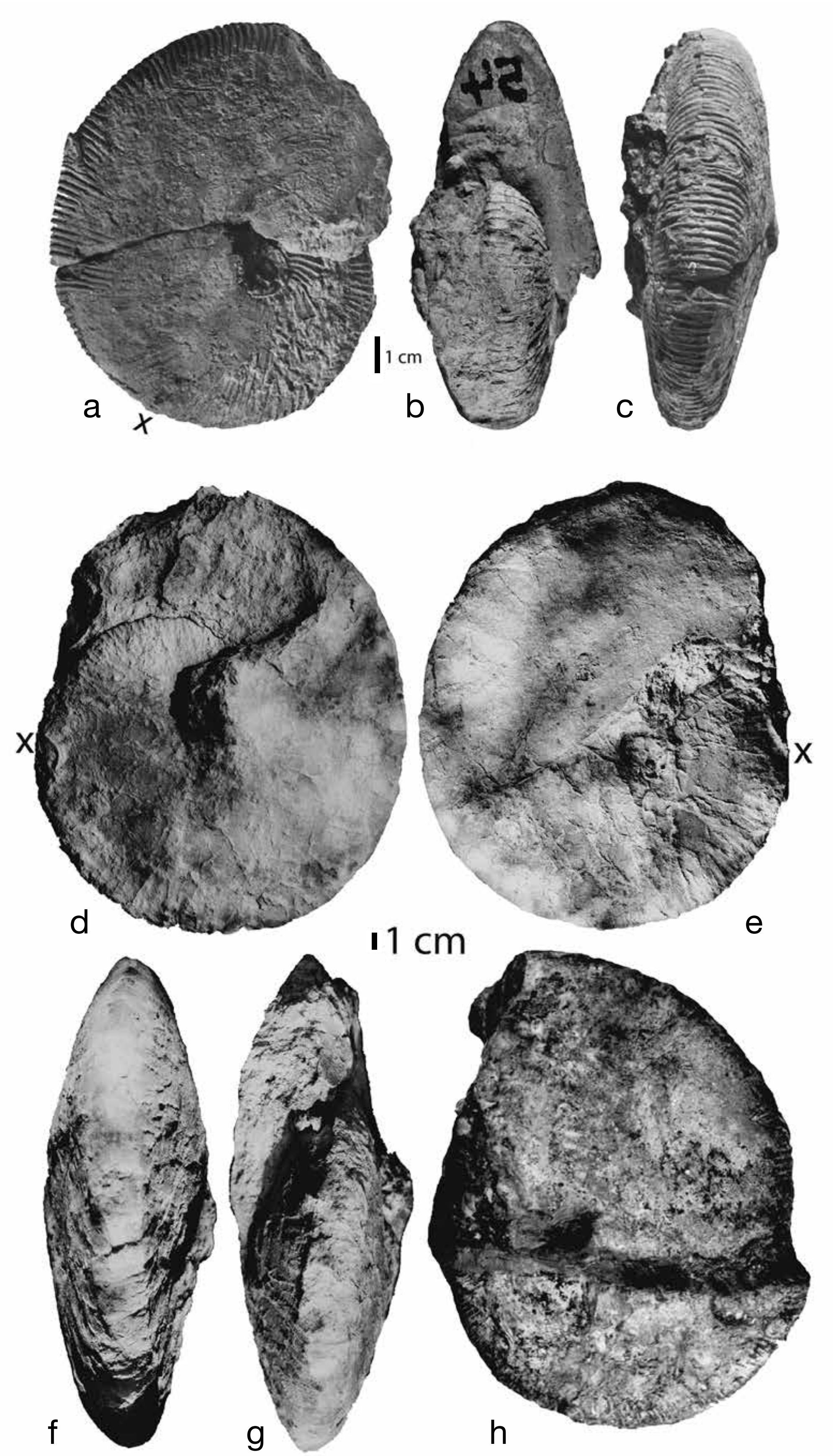


Figure 8: *Macrocephalites triangularis* Spath (Macroconch and miroconch). **(a–c)** *M. triangularis* Spath (miroconch), specimen no. Ju/27/158, **(a)** lateral view, **(b)** apertural view, **(c)** ventral view. **(d–g)** *M. triangularis* Spath (Macroconch). **(d–g)** specimen no. SJ/Ju/1999/A4/6, **(d)** lateral view, **(e)** opposite lateral view, **(f)** ventral view, **(g)** apertural view. h: specimen no. SJ/Ju/1999/A4/8, lateral view. All specimens are from the Yellow Bed (bed A4), Jumara Dome. Cross (x) marks the beginning of body chamber. Bars represent 1cm.

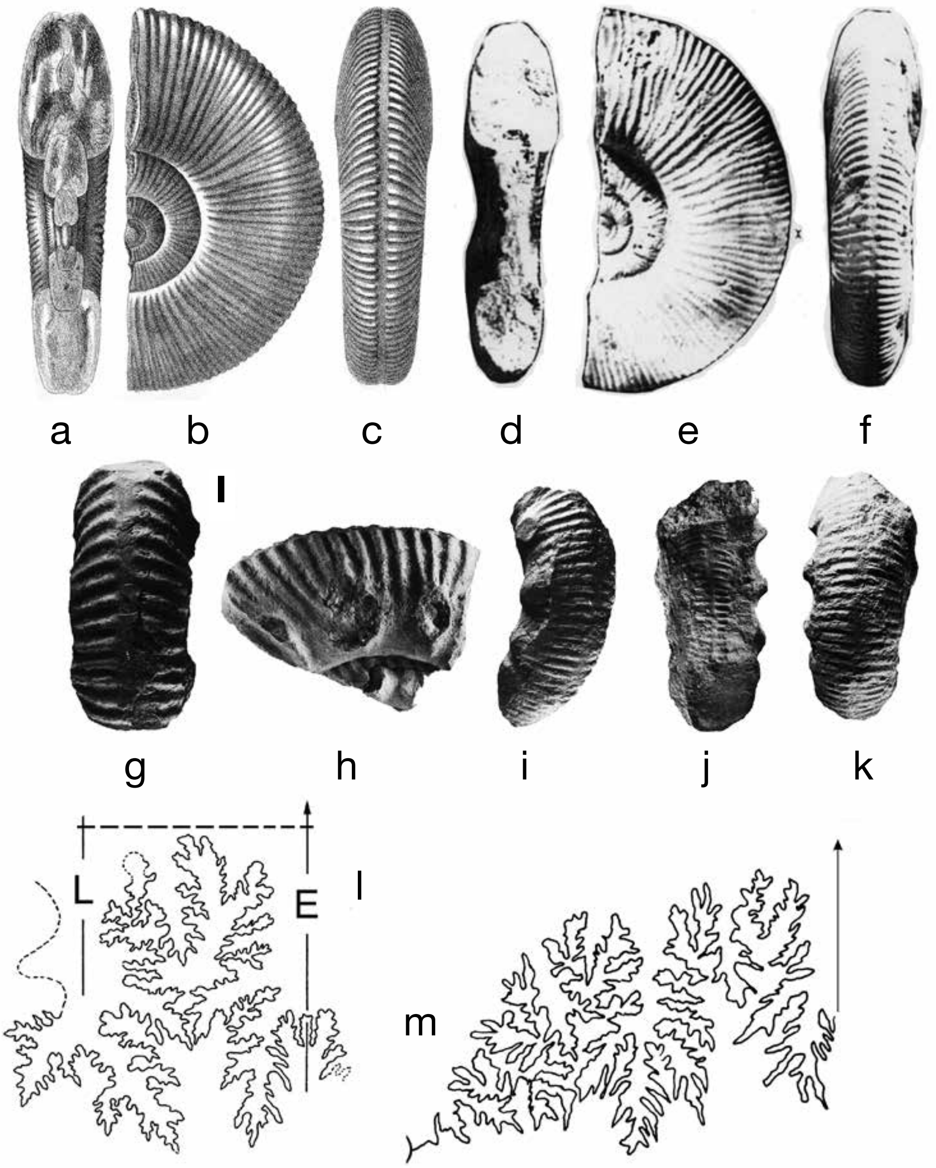


Figure 9: *Epimorphoceras decorum* (Waagen) (Macroconch), **(a–f, m)** Holotype, Geological Survey of India Type No. 2096. **(a–c)** Illustration from Waagen (1875: p 208, pl. LVII, fig. 3a–d). **(d–f)** Actual specimen refigured from Kayal & Bardhan (1988: p. 44, fig. 3). **(g–k)** *Reineckeia* sp. A and B (Macroconch), Yellow Bed, bed A4 (refigured from Jain et al. 1996: p. 137, figs. 4–9). **(g–h)** *Reineckeia* sp. A (RUC Ju/27/57), fragment of inner and intermediate whorls, wholly septate. **(i–k)** *Reineckeia* sp. B (RUC/27/58), fragment of an intermediate whorl, wholly septate with umbilical seam indicating former presence of another whole whorl. **(l)** Septal suture partly exposed on *Reineckeia* sp. A shown in Figs. g–h: drawn at a whorl height of 45 mm. **(m)** Septal suture exposed on *E. decorum* (Waagen) (Macroconch) (arrow in Fig. e, marks where the suture is drawn), refigured from Waagen (1875: pl. LVII, fig. 3d). Bar represents 1cm.

phalites (=*Macrocephalites*) cf. *etheridgei* and equated them with the early Middle Bathonian Progracilis, middle Middle Bathonian Subcontractus and late Middle Bathonian Bremeri Zones, respectively (their tab. 2 on p. 633).

Roy et al. (2007) reported *Macrocephalites* cf. *etheridgei* Spath (m) (Fig. 10b, c) from their bed 2, an oolitic limestone (Fig. 13a), in association with *Prohecticoceras manjalense* Roy et al. (Fig. 16), *Procerites hians* (Waagen), *P.* (*Gracilisphinctes*) cf. *arkelli* and *Choffatia* sp. (p. 631). However, on the same page, in their fig. 3, *M*. cf. *etheridgei* clearly occurs above the latter three species (Fig. 13a). They dated the entire assemblage as Middle Bathonian and correlated the *M.* cf. *etheridgei* occurrence with the early part of the European late Middle Bathonian Bremeri Zone (their tab. 2 on p. 633). Their *Procerites* (*Gracilisphinctes*) cf. *arkelli* bearing horizon, which occurs slightly below (bed no. 2; Fig. 13a), was correlated with the early Middle Bathonian Progracilis Zone (their tab. 2 on p. 633), thus, encompassing the entire Middle Bathonian interval. Roy et al.'s (2007) record bears out three facts. Firstly, the stratigraphy is extremely broad, hence, ascertaining precise sampling location of the given ammonite species is difficult (see also Jain 2017 for the same problem with

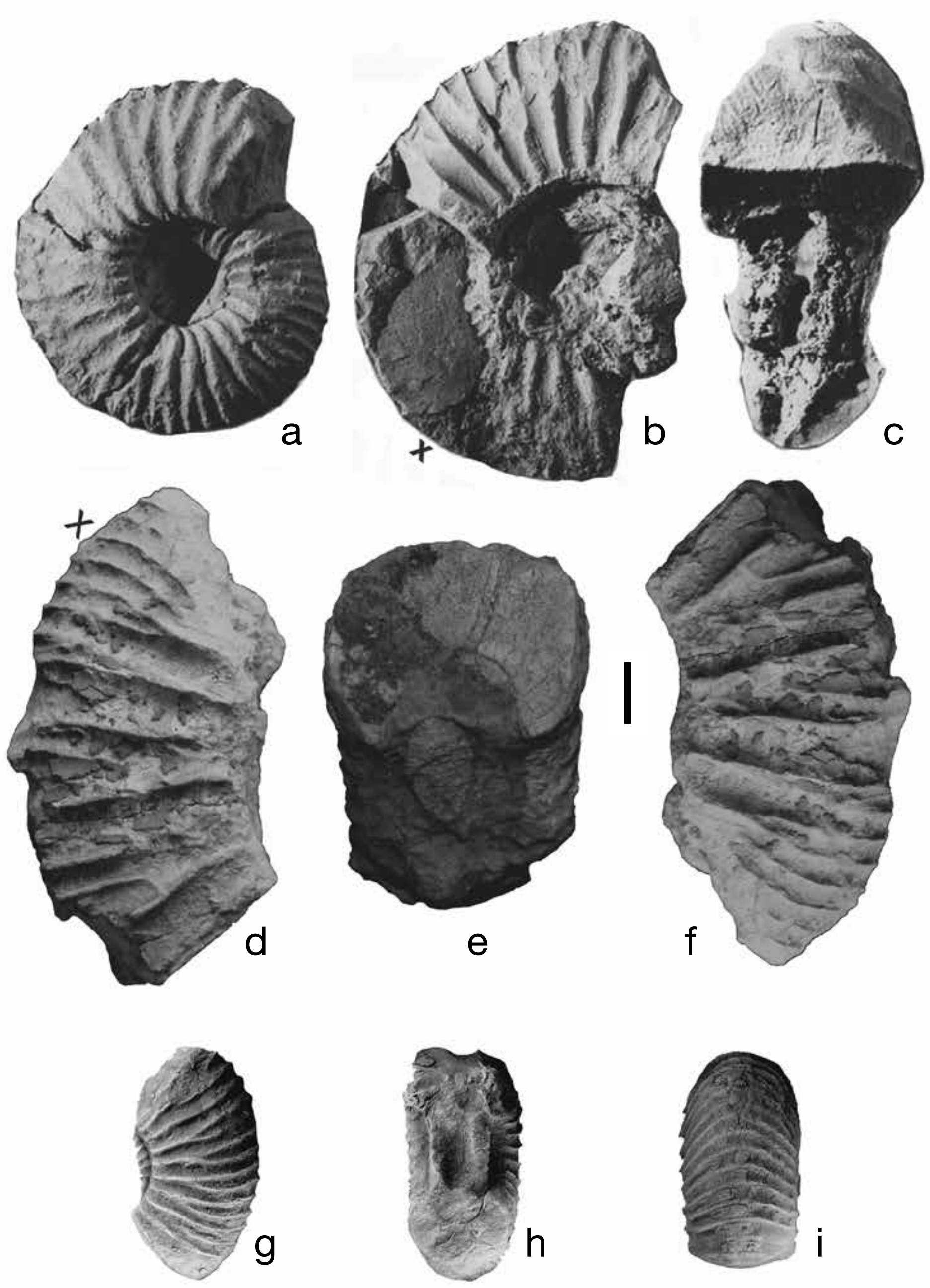


Figure 10: *Macrocephalites* cf. *etheridgei* (Spath) (microconch), (a–f). **(a)** specimen no. JUM 1000, lateral view, collected from Bed 2 of Jhura (refigured from Roy et al. 2007) (see Fig. 13c for stratigraphic position). **(b, c)** specimen no. JUM/ETH/1 collected from white limestone bed of Nara (refigured from Roy et al. 2007), **(b)** lateral view, **(c)** apertural view. **(d–f)** specimen no. Ju/SJ/2013/A4/14, Yellow Bed (bed A4) from Jumara, **(d)** lateral view, **(e)** apertural view showing the whorl section, **(f)** opposite lateral view. **(g–i)** *M. bifurcatus* transient aff. *bifurcatus* Boehm (microconch), specimen no. Ju/SJ/1999/A4/1, Yellow Bed (bed A4) from Jumara, **(g)** lateral view, **(h)** view showing the whorl section, **(i)** ventral view. Cross (x) marks the beginning of body chamber. Bar represents 1 cm.

another genera); secondly, macrocephalitids do not occur with other faunal elements (such as *P. manjalense*, *P. hians*, *P.* (*G.*) cf. *arkelli* and *Choffatia* sp.) and, thirdly, their *Prohecticoceras* (Fig. 16), spans from Early to Middle Bathonian (Roy et al. 2007: tab. 2 on p. 633). In this context, it must be kept in mind that in Europe, *Prohecticoceras* spans up to Late Bathonian, as well (Zatoń 2010).

Pandey & Pathak (2015) revisited the Nara Dome stratigraphy (Fig. 13b) with more precisely marked sampling for their ammonite content (see their fig. 2 on p. 35). On lithological grounds ("oolitic limestone" of Roy et al. 2007 = ?sandy limestone of Pandey & Pathak 2015), Roy et al.'s (2007) *M*. cf. *etheridgei*–bearing bed 2 is similar to beds 13–15 of Pandey & Pathak (2015) and Roy et al.'s bed 1 correlates with the interval of Pandey & Pathak's beds 10–12 (Fig. 13a, b). However, at Nara, neither the author nor Pandey & Pathak (2015) have noted the "oolitic limestone" of Roy et al. (2007) (Fig. 13a).

Pandey and Pathak's specimens (re–illustrated here in Figs 17, 18) are characteristically fragmen-

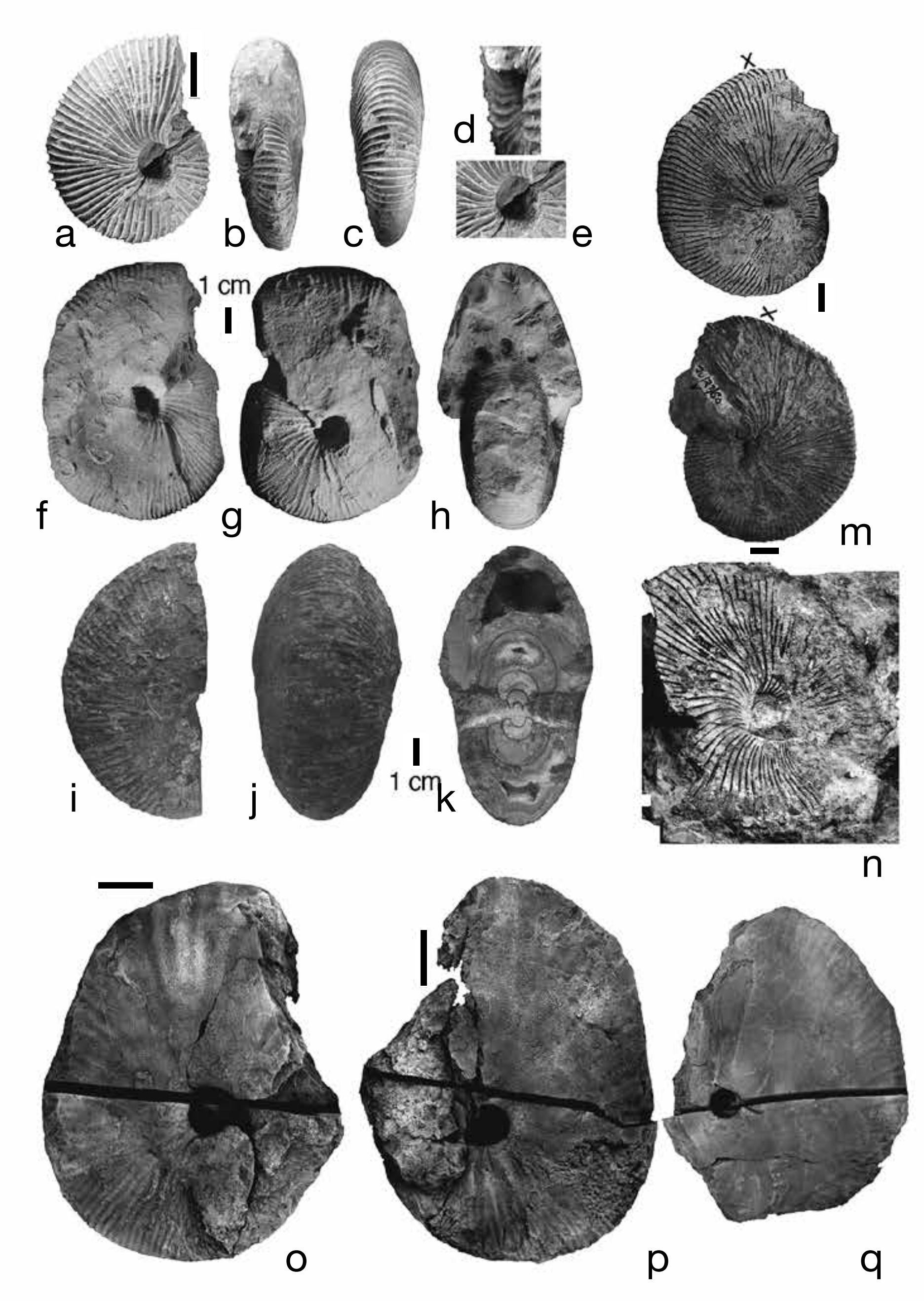


Figure 11: *Macrocephalites bifurcatus* transient *intermedius* (Spath) (Macroconch). **(a–h)** Variety B. **(a–e)** specimen no. SJ/Ju/1999/A4/3, **(a)** lateral view, **(b)** apertural view, **(c)** ventral view, **(d)** close up of the umbilical margin showing the nature of primary ribbing, **(e)** close up of the umbilical region showing the sharp overhanging umbilical edge, diameter = 51 mm. f–h: specimen no. SJ/Ju/1999/A4/4. **(f)** lateral view, **(g)** opposite lateral view, h: ventral view, diameter = 95mm. **(i–k)** Variety A. specimen no. SJ/Ju/1999/A4/5. **(i)** lateral view, **(j)** ventral view, **(k)** apertural view showing the whorl section, diameter = 103 mm. **(l, m)** *M. bifurcatus* transient *intermedius* (Spath) (microconch). **(l–n)** specimen no. Ju/27/602. **(l)** Lateral view, **(m)** Opposite lateral view, diameter = 83.3 mm. **(n)** specimen no. Ju/27/603, Lateral view, diameter=112.8 mm. **(o–q)** *M. bifurcatus* transient cf. *intermedius* (Spath) (Macroconch), septate, specimen no. SJ/Ju/1999/A2a/1, Bed A2a, Jumara Dome, diameter = 180 mm. **(o)** lateral view, **(p)** opposite lateral view. **(q)** specimen no. SJ/Ju/1999/A4/2, diameter = 145 mm. All specimens are from the Yellow Bed (bed A4), Jumara Dome. Cross (x) marks the beginning of body chamber. Bars represent 1cm.

tary, as most other Kachchh Bathonian records are. The bulk of their generic–level assemblage (containing *Procerozigzag* Arkell, *Siemiradzkia* Hyatt, *Berbericeras* Roman, *Parkinsonia* Bayle, *Ebrayiceras* Buckman, *Micromphalites* Buckman, ?*Telermoceras* Arkell, *Prohecticoceras* Spath, *Procerites* Siemiradzki *Cadomites* Munier–Chalmas and *Oecotraustes* Waagen) comes from their bed 9 (Fig. 13b). In absence of ventral views, the fragmentary records of *Parkinsonia* (Fig. 17d–g; could well be *Planisphinctes*), *Procerozigzag* (Fig. 17h, i; could be *Procerites*) and ?*Telermoceras* (Fig. 18j), must be considered with caution. However, taken together, it is a remarkable Early Bathonian record. In spite of the fragmentary nature of the specimens, the doubtful identification of some genera (?*Telermoceras*, *Parkinsonia* and *Procerozigzag*), and the poor illustration of important ones (*Zigzagiceras*, *Berbericeras*, and

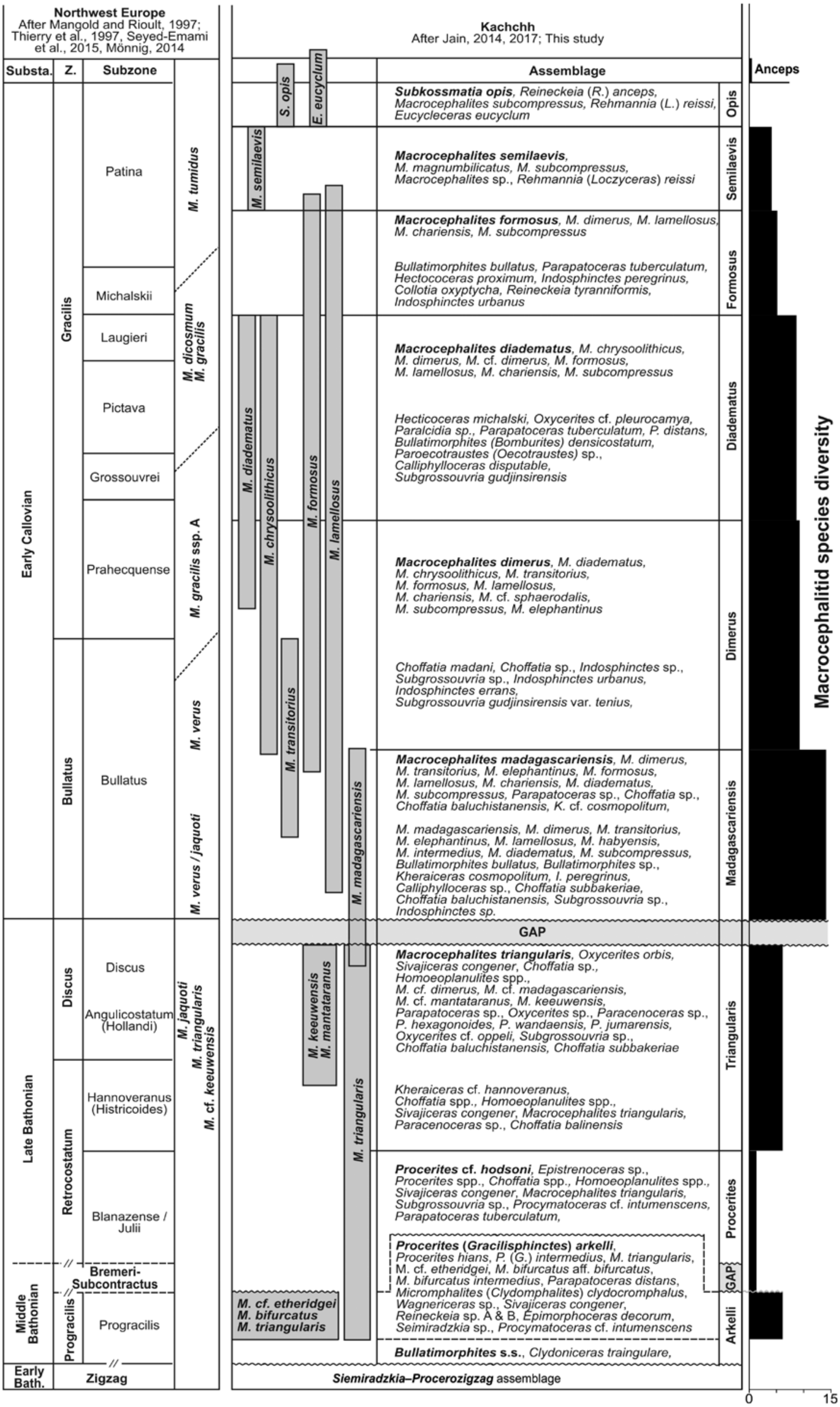


Figure 12: Ammonite assemblage adopted for this study (see text for explanation).

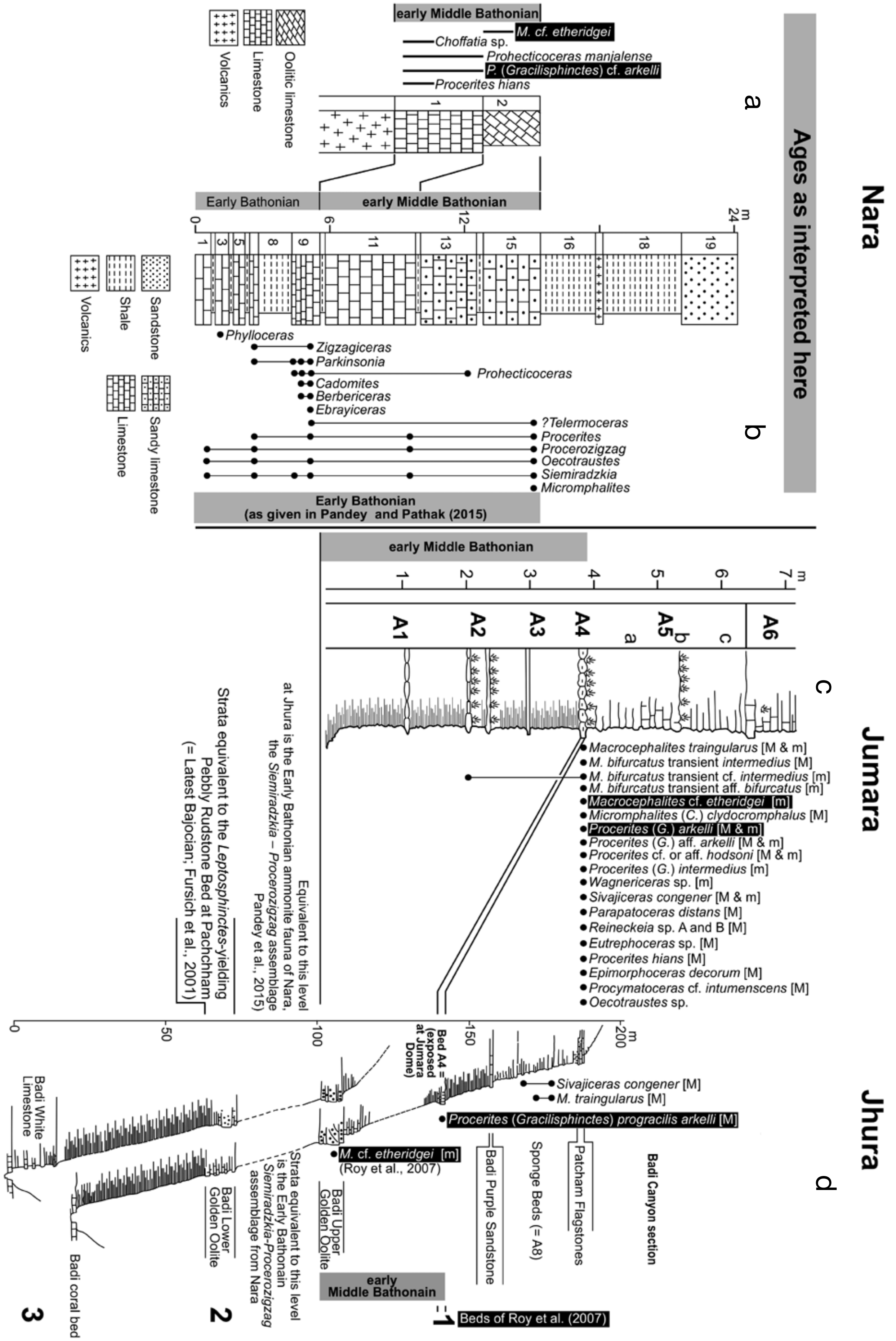


Figure 13: Ammonite content of **(a, b)** Nara, **(c)** Jumara (N23°41′37”, E69°04′00”) and **(d)** Jhura Domes (N23°24′57.2”, E69°36′32.5”).

Table 1: Macrocephalitid species diversity from Jumara based on the collection of 649 specimens (46% of them coming from the Bathonian–Early Callovian interval, alone).

BATHONIAN							CALLOVIAN																																	
Middle			Upper				Lower																														Middle			
Arkelli			Procerites			Triangularis	Madagascariensis				Dimerus						Diadematus							Formosus						Semilaevis						Opis	Anceps			
																																					Ramosa		Kleidos	
A2	A3	A4	A5	A6	A7	A8	B6	B8	B9	B10	B11	B12	B14	B15	B16	B18-21	B22	B23	B24	B26	B27	B28	B29	B30	B31	B32	B33	B34	B35	B36	B37	B38	B39	B41	B45	C1	C2	C3	C4	Bed numbers
		2																																						*M. bifurcatus bifurcatus*
		1																																						*M. bifurcatus* aff. *bifurcatus*
1		2																																						*M. bifurcatus intermedius*
		1																																						*M.* cf. *etheridgei*
		12	4	4		5																																		*M. triangularis*
		3	1		2	3																																		*M.* cf. *triangularis*
						2	1	1	4	2																														*M. madagascariensis*
						1																																		*M. keeuwensis*
						2																																		*M. mantataranus*
						1			2				3							2		1																		*M.* cf. *dimerus*
							2	1	4	3	2		2																											*M. tranistorius*
							2	3	5		1		2		1																									*M. elephantinus*
								2	1	2																														*M.* cf. *elephantinus*
									2	3	1	4	9	5		1	1	2	2	3	3	1	1	1		1	1		1											*M. dimerus*
									1	1		1	1		1			1	2	1	2	3	5	4	2		1	1	4											*M. formosus*
										1									1	2	2	1	3	1	2	4	1	1	3											*M. chariensis*
										3			1		2	1	1		2	3	2	1	2	1		4		1	3											*M. lamellosus*
										4	1						1						2						3	2			4	1	1				2	*M. subcompressus*
										1																														*M. habyensis*
										1																														*M. inflata*
										1																														*M. intermedius*
										1																														*M. flexuous*
												1	1	1	3	4	5	2	4	5	1	2	4																	*M. diadematus*
												1																												*M.* cf. *sphaerodalis*
																	1		2	1		2																		*M. chrysoolithicus*
																															2			3	2					*M. magnumbilicatus*
																																	1	1	1					*M. semilaevis*
																																			1					*Macrocephalites sp.*
1	0	21	5	4	2	14	5	7	19	23	5	7	19	6	7	6	9	5	13	17	10	11	17	7	4	9	3	3	14	2	2	0	5	5	5	0	0	0	2	*Macrocephalites* (total specimens)
1	0	6	2	1	1	6	3	4	7	14	4	4	7	2	4	3	5	3	6	7	5	7	6	4	2	3	3	3	5	1	1	0	2	3	4	0	1	0	1	Number of *Macrocephalites* species

Table 2: Basinal–level Bathonian–Callovian assemblages as understood in the present work.

Kachchh biozonation								
Stage	Substage	Zones	Subzone	Bed no. at Jumara	Ammonite assemblage (Nominal species in bold)	Marker Beds	Localities best exposed at: Primary	Localities best exposed at: Secondary
Oxfordian	Early	Maya-Helenae-Kranaus		E1	**Mayaites sp., Peltoceratoides (Peltoceratoides) constantii, Peltoceratoides (Parawedekindia) arduennensis,** Metapeltoceras diversiforme, Alligaticeras aff. polymorphum, Dichomosphinctes sp., Peltoceratoides (Peltomorphites) cf. propinquis, Euspidoceras (Euspidoceras) sp., Properisphinctes sp., Mayaites rotundus	Dhosa Oolite	Jara	Jumara
Callovian	Late	Athleta	Ponderosum	D15-D9	**Peltoceras (Peltoceras) ponderosum**, Peltoceras (P.) athleta, Peltoceras (P.) kachchhense, Peltoceras (P.) kumagunense, Peltoceras (P.) metamorphicum, Peltoceras (P.) solidum, Peltoceras (P.) aff. vijaya, Unipeltoceras sp., Euspidoceras (Euspidoceras) sp., Hubertoceras mutans, H. omphalodes, Metapeltoceras sp.		Jumara	Jara
			Athleta	D8-D1	**Peltoceras (Peltoceras) athleta**, Orionoides anguinus, Peltoceras (P.) kachchhense, Peltoceras (P.) metamorphicum, Peltoceras (P.) vijaya, Collotia fraasi, C. kachchhense, Euaspidoceras (Euaspidoceras) sp., Hecticoceras (Sublunuloceras) lariense var. plana, Hubertoceras mutans, H. omphalodes, Kinkiliniceras sp., Lytoceras sp., Obtusicostites buckmani, Paralcidia aff. obsolete, Subgrossouvria gudjinsirensis var. tenius	Athleta Sandstone	Jumara, Jara	Keera, Jara
	Middle	Obtusicostites		C37-C17	**Hubertoceras-Obtusicostites-Hecticoceras assemblage:** Hubertoceras omphalodes, H. hubertus var. densicostatum, H. mutans var. evolutum, O. buckmani, Obtusicostites aff. waageni, O. ushas, O. ushas var. compressa, Hecticoceras (S.) lariense var. plana, Erymnoceras jumariensis, Collotia fraasi, Kinkiliniceras aff. varuna, Lytoceras sp., Reineckeia (Reineckeia) waageni, Subgrossouvria intermedia, S. gudjinsirensis var. tenius		Jumara	Keera, Jara
				C16-C13	**Eucycloceras-Reineckeia-Hubertoceras assemblage:** Eucycloceras eucyclum, E. pilgrim, Hubertoceras omphalodes, H. mutans var. evolutum, Collotia (Reineckeia) octagona, Collotia oxyptycha, Obtusicostites sp., Putealiceras bisulcatum, Rehmannia (Loczyceras) reissi, Rehmannia (L.) rudis, Reineckeia (R.) waageni, R. (R.) crispa, R. (R.) stuebeli, Subgrossouvria gudjinsirensis var. tenius		Jumara	Keera, Jara, Habo
		Anceps	Kleidos	C12-C4	**Sivajiceras kleidos**, Collotia (Reineckeia) octagona, Reineckeia (R.) tyranniformis, R. (R.) waageni, R. (R.) crispa, Subgrossouvria gudjinsirensis var. tenius, Subkossmatia ramosa, Eucycloceras pilgrim, Kinkiliniceras aff. subwaageni, K. discoideum, Macrocephalites subcompressus, Paralcidia khengari, Phlycticeras gr. pustulatum, Putealiceras bisulcatum, Choffatia shakuntala	Ridge Sandstone - II (Zoophycos Beds - II)	Jumara, Jara	Keera, Jara, Habo
			Ramosa	C3-C2	**Subkossmatia ramosa**, S. opis, S. cognibrown, Reineckeia (Reineckeia) stuebeli, R. (R.) crispa, R. (R.) waageni, Rehmannia (Loczyceras) reissi, Eucycloceras eucyclum, Subgrossouvria gudjinsirensis var. tenius		Jumara	Keera, Jara, Habo
	Early	Opis		C1	**Subkossmatia opis**, Reineckeia (R.) anceps, Indosphinctes urbanus, M. subcompressus, Collotia oxyptycha, Eucycloceras eucyclum, Hecticoceras proximum	Ridge Sandstone - I (Zoophycos Beds - I)	Jumara	Keera, Jara, Habo
		Semilaevis		B45-B36	**Macrocephalites semilaevis**, M. magnumbilicatus, M. subcompressus, Phlycticeras polygonium, Rehmannia (Loczyceras) reissi, Indosphinctes peregrinus, I. choffati, Subgrossouvria gudjinsirensis var. tenius		Jumara	Keera, Jara, Habo
		Formosus		B35-B30	**Macrocephalites formosus**, Bullatimorphites bullatus, Collotia oxyptycha, Hecticoceras proximum, Indosphinctes peregrinus, I. urbanus, M. chariensis, M. dimerus, M. lamellosus, M. subcompressus, Paracenoceras sp., Parapatoceras tuberculatum, Reineckeia (R.) tyranniformis		Jumara	Jara, Habo
		Dimerus-Diadematus		B29-B11	**Macrocephalites diadematus, M. dimerus,** Oxycerites cf. pleurocamya, Hecticoceras michalski, Bullatimorphites (Bomburites) densicostatum, Calliphylloceras disputable, Choffatia madani, C. subbakeriae, Indosphinctes errans, Indosphinctes urbanus, M. formosus, M. lamellosus, M. elephantinus, M. chrysoolithicus, M. chariensis, M. subcompressus, M. transitorius, Paralcidia sp., Parapatoceras tuberculatum, P. distans, Paroecotraustes (Oecotraustes) sp., Subgrossouvria gudjinsirensis var. tenius		Jumara	Jara
		Madagascariensis		B10-B1	**M. madagascariensis**, Bullatimorphites bullatus, Kheraiceras cosmopolitum, Indosphinctes peregrinus, Choffatia baluchistanensis, M. elephantinus, M. chariensis, M. dimerus, M. formosus, M. lamellosus, M. subcompressus, M. transitorius, Parapatoceras sp.		Jumara	Jara
Bathonian	Late	Triangularis		A8-A6	**Macrocephalites triangularis, M. cf. manataranus, Sivajiceras congener,** Epistrenocers sp., Bullatimorphites sp., Oxycerites sp., M. dimerus, Choffatia cf. furcula, C. baliensis, C. baluchistanensis, C. subbakeriae, Paracenoceras hexagonoides, P. jumarensis, P. wandaensis	Sponge Beds / Raimalro Lismetone	Jumara	Bela Island (Mouwana Dome)
		Procerites		A5	**Procerites cf. hodsoni,** Procerites sp., M. triangularis, Procymatoceras cf. intumescens, Homoeoplanulites sp., Micromphalites aff. hourcqui,		Jumara	Pachchham Island (Goradongar, Kaladongar)
	Middle	Arkelli		A4-A1	**Procerites (Gracilisphinctes) arkelli, Macrocephalites cf. etheridge,** M. triangularis, M. bifurcatus bifurcatus, M. bifurcatus intermedius, Procerites hians, Epimorphoceras decorum, Sivajiceras congener, Parapatoceras distans, Reineckeia sp. A and B, Eutrephoceras sp., Seimiradzkia cf. verciacensis, Procerites cf. schloenbachi (Grossouvre), Micromphalites (Clydomphalites) cf. clydocromphalus, Micromphalites (Clydomphalites) sp. indet., Micromphalites aff. hourcqui, Clydoniceras triangulare, Clydoniceras pachchhamensis, Clydoniceras sp., Bullatimorphites (s.s.)	Yellow Bed, Goradongar Yellow Flagstone	Jumara, Nara	Jhura, Pachchham Island (Goradongar, Kaladongar)
					Macrocephalites cf. etheridgi		Jhura, Nara	Pachchham Island (Goradongar, Kaladongar)

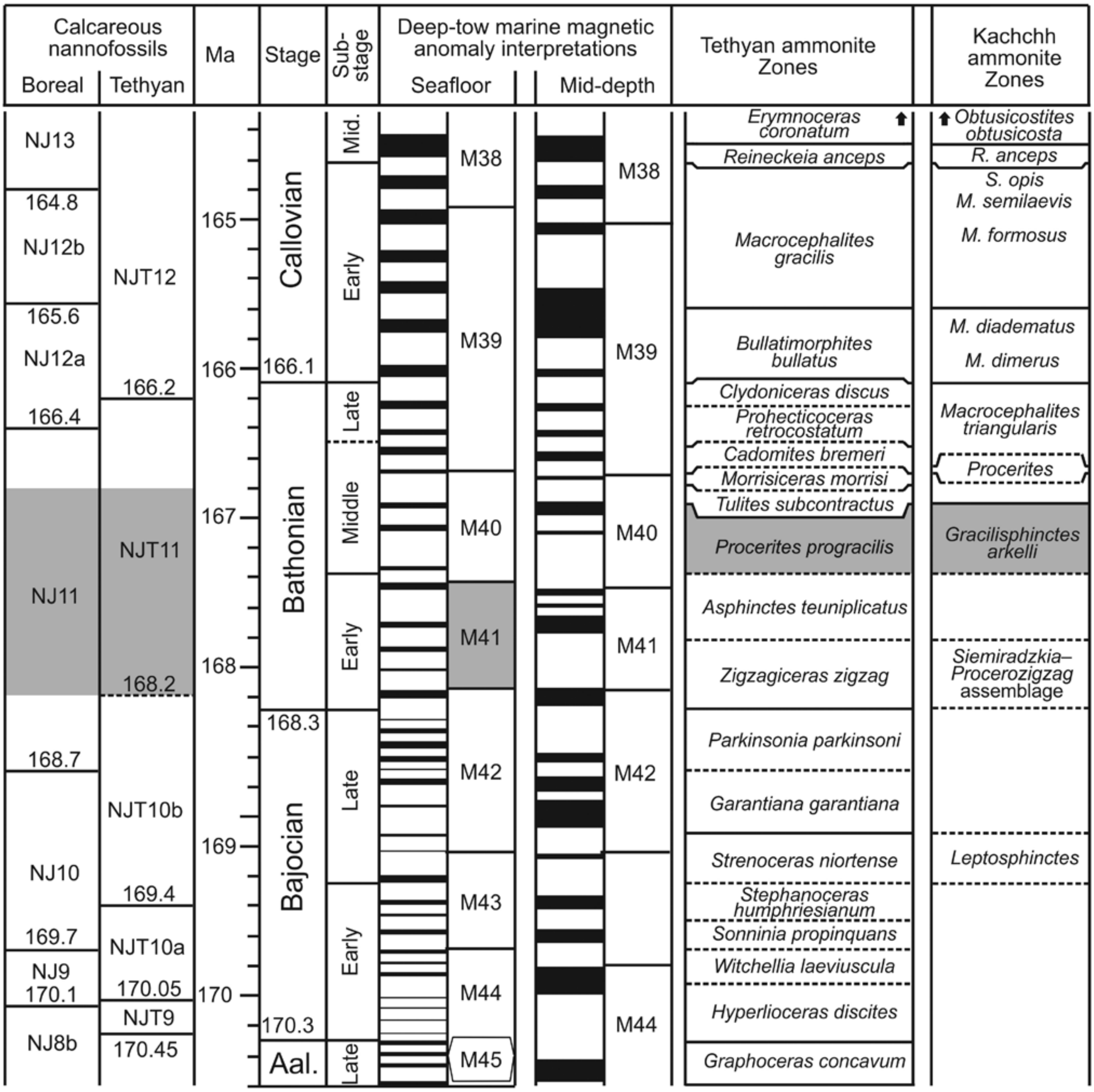


Figure 14: Global Nannofossil zones, Magnetostratigraphy, and ammonite biozonation. Those in dark gray are suggested ages of Yellow bed (bed A4); Early to early Middle Bathonian (168.2–167.2 Ma) based on calcareous nannofossils (Rai in Jain et al. 2013); M41 based on magnetostratigraphy (Mamilla et al. 2016) and *Procerites progracilis* Zone based on ammonites (Jain 2014; this study). All ages are calibrated to Gradstein et al. (2012) timescale (= GTS, 2012).

Cadomites; see Figs 17a–c, 18a, b, c), it is still safe to assign this "*Siemiradzkia–Procerozigzag* assemblage" (specimens from beds 0–9 only) to an Early Bathonian age, albeit not including their beds 10–15 in it (Fig. 13b). Their younger beds (10–15) can be correlated with the basal bed at Jumara, the Yellow bed of Jain (2014); both containing *Micromphalites*, *Procerites*, *Oecotraustes*, and *Siemiradzkia* (see Jain 2014; the *Siemiradzkia* of Jain et al. 1996 is *Wagnericeras* sp. (m); present interpretation). Thus, the Nara Dome sediments (except beds 10–15) are older than those occurring at Jumara (Fig. 13a–c).

2.4 Jhura Dome

Roy et al. (2007) reported *Macrocephalites* cf. *etheridgei* Spath (Fig. 10a) from their bed 2, a "golden oolite and shale alternation" (Fig. 13d), and correlated the strata with the late Middle Bathonian Standard European Bremeri Zone (Roy et al. 2007; Tab. 2). Recently, Jain et al. (1996) and Jain (2014) recorded *Procerites* (*Gracilisphinctes*) aff. *arkelli* Collignon (M) from the overlying (~40 m) bed 3 of Roy et al. (2007), a "hard slabby grayish yellow limestone with thinner and distant golden oolite bands and shale alternations" (Fig. 13d). But, Roy et al. (2007,

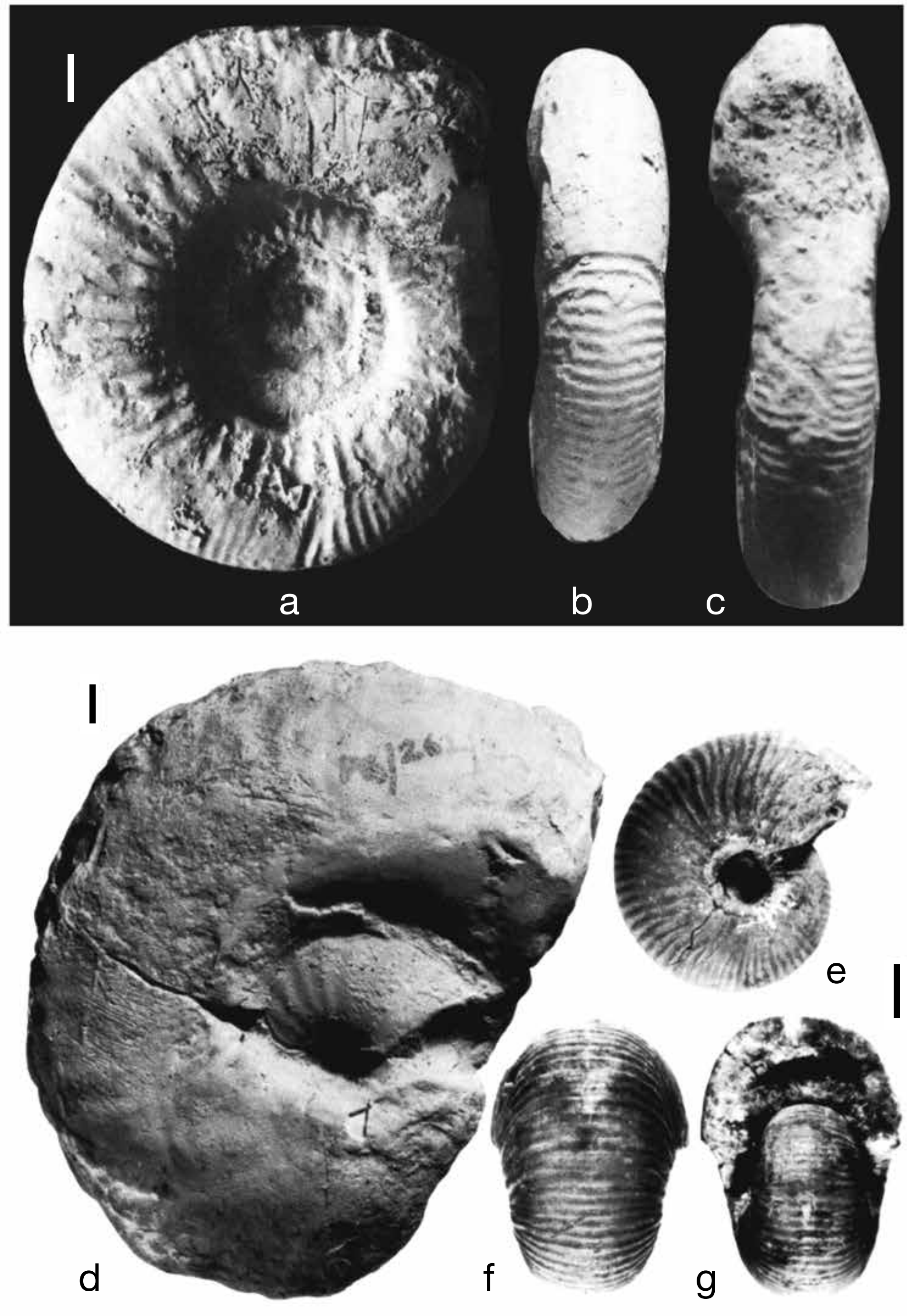


Figure 15: (a–c) *Leptosphinctes* sp. (Macroconch), septate, specimen no. PK/148/10a, bed 11, diameter = 108mm, north–east of Kuran, Kaladongar, Pachchham Island (see Fig. 1b) (refigured from Jaitly & Singh 1983: fig. 2, p. 94). **(d–g)** *Bullatimorphites* s. s. (refigured from Pandey & Westermann 1988: p. 149, fig. 2) from the lower level of Goradongar Flagstone Member (Middle Bathonian), see text for explanation and Fig. 2. **(d)** 130 mm, almost complete but lacking only the ventral part of the peristome, **(e–g)** 43 mm, penultimate whorl. Bars represent 1 cm.

table 2) correlated the occurrence of *Procerites* (*G.*) *arkelli* with the early Middle Bathonian European Progracilis Zone. Therein lies the problem. At Jhura, *Macrocephalites* cf. *etheridgei* Spath occurs (according to Roy et al. 2007) earlier than *Procerites* (*Gracilisphinctes*) aff. *arkelli* Collignon (M) (Fig. 13d) but at Nara (according to Roy et al. 2007), it occurs later (Fig. 13a) and both occur together at Jumara (Jain 2014; Fig. 13c). It must be noted that at Jhura, the gap between the occurrences of the two genus is almost 40 m (Fig. 13d). Hence, a more detailed bed–by–bed collections may resolve this discrepancy. For now, Roy et al.'s (2007) lower part of bed 2 (Badi Lower Golden Oolite; Fig. 13d), on lithostratigraphic grounds has already been correlated with the early Late Bajocian *Leptosphinctes*–yielding Pebbly Rudstone Bed of the Pachchham Island (Fürsich et al. 2001; Jain 2014; see also Fig. 2). The overlying Badi Upper Golden Oolite bed is from where Roy et al. (2007) recorded their *M*. cf. *etheridgei* (Fig. 13). Thus,

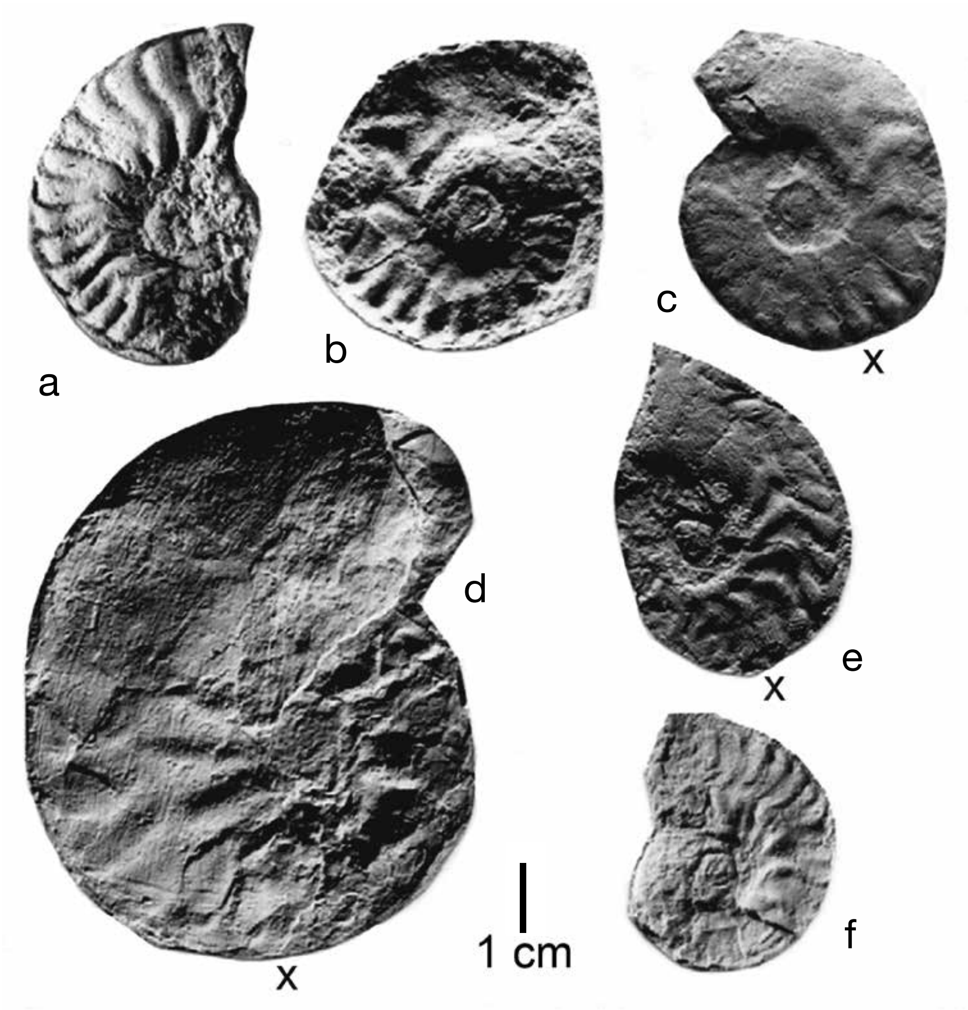


Figure 16: *Prohecticoceras manjalense* Roy et al., 2007 (Macroconch and microconch), **(a–f)** refigured from Roy et al. 2007: p. 644, fig. 10.4–10.8. **(a)** lateral view of a phragmocone, specimen no. JUM/0804/6, Nara (Macroconch). **(b, c)** (microconch), **(b)** lateral view of the Holotype, **(c)** cast of Holotype, specimen no. JUM/0804/8. **(d)** lateral view of adult specimen; specimen no. JUM/0804/5 from Nara (Macroconch). **(e)** Cast of Geological Survey of India Type 1919; an adult shell with body chamber preserved from bed 1 of Nara. **(f)** lateral view, specimen no. JUM/0804/12, (microconch). All specimens are from Nara. Cross (x) marks the beginning of body chamber.

it is safe to assume that between the Early Bajocian Badi Lower Golden Oolite and the early Middle Bathonian Badi Upper Golden Oolite bed, lies the Early Bathonian fauna of Nara (which, coincidently is also of the same thickness at Nara, 24 m; Fig. 13).

2.3 Jumara Dome

Jain (1996, 2014) assigned the Yellow bed assemblage to an early Middle Bathonian age and correlated the same with the Standard European Progracilis Zone (Figs 1, 3–12). At Jumara, as compared to Nara, both *Macrocephalites* and *Gracilisphinctes* occur together in the Yellow Bed (= bed A4; Figs 12, 13), the latter in larger numbers and in size, too. *Prohecticoceras* has not yet been recorded, so far from Jumara or elsewhere within the Kachchh basin. Jain (2014), for this assemblage, erected the Arkelli Zone that included the common occurrences of *M.* cf. *etheridgei* Spath and *Procerites* (*Gracilisphinctes*) *arkelli* from Nara, Jumara and Jhura (Fig. 13), and of the latter form, from the Pachchham Island (see Pandey & Callomon 1995).

Higher up, within the Late Bathonian, there are additional problems vis–à–vis faunal age assignment and the placement of some ammonite records. Roy et al. (2007) marked the presence of *Epistrenoceras* (Figs 19a–d) from their bed 1, the lower beds of Jumara. But, in their initial paper (Kayal & Bardhan 1998: p. 933), the same species came from the “coralline rudstone alternating with white– to brown–colored wackestone; another important ammonite species is *Epimorphoceras decorum* (Waagen), besides diverse and abundant corals”. There are two problems with this statement: firstly, the “coralline rudstone alternating with white– to brown–colored wackestone” is not part of the basal beds at Jumara but is, in fact, the Upper Diverse Coral Bed (bed A5b of Jain et al. 1996) (Fig. 20) that contains profuse coral heads and secondly, *Epimorphoceras decorum* (Waagen) (refigured in Fig. 9a–f) did not come from this bed but from the Lower Diverse Coral Bed

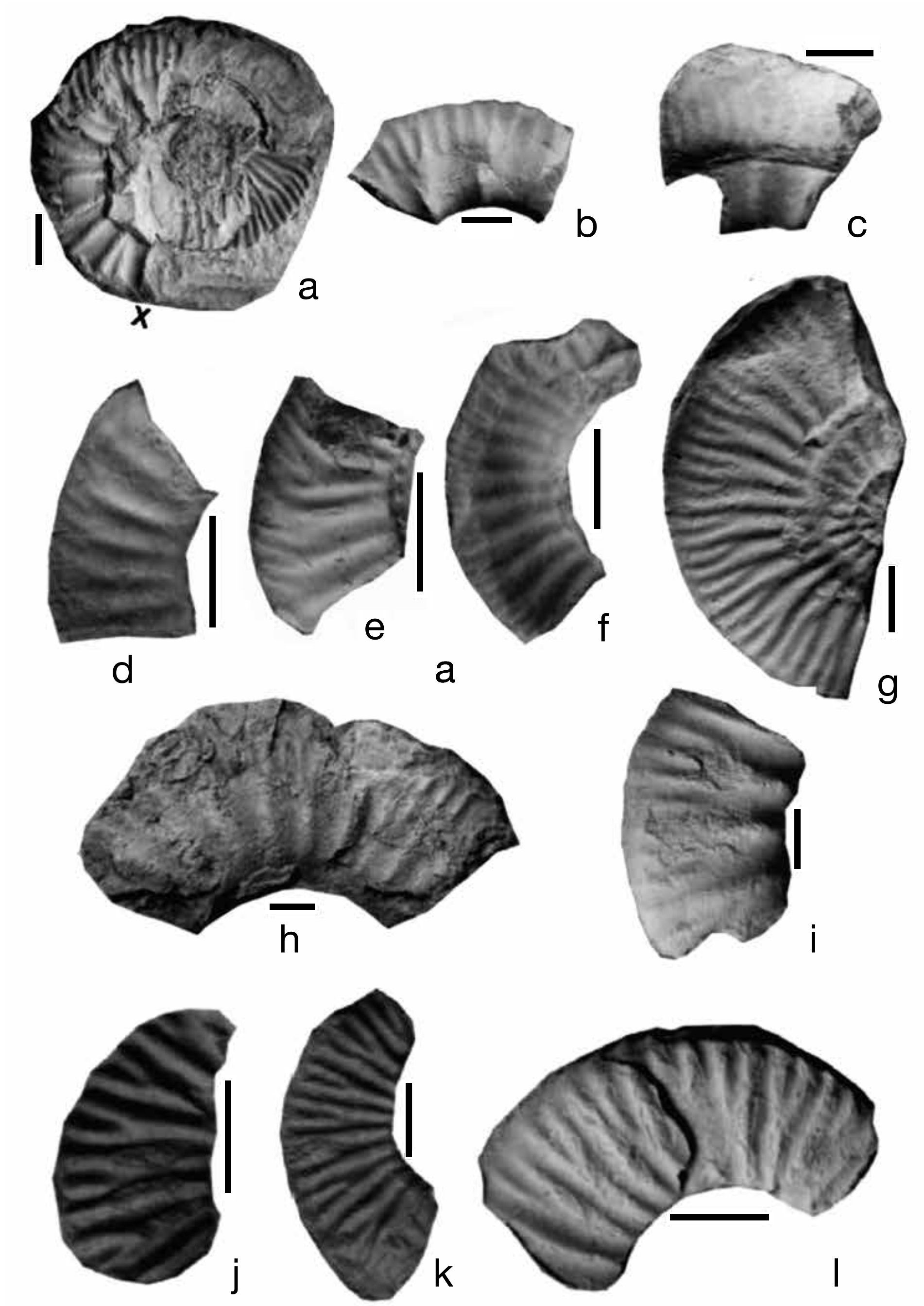


Figure 17: The Early Bathonian *Siemiradzkia–Procerozigzag* assemblage from Nara (refigured from Pandey & Pathak 2015: pls. 1–3). See also Fig. 13. **(a–c)** *Zigzagiceras* sp., body chamber fragments, lateral views. **(a)** specimen no. NR 9c/15/13, **(b)** specimen no. NR 9c/57/13, **(c)** specimen no. NR 9c/ 59/13, **(d–g)** *Parkinsonia* spp., **(d)** specimen no. NR 9c/83/13, **(e)** specimen no. NR 9c/12/13, **(f)** specimen no. NR 7/40/13 from bed 7, **(g)** specimen no. NR 9c/82/13. Except (f), all are from bed 9c, **(h–j)** *Procerozigzag* sp., **(h)** specimen no. NR 7/46/13 from bed 7, septate, **(i)** specimen no. NR 13/95/13 from bed 13, body chamber fragment, **(j)** specimen no. NR 9c/70/13 from bed 9c, **(k–m)** *Siemiradzkia* spp., body chamber fragments, **(k)** specimen no. NR 9c/1/13 from bed 9c, **(l)** specimen no. NR 9a/111/13 from bed 9a. It must be noted that in absence of ventral views, the fragmentary records of *Parkinsonia* (Figs. d–g; could well be *Planisphinctes*), *Procerozigzag* (Figs. h, i; could be *Procerites*). Hence, these records must be considered with caution. However, taken together, it is a remarkable Early Bathonian record. Cross (x) marks the beginning of body chamber. Bars represent 1 cm.

(bed A4; Fig. 20). The holotype of *E. decorum* (Waagen) (refigured in Fig. 9a–f) kept at the museum of the Geological Survey of India (Calcutta) has the yellow matrix, characteristic of all Yellow Bed (bed A4) ammonites. The subjacent bed A5a has yielded the dimorphic pair of *Procerites* cf. or aff. *hodsoni* Arkell (Jain et al. 1996: p. 134) (see Figs 19, 20).

Another bone of contention is the occurrence of *Bullatimorphites* by Bardhan et al. (1988) (refigured in Fig. 19e). They recorded this poorly–illustrated species from a “cream–colored limestone 15 m below the Patcham–Chari boundary” (Bardhan et al. 1988: p. 22). This puts the specimen within Bed A8 (Sponge Beds) (see Fig. 20 for bed thickness); although Bardhan et al. (1988) did not mention where their “Patcham–Chari boundary” was? Later, curi-

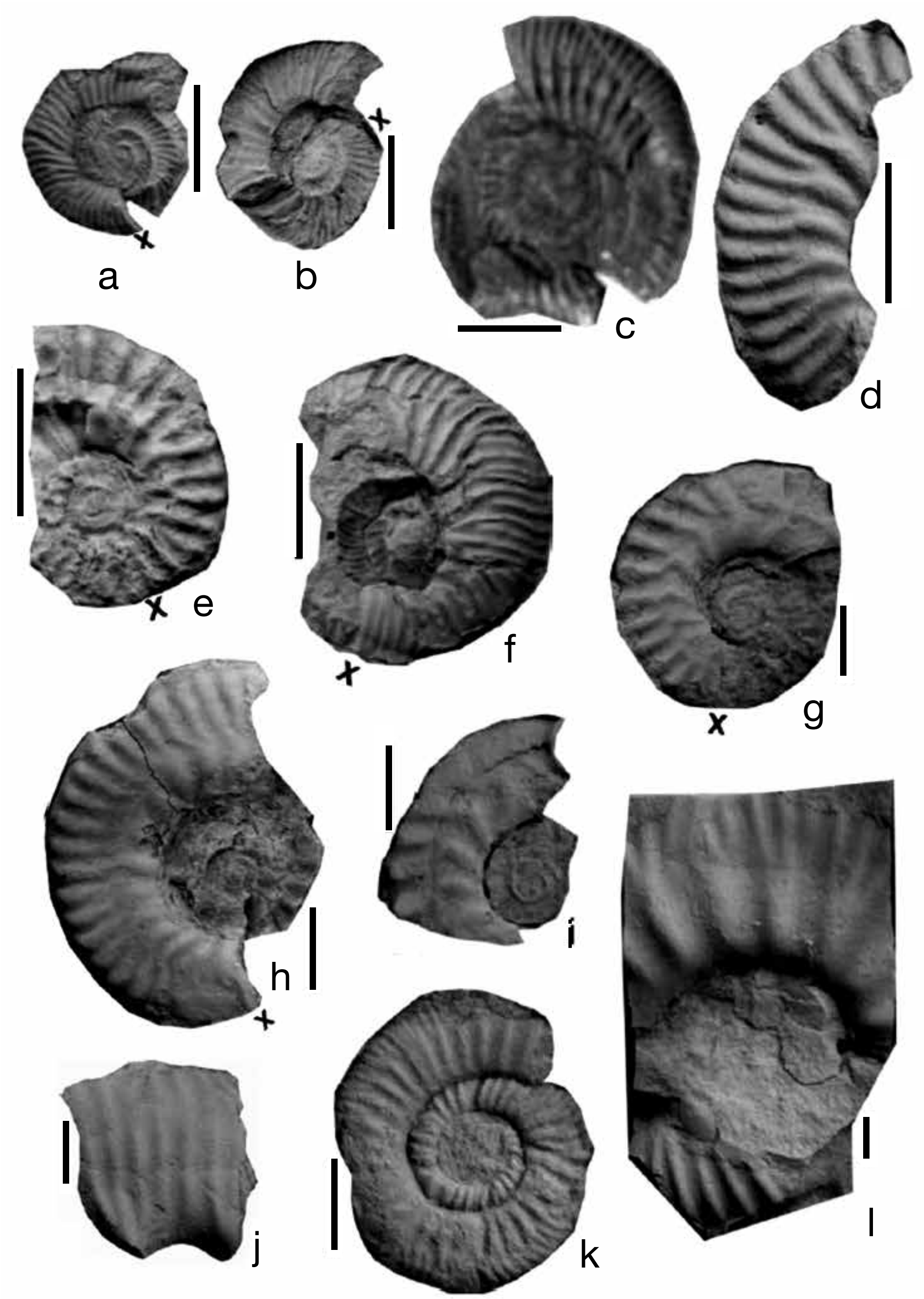


Figure 18: The Early Bathonian *Siemiradzkia–Procerozigzag* assemblage from Nara (refigured from Pandey & Pathak 2015: pls 1–3). See also Fig. 13. **(a, b)** *Berbericeras* sp., **(a)** specimen no. NR 9c/84/13 from bed 9c, **(b)** specimen no. NR 9b/56/13 from bed 9b, **(c)** *Cadomites* sp., specimen no. NR 9c/80/13 from bed 9c, septate, **(d, e)** *Oecotraustes* sp., **(d)** specimen no. NR 15/99/13 from bed 15, body chamber fragment, **(e)** NR 1/31/13 from bed 1, **(f)** *Ebrayiceras* sp., specimen no. NR 9c/66/13 from bed 9c, **(g–i)** *Prohecticoceras* spp., **(g)** specimen no. NR 9c/65/13, **(h)** NR 13/92/13 from bed 13, body chamber fragment, **(i)** specimen no. NR 9c/5/13 from bed 9c, **(j)** ?*Telermoceras* sp., specimen no. NR 9c/19/13 from bed 9c, body chamber fragment, **(k–l)** *Procerites* spp., **(k)** specimen no. NR 9c/8/13 from bed 9c septate, **(l)** specimen no. NR 11/87/13 from bed 11, body chamber fragment. It must be noted that in absence of ventral views, the fragmentary records of ?*Telermoceras* (18j), must be considered with caution. However, taken together, it is a remarkable Early Bathonian record. Cross (x) marks the beginning of body chamber. Bars represent 1cm.

ously, Kayal & Bardhan (1998: p. 933, fig. 2) placed both beds A7–A8 (Fig. 20) within the Lower Callovian Chari Formation (Figs 20, 21), and the *Bullatimorphites* specimen above the boundary!

Bardhan et al. (2002) recorded *Kheraiceras* cf. *hannoveranus* (Roemer) from their Bed 4 (top of the Patcham Formation at Jumara = bed A8; Fig. 20). *K. hannoveranus* is the index of the mid–Late Bathonian Hannoveranus subzone (Retrocostatum Zone, Western Europe) in Central Europe and occurs just below the *Epistrenoceras*–yielding Histricoides subzone, the topmost subzone of the Retrocostatum/Orbis zones (Möning 2014). In the Kachchh basin, however, *Epistrenoceras* occurs below *K.* cf. *hannoveranus* (Bardhan et al. 1988, 2002) (Fig. 20). But, then, in Europe, *K. hannoveranus* has a long-range

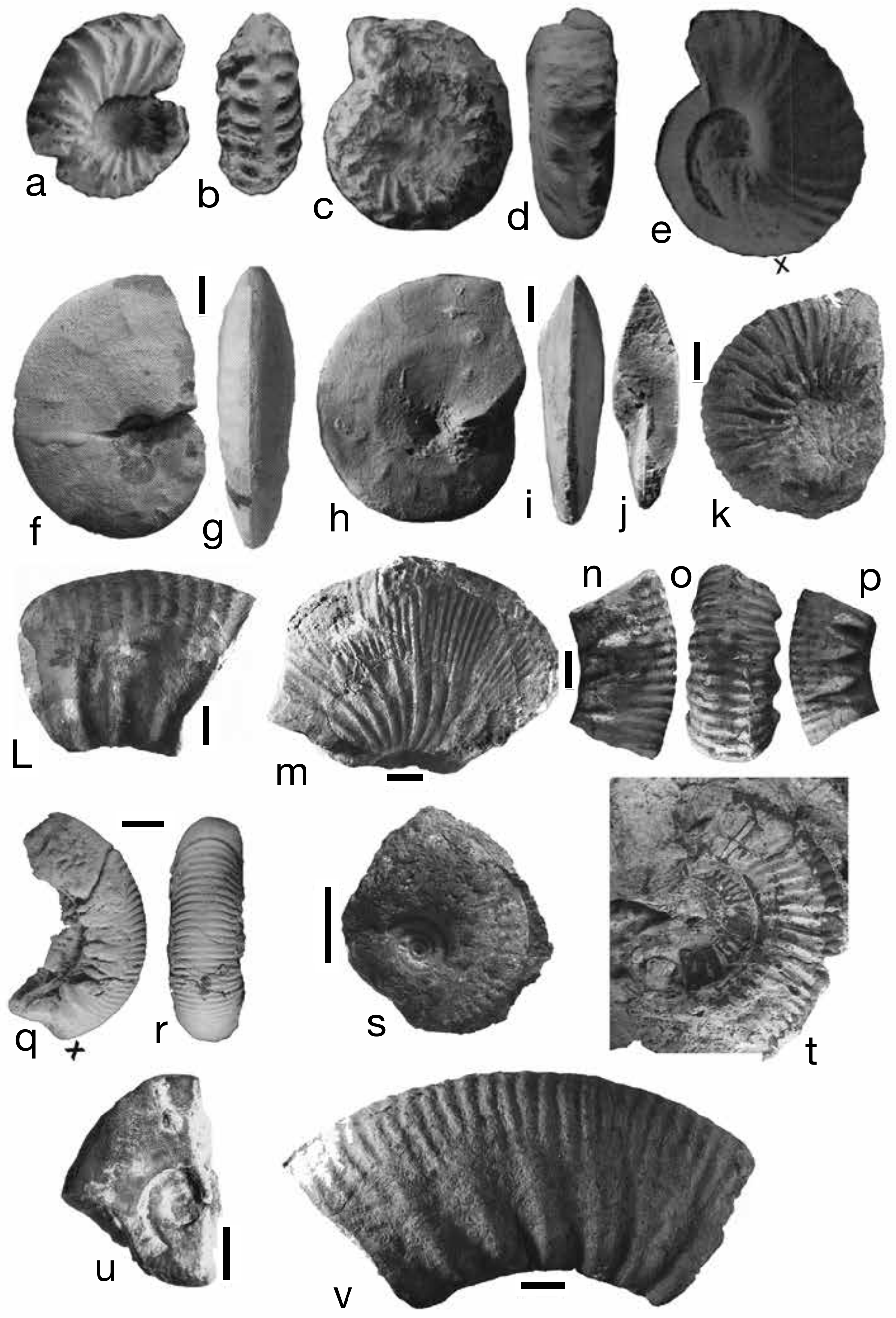
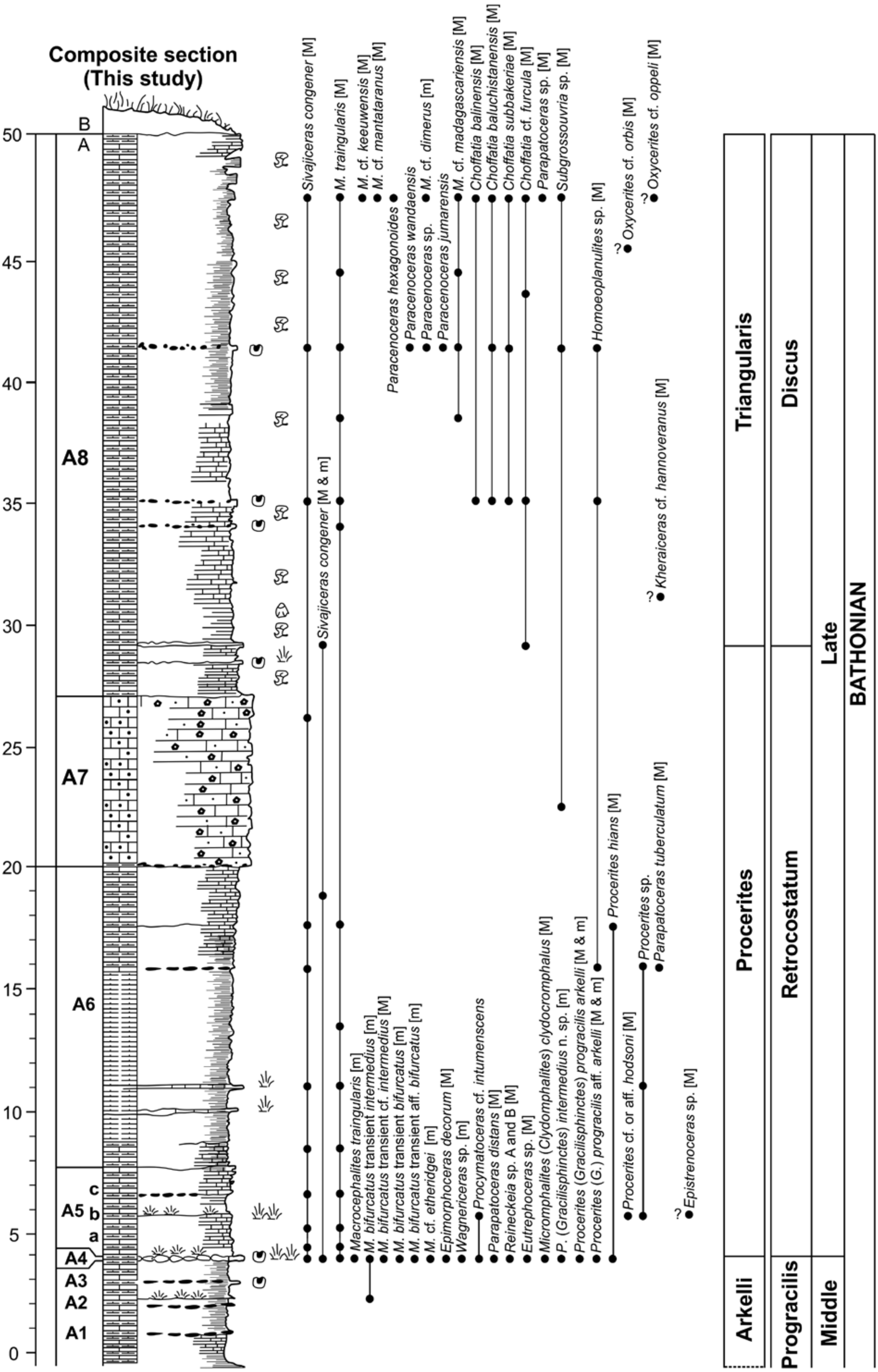


Figure 19: Additional Bathonian taxa. **(a–d)** *Epistrenoceras* sp. A (microconch) (refigured from Kayal & Bardhan 1998: p. 933, pl. 1), septate specimens, from "Bed 1, coralline rudstone alternating with white–to brown–colored wackestone", Jumara (see text for explanation). a–b: specimen no. JUM/J/T/32, **(a)** lateral view, **(b)** ventral view, **(c, d)** septate specimen no. JUM/J/T/33, **(c)** lateral view, **(d)** ventral view, **(e)** *Bullatimorphites* sp. (refigured from Bardhan et al. 1988) = *Bullatimorphites* cf. *hannoveranus*, specimen no. JUM P–2, diameter = 59 mm, from a "cream–colored limestone 15 m below the Patcham–Chari boundary". See text for explanation, **(f, g)** *Oxycerites* cf. *oppeli* Elmi (refigured from Pandey et al. 2012: pl. 3, fig. 4), specimen no. Jm–II/38/7, from the top of Bed A8 (Sponge Beds; see text for explanation), **(f)** lateral view, **(g)** ventral view, **(h–j)** *Oxycerites* cf. *orbis* (Giebel) (refigured from Roy et al. 2007: p. 644, fig. 10.9–10.11), specimen no. JUM/O/1, from the top of Bed A8 (Sponge Beds; see text for explanation), **(h)** lateral view, **(i)** ventral view, **(j)** apertural view, **(k)** *Macrocephalites* cf. *dimerus* (Waagen) (microconch), specimen no. Ju/22/38, from the top of Bed A8 (Sponge Beds), **(l)** *Choffatia* cf. *furcula* Neumayr (microconch), specimen no. Ju/24/166b, from the top of Bed A8 (Sponge Beds), **(m)** *Macrocephalites* cf. *madagascariensis* (Macroconch), septate, specimen no. Ju/22/200, from the top of Bed A8 (Sponge Beds), **(n–p)** *Sivajiceras* cf. *congener* (Waagen) (Macroconch), inner whorl, specimen no. Ju/24/9, from Bed A6, **(n)** lateral view, (o) ventral view, **(p)** opposite lateral view, **(q, r)** *Subgrossouvria* sp. indet., specimen no. Ju/23/60, from Bed A7, **(q)** lateral view, **(r)** ventral view, **(s)** *Oecotraustes* sp. indet., specimen no. Ju/23/62, lateral view from Bed A7, **(t)** *Procerites* cf. or aff. *hodsoni* (Macroconch), specimen no. Ju/26/168, lateral view from Bed A4, **(u)** *Oecotraustes* sp. indet., specimen no. Ju/26/169, lateral view from Bed A4, **(v)** *Procerites* cf. *hians* (Waagen) (Macroconch), specimen no. Ju/24/166, lateral view from Bed A6. For all specimens, see Figs 24, 25 for their exact stratigraphic position. Cross (x) marks the beginning of body chamber. Bars represent 1cm.

Figure 20 (Page 25): Profile, Biozonation and ammonite content of the Patcham Formation exposed at the Jumara Dome, north–west of the village of Jumara. The ammonite records of Kayal & Bardhan (1998), Roy et al. (2007), and Pandey et al. (2012) are incorporated and mentioned. The Chrysoolithicus Zone of the former two is not accepted as *Macrocephalites chrysoolithicus* has never been illustrated or its exact sampling location ever mentioned. *M. chrysoolithicus* is a typical mid-Early Callovian form that dominates in the Keera Dome (with a Zonal status; see also Krishna et al. 1988; Krishna & Cariou 1993; Krishna & Ojha 1996, 2000). The Patcham–Chari boundary is concealed under debris and represents a gap in the lithosection (between beds A and B) at the top of the Patcham Formation. The boundary exposed at the top of the northern limb (Fig. 7b) is a lithological boundary between beds A6 and A7 but is often confused as the Patcham–Chari boundary (see also inset in Fig. 25). 1: Sample location of *Micromphalites* (*Clydomphalites*) *clydocromphalus* Arkell (Macroconch), specimen no. SJ/Ju/14/A4/1. 2: Sample location of *Macrocephalites subcompressus* (Waagen) (microconch), specimen no. Ju/12/76.


Composite section
(This study)
B
A
A8
A7
A6
A5
a
b
c
A4
A3
A2
A1
0
5
10
15
20
25
30
35
40
45
50
Sivajiceras congener [M]
M. traingularis [M]
M. cf. keeuwensis [M]
M. cf. mantataranus [M]
Paracenoceras hexagonoides
Paracenoceras wandaensis
Paracenoceras sp.
M. cf. dimerus [m]
Paracenoceras jumarensis
M. cf. madagascariensis [M]
Choffatia balinensis [M]
Choffatia baluchistanensis [M]
Choffatia subbakeriae [M]
Choffatia cf. furcula [M]
Parapatoceras sp. [M]
Subgrossouvria sp. [M]
Homoeoplanulites sp. [M]
Oxycerites cf. orbis [M]
Oxycerites cf. oppeli [M]
Sivajiceras congener [M & m]
Kheraiceras cf. hannoveranus [M]
Macrocephalites traingularis [m]
M. bifurcatus transient intermedius [m]
M. bifurcatus transient cf. intermedius [M]
M. bifurcatus transient bifurcatus [m]
M. bifurcatus transient aff. bifurcatus [m]
M. cf. etheridgei [m]
Epimorphoceras decorum [M]
Wagnericeras sp. [m]
Procymatoceras cf. intumenscens
Parapatoceras distans [M]
Reineckeia sp. A and B [M]
Eutrephoceras sp. [M]
Micromphalites (Clydomphalites) clydocromphalus [M]
P. (Gracilisphinctes) intermedius n. sp. [m]
Procerites (Gracilisphinctes) progracilis arkelli [M & m]
Procerites (G.) progracilis aff. arkelli [M & m]
Procerites hians [M]
Procerites cf. or aff. hodsoni [M]
Procerites sp.
Parapatoceras tuberculatum [M]
Epistrenoceras sp. [M]
Arkelli
Procerites
Triangularis
Progracilis
Retrocostatum
Discus
Middle
Late
BATHONIAN

spanning from the Bathonian Retrocostatum Zone to the basal Callovian (Callomon et al. 1989; pers. comm. Eckhart Möning, 2017).

Recently, Pandey et al. (2012: pl. 3, fig. 4) recorded *Oxycerites* cf. *oppeli* Elmi from the top of bed A8 (Sponge Beds; Fig. 19f, g) and assigned this level to their Oxycerites Zone, and correlated the strata with the topmost part of the Standard European Discus Zone. Roy et al. (2007: p. 630) from the same level had earlier recorded *Oxycerites* cf. *orbis* (Fig. 19h–j) and correlated the same strata with the Standard European Orbis Zone, a zone below Discus (Fig. 12). *O*. *oppeli* Elmi is a younger synonym of *O*. *orbis* (Westermann & Callomon 1988: p. 3) and in Europe, spans the entire Late Bathonian as well as in the basal Callovian. In Central Europe, the acme of the species lies at the boundary of the Late Bathonian Orbis and Discus zones. Since, the sampling of both Roy et al. (2007) and Pandey et al. (2012) are broad, it is safe to assign bed A8 (the Sponge Bed = Triangularis Zone) to encompass an interval from Orbis to Discus zones, for now (Fig. 20). In Europe, such morphotytpes are typical for upper Orbis/Retrocostatum and Discus zones (Fig. 20).

Earlier, Callomon (1993), based on the occurrence of the dimorphic pair of *Sivajiceras congener* (Waagen) (re–illustrated in Fig. 6c–h) from the base of the Sponge Beds (bed A8; see Fig. 20 for exact location) in association with *Macrocephalites triangularis* Spath (M) (from the southern limb of the Jumara Dome) assigned the Sponge Beds to Late Bathonian age on grounds that *S*. *congener* closely resembles "the mid–Late Bathonian European *Procerites imitator* of the Orbis Zone" (Callomon 1993). Interestingly, *P. imitator* also occurs within the early Middle Bathonian Progracilis Zone (Hahn 1969; Dietl 1990; Page 1996). Now, dimorphic pairs have been recorded from both the Yellow Bed (bed A4; Jain 2014) and bed A6 (Figs 20, 21a), suggesting a similar longer range for this species within the Kachchh basin, also.

Recently, Pandey et al. (2012) recorded specimens of *Macrocephalites mantataranus* Boehm (their pl. 1, text–figs. 1–3) form the Yellow Bed (Bed A4). However, these are clearly misidentified and are microconch's of *M*. *bifurcatus* transient *intermedius* (Spath), that are well–illustrated by Westermann & Callomon (1988: pl. 7, text–figs 2, 3) and Jain (2014: fig. 25) (re–illustrated here in Fig. 11l–n). The ribbing pattern of *M. mantataranus* is decidedly much coarser and straighter (Westermann & Callomon 1988: pl. 10, text–figs 2, 3). Hence, their Mantataranus Zone stands invalid. *M. mantataranus* Boehm is a typical Late Bathonian Indonesian form that now occurs in Kachchh, Madagascar and Europe (Jain 2019b; see also Figs 22, 23).

Additionally, Pandey et al. (2012) marked the occurrence of *Epistrenoceras* (of Roy et al. 2007) from their bed 24, the "grayish yellow Coral Limestone" (= the Yellow Bed, bed A4 of present work), and recorded the presence of *Sivajiceras congener* (Waagen) only above this bed (Pandey et al. 2012: p. 9, fig. 2)! Clearly, both placements are wrong (see discussion above on *Epistrenoceras* sp.). Pandey et al. (2012: p. 9, fig. 2) also marked the presence of *Kheraiceras* cf. *hannoveranus* of Roy et al. (2007) from their bed 54 (= bed A7), whereas Roy et al. (2007: p. 630, fig. 2) clearly recorded the specimen above the strata and within the Sponge Beds (A8) (see Fig. 20).

Now, based on the collections of more than 649 specimens (45% of them coming from the Bathonian–Early Callovian interval), a more detailed bed–by–bed occurrence of macrocephalitids and associated taxa at Jumara is provided (Figs 20, 21; Tab. 1) along with a brief note on the Bathonian–Callovian assemblages, at the basin–level (Tab. 2).

2.5 Jara Dome

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) (Fig. 1). Recently, Jain (2019b) documented the presence of definite Late Bathonian strata at the core of the dome and recorded characteristic Indonesian ammonites *Macrocephalites keeuwensis* Boehm (M and m) (Fig. 22a–g, M and m, respectively) (Jain 2019b). Coeval sediments from the adjoining Jumara Dome (bed A8) have also yielded *M*. cf. *mantataranus* Boehm (M) (Fig. 22h–k) (Jain & Desai 2014) and *M*. *keeuwensis* var. aff. forma *flexuosa* Boehm (m) (Fig. 22l–n). Based on these finds, the age of the Indonesian *M*. *keeuwensis* Association was re–evaluated as also the age of the nominal species (*M*. *keeuwensis* Boehm) that now occurs in Kachchh, Madagascar and Europe (Fig. 23). A new Late Bathonian age was proposed for the Association (Jain 2019b; Fig. 23c) that hitherto was assigned on balance to straddle between "late Early Callovian–latest Bathonian" (Westermann and Callomon, 1988). Based on the presence of *Oxycerites* cf. *oppeli* (Pandey et al. 2012) and of *O*. cf. *orbis* (Roy et al. 2007) from bed A8 (= Triangularis Zone), the Indonesian *M*. *keeuwensis* Association in Kachchh can safely be correlated with the interval from the upper part of the Retrocostatum to the Discus zones (see Fig. 23c).

3. Ammonite biozonation

The lack of well–preserved and the occurrences of largely fragmented specimens has been the Achilles' heels for improving the Bathonian ammonite biostratigraphy for the Kachchh basin. But added to this conundrum are other factors that have complicated the biostratigraphy even more, such as species misidentification, rampant clubbing of fossil occurrences with little regard for precise sampling and stratigraphy, and more importantly citing important discoveries such as those of *Ebrayiceras* and *Wagnericeras*,

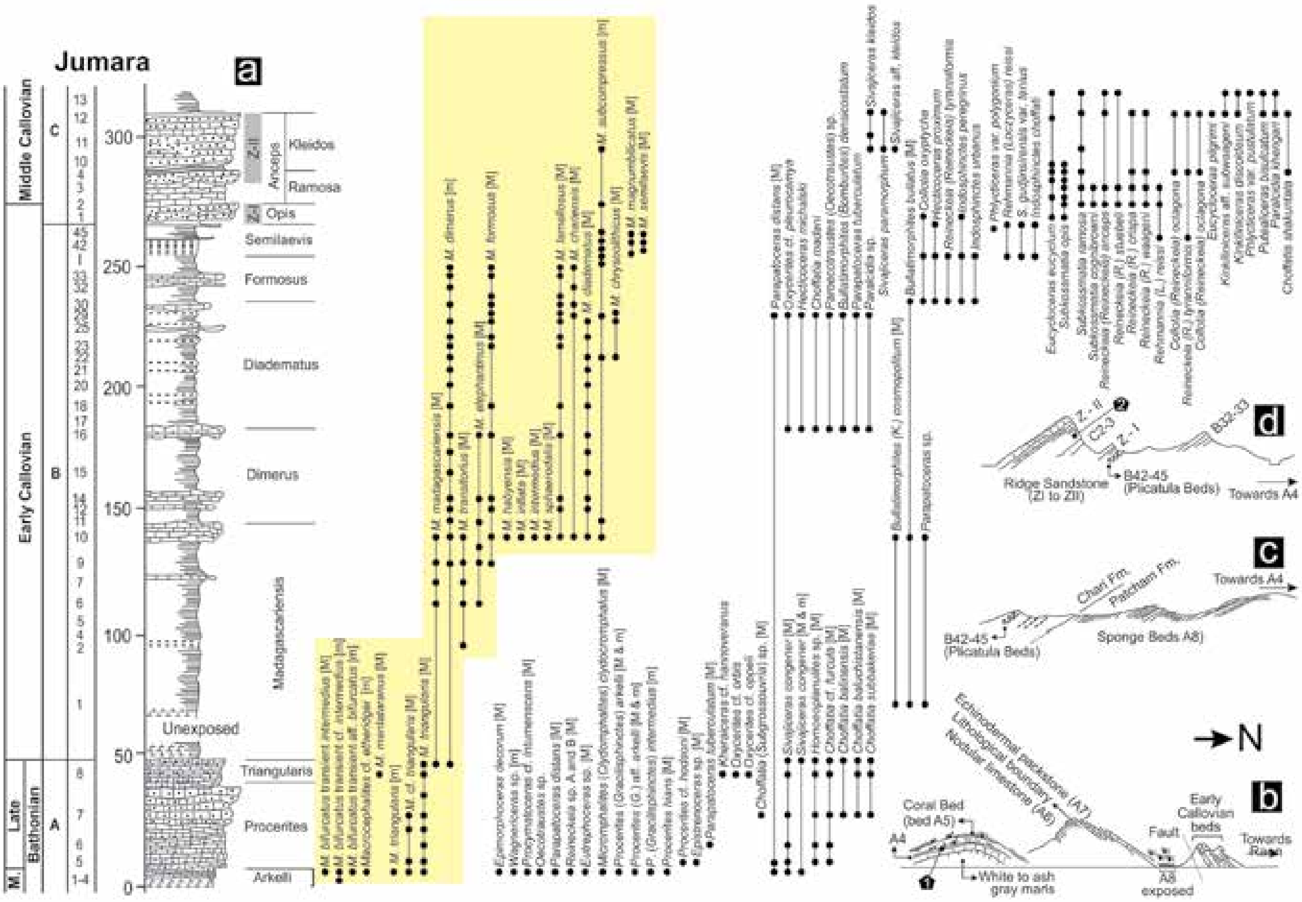


Figure 21: Detailed ammonite content for the early Middle Bathonian to mid–Middle Callovian duration at Jumara. **(a)** Macrocephalitid content (in gray), **(b–d)** The right side of (c) overlaps with the left side of (b) and so on for (d) with (c), also. North is towards the Rann, on the right side of the diagram. The best exposures of beds A1–A5 are close to the core of the dome (Fig. b), A6 and A7 above it (see b). Bed A8 is exposed both at the southern limb (Fig. b) and the northern limb (left hand side of Fig. c). At the southern limb (Fig. b) it is very much condensed due to folding. The best exposure for bed A8, however, is in the northern limb (Fig. c) where it is low–dipping but its top beds are covered with alluvium/agricultural lands, so that the Patcham–Chari boundary is not visible. Further south to this, are the Lower Callovian Chari Formation beds up until B45–C1 (Fig. c). Beds C1–C2 (see d) forms the first ridge of the Ridge Sandstone (the Zoophycos Beds – I) and the succeeding beds C3–C13 form the second ridge of the Ridge Sandstone (the Zoophycos Beds – II) (see Fig. 26 for ammonite content for the Zoophycos Beds).

among others, without illustration or description. Additionally, Kachchh workers consistently refuse to cite works of others, even working in the same locality and thus, unnecessary create their own set of biozones without comparison with pre–existing ones. It is in this backdrop, (a) an overview of the current status of the Bathonian biostratigraphy for the Kachchh basin is provided, (b) major ammonite localities and their inherent contradictions of fossil occurrences are discussed, (c) valid ammonite content is illustrated with precise stratigraphy (estimating the occurrences as precisely as possible) to have an idea of assemblage complexity, and finally, (d) present an updated ammonite range chart based on present records and incorporating valid data of other ammonite workers.

The Jumara Dome is by far the richest ammonite locality, followed by records from Nara, Jhura, Jara and Keera (Fig. 2); the latter two localities have only their basal part (core) representing latest Bathonian (for Keera: see Prasad 1998; Jain & Pandey 2000; for Jara: see Jain & Desai 2014; Jain 2019b), whereas the former two exhibit the Early–Middle Bathonian interval (Fig. 2). Records from Keera are either in part illustrated but strongly contested (see Prasad 1998) or just noted in passing (Jara: Cariou & Krishna 1988). Newer Late Bathonian finds with improved stratigraphy from Jara and Jumara domes are discussed below.

The ammonite biostratigraphy of the Kachchh basin epitomizes that of a distinct marine palaeobiogeographic province, the Indo–Malgach (Indo-Madagascan), Indo-Himalayan, Indo-East African or Ethiopean Province of various authors (see also Westermann 2000). The Bathonian ammonite faunas of this Province differs sufficiently from those of Europe; hence, it becomes necessary to work out an independent regional chronostratigraphy. Contextually, the age (based on the first and last occurrences) of a particular species, within the Kachchh basin, may differ slightly to significantly with European and Submediterranean occurrences (Jain 2014).

The presence of Late Bajocian is marked by the record of a single specimen of *Leptosphinctes* (Fig.

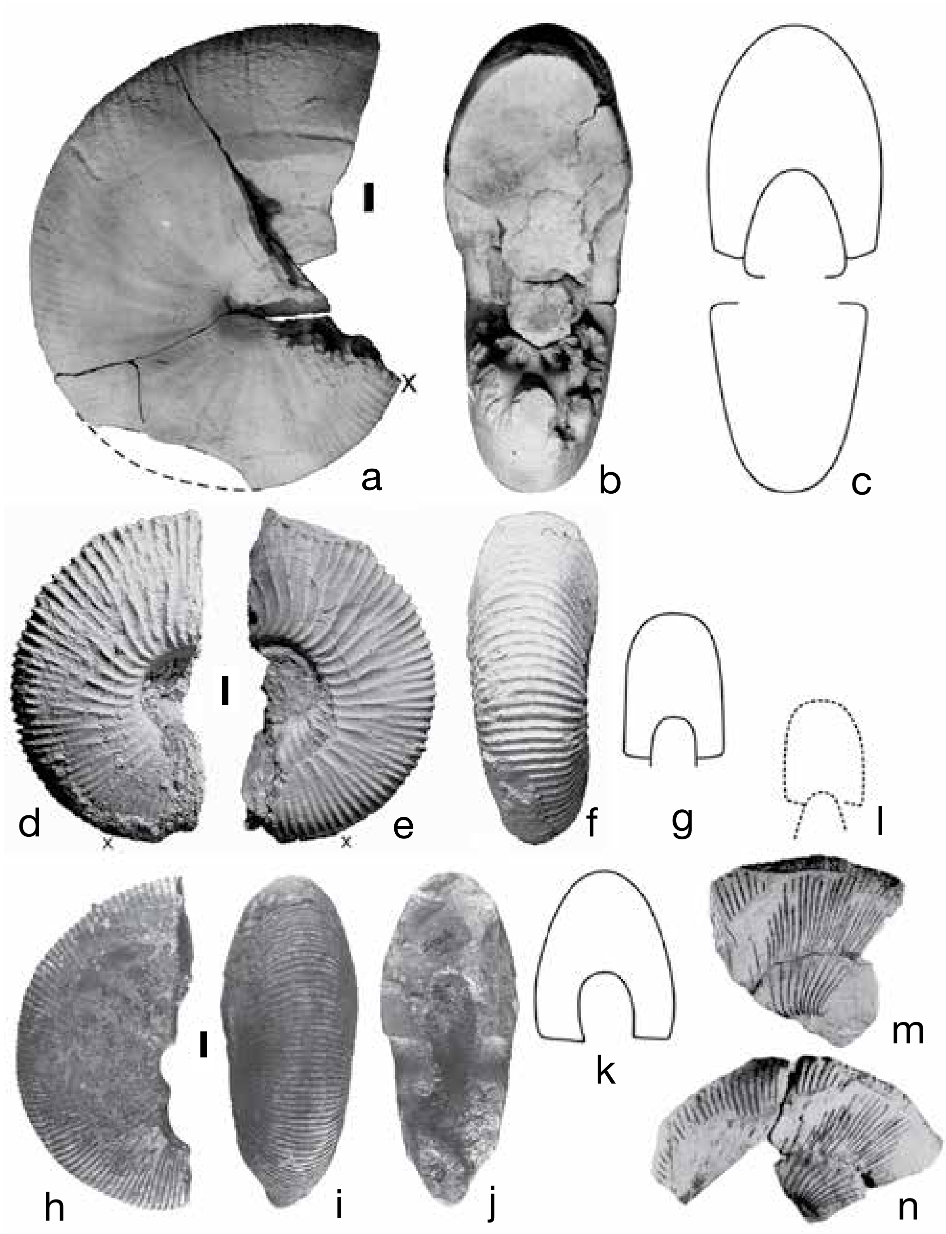


Figure 22: *Macrocephalites keeuwensis* Boehm (Macroconch). **(a–c)** Jara, specimen no. Ja/SJ/1999/Core/1, measured diameter = 172 mm, phragmocone = 132 mm. **(a)** lateral view, **(b)** ventral view, **(c)** whorl section. **(d–g)** *Macrocephalites keeuwensis* Boehm (microconch). Jara specimen no. Ja/SJ/1999/Core/2, measured diameter = 107 mm, phragmocone = 80 mm. **(d)** lateral view, **(e)** opposite lateral view, **(f)** ventral view, **(g)** whorl section. **(h–k)** *Macrocephalites* cf. *mantataranus* Boehm (Macroconch), fully septate specimen from bed A8 (Sponge Beds), Jumara, specimen no. Ju/22/8c, measured diameter = 110 mm (H: 52 mm; T = 46; U = 15 mm; see Jain, 1996; Jain and Desai, 2014). **(h)** lateral view; **(i)** opposite lateral view, **(j)** ventral view, **(k)** whorl section. **(l–n)** *Macrocephalites keeuwensis* aff. var. forma *flexuosa* Boehm (microconch), specimen no. Ju/22/148. Both specimens (a–e) come from the top of the Sponge Beds (bed A8), Patcham Formation, Jumara, specimen no. Ju/22/122. Bars represent 1cm.

15a–c) from the Pachchham Island (Figs 1c, 2). *Leptosphinctes* characterizes the early Late Bajocian Niortense Zone (Fig. 14). However, between this and the following Early Bathonian *Siemiradzkia–Procerozigzag* assemblage (from Nara, Mainland Kachchh; Figs 1c, 2), there is a large gap of ~200 m where no ammonites have been recorded (Fig. 2). Figure 12 summarizes the identified biozonation, ranges of major species, assemblage and macrocephalitid species diversity for the Kachchh basin, as noted in this study; these are discussed below.

3.1 *Siemiradzkia–Procerozigzag* assemblage (Early Bathonian)

The Nara Dome assemblage includes the presence of *Zigzagiceras*, *Parkinsonia*, *Procerozigzag*, *Berbericeras*, *Cadomites*, *Ebrayiceras*, ?*Telermoceras*, *Siemiradzkia*, *Prohecticoceras* and *Procerites* (beds 0–9 of Pandey & Pathak 2015; Fig. 13b). This assemblage characterizes the Zigzag Zone fauna of Early Bathonian age within the Submediterranean province (Cariou & Hantzpergue 1997; Fernández–

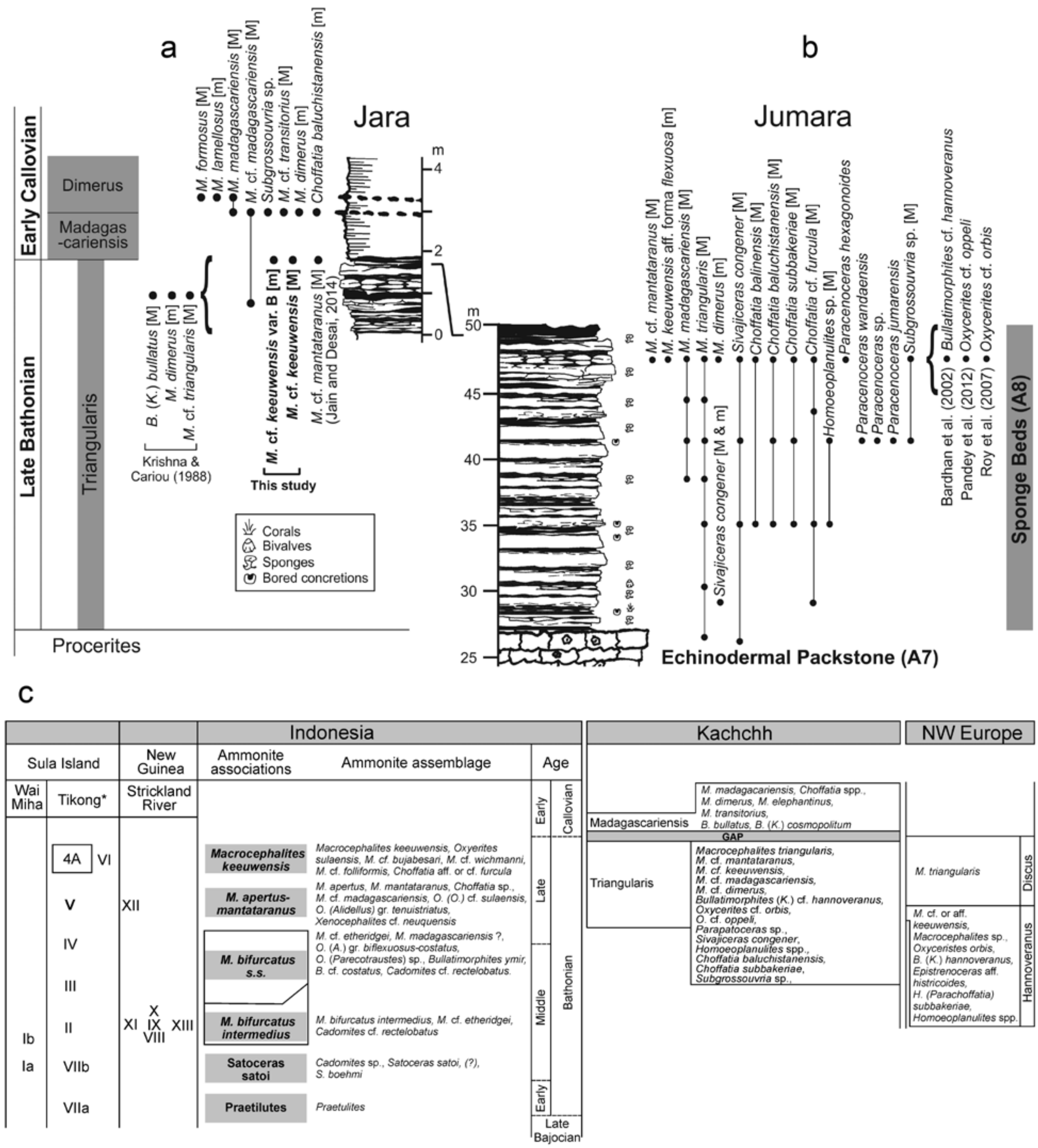


Figure 23: Late Bathonian exposures at **(a)** Jara and **(b)** Jumara Domes with their ammonite content. **(c)** Indonesian ammonite associations, ammonite content and correlation with Kachchh and NW European faunal content.

López 2000; Fernández–López et al. 2006, 2009a, 2009b; Olivero et al. 2010; Zaton 2010; Dietze et al. 2014).

The presence of *Prohecticoceras*, that spans from beds 9–13 (Fig. 13b), is interesting as this taxon spans the entire Bathonian (Fernández–López et al. 2009b; Zatoń 2010). In Argentina (South Tethys), its first occurrence has been used to identify Early Bathonian sediments (Groschke & Hillebrandt 1994; Riccardi & Westermann 1999), whereas in Mexico, the Late Bathonian Retrocostatum Zone was identified by the occurrences of *Prohecticoceras blanazense*, associated with *Epistrenoceras*, *Lilloettia* and *Neuqueniceras* (Sandoval and Westermann, 1986; Sandoval et a1. 1990; Fernández–López et al. 2009b). Both *Prohecticoceras* (Nara) and *Epistrenoceras* (Jumara; see below) do not occur together within the Kachchh basin. *Epistrenoceras* occurs much higher, with characteristic Retrocostatum Zone fauna of *Kheraiceras* cf. *hannoveranus* (Bardhan et al. 2002), *Oxycerites* cf. *oppeli* (Pandey et al. 2012) and of *O*. cf. *orbis* (Roy et al. 2007) at Jumara (Figs 20,

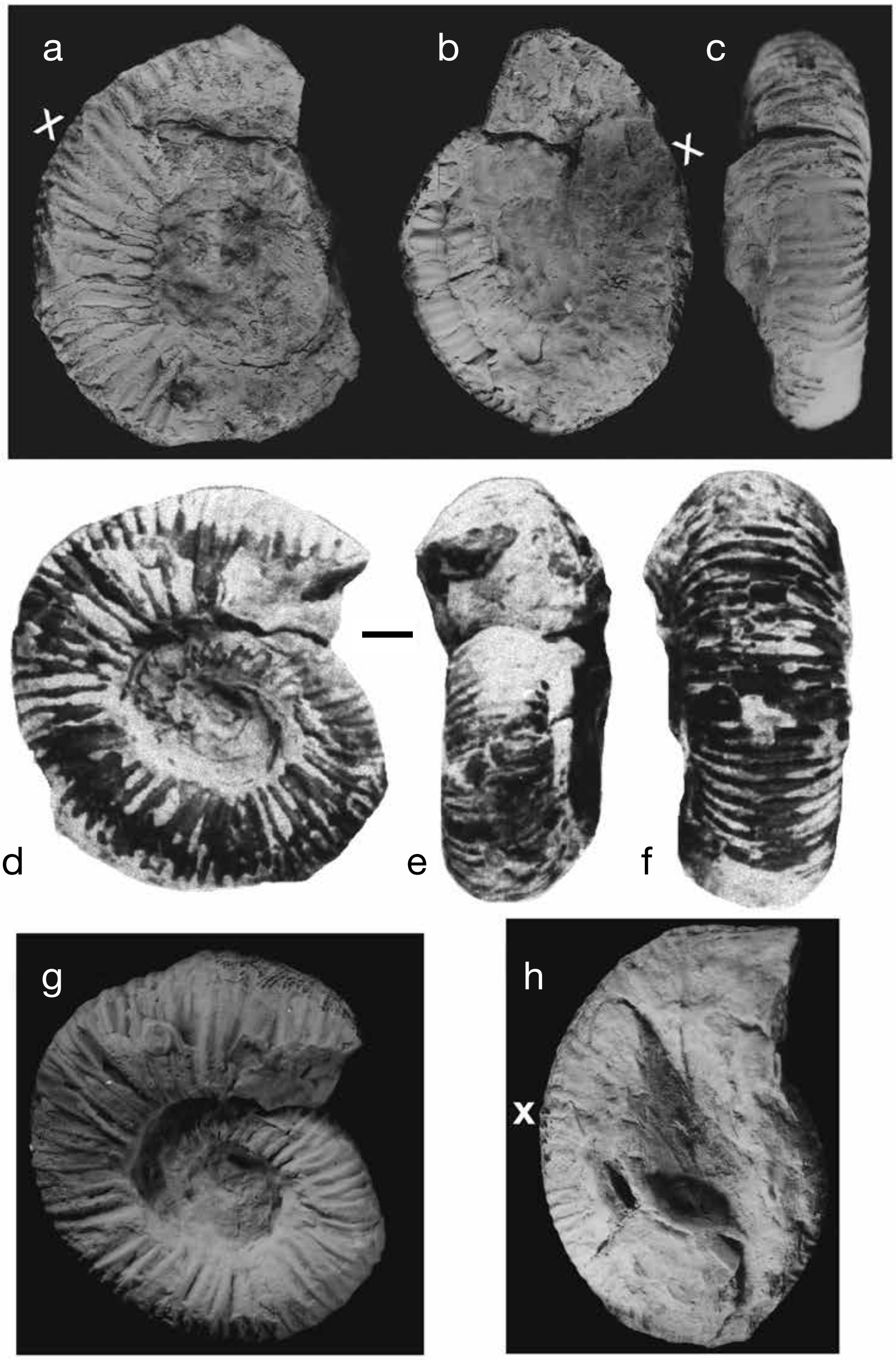


Figure 24: (a–h) *Wagnericeras* sp. (microconch), **(a–c)** specimen no. Ju/27/06, **(a)** lateral view, **(b)** opposite lateral view, **(c)** ventral view, diameter = 30.16 mm, **(d–g)** specimen no. Ju/27/07, **(d)** lateral view, **(e)** apertural view, **(f)** ventral view, **(g)** lateral view at an angle to show the ribbing pattern, diameter = 27.5 mm, **(h)** specimen no. Ju/27/08, lateral view, diameter = 30.4 mm. All specimens are from the Yellow Bed, bed A4, Jumara. Cross (x) marks the beginning of body chamber. Bar represents 1cm.

21). In SW Germany, *Prohecticoceras* occurs in the early Late Bathonian Retrocostatum Zone (Dietze et al. 2014). *Procerites* occurs throughout the Kachchh basin, and, globally (see also Zaton 2010; Dietze et al. 2014), spans from the Early (Nara Dome) to the Late Bathonian (Jumara Dome) interval, as in Kachchh (Fig. 13b).

3.2 Arkelii Zone (early Middle Bathonian)

The earliest record of *Macrocephalites* (*M*. cf. *etheridgei* Spath (m) by Roy et al. 2007) comes from Jhura (Fig. 10a) from the Badi Upper Golden Oolite bed (Fig. 13d), a stratum that is 24 m above the early Late Bajocian *Leptosphinctes*–yielding Pebbly Rudstone bed (of Fürsich et al. 2001; Fig. 2). This 24 m gap fits well, as it is of the same thickness,

Table 3: Dimensions of *Wagnericeras* sp. indet. (microconch), Yellow Bed, bed A4, Jumara. All dimensions are measured on the body chamber.

Sp. no.	D	H	T	U	T/H	U/D	Figures
Ju/27/06	30,16	8,41	9,69	12,43	1,15	0,41	Plate 15a–c
Ju/27/07	27,51	8,97	11,18	11,12	1,25	0,4	Plate 15d–g
Ju/27/08	30,44	7,79	8,44	11,91	1,08	0,39	Plate 15h
Ju/27/09	25,66	8,22	9,2	9,39	1,12	0,37	–

as the Early Bathonian strata exposed at Nara (Fig. 13). The coeval Yellow Bed (= bed A4 of Jumara) at Jhura, has also yielded *Procerites* (*Gracilisphinctes*) cf. *arkelli* Collignon (M) (Jain 2014), and is almost 40 m above the occurrence of *M*. cf. *etheridgei* Spath (Fig. 13). Thus, both on lithostratigraphic and faunal grounds, this is the earliest occurrence of a macrocephalitid, *M.* cf. *etheridgei* Spath (Fig. 13).

Roy et al.'s (2007) record of *Macrocephalites* cf. *etheridgei* Spath (m) from Nara Dome is contentious. But, if the present assignment of beds is accepted (Fig. 13), that of Pandey & Pathak's (2015) beds 10–15 of early Middle Bathonian age with co–occurrences of *Procerites*, *Oecotraustes*, *Siemiradzkia* and *Micromphalites* (all occurring in the Yellow Bed of Jumara also; Jain 2014) and of coeval *M.* cf. *etheridgei* (m), recorded in the Middle Bathonian sediments of Jhura (Roy et al. 2007), then, *M*. cf. *etheridgei* (m) occurs in the early Middle Bathonian

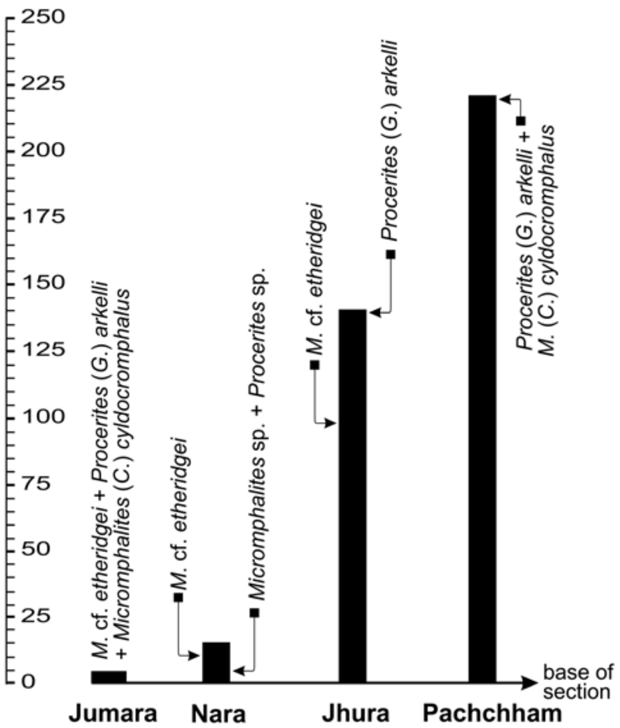


Figure 25: Middle Bathonian field records of *Macrocephalites* cf. *etheridgei* (Spath) (microconch), *Procerites* (*Gracilisphinctes*) *arkelli* Collignon (Macroconch), *Micromphalites* (*Clydomphalites*) *clydocromphalus* Arkell (Macroconch) and *Procerites* sp. from Kachchh. In Jumara, the former three are recorded from the Yellow bed (bed A4) at 5.2 m from the base of the section. Similar are the occurrences (height in m from the base of the individual sections) of all forms from Nara, Jhura and Pachchham.

strata at Nara, Jumara and Jhura. The best exposure for this interval is at the Jumara Dome. Here, the fauna is prolific and well–dated as the early Middle Bathonian Arkelli Zone and equated with the early Middle Bathonian European Progracilis Zone (Jain 2014) (Fig. 12) and with the Indonesian *M*. *bifurcatus* Association (Westermann and Callomon, 1988). Besides the presence of characteristic *P.* (*G.*) *arkelli*, *Bullatimorphites* (Fig. 15d–g; Pachchham Island), *Wagnericeras* (Fig. 24; Jumara), and *Oecotraustes* (Fig. 19u; Jumara) also co-occur within the standard early Middle Bathonian Progracilis Zone (Dietze et al., 2014). Additionally, the close morphological and stratigraphical similarity of the endemic macroconchiate *Sivajiceras congener* (Waagen) (Fig. 20) with the European *Procerites imitator* that similarly co-occurs within the Progracilis Zone (Dietze et al. 2014), lends further support to the correlation of the Arkelli Zone to the early Middle Bathonian Progracilis Zone (Jain 2014) (Fig. 12).

It must be mentioned that there is a distinct erosional contact between beds A4 and A5 that might also explain the absence of characteristic Subcontractus and the succeeding Morrisi zone faunas within Kachchh; both *Tulites* and *Morrisiceras* have not yet been recorded, so far. Jumara, being deposited at deeper settings (Jain et al. 2019) is the best representative exposure for Middle Bathonian fauna within the Kachchh basin, and traditionally, has also been the best candidate for constructing the Middle Bathonian biozonation (Jain 2014). Hence, Jumara would have been the best locality for their occurrence, too. This interval fauna has yet to be documented.

3.3 Procerites Zone (early Late Bathonian)

Two Late Bathonian zones are identified – Procerites (beds A5–A7) and Traingularis (bed A8) (see Fig. 12 for biozonation and Figs 20, 21 for faunal distribution). Earlier, from Jumara, Jain et al. (1996: p. 134) noted the common presence of *Procerites* cf. or aff. *hodsoni* Arkell (M and m) from bed A5a (Fig. 19t) and later Jain and Pandey (2000) constituted the Procerites Zone, and correlated the same with the Standard European Hodsoni Zone (Fig. 12). The dimorphic record of *Sivajiceras congener* (Waagen) has been recorded from the base of the Sponge Bed (from bed A8 at +28 m from the base; Fig. 20). This macroconchiate form closely resembles the European *Procerites imitator* Buckman, that, as in Kachchh, also spans from early Middle (Progracilis Zone) to mid–Late Bathonian (Orbis Zone) (Callomon 1993;

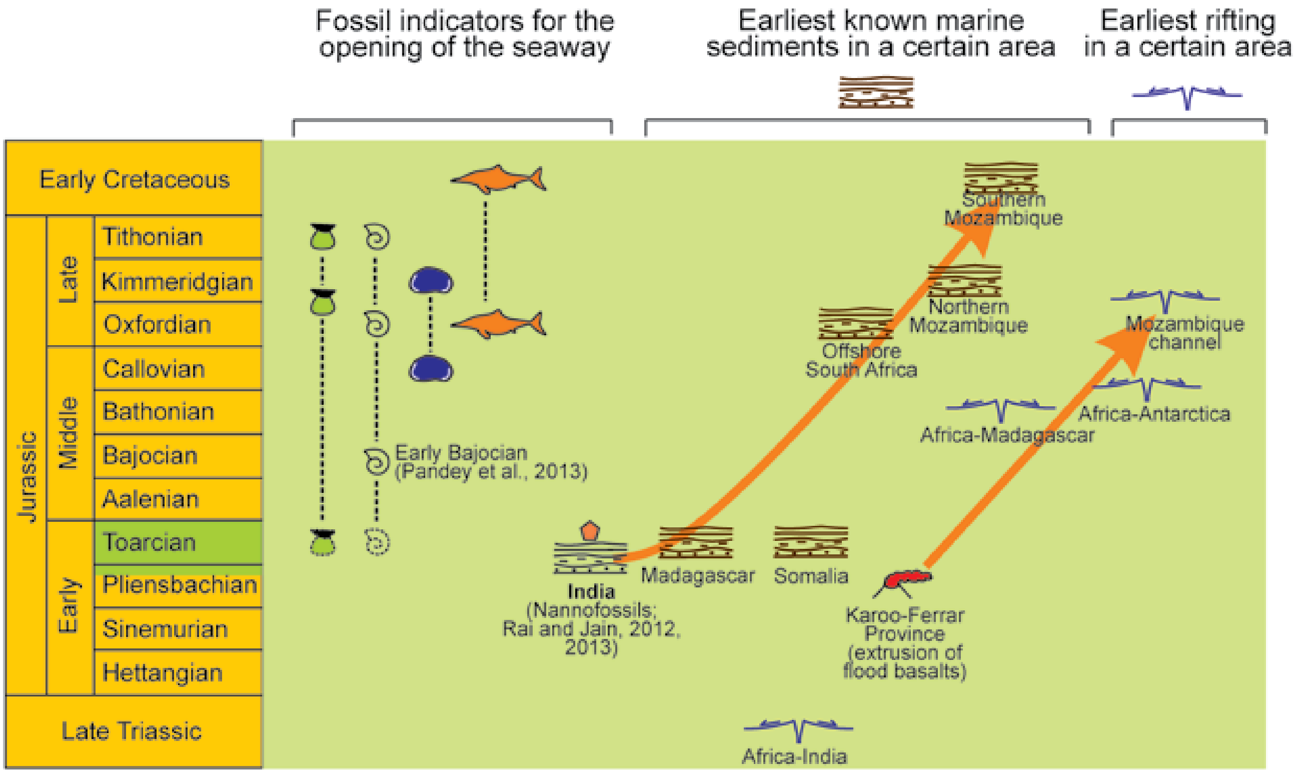


Figure 26: Indicators for the break–up of Gondwana during the Jurassic (Mad.: Madagascar; MC: Mozambique Channel; star indicates the position of the Kachchh basin) (modified from Alberti et al., 2012).

Dietze et al. 2014). Both Roy et al. (2007) and Pandey et al. (2012) have also recorded *Procerites* sp. up until bed A7, and in the present study *Procerites* cf. *hians* has also been recorded from bed A6, at +17 m from the base (Figs 19v, 20). Two additional forms have been added from bed A7 – *Choffatia* (*Subgrossouvria*) sp. (Fig. 19q, r) and *Oecotraustes* sp. (Fig. 19s). Thus, for now, beds A5b–A7 are assigned to the Procerites Zone and correlated with the lower part of the Retrocostatum Zone (Fig. 12).

3.4 Triangularis Zone (middle to late Late Bathonian)

Bed A8 constitutes the Triangularis Zone and is correlated with the interval from the upper part of the Retrocostatum to the Discus zones (Fig. 12) based on the strength of the occurrences of *Epistrenoceras* and *Kheraiceras* cf. *hannoveranus*, on the lower side, and *Oxycerites* cf. *oppeli* (Pandey et al. 2012) and of *O*. cf. *orbis* (Roy et al. 2007), from the upper part of bed A8 (see Figs 20, 21). The additional presence of *M*. cf. *mantataranus* Boehm (M) further strengthens this age assignment (Westermann & Callomon 1998; Jain & Desai 2014). A detailed faunal content is given in Figures 20, 21. Some additional forms have also been recorded from bed A8; these include *Macrocephalites* cf. *dimerus* (Fig. 19k), *Choffatia* aff. *furcula* (Fig. 19l), *M*. cf. *madagascariensis* (Fig. 19m) and *Sivajiceras* aff. *congener* (Fig. 19n–p). It must be mentioned that the Triangularis Zone is best developed at Jumara (all the aforementioned forms have come from this dome). However, the nominal species – *Macrocephalites triangularis* Spath occurs both at the Island Belt (Pachchham: Jain & Pandey 2000; Mouwana Dome: Singh et al. 1979) as well as in the Mainland Kachchh (Jara and Keera: Prasad 1998; Jara, Jhura and Jumara: this study).

4. Persisting problems and future direction

Papers by Pandey & Callomon (1995) and Roy et al. (2007) have opened a Pandora's Box with respect to the age assignment for the Bathonian ammonite fauna within the Kachchh basin. The former, based on the association of *Micromphalites* (*Clydomphalites*) with *Procerites* (*Gracilisphinctes*) *arkelli* (occurring some 220 m from the base of the section) (Fig. 25) assigned an early Middle Bathonian age and correlated their assemblage (largely dominated by *P.* (*G.*) *arkelli*) with the European Progracilis Zone (Pandey & Callomon 1995). Later, Roy et al. (2007) noted three faunal horizons for their Middle Bathonian record. Starting from the base, they correlated the occurrence of *Procerites* (*Gracilisphinctes*) cf. *arkelli* with the early Middle Bathonian Progracilis Zone (as also done by Pandey & Callomon 1995), followed by their *Prohecticoceras manjalense* Roy et al. horizon with the Morrisi–Subcontratus zones, and their topmost level, marked by the occurrence of *M.* cf. *etheridgei*, with the early part of the European late Middle

Bathonian Bremeri Zone. This assignment poses a problem as at Jhura (Fig. 25), *M.* cf. *etheridgei* occurs much earlier than *Procerites* (*G.*) *arkelli*, but later at Nara (*Procerites* sp.), and together at Jumara, the depocenter of the basin (Figs 13, 25; Jain 2014, and this study).

Thus, as pointed out by Jain (2014), the species of *Procerites* seems to be the only tying point for correlation, particularly *Procerites* (*Gracilisphinctes*) *arkelli* (Fig. 25), and hence, necessitated the erection of the Arkelli Zone (Jain 2014). This zone exhibits Madagascan (*P.* (*G.*) *arkelli*)), Saudi Arabian ((*Micromphalites* (*Clydomphalites*)) and Indonesian (*M.* cf. *etheridgei*) signatures (Jain 2014). It is quite possible that the Yellow Bed (bed A4) exposed at Jumara is either a highly condensed bed or the upper part of the broader Arkelli Zone, that actually spans the entire Middle Bathonian (Jain 2014) and correlated with the early Middle Bathonian Progracilis Zone, with the Pachchham Island exposures exhibiting its basal part, as earlier proposed by Jain (2014). However, this suggestion needs further research and more rigorous basin–wide sampling.

What also needs confirmation is the presence of Morrisi–Subcontratus zones (according to Roy et al. 2007) within the Kachchh basin as none of the diagnostic forms of the said zones have yet been recorded. Elsewhere in Kachchh, this time interval is either absent or marked by a stratigraphic hiatus (Fig. 12). The presence of these zones based on the lone presence of *Prohecticoceras manjalense* Roy et al., a genus that spans the entire Bathonian, seems a bit of a stretch.

For now, based on this study and previous reports, the timing of the deposition of the Kachchh basin is improved in the grand scheme of the break–up of Gondwana during the Jurassic (Fig. 26).

5. Conclusion

The Bathonian stratigraphy, biostratigraphy and faunal systematics for the Kachchh basin are in an urgent need of revision and re-evaluation. Making numerous short–duration biozones, subzones and horizons to specifically correlate with European and Submediterranean occurrences (without illustration) might not be a good idea for the Bathonian where like lithology, fauna also changes from dome to dome. A zonal index in one dome, might not be the same in the next nearby domal outcrop; for example, Keera is marked by the dominance of *Macrocephalites chrysoolithicus* but at the Jumara (<20 km West), the same interval is dominated by *M. dimerus* and *M. diadematus*! Additionally, Kachchh, being a relatively shallow terrigenous– and freshwater–influenced siliclastic basin, with a largely middle to outer neritic paleodepth (<75 m), also would have put ecological constrains on the ability of species to occupy their preferred niches and consequently on their distribution pattern. Thus, within the Kachchh basin, it is also plausible that the inferred age of a particular species, may differ slightly to significantly with the corresponding European and Submediterranean occurrences. Hence, it becomes necessary to work out an independent regional standard chronostratigraphy first, that may have short common intervals with European and Submediterranean faunal elements.

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Appendix

Chari Formation

Shales, soft, fine–grained, lowest part not exposed – contact not seen

Patcham Formation

A8 Jumara Sponge Beds.

Limestones, well–bedded, in many alternating courses of hard and soft micrite, white, some nodular and burrowed, with three layers of cobbles of remanie early–diagenetic concretions, heavily bored and sometimes encrusted, Abundant sponges throughout but more concentrated at some levels, silicified, beautifully preserved and weathered out in profusion. Also, diverse and abundant rhynchonellids, occasional terebratulids, rare corals; some bivalves. The Sponge Beds are best seen on the NW dip–slope above the Echinodermal Packstone (Bed A7), running into the Rann. They are also extensively exposed to the SW of the core, lying almost horizontally and traversed by the track leading to the Rann.

A7 Echinodermal Packstone.

Calcarenite packstone of echinodermal bioclasts in fine–sandy matrix, in several courses, some cross–bedded, hard, resistant, weathering light brown, resembling and in the past mistaken for sandstone, forming the semi–elliptical ridge bordering the core on the north side, sparsely fossiliferous.

– sharp boundary

A6 Limestones, fine–grained, micritic, weathering white to cream, well–bedded, in many courses, mostly sparsely fossiliferous. A more persistent, prominent bed marks a small platform, a coarsely bioclastic shell–bed with *Eligmus* and corals lies at +4 m, and further corals occur scattered throughout.

A4–A5 Jumara Coral Beds (Patcham Coral Beds of Spath)

Limestones, fine–grained, micritic, marly, well–bedded as in A6, in part bioturbated, more abundantly fossiliferous, especially with corals:

– **5b**: Upper Diverse Coral Bed

– sharp boundary

A4 Lower Diverse Coral Bed and Yellow Bed.

Limestone, harder calcarenitic biomicrite or packstone, bioturbated, somewhat rubbly and ferruginous, weathering yellow. Highly fossiliferous: a lawn of corals now embedded in the upper part of the bed, with a diverse fauna of bivalves, brachiopods and gastropods. Ammonites not uncommon but usually fragmentary or crushed, the test often preserved in dark, recrystallized calcite.

A1–A3: Patcham Shelly Limestones of Spath

A3 Marls or marly limestones, light, soft, recessive, poorly exposed

3b: thin bed of shell–brash, hard, platy, weathering brown,

A2 Microsolena Bed.

Marly limestones with two thin packstone interbeds supporting layers of corals:

– **2c**: packstone, harder, thin, with bored pebbles, overlain by as assemblage of well–spaced corals of low diversity

2a: another packstone, thin, overlain by an almost monospecific layer of large, round heads of *Microsolena*

A1 Marls or soft, micritic limestones, white, seen in gullies

1b: *Elligmus* Bed: packstone, rubbly, shelly, thin, with abundant bivalves

– lower beds not exposed