On the occurrence of the Indonesian ammonite *Macrocephalites keeuwensis* Boehm [M & m] from Kachchh (Western India)

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Abstract

The dimorphic occurrence of the Indonesian ammonite *Macrocephalites keeuwensis* Boehm is reported co-occurring with the Late Bathonian *Macrocephalites* cf. *mantataranus* Boehm [M] from the basal sediments (ash gray marl-limestone intercalations) of the Jara Dome (Kachchh, Western India). Coeval sediments from the adjoining Jumara Dome also record *M.* cf. *mantataranus* Boehm [M] and *M. keeuwensis* var. aff. forma *flexuosa* Boehm [m]. Based on these finds, the age of the Indonesian *M. keeuwensis* Association is re-evaluated as also the age of the nominal species that now occurs in Kachchh, Madagascar and Europe. A new Late Bathonian age is proposed for the Association that hitherto was assigned on balance to straddle between "late Early Callovian–latest Bathonian". It is speculated that *M. keeuwensis* Boehm [M & m] gave rise to two distinct lineages and the paper documents the separation of these two different lines. One that gave rise to the Early Callovian *M. lamellosus* (Sowerby), and which in turn to the late Early Callovian *Subkossmatia opis* Spath. On the other hand, the dimorphic pair also gave rise to the early–middle Early Callovian *Macrocephalites formosus* (Waagen), which in turn gave rise to the late Early Callovian *M. semilaevis* Spath. *M. keeuwensis* [M & m], in turn, arose from the late Middle Bathonian *M. bifurcatus* transient *intermedius* Boehm (from one of its varieties, A or B). All forms occur in Kachchh. *M. lamellosus* (Sowerby) [M & m] and *M. formosus* [M & m] are now reported from Kachchh.

Key words: *Macrocephalites*, Bathonian, Indonesia, Kachchh, Western India

1. Introduction

The presence of an Middle Bathonian assemblage of Indonesian macrocephalitids in Kachchh (*Macrocephalites bifurcatus* transient *intermedius* [M], *M. bifurcatus* transient cf. *intermedius* [M], *M. bifurcatus* transient aff. *bifurcatus* [m] and *M.* cf. *etheridgei* Spath [m] have been noted from the Jumara Dome, Kachchh (Western India; Fig. 1) (Jain 2002, 2014; see also Roy et al. 2007). However, similar records of Indonesian ammonites from higher up in the Late Bathonian, are rare (Jain & Desai 2014).

The present contribution reports the occurrence of the dimorphic Indonesian ammonite *Macrocephalites keeuwensis* Boehm [M & m] from the ash gray marl–limestone intercalations from the core of Jara Dome (Figs 2, 3) from where recently, the Late Bathonian *M.* cf. *mantataranus* Boehm [M] was also recorded (Jain & Desai 2014). From coeval sediments from the adjoining Jumara Dome (Fig. 1), the presence of *M.* cf. *mantataranus* Boehm [M] (Jain & Desai 2014) and now *M. keeuwensis* var. aff. forma
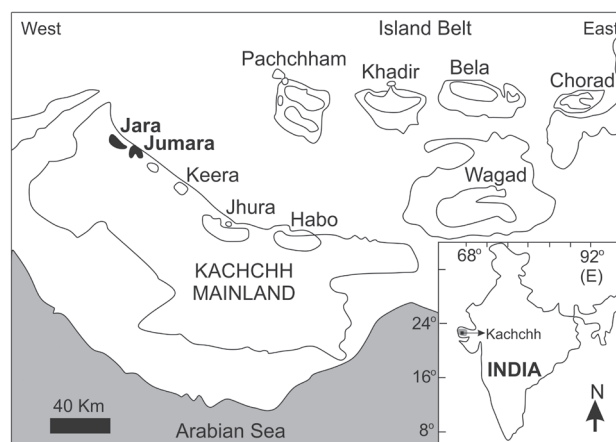

Fig. 1: The Kachchh basin is characterized by residual basement ridges, now exposed as domal outcrops or uplifts viz. the Kachchh Mainland, Pachchham, Khadir, Bela, Chorad and Wagad. These constitute islands in an otherwise flat lying surface with the latter five being collectively referred as "Islands". Two domal outcrops within the Kachchh Mainland are studied for this contribution – Jara and Jumara.

flexuosa Boehm [m] are also recorded (Fig. 3). Based on these finds, the age of the Indonesian *M. keeuwensis* Association is re-evaluated as Late Bathonian nominal species that occurs in Kachchh, Madagascar and Europe (Fig. 4). Its biostratigraphic and biogeographic implications are also discussed.

2. Geological setting

Kachchh is a pericratonic epicontinental basin borne out from the rifting of the Indian plate from the Gondwana in the Late Triassic with the deposition of nearly 1500 m of carbonates and siliclastics (Jain et al. 1996). Residual basement ridges, now exposed as domal outcrops or uplifts that provide an opportunity to study its faunal and sedimentary history during the Mesozoic, characterize the basin. The six major uplifts (Kachchh Mainland, Pachchham, Khadir, Bela, Chorad and Wagad (Fig. 1), constitute islands in an otherwise flat lying surface with the latter five being collectively referred as "Islands" (Fig.

1). The domal outcrops within the Kachchh Mainland (like Jumara and Jara, the localities studied for this contribution; see Fig. 1) follow an East–West trending lineament with the general regional slope of the basin being WSW.

2.1. Jara Dome

The Jara Dome (Fig. 2), like all other domal outcrops in Kachchh is heavily faulted with a 248 m thick succession of Middle Jurassic rocks exposed in the northwestern fringe of the Kachchh Mainland, western India (23°43'00"N: 68°57'52"E to 23°45'00"N: 65°00'00"E). Here, as well as in other domal outcrops, the exact delineation of the Bathonian–Callovian boundary has remained elusive in spite of the fact that the basal sediments (ash gray marl–limestone alternations within 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 & Pandey 2000). Alt-
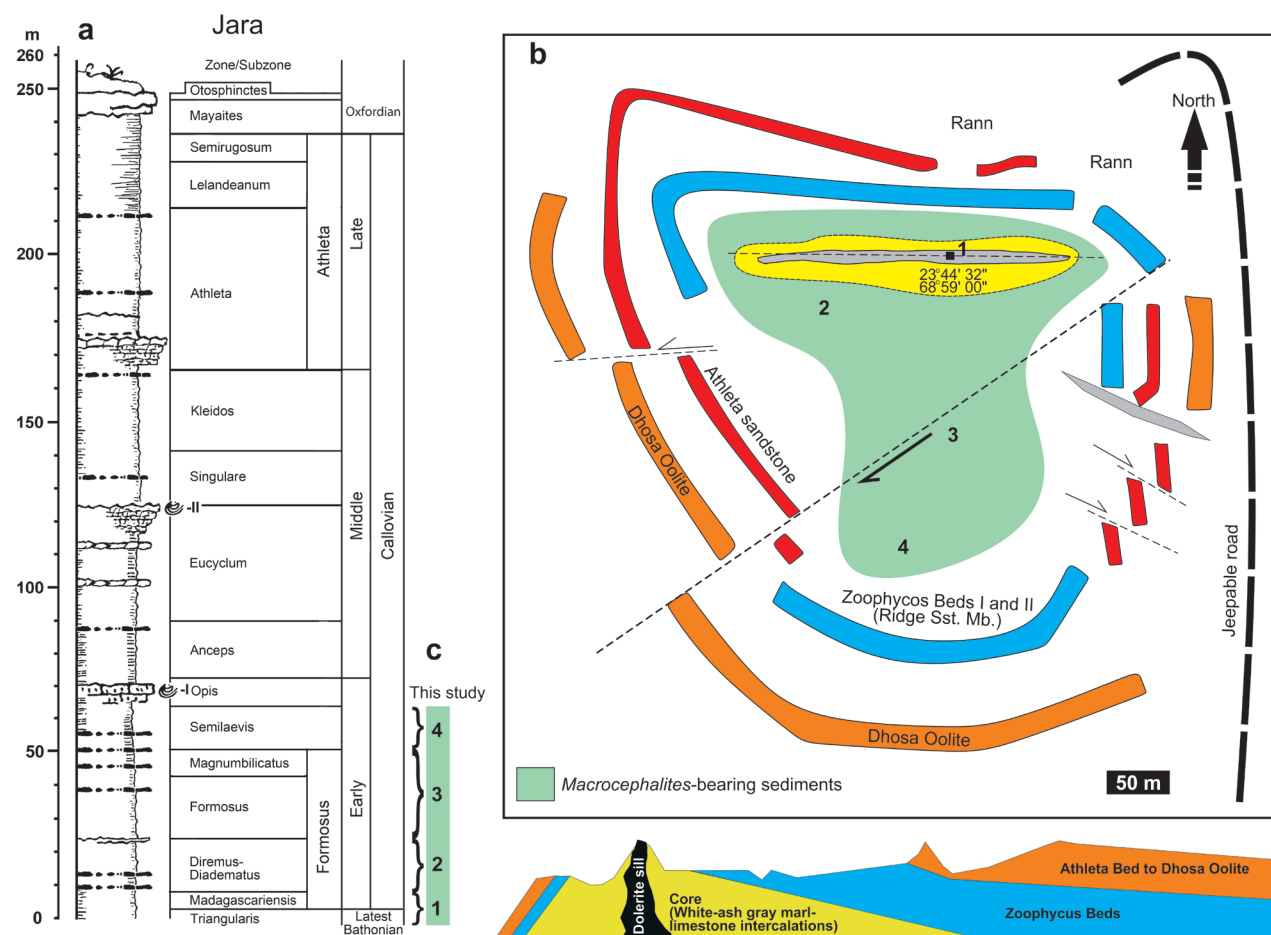

Fig. 2: (a) Jara is a heavily faulted quaquaversal domal outcrop yielding Late Bathonian–?Middle Oxfordian ammonites. **(b, c)** The core of the dome is best exposed as a linear outcrop within the center of the dome from where dimorphic occurrence of the Indonesian ammonites *Macrocephalites keeuwensis* Boehm is reported here associated with the Late Bathonian *Macrocephalites* cf. *mantataranus* Boehm [M] from the basal sediments (marl–limestone intercalations). The late Early–early Middle Callovian Zoophycos Beds I and II (Ridge Sandstone Member) form prominent ridges, followed by shales and then another cliff–forming Early–?Middle Oxfordian Dhosa Oolite bed. The shales between the core and the Zoophycos Bed I are *marcocephalites*–bearing, forming biozones (a). A detailed biozonation will be published elsewhere. Fig. 2b, courtesy Bhawanisigh G. Desai.

hough, Jumara is located barely ~12 km east of Jara (Fig. 1), unlike at Jumara, stratigraphically controlled ammonite records from the basal sediments at Jara have only been noted in passing (Bhaumik et al. 1993; Krishna & Ojha 2000), resulting in conflicting ages that have ranged from Late Bathonian to Early Callovian (Prasad 1998; Bhaumik et al. 1993). Even the nannofossil record has been equally ambiguous (Rai, 2003). Recently, the find of *M*. cf. *mantataranus* Boehm [M] from the basal sediments at Jara (Jain & Desai 2014) have enabled to fix a definite Late Bathonian age to the core sediments of the Jara Dome (Fig. 2: site 1). From the same sediments, the dimorphic pair of the Indonesian ammonite *Macrocephalites keeuwensis* Boehm [M & m] is now reported and described below.

2.2. Jumara Dome

The Jumara Dome (Fig. 1; 23°41'13.6"N; 69°02'51.00"E), the depocentre of the basin is a classical Jurassic locality that exhibits not only the most expanded Callovian sequence for the Kachchh basin but also for the entire northern peri-Gondwana margin (see Jain 2014 for a detailed description and faunal content of the dome). The dome possesses 422 m thick sequence of Middle Jurassic strata constituting 8 beds in the Patcham Formation (Bathonian; A1–A8; 48 m), 46 beds in the Lower Chari Formation (Lower Callovian; B1–B45 and C1; 229

m), 37 beds in the Middle Chari Formation (Middle Callovian (C2–C37 and D1; 68 m) and 14 beds (D2–D15) in the Upper Chari Formation (Late Callovian; 74 m). Bed E1, the Dhosa Oolite bed (Early–?Middle Oxfordian) tops the Chari Formation (see also Jain 1996). The present study is restricted to the topmost unit of the Patcham Formation, bed A8, the ash gray marl–limestone alternations (Fig. 3).

3. Age of *Macrocephalites keeuwensis* Boehm

Macrocephalites keeuwensis Boehm was first described from Indonesia, where the fossil record is characterized by "…faunas that can be securely dated are very intermittent" and "the stratigraphic record, at least as revealed by ammonites, is regionally highly discontinuous" (Westermann & Callomon 1988: p. 6). The Bathonian–Callovian fauna of Indonesia collected from 15 stratigraphical separate assemblages from Taliabu in the Sula Islands (the classical area of "Keeuw") and Strickland River, Papua New Guinea (see also Sato et al. 1978; Westermann et al. 1979) were recently re-evaluated and placed chronologically by Westermann & Callomon (1988) (see Fig. 4).

The youngest of all is the *Macrocephalites keeuwensis* Association dated on balance "as late Early Callovian, although latest Bathonian cannot be
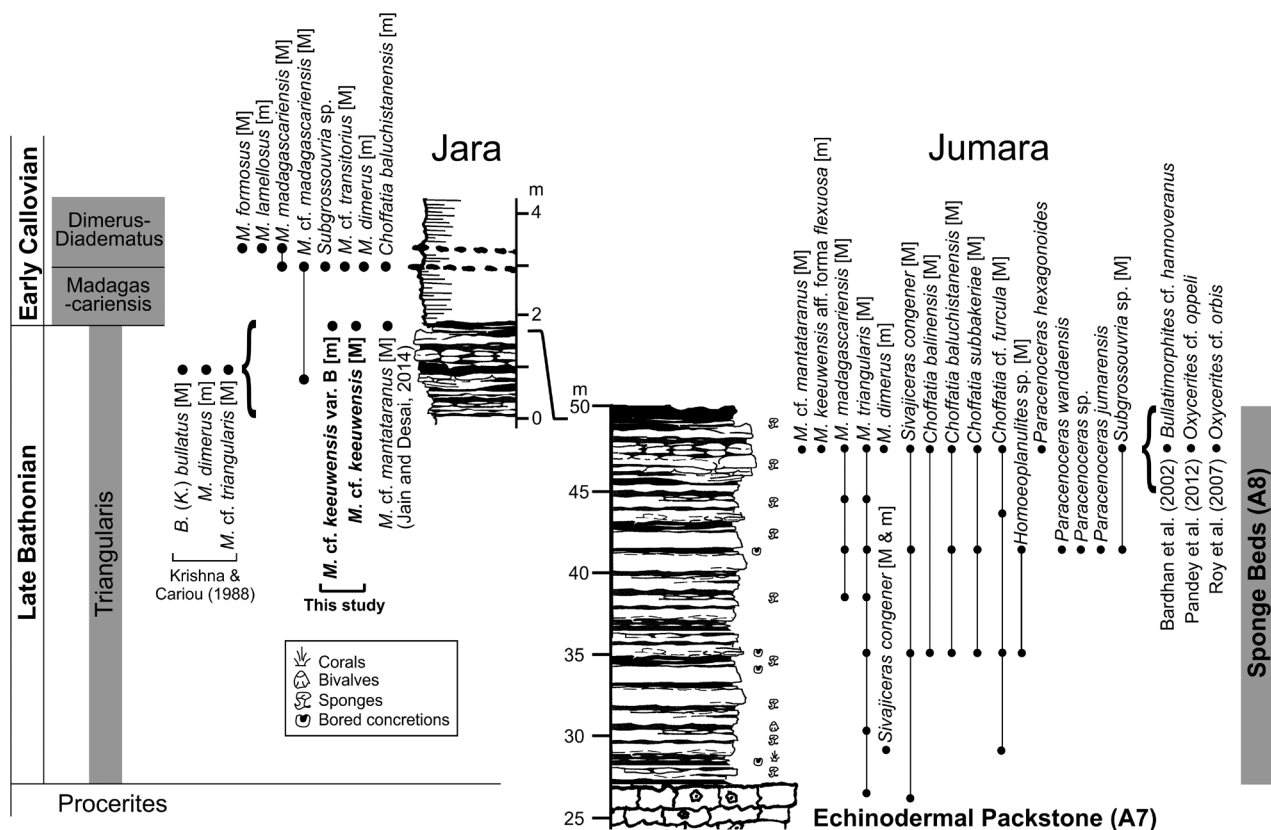

Fig. 3: Late Bathonian exposures at Jara (a) and Jumara Domes (b) with their ammonite content.

Indonesia					Age		Kachchh		NW Europe
Sula Island		New Guinea	Ammonite associations	Ammonite assemblage					
Wai Miha	Tikong*	Strickland River							
					Early	Callovian	Madagascariensis — *M. madagacariensis, Choffatia* spp., *M. dimerus, M. elephantinus, M. transitorius, B. bullatus, B. (K.) cosmopolitum*		
							GAP		
4A VI			*Macrocephalites keeuwensis*	**Macrocephalites keeuwensis**, *Oxyerites sulaensis, M.* cf. *bujabesari, M.* cf. *wichmanni, M.* cf. *folliformis, Choffatia* aff. or cf. *furcula*	Late	Bathonian	Triangularis — *Macrocephalites triangularis,* **M. cf. keeuwensis**, *M.* cf. *mantataranus, M. madagascariensis, M. dimerus, Choffatia* aff. or cf. *furcula, Oxycerites* cf. *orbis, O.* cf. *oppeli, Epistrenoceras* sp., *Bullatimorphites (K.)* cf. *hannoveranus, Sivajiceras congener, Choffatia subbakeriae, C. balinensis, Choffatia* spp.	*M. triangularis* — Discus	
V	XII		*M. apertus-mantataranus*	*M. apertus, M. mantataranus, Choffatia* sp., *M.* cf. *madagascariensis, O. (O.)* cf. *sulaensis, O. (Alidellus)* gr. *tenuistriatus, Xenocephalites* cf. *neuquensis*				**M. cf. or aff. keeuwensis**, *Macrocephalites* sp., *Oxyceristes orbis, B. (K.) hannoveranus, Epistrenoceras* aff. *histricoides, H. (Parachoffatia) subbakeriae, Homeoplanulites* spp. — Hannoveranus	
IV			*M. bifurcatus s.s.*	*M.* cf. *etheridgei, M. madagascariensis* ?, *O. (A.)* gr. *biflexuosus-costatus, O. (Parecotraustes)* sp., *Bullatimorphites ymir, B.* cf. *costatus, Cadomites* cf. *rectelobatus.*	Middle				
III									
II	X IX XI XIII VIII		*M. bifurcatus intermedius*	*M. bifurcatus intermedius, M.* cf. *etheridgei, Cadomites* cf. *rectelobatus*					
Ib / Ia	VIIb		Satoceras satoi	*Cadomites* sp., *Satoceras satoi*, (?), *S. boehmi*	Early				
	VIIa		Praetilutes	*Praetulites*	Late Bajocian				

Fig. 4: Indonesian ammonite associations, ammonite content and correlation with Kachchh and NW European faunal content (see text for explanation).

ruled out" (Westermann & Callomon 1988: p. 6). The Association is characterized by the presence of *M. keeuwensis* Boehm with several of its varieties (α–δ; see also Boehm 1912; Spath 1927–33; Westermann & Callomon 1988). Besides the nominal species, this youngest assemblage also contains endemic *Macrocephalites* cf. *bujabesari*, *M.* cf. *wichmanni*, *M.* cf. *folliformis*, *Oxyerites sulaensis* Westermann and Callomon, and the cosmopolitan *Choffatia* aff. or cf. *furcula* (see Fig. 4). One of the specimens from this assemblage (figured by Boehm 1912: pl. 38, fig. 2) closely matches with the recently collected *Macrocephalites* from the Late Bathonian Orbis Zone of Franconia, South Germany (Dietl & Callomon 1988).

Now the dimorphic pair of *Macrocephalites keeuwensis* Boehm [M & m] (Figs 5, 6) in association with typical Late Bathonian *M.* cf. *manatatranus* Boehm [M] (Jain & Desai 2014) from the Jara Dome and *M. keeuwensis* var. aff. forma *flexuosa* [m] (Fig. 7) associated with *M.* cf. *manatatranus* Boehm [M] (Fig. 8) along with *M. triangularis* Spath [M] and *Sivajiceras congener* [M] from the top of the Patcham Sponge Beds (bed A8 of present work) from the Jumara Dome are reported here. At Jumara, coeval levels have also yielded characteristic Orbis–Discus Zone fossils of *Oxycerites* cf. *orbis* (Roy et al. 2007), *O.* cf. *oppeli* (Pandey et al. 2012) and *Bullatimorphites* cf. *hannoveranus* (Bardhan et al. 2002) (Fig. 3). Hence, based on the common presence of Indonesian *Macrocephalites keeuwensis* Boehm [m] in Kachchh and Madagascar (Thierry 1978) and in Europe (Fig. 6f), the *M. keeuwensis* Association in Indonesia can now be unequivocally dated as Latest Bathonian (Fig. 4).

In central Nepal, only the subjacent Bifurcatus and Apertus Association of Sula Island (Indonesia) (Fig. 4) have been recorded with an unconformity at the top of the Apertus Association (Cariou & Enay 1999). The Apertus Association ammonites come from two levels (see Cariou & Enay 1999: p. 704). From the lower level, bed 10 yielded *Macrocephalites apertus* Spath, M. *mantataranus* Boehm, *M. bifurcatus* transient *bifurcatus* Boehm [m], *M. bifurcatus* transient *intermedius* (Spath) [M], *Homeoplanulites (Parachoffatia)* aff. *evolutum* Sandoval and *Oxycerites sulaensis* Westermann and Callomon. Bed 11 yielded *Macrocephalites triangularis* Spath, *M. chrysoolithicus* (Waagen), *Choffatia* cf. *madani* Spath and *Oxycerites sulaensis* Westermann and Callomon. Cariou & Enay (1999) considered their bed 10 as Late Bathonian (=Apertus Association of Sula Island) and their bed 11 as Early Callovian. Clearly, the latter should have also been dated as Latest Bathonian, in commonality with the Kachchh Late Bathonian Triangularis Zone fauna (Fig. 2; see also Jain 2014).

4. Discussion

Based on present finds, *Macrocephalites keeuwensis* Boehm [m] (Fig. 6a–d) now occurs in definitely Late Bathonian sediments in Kachchh, Madagascar and Europe (Orbis Zone; see Dietl & Callomon 1988; Thierry 1978) (Fig. 4). *M.* cf. *manatatranus* Boehm [M] has already been recorded from the Triangularis Zone (= Orbis–Discus Zones) of Jumara (Fig. 8) in association with *M. keeuwensis* var. aff. *forma flexuosa* [m] (Fig. 7), *M. triangularis* Spath [M] and *Sivajiceras congener* (Waagen) [M] and the characteristic Orbis–Discus Zone fossils of *Oxycerites* cf. *orbis* (Roy et al. 2007), *O.* cf. *oppeli* (Pandey et al. 2012), *Bullatimorphites* cf. *hannoveranus* (Bardhan et al. 2002) from the top of the Patcham Sponge Beds (bed A8 of present work) (Fig. 3) (see also Jain & Desai 2014). *M. manatatranus* Boehm [M] also occurs in Central Nepal in Late Bathonian sediments (Cariou and Enay, 1999). *M. triangularis* and *S. congener* are long ranging forms (late Middle to Latest Bathonian; Jain
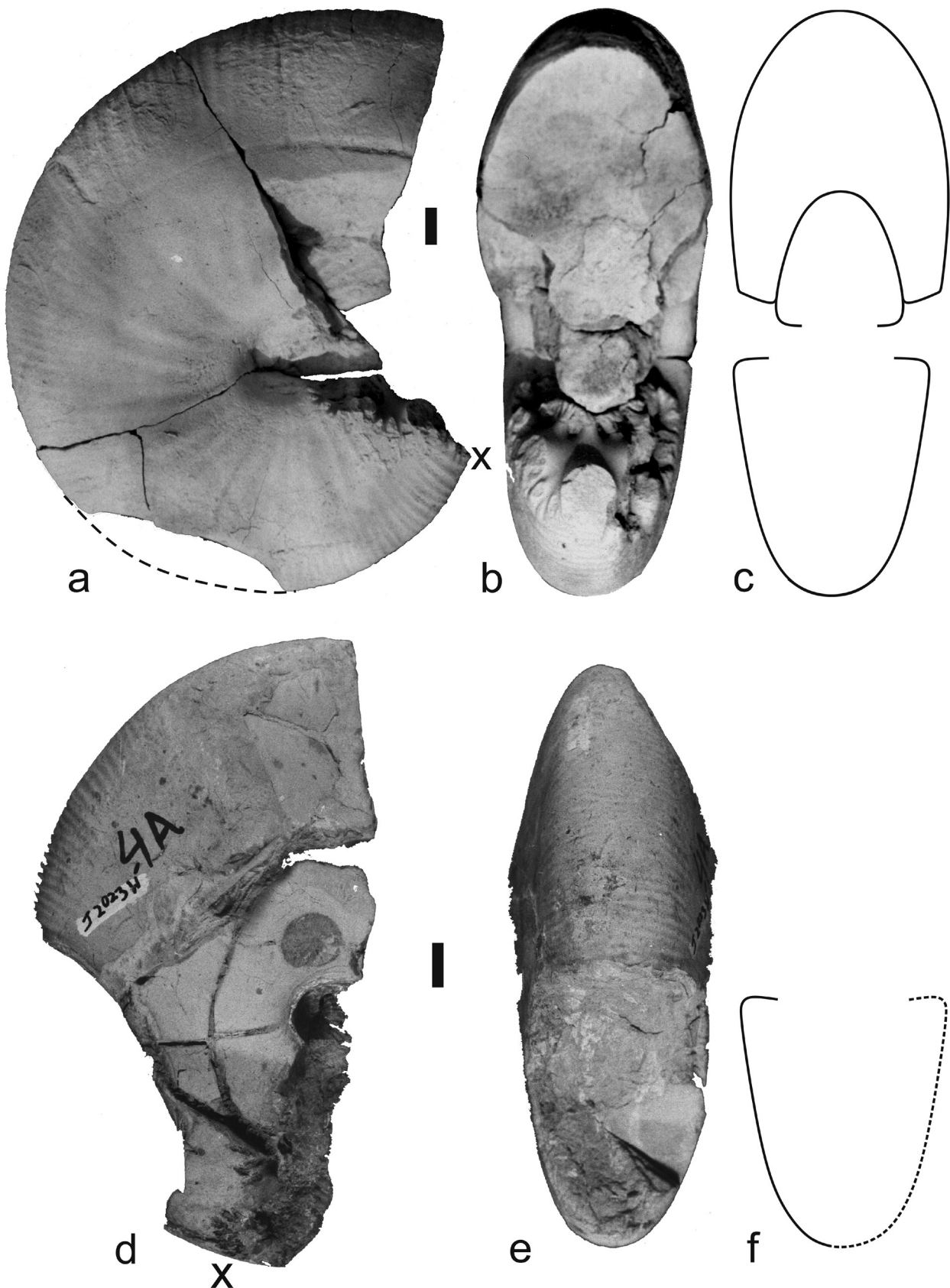
Fig. 5: *Macrocephalites keeuwensis* Boehm [M]. **(a–c)** Jara, specimen no. Ja/SJ/1999/Core/1, measured diameter = 172 mm, phragmocone = 132 mm. **(d–f)** Specimen lent to the author by the late Dr. G.E.G. Westermann (Canada), specimen no. J2023W, Locality 4A, Assemblage V1 of Tikong, Indonesia, phragmocone = 103 mm, measured diameter = 115.3 mm (see text for explanation).
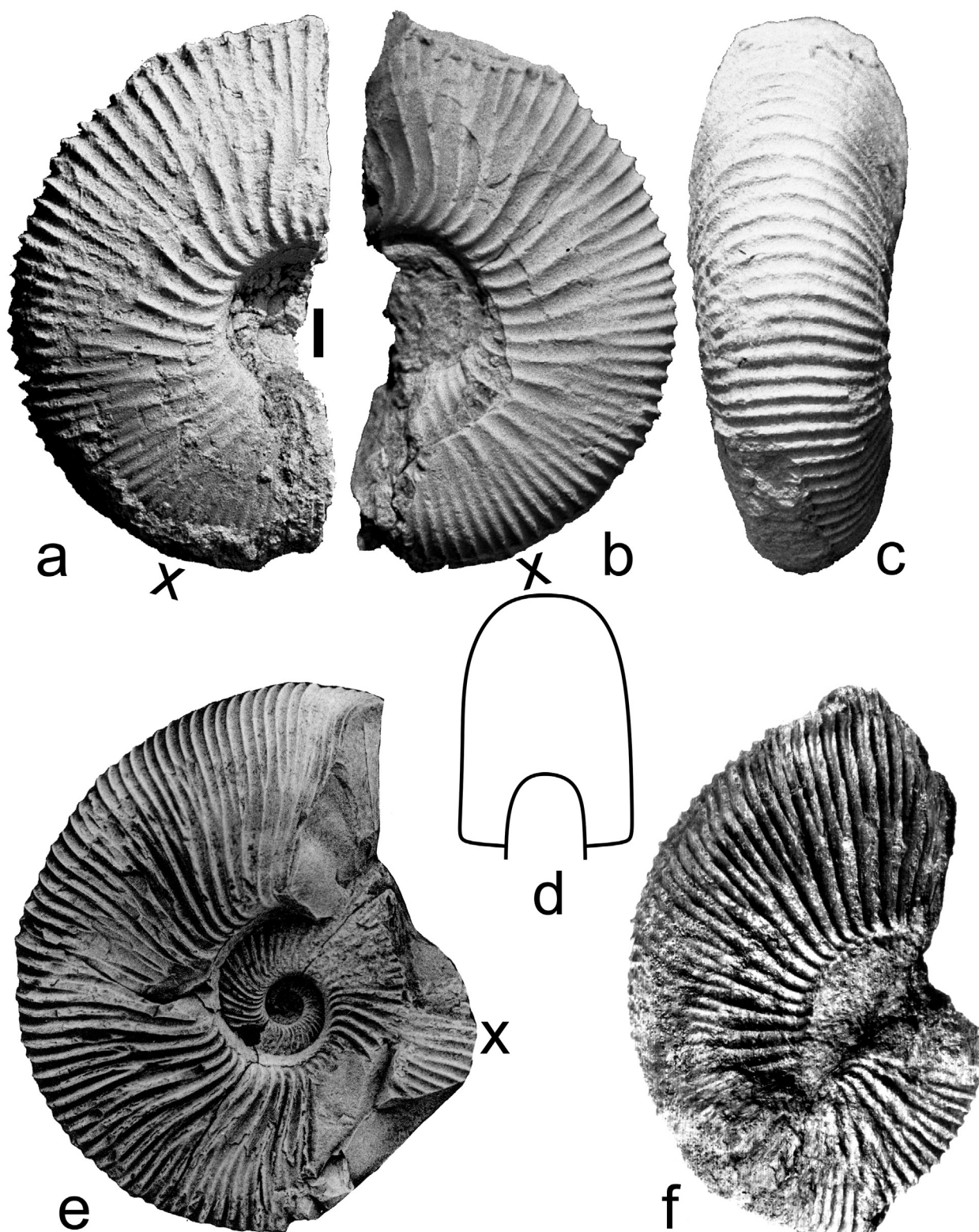
Fig. 6: *Macrocephalites keeuwensis* Boehm [m]. **(a–d)** Jara specimen no. Ja/SJ/1999/Core/2, measured diameter = 107 mm, phragmocone = 80 mm. **(e)** *M. keeuwensis* var. B [m] refigured from Boehm (1912: pl. 38, fig. 1; see also Westermann & Callomon 1988: pl. 13, fig. 1). **(f)** *Macrocephalites* cf. / aff. *keeuwensis* Boehm, Late Bathonian (Orbis Zone), refigured from Dietl & Callomon (1988: pl. 3, fig. 1).

2014) and *Oxycerites sulaensis* Westermann and Callomon which occurs in the Indonesian *M. keeuwensis* Association is a close homeomorph of the well-known Early Bathonian European *O. yeovilensis* Rollier (Westermann & Callomon 1988). The other persisting form is that of *Choffatia* (*Homoeoplanulites*), which had already appeared in the late Middle Bathonian Bremeri Zone, and is also long ranging.

Contextually, both associations at Sula Island (Westermann & Callomon 1988) and Madagascar

(Thierry 1978) are discontinuous, and hence hard to date precisely, whereas in Central Nepal, the fauna above the Apertus Zone is not present (Cariou & Enay 1999). *Macrocephalites apertus* Boehm has not been recorded from Kachchh. Hence, the best available choice to date the *M. keeuwensis* Association lies either in the assemblages of Kachchh or in Europe (Dietl 1981; Dietl & Callomon 1988; Callomon 1993; Jain 2014). Common occurrence of index forms are noted in both the latter two localities (Fig. 4), although in the Franconian Alb, it is much more well-resolved (Dietl 1981; Dietl & Callomon 1988; Mönnig 2015). Nevertheless, based on common species (Fig. 4), the *M. keeuwensis* Association can be safely dated to lie around the Orbis–Discus Zones of Latest Bathonian age, as also earlier suggested by Westermann & Callomon (1988: p. 6) but due to lack of characteristic species, now noted, hampered precise age determination, then.

Based on present finds and on stratigraphic, morphological and morphometric considerations, it is speculated, and also probably plausible, that *M. keeuwensis* Boehm [M & m] gave rise to two distinct lineages and the paper documents the separation of these two different lines. One, that gave rise to the Early Callovian *M. lamellosus* (Sowerby) and that in turn to the late Early Callovian *Subkossmatia opis* Spath (= the *Eucycloceras opis* var. *opis* of Jana et al. 2005) (Fig. 9). In this progression, the ribbing gets straighter, finer, denser and the shell increasingly gets compressed and more eccentrically coiled, but at the same time, retaining the somewhat subquadrate whorl section (Fig. 9). On the other hand, to the early–middle Early Callovian *Macrocephalites formosus* (Waagen), which in turn gave rise to the late Early Callovian *M. semilaevis* Spath.

Dimorphic pairs of *M. lamellosus* have now been recorded from the late Early Callovian Sameilaevis Zone (Fig. 10). Earlier, Krishna & Westermann (1987: p. 1576) have suggested that "there is a close agreement between the phragmocones of *M. lamellosus* [m] and the inner whorls of *M. madagascariensis* [M] in our samples, indicating that they are matching dimorphs". However, it is always best to look for dimorphism within the morphospecies rather than outside it, as noted in the present record (Fig. 10). The Macroconch, which is complete with an attached operculum, measures 150 mm with a phragmocone of 115 mm (T/H = 0.80; U/D = 0.22) (Fig. 10a, b). The holotype, a microconch and almost complete with only part of the body chamber damaged (Fig. 10c, d) measures 108 mm with a phragmocone of 71 mm (T/H = 0.89; U/D = 0.19). The macroconch shows increased extraumbilication (Fig. 10a). In both dimorphs, mature modification only includes strongly projected ribs and opening of the whorl (Fig. 10). Krishna & Westermann (1987) paired *M. lamellosus* [m] – *M. madagascariensis* [M], but, in contrast, Thierry (1978) considered the pairing of *M. subcompressus* (Waagen) [m] and *M. madagascariensis*

[M]. The holotype of *M. madagascariensis* [a Macroconch] measures 130 mm with a phragmocone of 109 mm and is much more inflated (T/H = 0.94–0.99) and involute (U/D = 0.14–0.15) at 130 and 109 mm diameters, respectively. Based on present finds, the *M. subcompressus* [m] – *M. madagascariensis* [M] pair seems more plausible.

On the other hand, the Kachchh *Macrocephalites keeuwensis* [M & m] (Fig. 5a–c), probably also gave rise to the early–middle Early Callovian *M. formosus* (Sowerby) (Fig. 11a–e) and that in turn gave rise to the late Early Callovian *M. sameilaevis* (Waagen). Krishna & Westermann (1987: p. 1576) suggested that *M. chariensis* and *M. formosus* intergrade and hence considered them to represent as a single species. However, here, following Spath (1927–33), both are considered as separate species with their dimorphic pairs (Fig. 11; *M. formosus* – Figs. 11a–e; *M. chariensis* – Figs. 11f–i). Both dimorphs are now recorded from the same bed (bed 23) from the middle–Early Callovian Diadematus Zone from the Jumara Dome. The Macroconch is large, discoidal and smooth measuring 230 mm with its microconch measuring 64 mm (Fig. 11a–e). The dimorphic pairs of *M. chaeiensis* (Waagen) are almost complete specimens with only part of the body chamber damaged (Fig. 11f–i). The Microconch comes from a stratigraphically slightly lower horizon, the middle–Early Callovian Diadematus Zone (Jumara Dome; diameter = 86 mm; T/H = 0.88, U/D = 0.14) and the Macroconch comes from the late Early Callovian Formosus Zone (Jumara Dome; diameter = 101 mm; T/H = 0.79, U/D = 0.14) (Fig. 12). In both the microconchs (Fig. 11a–f) and the macroconchs of *M. chaeiensis*, the crowding of ribs is noted; the lack of umbilical seam in all specimens, also suggests maturity (Fig. 11). Basinal biozonation for the localities mentioned (Keera, Jumara and Jara; Fig. 1) is given in Figure 12 and overall correlation with the Western European biozonation is given in Figure 13. A more detailed Early Callovian biozonation is being worked out and will be published elsewhere.

Earlier, Krishna & Cariou (1993) had suggested that *M. formosus* gave rise to *M. sameilaevis* (Fig. 14) and at the same time to *Subkossmatia opis*, also. The other lineage they proposed was their "Chrysoolithicus lineage" – *M. triangularis* – *M. madagascariensis* – *M. transitorius* – *M. chrysoolithicus* – *M. diadematus*. Contrary to their claim, the Kachchh ammonite fauna is not stratigraphically differentiated; the compressed species do occur together with the inflated species, although their relative percentage may differ and they themselves differ laterally in abundance from one dome to the other (Fig. 15).

Additionally, it is also speculated that both microconch [m] and macroconch [M] of *M. keeuwensis* Boehm, in turn, probably arose from *M. bifurcatus* transient *intermedius* (from one of its varieties, A or B). All the above forms have been recorded from Kachchh (Jain 1996, 2014).
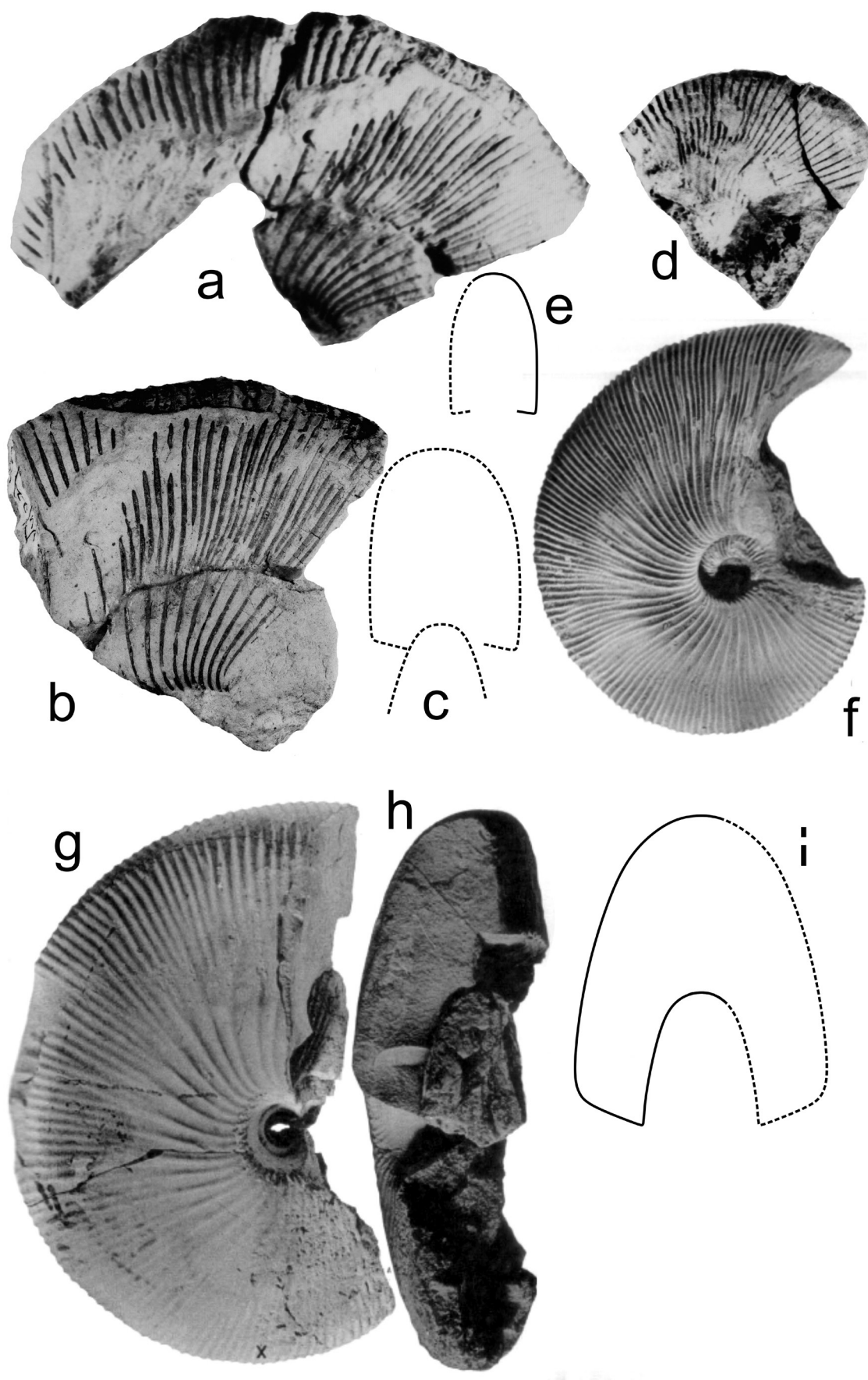
Fig. 7: *Macrocephalites keeuwensis* Boehm aff. var. forma *flexuosa* [m]. **(a–c)** Jumara, specimen no. Ju/22/122. **(d–e)** Jumara, specimen no. Ju/22/148. Both specimens (a–e) come from the top of the Sponge Beds (bed A8; see Fig. 3), Patcham Formation, Jumara, (b) is the close–up of (a) to show the umbilical region. **(f)** *Macrocephalites keeuwensis* var. forma *flexuosa* [m] refigured from Westermann & Callomon 1988: pl. 12, fig. 4; IMC 444, Assemblage VI; see Fig. 4). **(g–i)** *Macrocephalites keeuwensis* var. forma *flexuosa* [M] refigured from Westermann & Callomon 1988: pl. 13, fig. 3a, b; IMC 447, Assemblage VI; see Fig. 4). Fig. 7i is reconstructed from Fig. 7g.
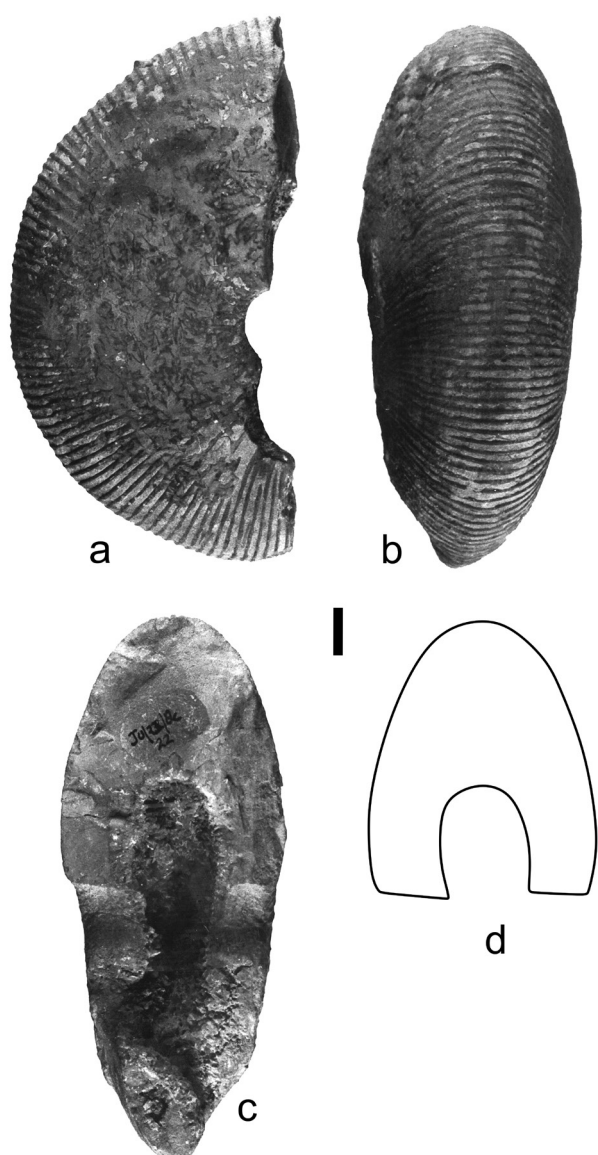
a b

I

d

c

Fig. 8: *Macrocephalites* cf. *mantataranus* Boehm [M], 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).

5. Paleobiogeography

Seyed-Emami et al. (2015) noted in their description of Macrocephalitinae from Iran that Latest Bathonian–Earliest Callovian duration is marked by the dominance of *Macrocephalites* and *Homoeoplanulites* in both Subboreal and Submediterranean Provinces, whereas in Kachchh (and in general, within the Indo-Madagash Province), *Macrocephalites* and *Choffatia* dominate (and to a minor extent subgenus *Subgrossouvria* and Genus *Indosphinctes*). Genus *Macrocephalites*, in Europe, occurs in the Late Bathonian of Southern Germany where now both *Macrocephalites triangularis* and *M.* cf. or aff. *keeuwensis* (Dietl & Callomon 1988; = *M.* cf. *keeuwensis* of Mönnig 2015) have been recorded; the latter comes from the middle–Late Bathonian Hannoveranus subzone, Retrocostatum Zone (Dietl & Callomon 1988; Mönnig

1996, 2014) (Fig. 13). Sporadic occurrences of Late Bathonian–Early Callovian *M. madagascariensis* and the Early Callovian *M. chrysoolithicus*, *M. lamellosus* and *M. subcompressus* have also been mentioned occasionally (see also Cariou et al. 1990).

It seems that the small, compressed and sharply ribbed *Macrocephalites keeuwensis* Boehm [m] (Fig. 4) is cosmopolitan, following the Late Bathonian transgression and migrated from Indonesia via Kachchh to Madagascar and on to Europe, along the southern peri-gondwana margin. But, it did not reach further to Iran, Tibet and the Russian platform, however, the genus, as such, did (see also Mönnig 2015). Compressed forms such as *M. lamellosus* Sowerby [m] and *M.* cf. *subcompressus* (Waagen) [m] have been recorded from Iran and *M. madagascariensis* Lemoine and *M. semilaevis* (Waagen) [M] from Tibet (Yin 2016) suggesting dilution of ammonite faunal provincialism and increased exchanges between the Indo-Madagascan and other provinces throughout the Early Callovian, and more so at the base of Early Callovian.

6. Systematic paleontology

All specimens presented here are part of the set of specimens that formed the basis for the author's dissertation and are accordingly kept in the collcetion of the Department of Geology, University of Rajasthan (Jaipur, India).

Genus *Macrocephalites* Zittel, 1884

Type species: *Ammonites macrocephalus* Schlotheim, 1813

Macrocephalites keeuwensis Boehm 1912 [M and m]

Figs. 5–7, 16, 17

Microconch [m]

1890 *Ammonites calloviensis* Etheridge, p. 175, pl. 29, fig. 5.
1908 *Macrocephalites* cf. *macrocephalus compressus* Boehm, p. 331, pl. 12, fig. 2.
1912 *Macrocephalites keeuwensis α* Boehm, p. 160, pl. 36, figs 2–4 only [fig. 3a, b, lectotype].
1912 *Macrocephalites keeuwensis β* Boehm, p. 161, pl. 38, figs 1 and 2a, b only.
1912 *Macrocephalites keeuwensis α – β* Boehm, p. 163, pl. 41, fig. 3.
1913 *Macrocephalites keeuwensis* Boehm, p. 15, pl. 5, fig. 1.
1928 *Dolikephalites keeuwensis* Spath, p. 205 [lectotype designated: Boehm 1912, pl. 36, fig. 3a, b].
1928 *Dolikephalites flexuosus* Spath, p. 210, pl. 32, fig. 4. [for Etheridge 1890, pl. 29, fig. 5; holotype refigured].
1958 *Macrocephalites flexuosus* Collignon, pl. 18, fig. 77.
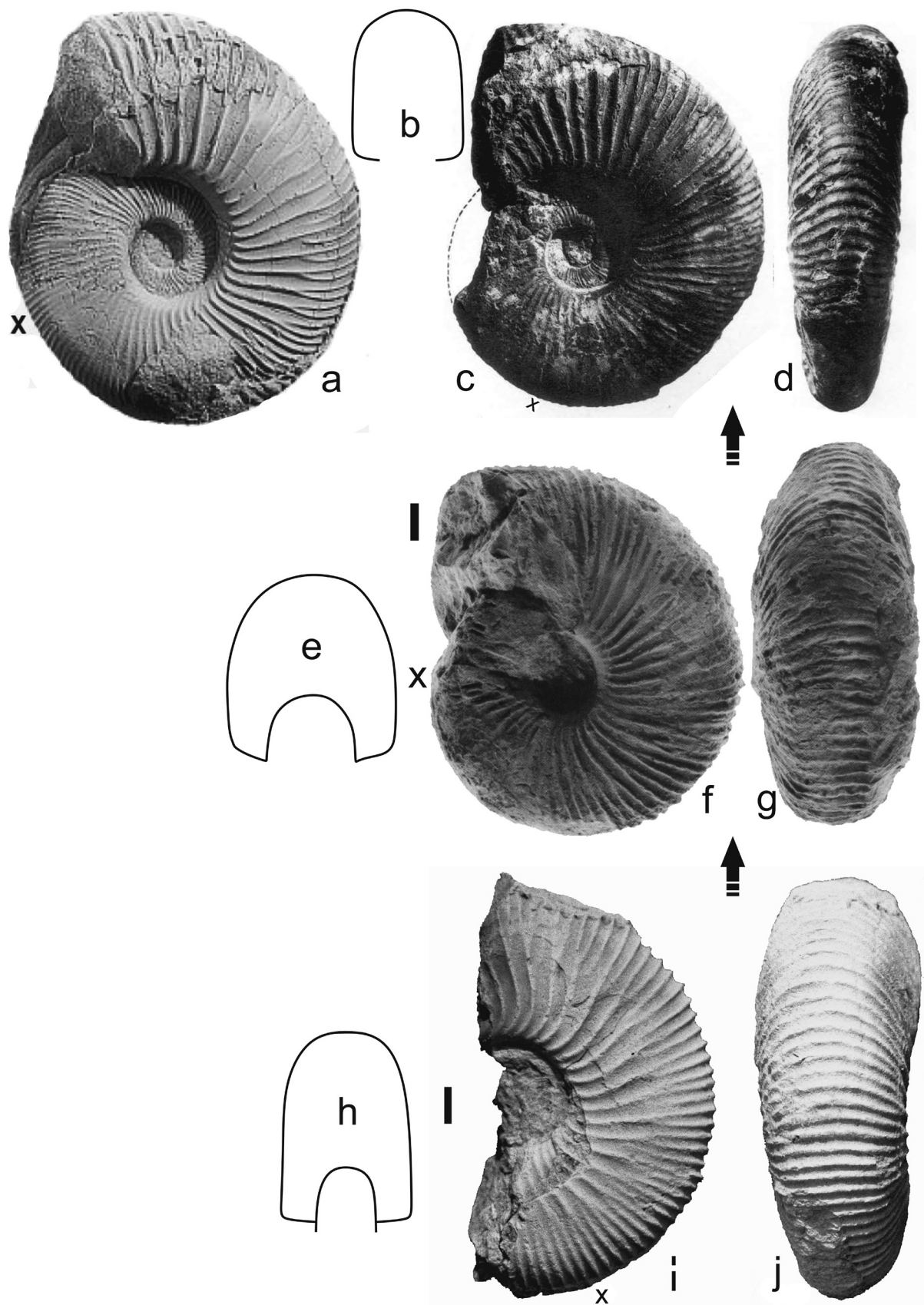1978 *Macrocephalites* (*Dolikephalites*) *keeuwensis* – Sato et al., p. 12.

Fig. 9: Proposed evolution of *Macrocephalites keeuwensis – M. lamellosus – Subkossmatia opis*. **(a–d)** *Subkossmatia opis* Spath. a: Microconch refigured from Jana et al. (2005), their *Eucycloceras opis* var. *opis* [m], specimen no. JUM 378, bed 6 from Keera, diameter = 98 mm. b–d: holotype [m] refigured from Spath (1928: pl. 39, figs 2, 7). **(e–g)** *Macrocephalites lamellosus* (Sowerby). Microconch holotype refigured from Spath (1928: pl. 19, fig. 8a, b), measured diameter = 108 mm; phragmocone = 71 mm, Keera Dome, Kachchh (see text and Fig. 10c, d for details). **(h–j)** *Macrocephalites keeuwensis* Boehm [m] from Jara, present study, see text and Fig. 6a–c for details. In this progression (*M. keeuwensis–M. lamellosus–S. opis*), the ribs get straighter, finer, denser and the shell increasingly gets compressed and more eccentrically coiled, but at the same time, retaining the somewhat subquadrate whorl section.
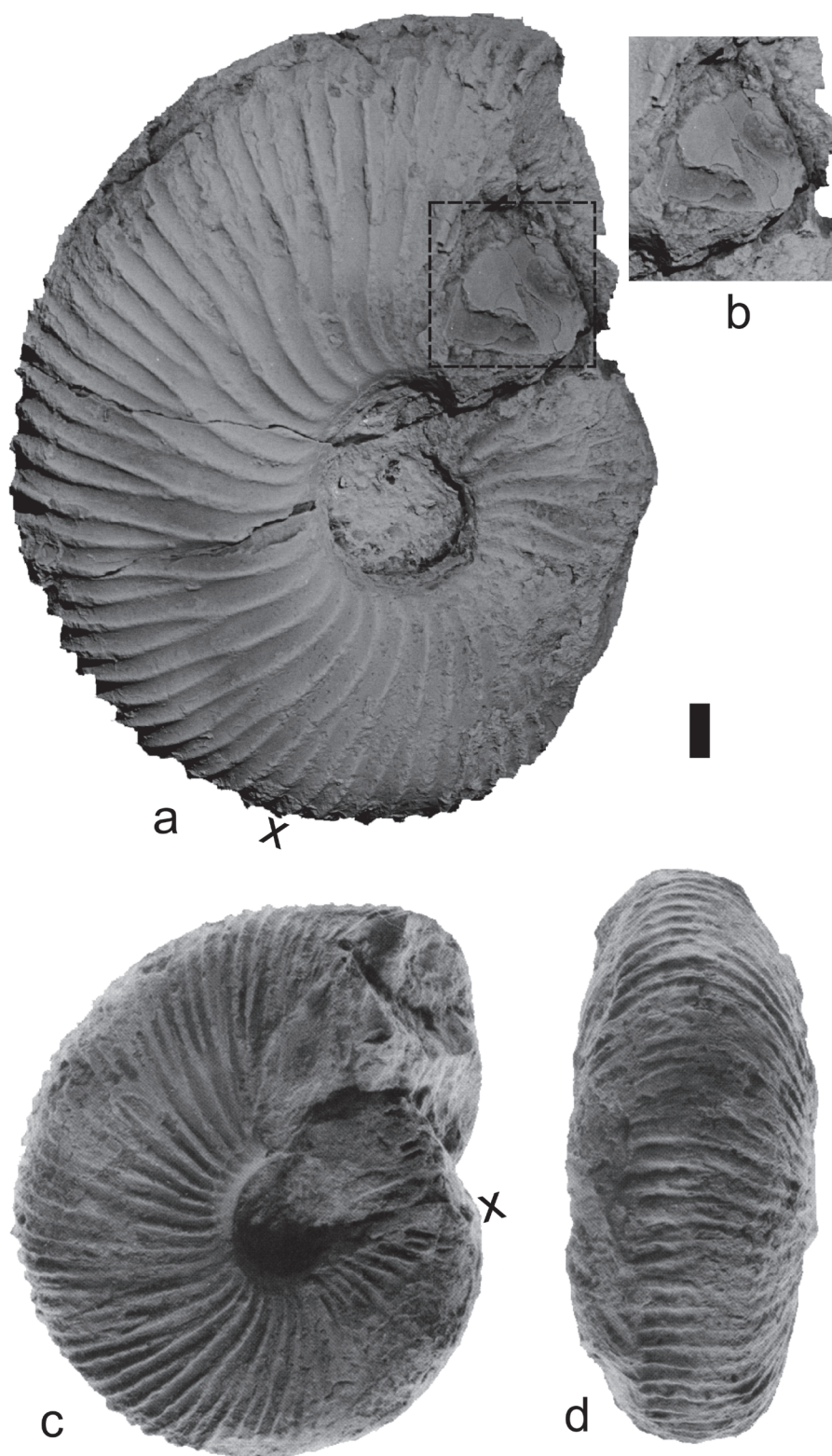
Fig. 10: *Macrocephalites lamellosus* (Sowerby) [M and m]. The dimorphic pair have been recorded from the late Early Callovian Samei-laevis Zone (see Fig. 13). **(a, b)** [M]: specimen no. Ju/12/25, Jumara, bed B36, Sameilaevis Zone, measured diameter = 150 mm, phrag-mocone = 115 mm (at D: 150, H: 66.5; T: 53.3; U = 33.6; T/H = 0.80; U/D = 0.22). **(c, d)** [m]: holotype refigured from Spath (1928, pl. 19, figs. 8a–b), measured diameter = 108 mm; phragmocone = 71 mm (at D: 108, H: 49.7; T: 44.3; U = 20.4; T/H = 0.89; U/D = 0.19). The microconch come from the adjoining Keera Dome, Kachchh (see Fig. 1), middle–Early Callovian Diadematus Zone (see Fig. 13). Note that the Macroconch is complete with attached operculum (b) and the microconch has only part of the body chamber damaged and is almost complete. In both dimorphs, ribbing projects strongly at the end of the whorl. Krishna & Westermann (1987) had suggested dimorphic pairing between *M. lamellosus* [m] and *M. madagascariensis* [M]. However, Thierry (1978) considered the pairing of *M. subcompressus* [m] and *M. madagascariensis* [M]. The holotype of *M. madagascariensis* [a Macroconch] measures 130 mm with a phragmocone of 109 mm; it is much more inflated (T/H = 0.94–0.99) and involute (U/D = 0.14–0.15) at 130 and 109 mm diameters, respectively. Based on present find, the latter seems more plausible.
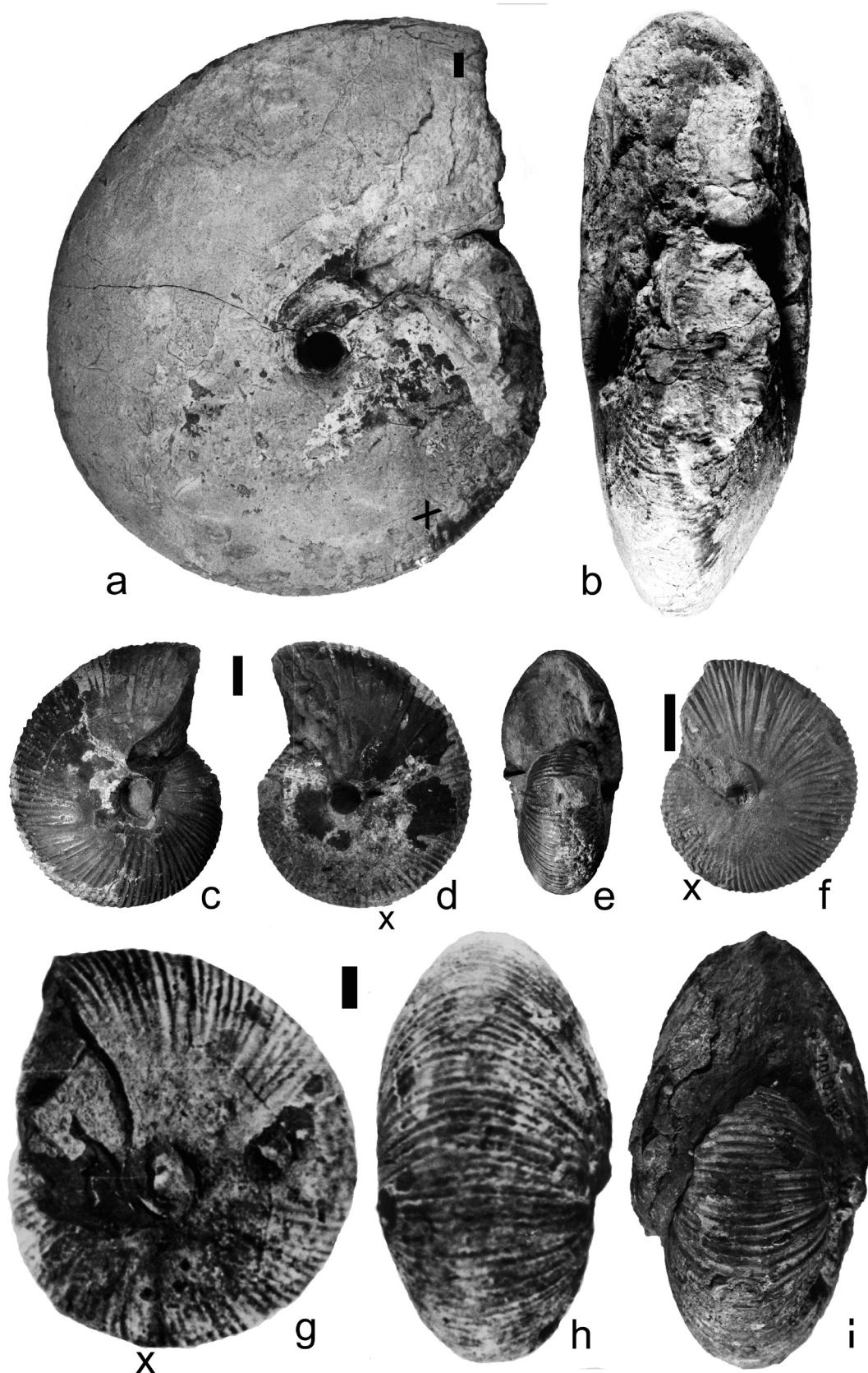
Fig. 11: *Macrocephalites formosus* (Sowerby) [M and m] and *M. chaeiensis* (Waagen) [M and m]. **(a–e)** *M. formosus* (Sowerby) [M and m], both from bed B23, middle–Early Callovian Diadematus Zone, Jumara (see Fig. 13). a–b: Macroconch, specimen no. Ju/12/20, measured diameter = 230 mm, c–e: Microconch, specimen no. Ju/12/50, measured diameter = 64 mm. f–i: *Macrocephalites chaeiensis* (Waagen) [M and m], almost complete specimens with part of the body chamber damaged. **(f)** [m], specimen no. Ju/12/40, bed B29, middle–Early Callovian Diadematus Zone (see Fig. 13), Jumara measured diameter = 86 mm (H = 45, T = 39.6, U = 8.1, T/H = 0.88, U/D = 0.14). **(g–i)** [M], specimen no. Ju/9/185, bed B29, late Early Callovian Formosus Zone, measured diameter = 101 mm (H = 57.4, T = 55.7, U = 13.82, T/H = 0.79, U/D = 0.14) (see Fig. 13). In both the microconchs (a–f), crowding of ribs is noted. Lack of umbilical seam in all specimens, also suggests maturity.

1978 *Macrocephalites (Dolikephalites)* cf. *subcompressus* – Sato et al., p. 12.

1978 *Macrocephalites macrocephalus keeuwensis* dim. micr. [= *Dolikephalites flexuosus*] – Thierry, p. 285, pl. 21, fig. 9 a, b [Boehm 1912, pl. 36, fig. 3 a, b, refigured = lectotype Spath 1928, textfig. 103].

1988 *Macrocephalites keeuwensis* Boehm 1912 [m] – Westermann & Callomon, p. 63, pl. 11, fig. 5; pl. 12; pl.   13, figs 1, 2.

1988 *Macrocephalites* cf. / aff. *keeuwensis* Boehm 1912 [m] – Dietl & Callomon, pl. 3, fig. 1.

cf. 1996 *Macrocephalites subcompressus* (Waagen) – Jain, p. 81, pl. 10, fig. 4

cf. 1996 *Macrocephalites flexuosa* (Spath) – Jain, p. 85, pl. 11, fig. 3

Macroconch [M]

cf. 1912 *Macrocephalites keeuwensis α – γ* Boehm, p. 164, pl. 42, fig. 2.

1912 *Macrocephalites keeuwensis α – γ* Boehm, p. 164, pl. 43, fig. 1.

cf. 1912 *Macrocephalites* sp. Boehm, p. 166, pl. 44, fig. 1a, b.

1978 *Macrocephalites (Macrocephalites)* aff. *fomosus mantataranus* – Sato et al., p. 12 only.

cf. 1978 *Macrocephalites macrocephalus keeuwensis* [=*M. keeuwensis α – γ*] – Thierry, p. 282, pl. 18, fig. 2a, b [?Boehm 1912, pl. 42, fig. 2 refigured], textfig. 102 (part).

Type: Boehm 1912: pl. 36, fig. 3a, b; lectotype designated by Spath 1928, p. 205 [m].

Material: 5 fragmentary specimens; One unillustrated macroconch [M] lent by Late G. E. G. Westermann, (1994, during the author's dissertation) from locality 4A, Assemblage V1 of Tikong, Indonesia (specimen no. J2023W mentioned in Westermann and Callomon, 1988, p. 63) (Fig. 3d–f); 2 specimens from the core of Jara Dome – one [m], var. B (specimen no. Ja/SJ/1999/Core/1); +2.5 m from the base; one [M] (specimen no. Ja/SJ/1999/Core/2) (Fig. 3a–c); 2 specimens from top of Sponge Bed (A8) of the Jumara Dome – var. aff. forma *flexuosa* [m] (specimen nos. Ju/22/122 and 148) (Fig. 7a–e).

Remarks [M]: In 1994, during my dissertation, the late Dr. G.E.G. Westermann (Canada) lent me a specimen (J2023W from Locality 4A, Assemblage V1 of Tikong, Indonesia) (Fig. 4, figured in Fig. 5d–f) of a macroconch of *Macrocephalites keeuwensis* Boehm which he had mentioned in his publication (Westermann & Callomon 1988) as material on p. 63 and on page 66 it was specifically mentioned – "The second, crushed specimen is somewhat larger with a (reconstructed) estimated diameter of 180 mm, and its body chamber has entirely smooth flanks." I am here illustrating this specimen for the first time as now comparable forms have been found in Kachchh from Jara; both are described below (Fig. 5). The phragmocone of J2023W measures 103 mm and adding a standard ¾ additional whorl for body chamber, the estimated diameter measures to 180

mm. The Macroconch of *Macrocephalites keeuwensis* Boehm described by Westermann & Callomon (1988: pl. 13, fig. 3a–c) is the Macroconch of one of their formas (forma *flexuosa*) (re-figured in Fig. 7g–i; Fig. 7i is reconstructed from 7h).

Thierry (1978: p. 282) noted that 20 macroconch specimens were available to him from Boehm's collection (Geological Institute of Utrecht, Holland), only 3 were (in part) with preserved body chamber measuring 163, 148 and 130 mm diameters. He choose the specimen illustrated in plate 42, figure 2 (Boehm 1912) from Keeuw (Taliabu Island, Sula Islands), Indonesia as type (refigured here in Fig. 16). This is a smooth, compressed form with a somewhat triangular whorl section; the body chamber occupies half to three quarters of a whorl. Thierry (1978) further noted that *M. keeuwensis* Boehm is a small-sized species (adult diameter 150–170 mm), discoidal, ornamented with moderately fine to medium ribbing. The phragmocone measures 90–100 mm with an oval whorl section. At this stage, the primary ribs are numerous and straight, slightly flexing towards the end of the phragmocone and dividing (mono-, di-, or polyschizotomes) into secondary ribs, to which are added numerous intercalary ribs, all passing the ventral border straight. Umbilical edge remains sharp and the walls vertical (Fig. 16). The early stages are unknown.

Description: Macroconch [M]—Shell is large (diameter = 172 mm; phragmocone = 132 mm; maximum estimated diameter = 231 mm), nearly complete (judging by the absence of umbilical seam) and discoidal. Early whorls, though not clearly discernable, are moderately depressed (see Figs. 5b–c; T/H = 1.20). At the body chamber, the umbilicus is narrow (U/D = 0.14) and funnel-shaped (66% broader at the top than at the bottom; conical; Fig. 5a). Umbilical margin is sharp. Flanks are moderately converging with a broadly rounded, somewhat tabulate venter. Whorl section changes from subtriangular to somewhat subquadrate, from the phragmocone to the body chamber, respectively. Ribbing is moderately fine with long primaries that arise from just below the umbilical shoulder with a slight backward bent at the umbilical region and then project forward, dividing indistinctly on the outer third of the flank into two or three secondaries that cross the venter straight. There are ~15 primaries per half whorl at the body chamber. They persist well into the body chamber but fade by 160 mm with an eventual smoothening of the lateral flanks. The only ribbing modifications noted at the body chamber is that the primaries become somewhat more forwardly projected than they are on the visible end part of the phragmocone (Fig. 5a); in the latter part, they are somewhat straighter, radial and closely spaced. However, with regards to lateral smoothening (the other adult modification), in the crushed Indonesian specimen (Fig. 5d), it is somewhat early (at the end of the phragmocone at
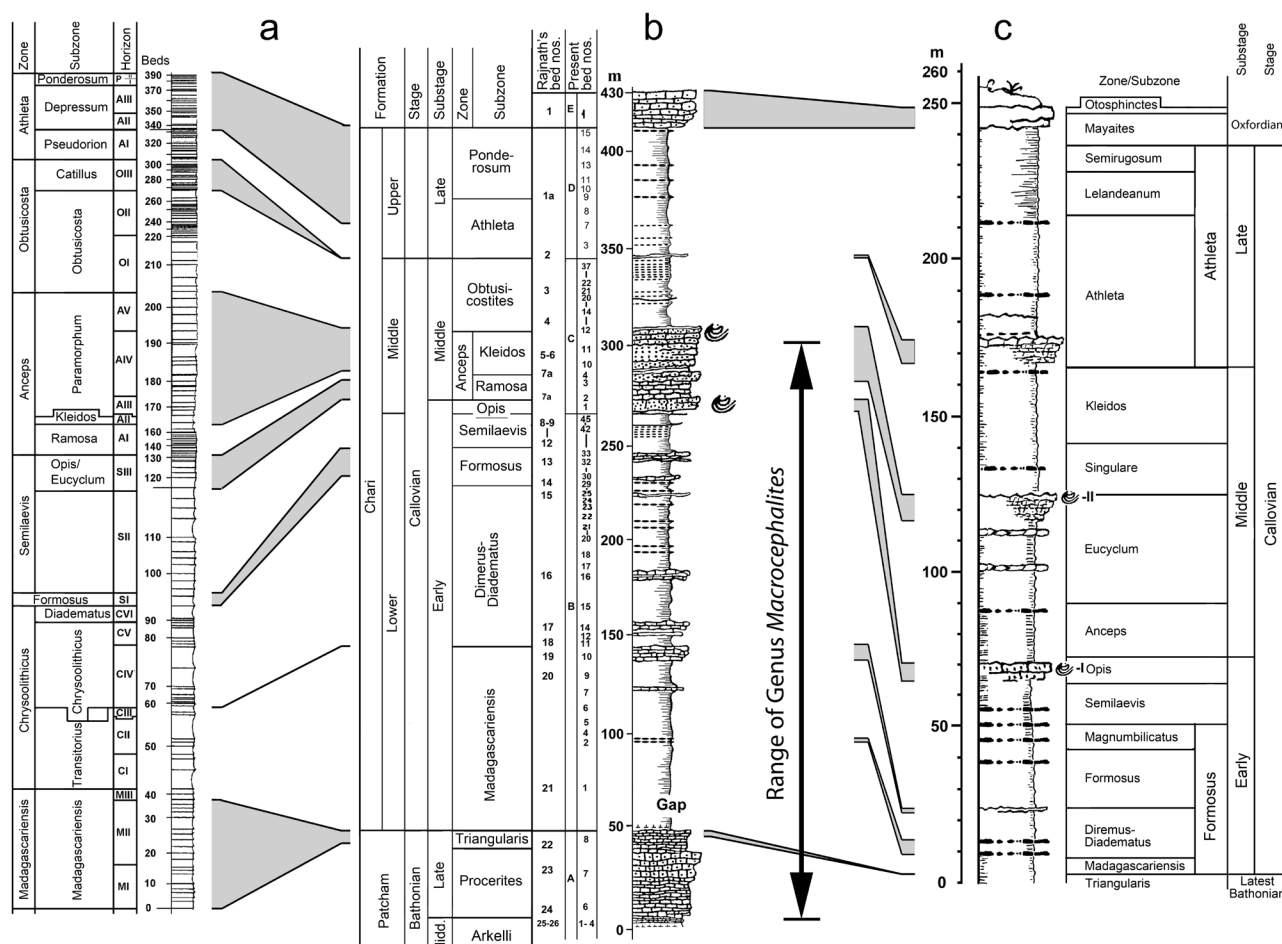
Fig. 12: Biozonation at the three domal localities of Kachchh discussed in this contribution. **(a)** After Krishna and Ojha (1996). **(b, c)** present study from Jumara and Jara Domes, respectively. Both Jara and Jumara records are from the Late Bathonian Triangularis Zone.

102 mm) and very pronounced with secondaries restricted to the outer third of the flank, thereafter.

Microconch [m]—*Macrocephalites keeuwensis* Boehm var. B [m]: Shell of medium diameter (107 mm), and nearly complete (as suggested by the absence of umbilical seam and the strong attenuation of ribbing; Figs. 6a, b), moderately evolute (U/D = 0.16–0.20), compressed (T/H = 0.79) and densely ribbed with ~23 primaries and ~51 secondaries per half whorl. Phragmocone (80 mm) is typically involute (U/D = 0.16), with a compressed subrectangular to trapezoidal whorl section (Fig. 6d). The primaries arise obliquely on the umbilical wall, curve with strong adoral concavity across the umbilical margin and reach with gentle projection to almost middle-flank. At the end of the body chamber, they tend to project more strongly and are thus are more concave at the umbilical region. The secondaries arise mostly by virgatotome polyfurcation and by intercalation at about middle-flank but at somewhat uneven whorl-height. They are more or less markedly rectiradiate and cross the venter straight at the phragmocone and with a slight and broad adoral convexity at the body chamber. The umbilical wall remains vertical, and the edge sharp. The flanks become subparallel to gently converging with a broad, evenly rounded

and slightly tabulate venter. The ribbing, even at the body chamber, remains dense but increases somewhat in spacing; it is still very sharp and prominent. At the body chamber, the shell egresses, resulting in a somewhat elliptical coil.

Macrocephalites keeuwensis Boehm aff. var. forma *flexuosa* [m]

Shell evolute, compressed and fragmentary but shows strong projection and increased closeness of ribs (crowding) on the body chamber (Fig. 7a, b, d) suggesting shell maturity reminiscent of that noted in *Macrocephalites keeuwensis* var. forma *flexuosa* Boehm [m] (Westermann & Callomon 1988: pl. 11, fig. 5a) (refigured in Fig. 7f [m]). The umbilical edge, though little available for observation, is characteristically sharp and the wall slanting inward. Primaries and secondaries, per quarter whorl, number ~12 and ~28, respectively. No other comparable Kachchh macrocephalitids are known at the coeval Bathonian–Callovian interval.

Northwest Europe
After Mangold and Rioult, 1997; Thierry et al., 1997, Seyed-Emami et al., 2015, Mönnig, 2014

Kachchh
After Jain, 2014, This study

Stage	Bremeri/	Zone	Subzone	NW Europe zones	Kachchh markers	Assemblage	Kachchh zone
Middle Callovian	Anceps		Stuebeli	*M. tumidus*	*S. opis* / *E. eucyclum*	*Subkossmatia opis, Reineckeia (R.) anceps, Macrocephalites subcompressus, Rehmanni (L.) reissi, Eucycleceras eucyclum*	Opis
Early Callovian	Gracilis		Patina	*M. tumidus*	*M. semilaevis*	*Macrocephalites semilaevis, M. magnumbilicatus, M. subcompressus, Macrocephalites sp., Rehmanni (Loczyceras) reissi*	Semilaevis
			Michalskii	*M. dicosmum / M. gracilis*		*Macrocephalites formosus, M. dimerus, M. lamellosus, M. chariensis, M. subcompressus*	Formosus
						B. (Kheraiceras) bullatus, Parapatoceras tuberculatum, Hectococeras proximum, Indosphinctes peregrinus, Collotia oxyptycha, Reineckeia tyranniformis, Indosphinctes urbanus	
			Laugieri			*Macrocephalites diadematus, M. chrysoolithicus, M. dimerus, M. cf. dimerus, M. formosus, M. lamellosus, M. chariensis, M. subcompressus*	Diadematus
			Pictava		*M. diadematus / M. chrysoolithicus / M. formosus / M. lamellosus*	*Hecticoceras michalski, Oxycerites cf. pleurocamya, Paralcidia sp., Parapatoceras tuberculatum, P. distans, Bullatimorphites (Bomburites) densicostatum, Paroecotraustes (Oecotraustes) sp., Calliphylloceras disputable, Subgrossouvria gudjinsirensis*	
			Grossouvrei				
			Prahecquense	*M. gracilis ssp. A*		*Macrocephalites dimerus, M. diadematus, M. chrysoolithicus, M. transitorius, M. formosus, M. lamellosus, M. chariensis, M. cf. sphaerodalis, M. subcompressus, M. elephantinus*	Dimerus
	Bullatus		Bullatus	*M. verus*	*M. transitorius*	*Choffatia madani, Choffatia sp., Indosphinctes sp., Subgrossouvria sp., Indosphinctes urbanus, Indosphinctes errans, Subgrossouvria gudjinsirensis var. tenius,*	
				M. verus / jaquoti	*M. madagascariensis*	*Macrocephalites madagascariensis, M. dimerus, M. transitorius, M. elephantinus, M. formosus, M. lamellosus, M. chariensis, M. diadematus, M. subcompressus, Parapatoceras sp., Choffatia sp., Choffatia baluchistanensis, B. (K.) cf. cosmopolitum,*	Madagascariensis
						M. madagascariensis, M. dimerus, M. transitorius, M. elephantinus, M. lamellosus, M. habyensis, M. intermedius, M. diadematus, M. subcompressus, Bullatimorphites (K.) bullatus, Bullatimorphites sp., B. (Kheraiceras) cosmopolitum, I. peregrinus, Calliphylloceras sp., Choffatia subbakeriae, Choffatia baluchistanensis, Subgrossouvria sp., Indosphinctes sp.	

GAP

Stage	Zone	Subzone	NW Europe markers	Kachchh markers	Assemblage	Kachchh zone
Late Bathonian	Discus	Discus	*M. jaquoti / M. triangularis / M. cf. keeuwensis*	*M. keeuwensis / M. mantataranus*	*Oxycerites orbis, Sivajiceras congener, Choffatia sp., Homoeoplanulites spp., Macrocephalites triangularis, M. cf. dimerus, M. cf. madagascariensis, M. cf. mantataranus, **M. keeuwensis**, Parapatoceras sp., Oxycerites sp., Paracenoceras sp., P. hexagonoides, P. wandaensis, P. jumarensis, Oxycerites cf. oppeli, Subgrossouvria sp., Choffatia baluchistanensis, Choffatia subbakeriae*	Triangularis
		Angulicostatum (Hollandi)				
	Retrocostatum	Hannoveranus (Histricoides)		*M. triangularis*	*Epistrenoceras sp., B. (Kheraiceras) cf. hannoveranus, Choffatia spp., Homoeoplanulites spp., Sivajiceras congener, Macrocephalites triangularis, Paracenoceras sp., Choffatia balinensis*	
		Blanazense / Julii			*Procerites cf. hodsoni, Procerites spp., Choffatia spp., Homoeoplanulites spp., Sivajiceras congener, Macrocephalites triangularis, Subgrossouvria sp., Procymatoceras cf. intumescens, Parapatoceras tuberculatum,*	Procerites
Middle Bathonian	Bremeri	Fortecostatum		*M. cf. etheridgei / M. bifurcatus / M. triangularis*	*Micromphalites (Clydomphalites) clydocromphalus, Wagnericeras sp., Sivajiceras congener, Procerites hians, P. (Gracilisphinctes) arkelli, P. (G.) intermedius, Macrocephalites triangularis, M. cf. etheridgei, M. bifurcatus aff. bifurcatus, M. bifurcatus intermedius, Parapatoceras distans, Reineckeia sp. A & B, Epimorphoceras decorum, Seimiradzkia sp., Procymatoceras cf. intumescens*	Arkelli
		Bullatimorphus			*Clydoniceras traingulare, Bullatimorphites s.s.*	

Fig. 13: Bathonian–Callovian ammonite assemblages and biozonation at Kachchh and correlation with the Western European biozonation.
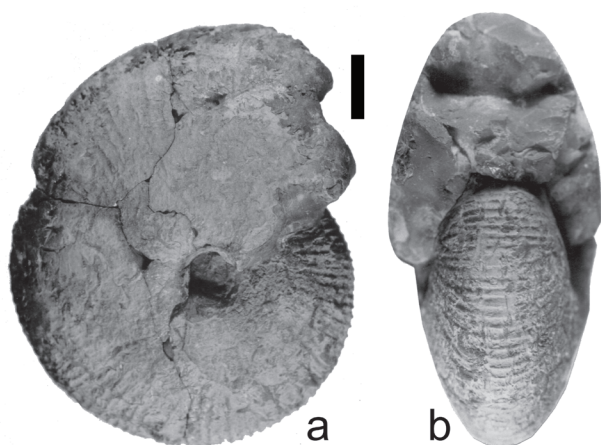
Fig. 14: (a, b) *Macrocephalites semilaevis* (Waagen) [M], fully septate specimen, specimen no. Ju/7/76, bed B36, late Early Callovian Semilaevis Zone (see Fig. 13), Jumara, diameter = 101 mm.

Remarks: Macroconch [M]: Thierry (1978: p. 282, pl. 18, fig. 2a, b; pl. 20, fig. 5a, b) illustrated two macroconch specimens; the one on plate 18, figure 2a, b, the holotype, is fragmentary and was refigured from Boehm's plate 42, figure 2 (refigured here for reference in Fig. 16); it measures 165 mm with a phragmocone of 135 mm.

Both Indonesian and the Jara macroconchs (Figs. 5, 16) resemble somewhat the early–middle Early Callovian *Macrocephalites formosus* (Waagen) [M] (Fig. 11a, b) recorded from almost all domal outcrops in Kachchh (Jain & Pandey 2000; Krishna & Ojha 1996), Madagascar (Thierry 1978) and Europe (Krishna & Cariou 1990; Cariou et al. 1993). In Kachchh, its acme marks a Zone, the Formosus Zone (Figs 12, 13), which is delimited at the base by the occurrence of *Collotia oxytypha* Neumayr and at the
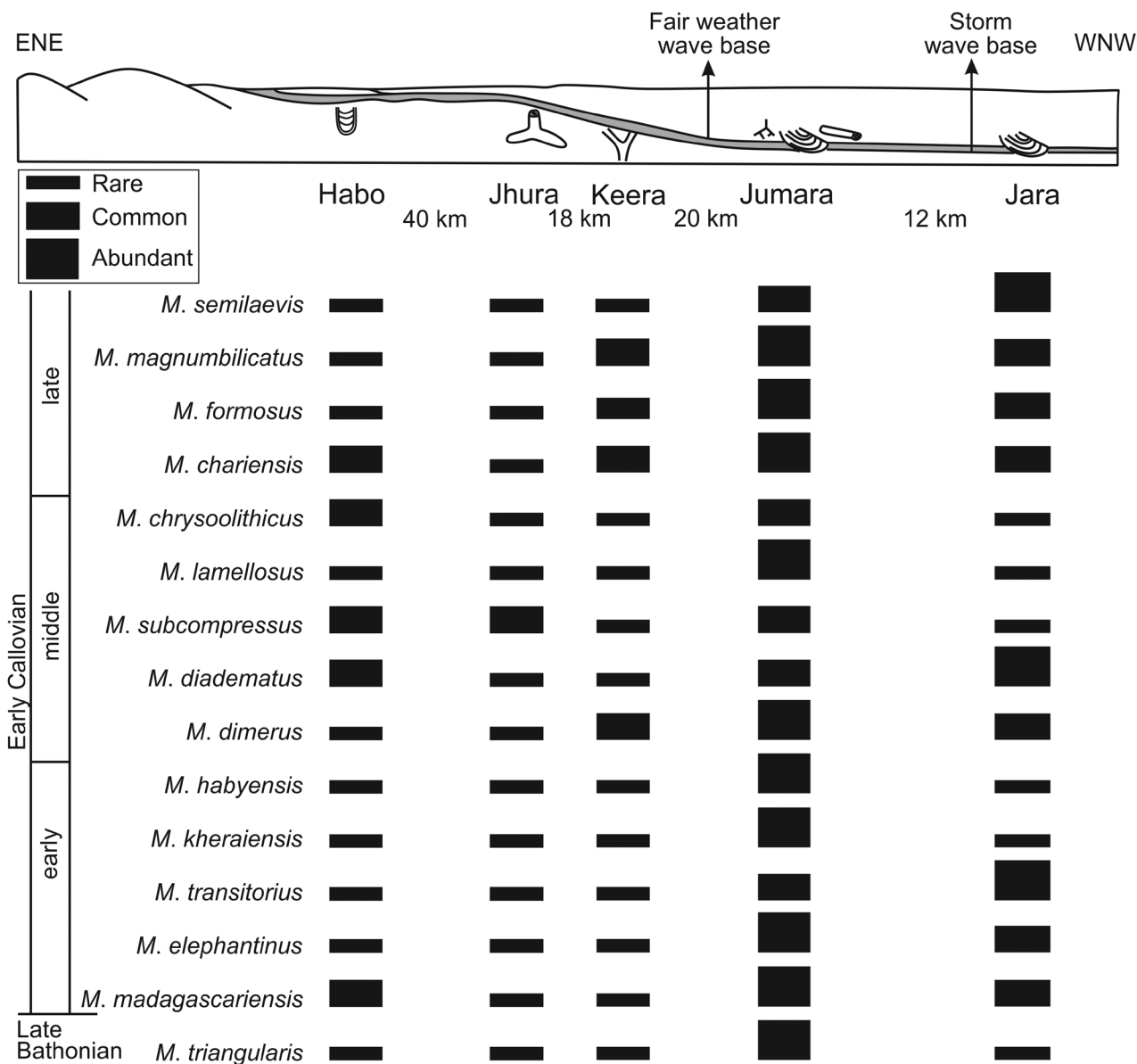

Fig. 15: Domal (from distal to proximal transect of the basin; Jara to Habo, respectively) distribution of macrocephalitid species within the Kachchh Basin. The ammonite fauna is not stratigraphically differentiated; the compressed species occur together with the inflated species, although their percentages may differ and they themselves differ laterally in abundance from one dome to the other.
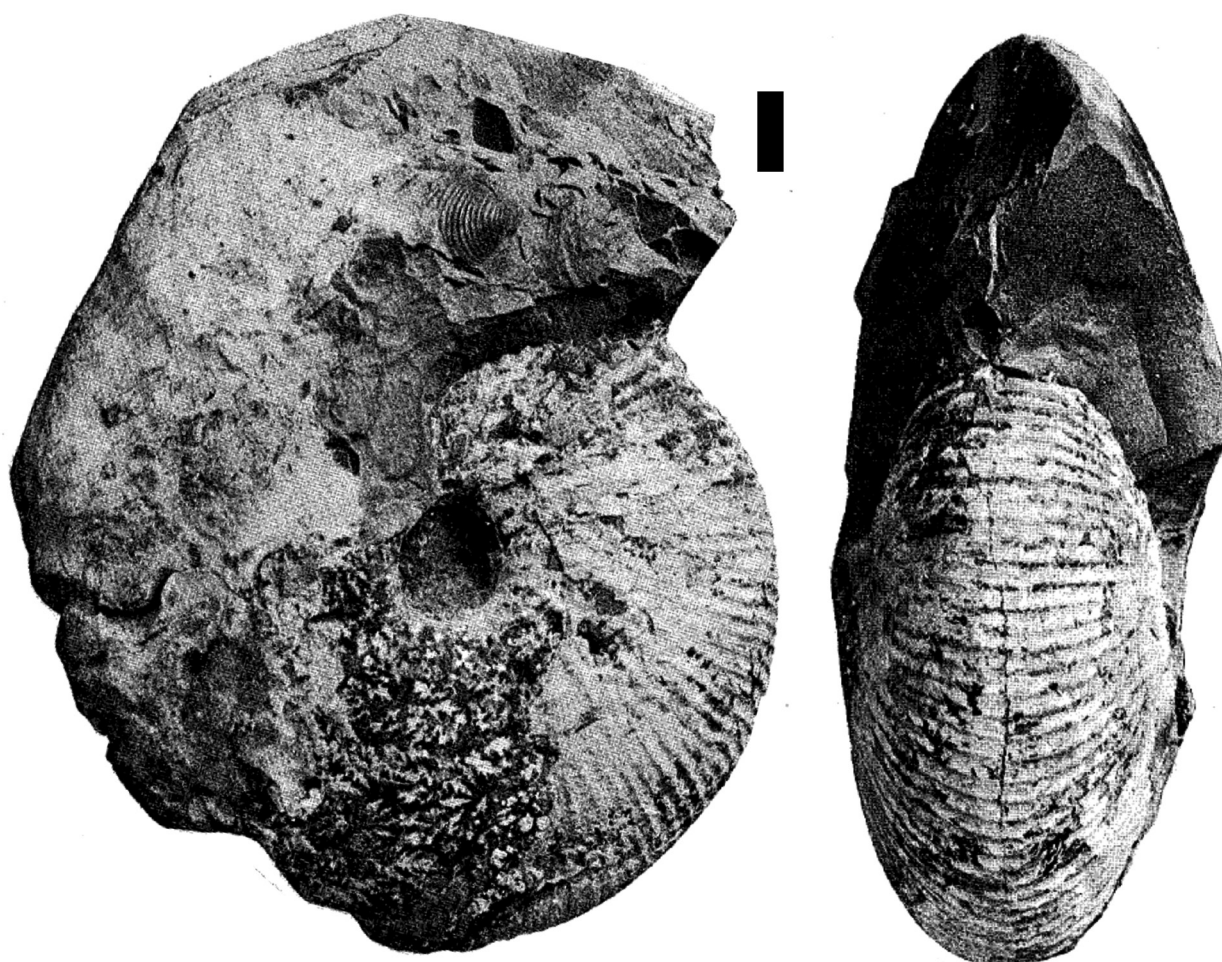
Fig. 16: *Macrocephalites keeuwensis* Boehm [M]. holotype refigured from Boehm (1912: pl. 42, fig. 2). It measures 165 mm with a phragmocone of 135 mm (see text for explanation and Appendix for dimensions).

top by *Hecticoceras proximum* Elmi (Krishna & Ojha 1996; Jain & Pandey 2000) and hence, is correlated with the standard European Proximum subzone, Gracilis Zone (Fig. 13). The Formosus Zone is best developed at Jumara (Krishna & Westermann 1987) where the nominal macroconch species, has a long range, from the Earliest Callovian Madagascariensis Zone to the middle–Early Callovian Formosus Zone, itself (Figs 12, 13).

The macroconch of *Macrocephalites formosus* is a large form (maximum estimated shell diameter in excess of 410 mm; phragmocone measures about 194 mm; Fig. 11a, b) (Bhaumik et al. 1993), is involute (U/D = 0.07), moderately compressed (T/H = 0.90) with smooth flanks, at or just after the phragmocone (although in some specimens, smoothening starts much before the end of the phragmocone). Umbilicus is deep and cylindrical with a venter that is narrow and acutely rounded (Fig. 11b). The large size, smooth flanks, deep cylindrical umbilicus and the narrow acutely rounded venter distinguish *M. formosus* from the macroconch of *M. keeuwensis* Boehm (compare Figs 5, 16 with Fig. 11) or any other Indonesian forms (Westermann & Callomon 1988; Thierry 1978).

The other closely comparable form is Collignon's *M. formosus* (1958: pl. 13, fig. 66) from his Macrocephalites triangularis Zone, Andranomantsy III, Madagascar. However, it is much smoother with pronounced extraumbilication and body chamber modifications and a vertical umbilical wall even at 182 mm shell diameter.

The macroconch of European *Macrocephalites gracilis* (Spath) (Cariou & Hantzpergue 1997: pl. 19, fig. 7a, b) in its outer whorl smoothening is comparable, but *M. gracilis* is more evolute, with a subtriangular whorl section, an acutely rounded venter with high vertical umbilical walls. It is the index of the European late Early Callovian Gracilis Zone (Fig. 13).

Microconch [m]: Westermann & Callomon (1988) identified four *M. keeuwensis* morphs (two formae and two varieties):

1 Forma *typica*: It is moderately involute (U/D = 0.17–0.20), compressed (W/H ≤ 0.8); densely ribbed (P ≥ 18–22) and includes the Lectotype.
2. Forma *flexuosa*: It is the most abundant form. It is involute (U/D ≤ 0.17), compressed (W/H ≤ 0.8) and densely ribbed (P ≥19). It includes *Dolikephalites flexuosus* Spath. Forma *flexuosa* is now

◌ W and C (1988, p. 69), IMC 441 [m] (var. forma *flexuosa*)

○ W and C (1988, pl. 12, fig. 4) [m] (var. forma *flexuosa*)

◉ W and C (1988, pl. 12, figs. 3a-b) [m] (var. forma *flexuosa*)

⬠ Boehm (1912, pl. 36, figs. 3a-b) [m] (Lectotype)

⊗ Westermann and Callomon (1988) [m]

■ Jara specimen [m] (Ja/SJ/1999/Core/1)

⬠ Boehm (1912, pl. 36, fig. 1) [M]

⬠ Boehm (1912, pl. 42, fig. 2) [M] (Holotype)

⬠ Boehm (1912, pl. 44, figs. 1a-b) [M]

✛ Indonesian specimen [M] (J2023W) (This study)

● Jara specimen [M] (Ja/SJ/1999/Core/2) (This study)

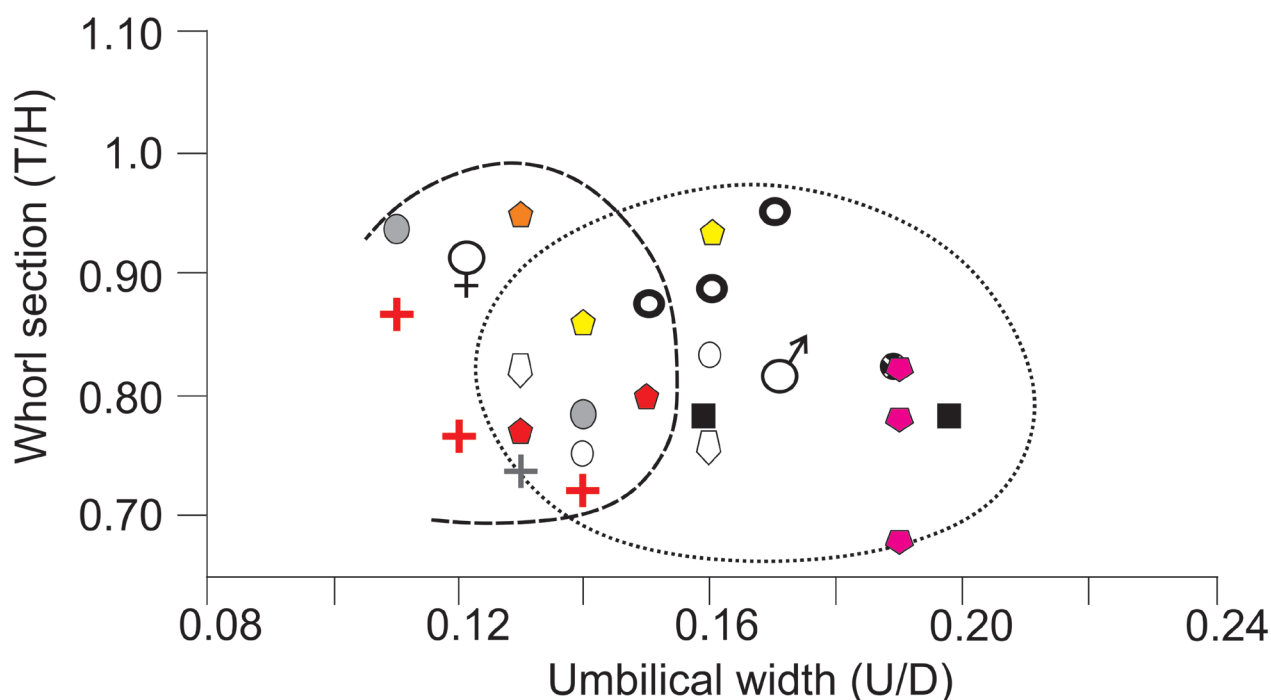✚ W and C (1988, pl. 13, figs. 3a-c) [M] (var. forma *flexuosa*)

Fig. 17: Whorl section (T/H) versus Umbilical width (U/D) of *Macrocephalites keeuwensis* Boehm [M and m] discussed in this contribution (see Appendix for corresponding dimensions).

recorded here and described below.

3. Var. A: It possesses weakly compressed whorls (W/H > 0.8) with subquadrate body chamber, medium umbilicus (U/D = 0.15–0.19) becoming moderately evolute at the body chamber. The ornamentation is coarse (P ≤ 19) and resembles *Macrocephalites subcompessus* (Waagen) from which it is distinguished by its sharp umbilical edge (as most Indonesian forms are).

4. Var. B: It is relatively evolute (U/D ≥ 0.20), particularly the body chamber (U/D = 0.25), and compressed (W/H ≤ 0.8). The ribs are strongly flexed and moderately dense (P = 17–20). It resembles *Subkossmatia* and *Eucycloceras*, from which its

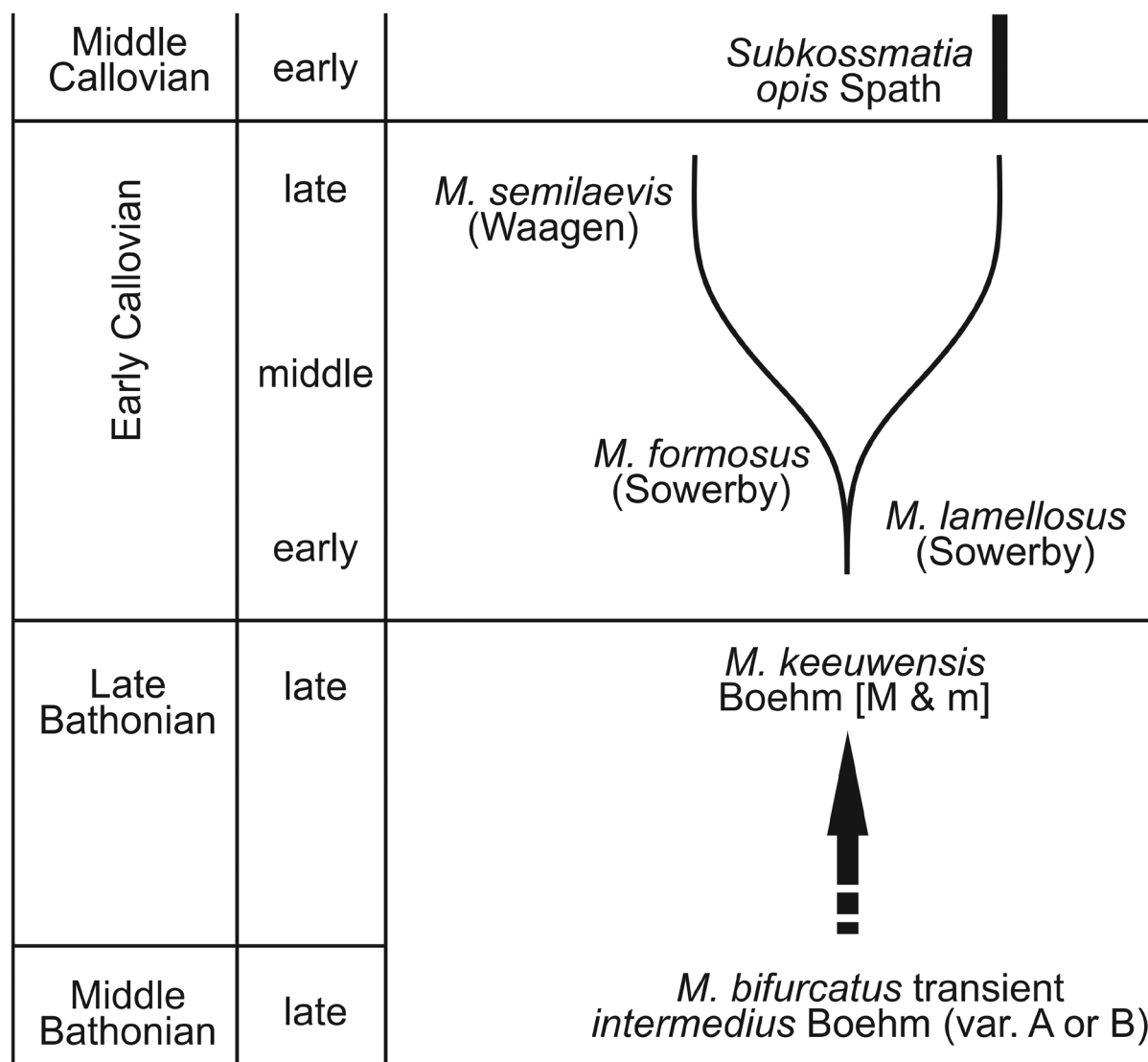|		
Middle Callovian	early	*Subkossmatia opis* Spath
Early Callovian	late	*M. semilaevis* (Waagen)
	middle	*M. formosus* (Sowerby) *M. lamellosus* (Sowerby)
	early	
Late Bathonian	late	*M. keeuwensis* Boehm [M & m]
Middle Bathonian	late	*M. bifurcatus* transient *intermedius* Boehm (var. A or B)

Fig. 18: Proposed lineages. It is speculated, that *M. keeuwensis* Boehm [M and m] gave rise to two distinct lineages; one, that gave rise to the Early Callovian *M. lamellosus* (Sowerby) and that in turn to the late Early Callovian *Subkossmatia opis* Spath. On the other hand, to the early–middle Early Callovian *Macrocephalites formosus* (Waagen), which in turn gave rise to the late Early Callovian *M. semilaevis* Spath.

sharp umbilical edge and dense, sharp ribbing on the body chamber distinguish it. Var. B is recorded here and described below.

Macrocephalites keeuwensis Boehm var. B [m]

The specimen figured is in its morphological and dimensional characteristics (Figs 6a–c, 17) an exact match with Boehm's (1912: pl. 38, fig. 1) *Macrocephalites keeuwensis* Boehm var. B [m] from "Keeuw" (refigured here in Fig. 6e), as also the European Late Bathonian (Orbis Zone) *Macrocephalites* cf. / aff. *keeuwensis* Boehm (Dietl & Callomon 1988; refigured here in Fig. 6f).

Thierry's (1978: pl. 21, fig. 9a) *Macrocephalites macrocephalus keeuwensis* (= *Dolikephalites flexuosus* sensu Spath) is somewhat comparable but is much smaller (86 mm) and more densely ribbed (26 primaries and 62 secondaries per half whorl).

Jeannet's (1955: pl. 22, fig. 1) *Macrocephalites* (*Pleurocephalites*) *uhligi* Lemoine and his *Macrocephalites* (*Kamptokephalites*) *lamellosus* Sowerby (1955: pl. 26, fig. 3) from Herznach, Switzerland (Enodatum subzone; top of Calloviense Zone; late Early Callovian) are comparable forms but possess a straighter ribbing pattern with a distinctly rounded umbilical shoulder.

The Kachchh *Macrocephalites lamellosus* (Sowerby) [m] (Fig. 10) which occurs stratigraphically just above (Earliest Callovian) the Jara microconch (Latest Bathonian) (Fig. 13), is also a closely comparable form but lacks the distinct primaries that show a strong adoral concavity across the umbilical margin as also the characteristic sharp umbilical edge, besides the former's microconch is much smaller and inflated with a broadly rounded venter (Fig. 10c–d). The dimorphic pair for *M. lamellosus* (Sowerby) has now been recorded from Kachchh (Fig. 10). The

Macroconch comes from the late Early Callovian Semilaevis Zone (bed B36 from Jumara); it is complete with an attached operculum (Fig. 10a, b) and measures 150 mm with a phragmocone of 115 mm. The holotype, a microconch, is almost complete at 108 mm from Early Callovian sediments of Keera (refigured here in Fig. 10c, d).

The Jara specimen (Fig. 6a–d) in its evoluteness and to some extent, in its ribbing pattern, closely resembles the latest Early–earliest Middle Callovian *Subkossmatia opis* (see refigured holotype in Fig. 9b–d and another example refigured in Fig. 9a from Jana et al. 2005, his *Eucycloceras opis* var. *opis* [m] from Keera) of the Eucycloceratinae (see also Jain & Pandey 2000 for stratigraphic distribution) as recognized by Spath (1928: p. 202, 210, pl. 39, figs 2, 7) (Fig. 13). As also noted by Spath, in *M. keeuwensis* Boehm only the body chamber egresses, while in *Subkossmatia* egression begins at the intermediate whorls, e.g. the entire ultimate septate whorl egresses, as noted in the fully septate holotype of *S. opis* (Fig. 9a). Additionally, *Subkossmatia* differs in possessing increasingly and more strongly projected secondary ribs. However, Westermann & Callomon (1988) noted that *M. keeuwensis* Boehm var. B is often indistinguishable from the nucleus of *Subkossmatia*, unless the septal suture is preserved showing the convex or "raised" umbilical saddle envelope of the former. Besides these, there are no other comparable forms of *M. keeuwensis* Boehm var. B [m].

Macrocephalites keeuwensis Boehm aff. var. forma *flexuosa* [m]

Two fragmentary specimens were found from the top of the Sponge Bed (bed A8; see Fig. 7a–e) associated with *M.* cf. *mantataranus* Boehm (Jain & Desai 2014) (Fig. 8). Based on this association, their close resemblance to the ribbing pattern of *M. keeuwensis* Boehm var. forma *flexuosa* [m] (Fig. 7f) and the fact that there are no other comparable compressed and densely ribbed macrocephalitid forms at this level, their affinity to *M. keeuwensis* Boehm var. forma *flexuosa* [m] is suggested (Fig. 7f).

Another closely comparable form is *Dolikephalites flexuosus* Spath (1928: p. 210, pl. 32, fig. 4), which has already been considered to be a synonymy of *M. keeuwensis* Boehm [m] (Westermann & Callomon 1988). Additionally, no Kachchh macrocephalitid form possesses such a sharp umbilical edge as the specimens presented here; a characteristic feature of Indonesian forms (Westermann & Callomon 1988). The crowding of the ribs and their strong forward projection suggests maturity of these fragmentary specimens (Fig. 7a, b, d). The macroconch (Fig. 7g–i; refigured from Westermann & Callomon 1988: pl. 13, fig. 3a, b) shows the same ribbing pattern, sharp umbilical edge and inwardly projected umbilical walls.

7. Conclusions

Co-occurrence of the dimorphic pairs of the Indonesian ammonites *Macrocephalites keeuwensis* Boehm [M & m] and *M. keeuwensis* var. aff. forma *flexuosa* Boehm [m] with *M.* cf. *mantataranus* Boehm [M] from Jara and Jumara Domes (Mainland Kachchh) enables to date not only the Indonesian *M. keeuwensis* Association but also the strata where the nominal species *M. keeuwensis* Boehm occurs in Kachchh, Madagascar and Europe as definitely Late Bathonian. The Late Bathonian age is additionally strengthened by reports from the Jumara Dome of characteristic Orbis–Discus Zone fossils of *Oxycerites* cf. *orbis* (Roy et al. 2007), *O.* cf. *oppeli* (Pandey et al. 2012) and *Bullatimorphites* cf. *hannoveranus* (Bardhan et al. 2002). Additionally, it is speculated, that *M. keeuwensis* Boehm [M & m] gave rise to two distinct lineages and the paper documents the separation of these two different lines (Fig. 18). One that gave rise to the Early Callovian *M. lamellosus* (Sowerby), and that in turn led to the late Early Callovian *Subkossmatia opis* Spath, as well as to the early–middle Early Callovian *Macrocephalites formosus* (Waagen), which in turn gave rise to the late Early Callovian *M. semilaevis* Spath (Fig. 18). The dimorphic pair of both *M. lamellosus* Sowerby and *M. formosus* (Waagen) are recorded. All the above forms now occur in Kachchh, Western India.

Acknowledgements

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Appendix: Measurements of *Macrocephalites keeuwensis* Boehm [M & m] in mm. T = Whorl thickness; H = Whorl height; T/H = Whorl section; U/D = Umbilical width.

Species	Sp. no.	Measured at	D	H	T	U	T/H	U/D
M. keeuwensis Boehm [M]	J2023W	Body chamber	115.3	52.1	38	14.9	0.73	0.13
	Ja/SJ/1999/ Core/2	Body chamber	172	75.6	59.6	23.7	0.79	0.14
		Phragmocone	132	46.1	43	15	0.93	0.11
	Boehm 1912: pl. 42, fig. 2 (holotype)	Body chamber	163	78	61	21	0.78	0.13
		Phragmocone	135	70	56	20	0.8	0.15
	Boehm 1912: pl. 44, fig. 1a, b	Body chamber	105	53	50	14	0.94	0.13
	Boehm 1912: pl. 36, fig. 1	Body chamber	102	54.5	47.1	13.5	0.86	0.13
		Phragmocone	82	45	42	13	0.93	0.16
var. B [m]	Ja/SJ/1999/ Core/1	Phragmocone	80	38.5	30.5	13	0.79	0.16
		Body chamber	107	44.2	34.7	21.4	0.79	0.20