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Note on the earliest records of genus *Macrocephalites* Zittel: implications for biostratigraphic correlations

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ABSTRACT

The Bathonian–Callovian (Middle Jurassic) genus *Macrocephalites* Zittel is distributed worldwide, and several of its species are used for inter- and intrabasinal biostratigraphic correlations. Here, the earliest occurrence of genus *Macrocephalites*, using an integrated approach incorporating data from ammonites, calcareous nannofossils and magnetostratigraphy from the Kachchh Basin of western India is presented. The calcareous nannofossils were extracted from the *Macrocephalites triangularis* Spath (m) sample, and the magnetostratigraphic data also comes from the same ammonite-bearing bed (Yellow Bed, bed A4), in the core of the Jumara Dome, Kachchh Basin. The sample yielded age-diagnostic calcareous nannofossil taxa with FOs (First Occurrence) of *Pseudoconus enigma*, *Cyclagelosphaera margerelii*, *Octopodorhabdus decussatus* and *Watznaueria barnesiae*, and the LO (Last Occurrence) of *Carinolithus magharensis*, thus, bracketing the age of the Yellow Bed between early to early middle Bathonian. An early middle Bathonian age was also proposed previously based on an ammonite assemblage and correlated with the Standard European early middle Bathonian Progracilis Zone. The magnetostratigraphic data yielded an early Bathonian age, but, it is of very low resolution, and possibly re-magnetised. The occurrence of *M.* aff. *triangularis* Spath from eastern Crimea from below the Bremeri Zone (middle Bathonian), corroborating the early middle Bathonian age arrived at for the earliest occurrence of *M. triangularis* in the Kachchh Basin, is also evaluated. The stratigraphic occurrence of a heavily encrusted *M. triangularis* specimen from Germany, and assigned to the lower Callovian, is also evaluated. The present data suggests that genus *Macrocephalites* Zittel was already well-established even in the early middle Bathonian, if not earlier, and that a relook/resampling is urgently needed with an integrated approach for southern Tethyan margin localities such as Madagascar and Sula Island.

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Introduction

Genus *Macrocephalites* Zittel is widely distributed, and several of its species are marker taxa that have been used for inter- and intrabasinal correlations with pervasive upper Bathonian–lower Callovian records (Thierry 1978; Dietl 1981; Krishna and Westermann 1987; Callomon et al. 1987; Dietl and Callomon 1988; Westermann and Callomon 1988; Möning 1995, 2014; Datta et al. 1996; Page 1996; Seyed-Emami et al. 2015; 2017; Dietl et al. 2021) but very rare middle Bathonian ones (Jain and Pandey 2000; Roy et al. 2007; Jain 2014, 2020; Gulyaev and Ippolitov 2023). It is these contentious middle Bathonian records that need a closer scrutiny and are the subject of this contribution.

Thus, this contribution evaluates the earliest records of the genus *Macrocephalites* Zittel from the Kachchh Basin (Nara, Jumara, Jhura and Mouwana domes), western India (Figure 1), and integrates data from ammonite and calcareous nannofossil assemblages, and magnetostratigraphy. Additionally, newer middle Bathonian macrocephalitid records from SW Somalia (Jain 2019a) and eastern Crimea (Gulyaev and Ippolitov 2023) are also evaluated vis-à-vis the earliest record of the genus. A lower Callovian occurrence of a typical upper Bathonian *Macrocephalites triangularis* Spath from the Swabian Alp, Germany (Dietl et al. 2021) is also evaluated. The contribution also provides a note on the way forward for macrocephalitid research and potential pitfalls/caveats in doing so.

Geological settings

The Jurassic outcrops in the Kachchh Basin (western India) constitute the Kachchh Mainland and the Island belt (Figure 1). On the Kachchh Mainland, the Middle Jurassic rocks occur in eroded cores of anticlinal domes that follow East-West trending fault-bounded lineaments; the Islands or Island Belt are small to moderate hills that rise from sand plains or salt-flats of the Rann (Figure 1). This contribution discusses new discoveries from the Bathonian strata exposed at the Jumara Dome and integrates earlier reports from coeval strata from Nara and Jhura domes (all in the Kachchh Mainland) and those from Pachchham (Gora Dongar and Kala Dongar) and Bela (Mouwana Dome) islands (Figure 1). A general Bathonian stratigraphy with associated beds and fossil occurrences discussed in this contribution is provided in Figure 2 (for details see Jain 2014).

Bathonian biostratigraphy of the Kachchh Basin

The ammonite biostratigraphy of the Kachchh Basin epitomises that of a distinct marine palaeobiogeographic province; as of yet, considered part of the Indo-East African Province (see Westermann 2000) (Figure 3). The Bathonian ammonite faunas of this province differ sufficiently from those of other provinces, thus making it necessary to work out an independent regional chronostratigraphy (see Callomon 1993; Krishna 2017). Contextually, the age (based on the first and last occurrences, FO

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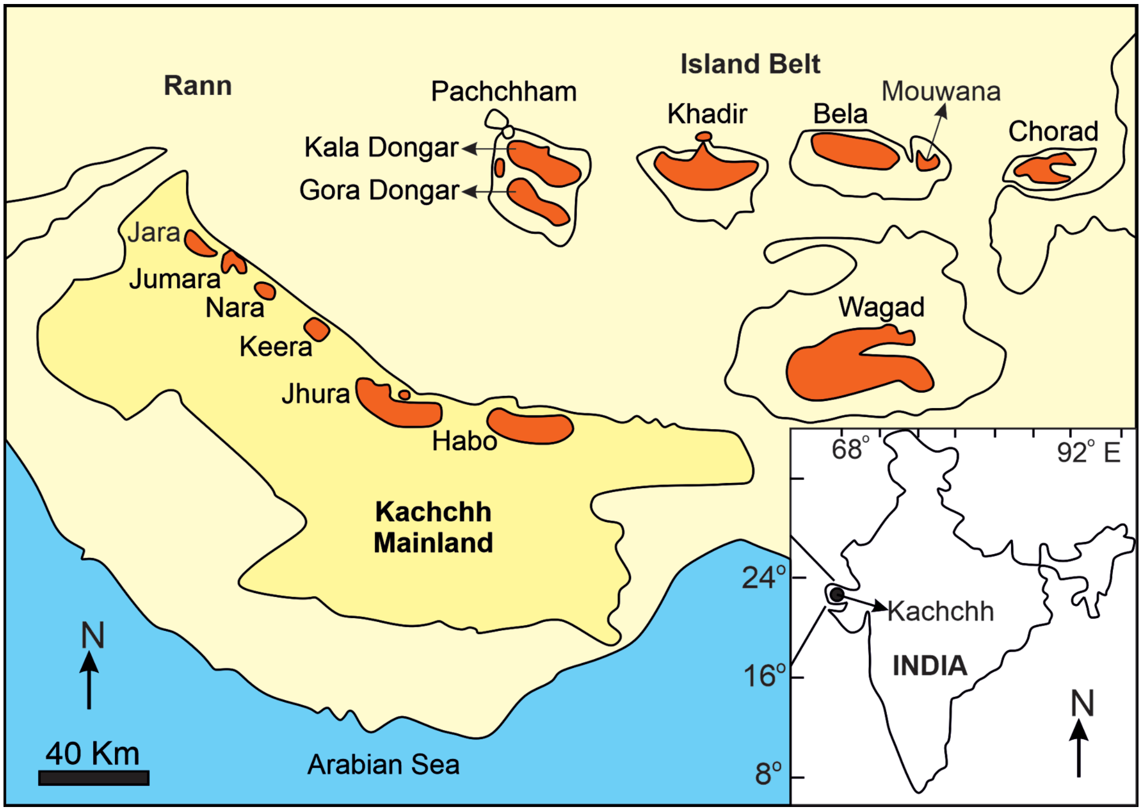

Figure 1. Geological map of the Kachchh Basin (mainland and Island Belt, western India), showing in red major Jurassic (Bathonian–Callovian) outcrops discussed in the text (in set: position of the Kachchh Basin in western India).

and LO, respectively) of a particular species (ammonite and/or calcareous nannofossils), within the Kachchh Basin, may differ slightly to significantly with the occurrences from other provinces (see Jain 2014). It is in this backdrop that an updated overview of the current status of the middle Bathonian biostratigraphy of the Kachchh Basin is provided below with a brief discussion on major ammonite reports and their inherent uncertainties.

Early Bathonian (Siemiradzkia–Procerozigzag assemblage)

Jain (2020) reviewed the fragmentary early Bathonian *Siemiradzkia–Procerozigzag* assemblage recorded from the Nara Dome (see Figures 1, 4A–B) by Pandey and Pathak (2015). This is an important finding and fills a gap in the Kachchh Bathonian biostratigraphy (Figure 4). The assemblage contains fragmentary specimens assigned to the following genera: *Zigzagiceras* Buckman, *Procerozigzag* Arkell, *Siemiradzkia* Hyatt, *Berbericeras* Roman, *Parkinsonia* Bayle, *Ebrayiceras* Buckman, ?*Telermoceras* Arkell and *Micromphalites* Buckman, in association with *Prohecticoceras* Spath, *Procerites* Siemiradzki, *Cadomites* Munier-Chalmas, *Oecotraustes* Waagen and *Phylloceras* Suess. Of these, the following genera were also recorded by Jain (2014, 2020) from the nearby Jumara Dome, Yellow Bed (bed A4; henceforth referred to as the Yellow Bed): *Siemiradzkia*, *Ebrayiceras*, *Micromphalites*, *Procerites* and *Oecotraustes*. Pandey and Pathak's (2015) record bears out two facts – first, the Bathonian Mainland Kachchh sedimentary sequence is much older than previously assumed (see Callomon 1993 for a brief review of faunal assemblages and their suggested ages) and secondly, *Macrocephalites*, for now, do not occur in the early Bathonian deposits.

Early middle Bathonian ammonite assemblage

Roy et al. (2007) recorded *Macrocephalites* cf. *etheridgei* Spath (m) from their bed 2, Badi Upper Golden Oolite from the Jhura Dome (see Figures 2, 4D); this occurrence is above the early Bathonian *Siemiradzkia–Procerozigzag* assemblage recorded by Pandey and Pathak (2015) from the Nara Dome (see Figure 4B). Recently, Jain (2020) reviewed the Nara Dome ammonite occurrences and assigned beds 10–15 of Pandey and Pathak (2015) to early middle Bathonian age based on similar co-occurrences of *Procerites*, *Oecotraustes*, *Siemiradzkia* and *Micromphalites* from the adjoining Jumara Dome also (= Yellow Bed; Arkelli Zone; see Jain 2014, 2020) and with the *etheridgei*-yielding bed at the Jhura Dome (see Figure 4). However, the Jhura Dome specimen of *M.* cf. *etheridgei* Spath (m) as recorded by Roy et al. (2007, p. 631) from their bed 2 was not illustrated.

The Nara Dome bed (bed 2 of Roy et al. 2007) containing *M.* cf. *etheridgei* Spath (m) (Figure 4A) is considered coeval with the Jhura Badi Upper Golden Oolite bed (Figure 4D) which is ~40 m above the Yellow Bed of Jumara, also containing *M.* cf. *etheridgei* Spath (m) (see Figure 4C). At Jhura (Figure 4D), coeval with the Jumara Yellow Bed (see Figure 2), and above the *M.* cf. *etheridgei* occurrence, Jain (2014) recorded *Procerites* (*Gracilisphinctes*) aff. *arkelli* (M) Collignon (M) (the *Gracilisphinctes* sp. of Jain et al. 1996) (Figure 4D). Thus, both on lithostratigraphic (see Fürsich et al., 2023) and faunal grounds, *M.* cf. *etheridgei* Spath is the earliest macrocephalitid and forms an early – middle Bathonian continuum, where macrocephalitids are present in the early middle Bathonian strata, if not earlier (see Figure 4).

Thus, in Kachchh, *M.* cf. *etheridgei* (m) occurs in the early Middle Bathonian strata at Nara, Jumara and Jhura; the best exposure for this interval being at Jumara, where the fauna is prolific and

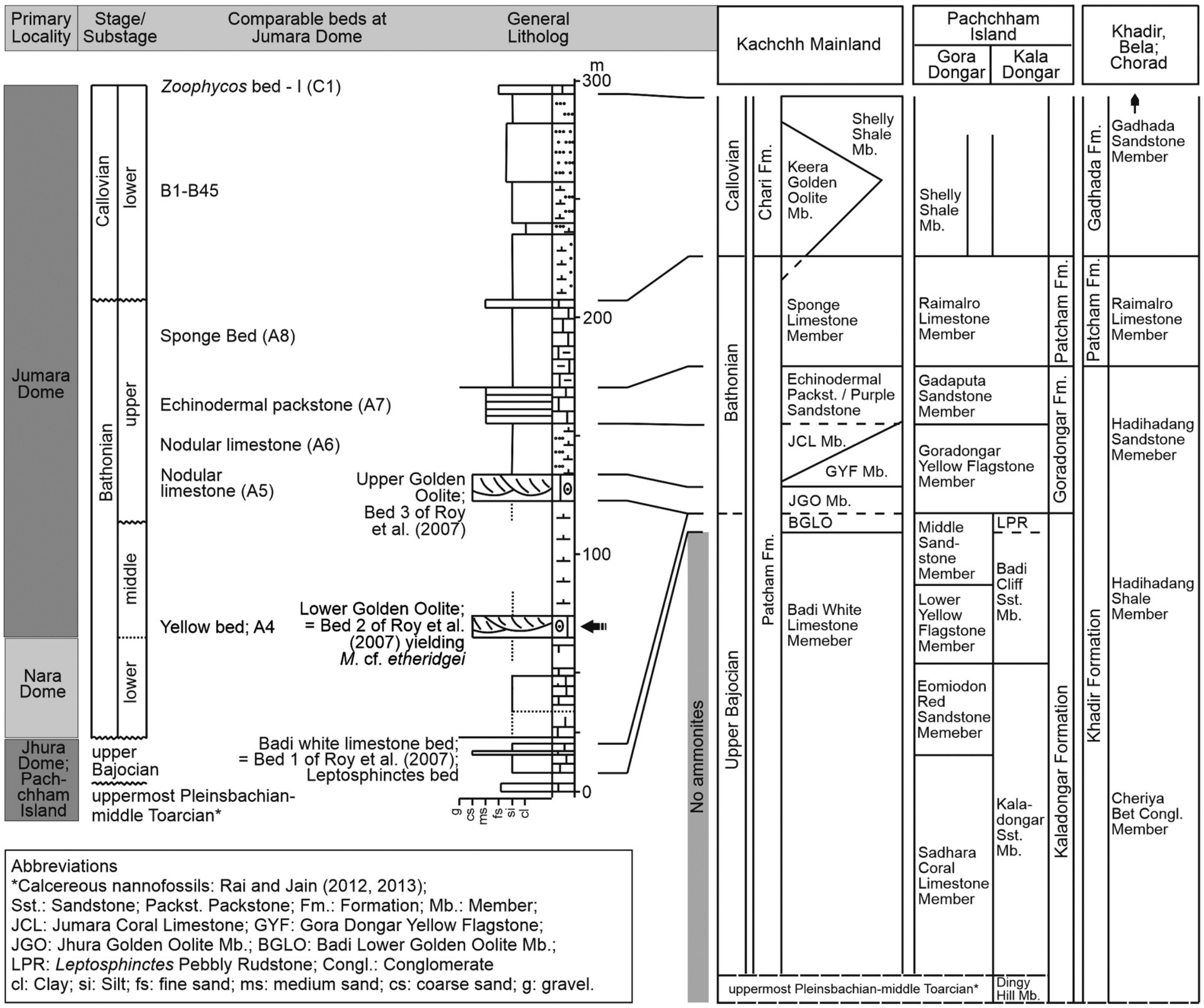

Figure 2. Bathonian–lower Callovian lithostratigraphic units and ages of the Kachchh Basin (mainland and Island Belt). Modified after Fürsich et al. (2001).

well dated as early Middle Bathonian Arkelli Zone and equated with the European Progracilis Zone, coeval with the Indonesian *M. bifurcatus* Association of Westermann and Callomon (1988) (see Jain 2014, 2020). However, as noted by Jain (2014), an earlier age for *M.* cf. *etheridgei* (m) at Jhura cannot be ruled out due to the ~40 m lower occurrence of *M.* cf. *etheridgei* (m) by Roy et al. (2007) (see Figure 4D).

Calcareous nannofossil assemblage

The calcareous nannofossil assemblages from the cores of almost all domal outcrops are contentious (see Rai and Jain 2013). Rai in Jain et al. (2013) and Rai et al. (2013) from a microconch specimen of *M. triangularis* Spath (m) from the Yellow Bed recorded a calcareous nannofossil assemblage containing *Axopodorhabdus cylindratus, Cyclagelosphaera margerelii, Calyculus* sp., *Pseudoconus enigma, Discorhabdus criotus, Ethmorhabdus gallicus, Carinolithus magharensis, Lotharingius crucicentralis, L. haufii, L. sigillatus, L. velatus, Octopodorhabdus deccusatus, Staurolithites* sp., *Watznaueria barnesiae, W. britannica, Zeugorhabdotus erectus, Cyclagelosphaera deflandrei* and *Diazomatolithus lehmanii*. Based on the FO (First Occurrence) of *O. deccusatus* in the early Bajocian and the LO (Last Occurrence) of *C. magharensis* in the middle Bathonian, these authors suggested an age ranging from early Bajocian to middle Bathonian for the Yellow Bed (Jain et al. 2013; Rai et al. 2013).

On close scrutiny, this assemblage bears out three points. (1) *W. barnesiae*, *Cy. margerelii* and *C. magharensis* are cosmopolitan marker taxa, hence useful for global correlations (see López-Otálvaro and Henriques 2018), (2) the assemblage is also marked by the presence of two leaked taxa, *C. deflandrei* and *D. lehmanii*, whose FOs are much higher up in the Oxfordian and Tithonian, respectively (see Table 1; see also Casellato 2010; Bown et al. 1988), (3) now based on a much refined age model (GTS 2020 after Gradstein et al. 2020), improved data from the nannotaxa website (www.mikrotax.org/Nannotax3/), and the presence of four marker taxa within the assemblage, *P. enigma*, *C. magharensis*, *Cy. margerelii* and *O. decussatus*, the age of the Yellow Bed is tentatively bracketed to lie between the lower to mid-calcareous nannofossil NJ11 Zone, i.e. early to early middle Bathonian (see Table 1; Figure 5).

However, as a caveat, it must be mentioned that although the FOs and LOs of marker taxa are globally robust biostratigraphical events (López-Otálvaro and Henriques 2018), but there also persists diachronism in some of their occurrences both in the Boreal (Bown et al. 1988; Bown and Cooper 1998) and Tethyan (Mattioli and Erba 1999) realms (see also López-Otálvaro and Henriques 2018). For example, the LO of *C. magharensis*, a marker taxa for the early Bathonian (middle part of the Zigzag Zone), is a good example of diachronic behaviour, whose LO differs in low, mid and high palaeolatitudes; its LO occurs somewhat earlier in the Boreal realm (López-Otálvaro and Henriques 2018).

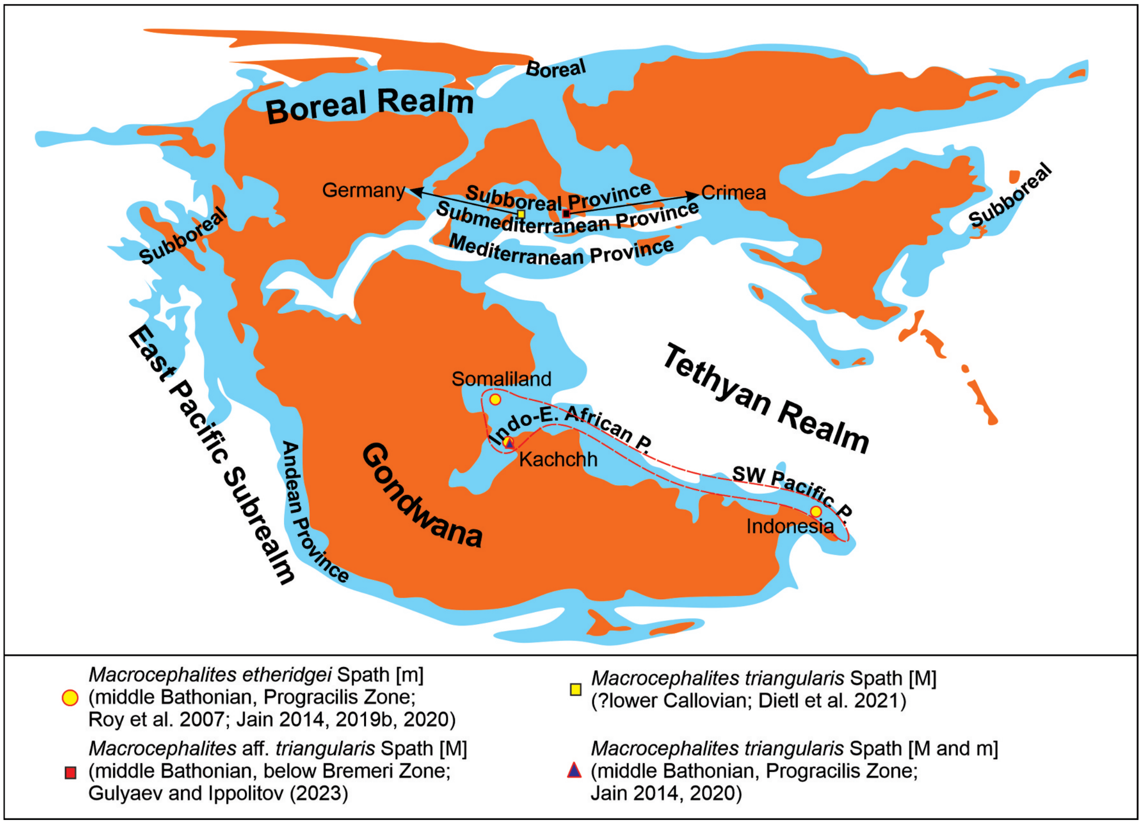

Figure 3. Bathonian–Callovian palaeogeographic map and ammonite provinces (modified after Seyed-Emami et al. 2015). The distribution of early middle Bathonian *macrocephalites* cf. *etheridgei* (Spath) is restricted to the southern margin of the Tethyan Indo-East African and South West Pacific provinces, whereas *macrocephalites triangularis* Spath has a somewhat broader spread in Kachchh, Swabian Alp (Germany: Dietl et al. 2021) and Crimea (Gulyaev and Ippolitov 2023). The eastern Crimean *macrocephalites* aff. *triangularis* Spath specimen may well be a new species, whereas the lower callovian German examples recorded from close to the Bathonian–Callovian boundary is heavily encrusted and may well be transported and/or redeposited. P.: province.

Thus, based on the calcareous nannofossil assemblage, a broad age straddling between early and early middle Bathonian is inferred for the Yellow Bed (see Figure 5; Table 1). Interestingly, recently Fürsich et al. (2023, p. 49) based on the lithostratigraphic and faunal grounds (presence of '*Eligmus* and *Procerites*') assigned the age of the 'basal most sediments of the Jumara Dome section' (i.e. beds A1-A3 of the present work; see Figure 4C) to the 'Zigzag to Aurigerus zones of the Early Bathonian' and based on the ammonite data set of Jain (2014, 2020), assigned the Yellow Bed to the 'early Middle Bathonian Progracilis Zone', as done by Jain (2014, 2020). Interestingly, these ages also corroborate the ages arrived at by using calcareous nannofossils (see Figure 5; Table 1). Additionally, this lowering of age is plausible as the record of *Macrocephalites* cf. *etheridgei* Spath from the neighbouring Jhura Dome (see Roy et al. 2007, p. 631; their bed 2) is ~40 m below the first occurrence of *P.* (*G.*) *arkelli* Collignon (see Figure 4C and discussed below in detail). The calcareous nannofossil content of the Jhura specimen has yet to be investigated.

Magnetostratigraphic data

Based on a very low resolution magnetostratigraphic data from the Yellow Bed (Jumara), Mamilla et al. (2016) correlated this bed with the standard magnetostratigraphic Zone M41 (= early Bathonian; see Figure 5). However, this record must be considered with caution not just because of its low resolution but the fact that the data records constant normal polarity, whereas, global records indicate the presence of 2–3 reversals (see Gradstein et al. 2020); this record may well be re-magnetised. Hence, more closely spaced data is needed to corroborate the identification of Zone M41 at the Jumara Dome.

Age-diagnostic middle Bathonian ammonite records from the Kachchh Basin: an update

Micromphalites (Clydomphalites) clydocromphalus Arkell (M)

Micromphalites Buckman is a typical lower Bathonian (Macrescens to Recintus subzones, Zigzag to Aurigerus zones, respectively) genus of Arabian origin that spread to the north (Europe) as well as to the south, until Madagascar (Collignon 1958) and the Kachchh Basin of western India during the middle Bathonian (see Jaitly and Singh 1984; Pandey and Callomon 1995). In Kachchh, *Micromphalites* (*Clydomphalites*) *clydocromphalus* Arkell (M) has been recorded both from the Pachchham Island (Goradongar) by Pandey and Callomon (1995) and from the Kachchh Mainland (Jumara Dome) by Jain (2014, 2020) (Figure 1). *Micromphalites* (*Clydomphalites*) sp. has also been recorded from Jumara (Jain 2020) and *Micromphalites* sp. from the Nara Dome by Pandey and Pathak (2015) (Figure 4). Jaitly and Singh (1984) recorded *Micromphalites hourcqi* Collignon from Kala Dongar (Pachchham Island Belt) (see Figure 1).

In Madagascar (Enay et al. 2001), as in Kachchh, the middle Bathonian age of *Micromphalites* is noted, and early Bathonian in Morocco, central Saudi Arabia, Spain and SE France (Mangold 1979; Torrens 1987; Enay et al. 2001; Énay and Mangold 2021). Based on the present data, it seems that the first record of this genus from the

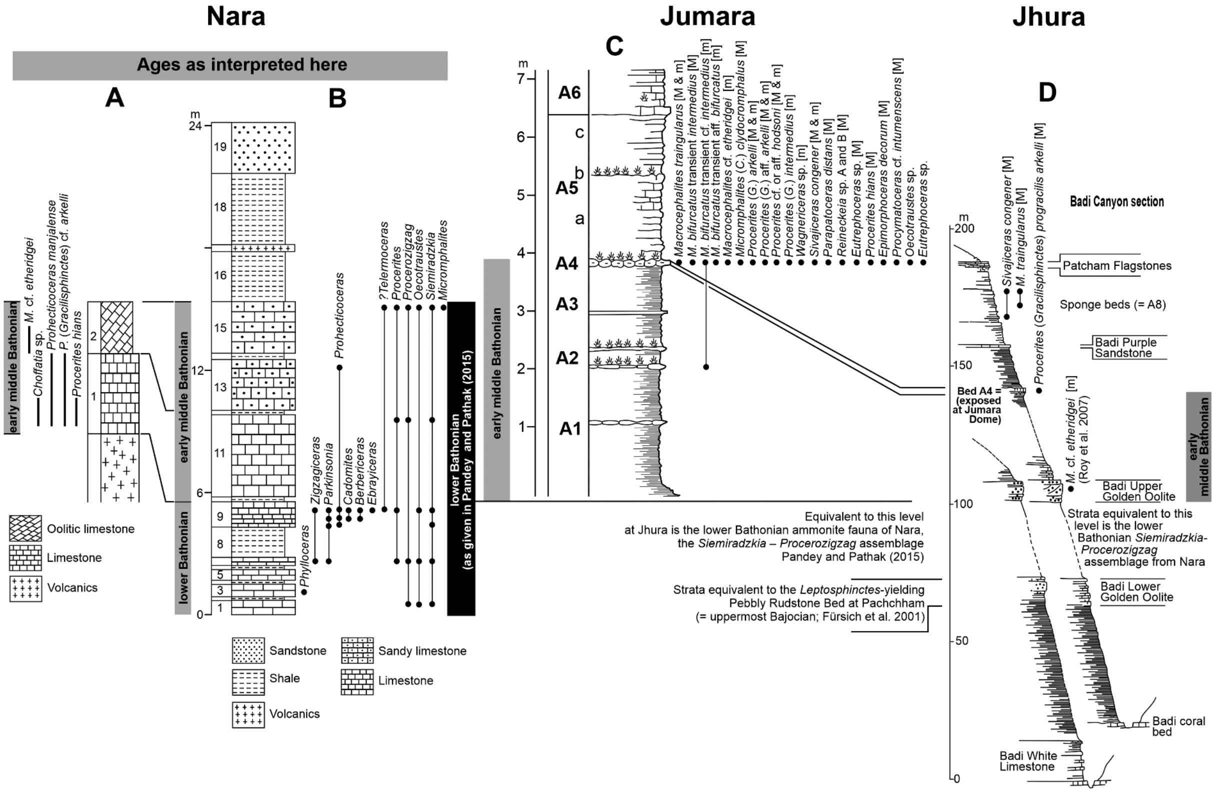

Figure 4. Lithostratigraphic logs, ammonite distributions and biostratigraphic correlation of lower-middle Bathonian rocks exposed in the Kachchh Mainland (modified after Jain 2014, 2020). A–B: Nara. C: Jumara. D: Jhura.

Kachchh Basin (in Nara, Jumara and Pachchham Island) occurred during the early middle Bathonian Progracilis Zone (see Pandey and Callomon 1995 for a brief review). Contextually, it must also be mentioned that the Kachchh *Micromphalites* populations is quite distinct from the Madagascan (Collignon 1958), Arabian (Arkell 1951–59) and the European ones (see Enay et al. 2001); the Kachchh forms are smaller (<60 mm), more discoidal (compressed) and lack the pronounced umbilical bulge which is noted in European forms (Enay et al. 2001, pls. 1–2 and Jain 2020, p. 6, fig. 3). Recently, Énay and Mangold (2021, p. 122) based on less imprecise Madagascan stratigraphy (sensu Collignon 1958), stated that all Kachchh '*Micromphalites*' specimens belong to the upper Bathonian, disregarding the well-studied and well-dated western Indian (Kachchh Basin) biostratigraphy (see Jain 2014, 2020; Krishna 2017; Fürsich et al., 2023). Even on lithostratigraphic grounds, let alone on fauna assemblages, this upper Bathonian age is impossible (see Jain 2020; Fürsich et al., 2023). Interestingly, at the Nara Dome (Figure 4B), *Micromphalites* occurs with ?*Telermoceras* (although this specimen is fragmentary and poorly preserved); it was assigned as age ranging between 'Late Bajocian – Early Bathonian' (Pandey and Pathak 2015). Arkell et al. (1957), however, provided an upper Bajocian age to *Telermoceras*. Nonetheless, taken together, the Nara assemblage (consisting of *Zigzagiceras*, *Procerozigzag*, *Siemiradzkia*, *Berbericeras*, *Parkinsonia*, *Ebrayiceras*, ?*Telermoceras*, *Micromphalites*, *Prohecticoceras*, *Procerites*, *Cadomites*, *Oecotraustes* and *Phylloceras*) is undoubtedly of early Bathonian age (see Pandey and Pathak 2015; Jain 2020).

Hence, for now, a conservative age of early middle Bathonian for the Yellow Bed assemblage, as proposed by Jain (2014, 2020), is reaffirmed, and the age assignment of *Micromphalites*–*Clydocromphalites* as proposed by Énay and Mangold (2021) to upper Bathonian needs revision in the light of more refined Kachchh lithostratigraphy (Fürsich et al., 2023) and biostratigraphy (Jain 2014, 2020; Krishna 2017).

Macrocephalites cf. etheridgei Spath (microconch)

Macrocephalites cf. *etheridgei* was first described from the Sula Island (Indonesia) where it occurs in the lower *M. bifurcatus intermedius* association (assemblages II, VIII-XI, XIII) and the succeeding *M. bifurcatus* association (assemblages I, III-IV) spanning mid- to upper middle Bathonian (see Westermann and Callomon 1988, p. 10). Based on the occurrence of the rare *Cadomites* cf. *rectelobatus* in both assemblages II (*M. bifurcatus intermedius*) and IV (*M. bifurcatus*), they tentatively correlated the two assemblages with the European upper middle Bathonian Bremeri Zone. Contextually, Galácz (1994) noted that the lectotype of *Cadomites rectelobatus* most likely originated from the base of the middle Bathonian Progracilis Zone (see also Mitta 2022). Mitta (2022) from the Kuban River Basin (Northern Caucasus, Russia), around the boundary interval between the Parkinsoni and Zigzag zones, recorded *Cadomites* sp. and *C.* ex gr. *rectelobatus*. In the Kachchh Basin, *Cadomites* sp. has also been recorded in early Bathonian sediments but with no *Macrocephalites* (Pandey and Pathak 2015). It is interesting to note that from Rajnath's bed 26 (1934, 1942 = Yellow Bed of the present work), Indonesian *Macrocephalites* cf. *etheridgei* Spath (m), *M. bifurcatus* transient aff. *bifurcatus* Boehm (m), *M. bifurcatus* transient *intermedius* (Spath) (M and m) and *M. bifurcatus* transient cf. *intermedius* Boehm (M) with the typical early middle Bathonian *Micromphalites* (*Clydomphalites*) *clydocromphalus* Arkell (M) have been recorded (see Jain 2014, 2020). Jain (2019a) also documented the occurrence of *M.* cf. *etheridgei* (Spath) from SW Somalia in association with *Sivajiceras congener* (Waagen) (M), a form that also co-occurs with *M.* cf. *etheridgei* in the Yellow Bed, Jumara Dome (see Jain 2014, 2020). Thus, *M.* cf.

Table 1. Age assignment of the identified calcareous nannofossils from the Yellow Bed (bed A4), Jumara Dome (Kachchh Basin, western India) (after Jain et al. 2013; Rai et al. 2013). 1: Bown & Cooper, 1998; 2: Mattioli & Erba 1999; 3: Casellato 2010; 4: Lees & Bown 2005; 5: Burnett 1998; 6: rough estimate (nannotaxa website); 7: Bown et al. 1998; SE: secondary events; ZM: zonal marker; *Watznaueria manivitae* is now considered as *cyclagelosphaera deflandrei* (see Bown and Cooper, 1998). All ages are after nannotaxa website (Gradstein et al. 2020 timescale; GTS, 2020). *It must be noted that the given ages are extrapolations (see Gradstein et al. 2020) and thus, should be considered with caution.

	First Occurrence (FO)					Last Occurrence (LO)				
Species	Age (Ma)*	Zone/Subzone	Stage	Reference	Event	Age (Ma)*	Zone/Subzone	Stage	Reference	Event
Leaked										
Cyclagelosphaera deflandrei	159.1	within NJT13b	Oxfordian	3		132.6		Hauterivian	6	
Diazomatolithus lehmanii	149.24		Tithonian	**7**		121.4		Early Aptian	6	
Marker										
Pseudoconus enigma	**168.7**	**base NJ11**	Bajocian	1	ZM	164.6	top NJ12a	Callovian	1	ZM
Carinolithus magharensis	179.53	within NJ8a	base Toarcian	1		**167**	**mid NJT11**	Bathonian	2	
Cyclagelosphaera margerelii	**168.7**	**base NJ11**	Bajocian	1	SE	66.04		top Thanetian	1	
Octopodorhabdus decussatus	**168.69**	**within NJ11**	Bajocian	1		161.99	NJ14	top Oxfordian	1	
Watznaueria barnesiae	**168.5**	**base NJT11**	Bajocian	2		66		top Maastrichtian	4	
		NJ9	Bajocian	1						
Long ranging										
Axopodorhabdus cylindratus	170.9		Bajocian	1		146.8	upper NJ17a	Tithonian	1	SE
Discorhabdus criotus	180.6	mid NJ7	Toarcian	1		159.1	NJ15a	top Oxfordian	1	
Ethmorhabdus gallicus	183.52	within NJ6	Toarcian	1		145.5	top NJ17b	Tithonian	1	SE
Lotharingius velatus	175.79	within NJ8b	Toarcian	1		165.71	NJ12a	Callovian	1	
Lotharingius crucicentralis	184.5	mid NJT5b	Pliensbachian	2	SE	156.8	top NJ15a	Oxfordian	1	ZM
Lotharingius hauffii	186.3	base NJ5a	Pliensbachian	1	ZM	165.71	NJ12a	Callovian	1	
Lotharingius sigillatus	185.1	lower NJ5b	Pliensbachian	1	SE	159.1	NJ15a	Oxfordian	1	
				2	ZM				1	
Calyculus sp.	188		Late Pliensbachian	6		154.8		Oxfordian	6	
Zeugrhabdotus erectus	192.9		base Pliensbachian	1		70.1		top Maastrichtian	6	
Watznaueria britannica	172.3	NJ9 zone	Aalenian	1	ZM	100.45	UC1a	Cenomanian	5	
Staurolithites sp.	196.3		Late Sinemurian	6		66		top Maastrichtian	6	

etheridgei has a wide geographic spread from the Sula Island (Indonesia) to the Kachchh Basin, SW Somalia, i.e. along the eastern part of the southern Tethyan margin in the middle Bathonian sediments (see Figure 5).

So the question is, what is the age of the *etheridgei*-bearing assemblage in the Kachchh Basin? Before answering this question, it must be kept in mind that during the Bathonian, European (the northern margin of the Tethys) assemblages reflected a Subboreal or Submediterranean provincial signature, whereas the southern margin of the Tethyan assemblages showed affinity with the Indo-East African and the SW Pacific provinces (Figure 5). Contextually, as pointed out by Pandey and Callomon (1995) and Jain (2014, 2020), the morphological similarities of the European early middle Bathonian *Procerites progracilis* with the coeval Kachchh and Madagascan *Procerites* (*Gracilisphinctes*) *arkelli* Collignon, possibly a subspecies of the former, are striking. Jain (2014, 2020) based on a new and a more diversified assemblage than the coeval one from the Gora Dongar (containing only *Procerites* and *Micromphalites*; Pandey and Callomon 1995) correlated his assemblage with the early middle Bathonian Progracilis Zone.

Interestingly, at Jhura, *M.* cf. *etheridgei* occurs much earlier than *Procerites* (*G.*) *arkelli*, but it occurs later at Nara, and together at Jumara, the depocentre of the basin (Figure 4; see Jain 2014, 2020). At lower levels, macrocephalitids do not occur either in the Kachchh Mainland (Nara; Pandey and Pathak 2015) or at the Pachchham Island (Pandey and Callomon 1995). Pandey and Callomon (1995) based on the association of *Micromphalites* (*Clydomphalites*) with *P.* (*G.*) *arkelli* assigned an early middle Bathonian age and correlated the assemblage with that of the European Progracilis Zone; later, a more diversified Arkelli Zone assemblage was recorded by Jain (2014) and also assigned to the Progracilis Zone (Jain 2020).

Macrocephalites triangularis Spath (M)

Jain (1996) reported and Jain (2014) illustrated the dimorphic pair of *Macrocephalites triangularis* Spath from the Yellow Bed. The macroconch of *M. triangularis* is quite common and has been recorded from almost all outcrops, except Habo (Figure 1). At Jara, from the basal stratigraphic levels, Cariou and Krishna (1988) noted in passing the presence of *M. triangularis*. At Jhura, *M. triangularis* occurs with the typical endemic Bathonian *Sivajiceras congener* (M and m) (see also Callomon 1993; Jain 2019b). At Keera, Krishna and Ojha (1996), from the basal beds noted (not illustrated) the occurrence of *M.* cf. *triangularis* from their MI – MII horizons (see also Jain and Pandey 2000). Later, Prasad (1998) from the same basal beds recorded and illustrated *M. triangularis* and rightly assigned an upper Bathonian age. At Jumara, the occurrence of *M. triangularis* is quite common and occurs at all levels within the Patcham Formation (beds A1-A8) (see Figure 4C). Datta et al. (1996) recorded 31 specimens from a 'cream colored limestone, coral biostrome alternations', their bed 1 (= beds A1–A5 of present work) (see Figure 4C). They also noted its sporadic occurrences in beds A6–A7 (Figure 4C). Thus, *M. triangularis* spans the entire Patcham Formation at Jumara but not beyond (see Figure 4C). Singh et al. (1979) also recorded several specimens of *M. triangularis* and *M.* aff. *triangularis* from the

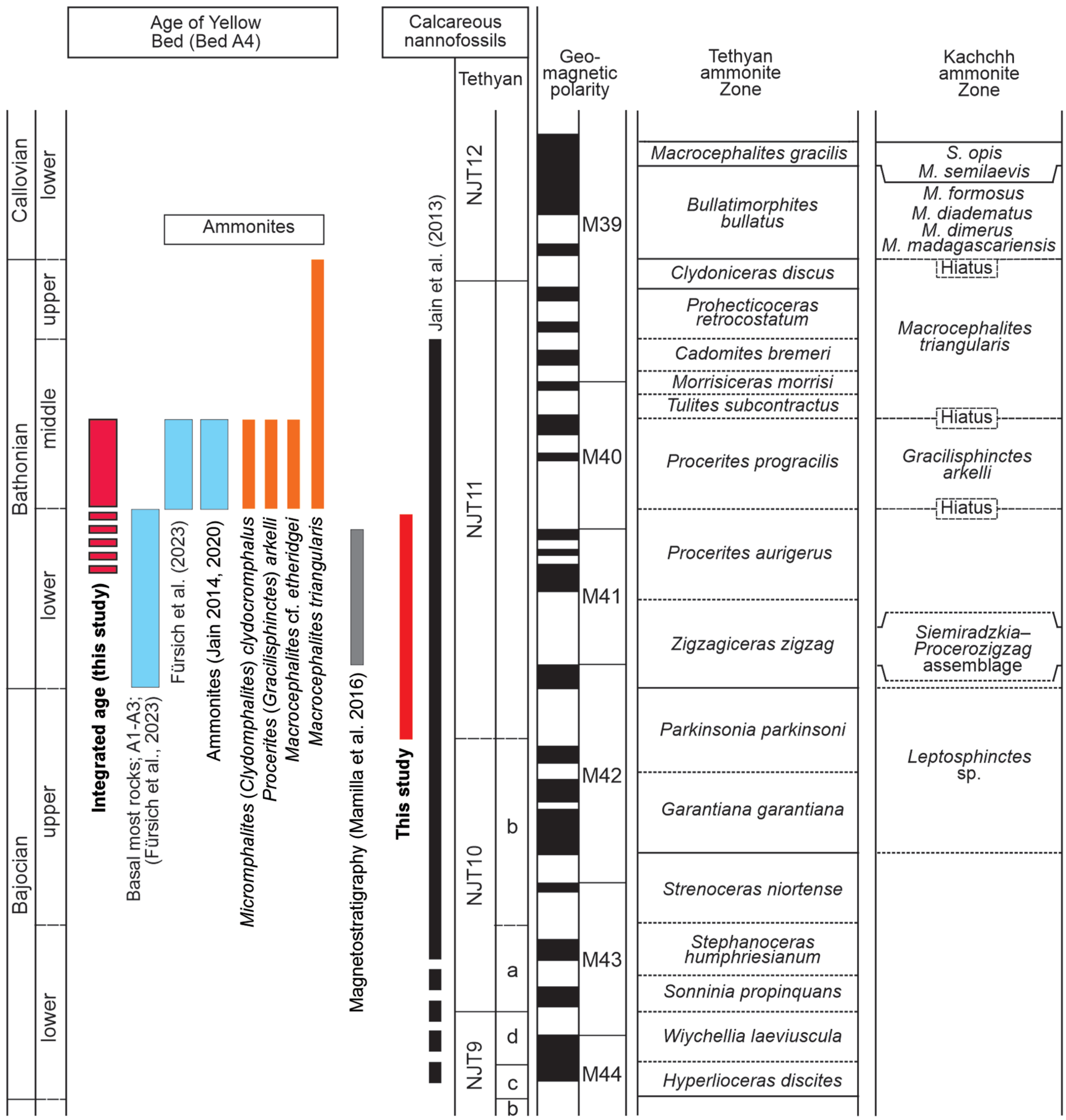

Figure 5. Summary of Bajocian–Callovian biostratigraphic markers from the Yellow Bed (bed A4), Jumara Dome. Abbreviation. *Ellipsa.*: *ellipsagelosphaera britannica*. The figure follows the Gradstein et al. (2020) timescale (= GTS, 2020).

Mouwana Dome (Bela Island) in the upper Bathonian sediments (Figure 1).

Thus, in the Kachchh Basin, *Macrocephalites triangularis* Spath ranges from the early middle Bathonian Progracilis Zone to the upper Bathonian Discus Zone (see Krishna and Westermann 1987; Jain 2014, 2020; Krishna 2017).

Out-of-India ammonite occurrences: a review

Macrocephalites triangularis Spath (M) from the Swabian Alb (southwestern Germany)

Dietl et al. (2021, p. 12, fig. 5.4) recorded a single, heavily encrusted specimen of *Macrocephalites triangularis* Spath and assigned its occurrence to the lower Callovian. However, the specimen's stated stratigraphic occurrence comes from two beds, between beds 5 and 6b; 'Bed 5 (bottom), Bed 6a: Keppleri Horizon, lowermost Herveyi Zone'. The authors noted that the 'marl between 6a and 6b' belong to the 'upper Discus Zone or lowermost Callovian' (Dietl et al. 2021, p. 7 and p. 14, table 2) and that 'There were no ammonites in beds 6b, 7 and 8, so the age of these beds remains unclear'. Considering the heavily encrusted nature of their only specimen within their entire assemblage, transport and re-deposition of the specimen cannot be ruled out to its present occurrence which they found very close to the Bathonian-Callovian boundary (Dietl et al. 2021).

Contextually, Dietl et al. (2021) also noted that 'The holotype of *M. triangularis* (Spath 1927–1933, pl. 21, fig. 1a, b) originates from the upper Patcham Group exposed in the Jumara Dome (Kachchh, Western India)'. This is not true as Spath (1927–1933) recorded the occurrence of the said holotype from the 'Grey Patcham Limestone = Coral Beds)' exposed at Jumara. Additionally, it has been well documented that the holotype of *M. triangularis* Spath has a distinctive yellow-coloured sediment attached to it, as noted for all the ammonites originating from the Yellow Bed (Jain et al. 1996; Jain 2014, 2020). The lower beds at the Jumara Dome have recently been differentiated (see Jain et al. 1996) as opposed to Spath's (1931) broad designations as 'Coral Beds' and 'Patcham Shelly Limestone' (i.e. Rajnath's beds 24–26; see Jain et al. 1996) (Figure 4C). Nevertheless, Spath (1927–1933, p. 181) also noted that *M. traingularis* occurs in 'Jumara (bed No. 13 or 14a), Blake Colln. A fragment from below bed 12'. Spath's (1931, p. 740) bed 13 is Rajnath's beds 22–24 (beds A7-A8 of present work), 14 is bed 25 (beds A5-A6 of present work) and the lowest bed, 'Patcham Shelly Limestone' of Spath (1931) is Rajnath's bed 26 (Yellow Bed of present work) (Rajnath 1934, 1942; Krishna and Westermann 1987; Jain et al. 1996) (Figure 4C). In all the aforementioned beds, Spath recorded *M. traingularis*, and from his bed 14 (= beds A5-A6 of present work), with *Sivajiceras congener* and *Procerites hians* (see Jain 2014, 2019a, b) (Figure 4C). Interestingly (Datta et al. 1996), from Jumara, also recorded 31 specimens of *M. traingularis* from 'cream colored limestone, coral biostrome alternations', their bed 1 (= beds A1–A5 of present work) (Jain et al. 1996; Jain 2014).

Thus, *M. traingularis* does not occur in the lower Callovian (Krishna and Westermann 1987; Krishna and Cariou 1993; Callomon 1993; Krishna 2017). It is a very characteristic Bathonian form with a persistent triangular whorl section, fine ribbing, strongly arched flanks and a narrow venter (see Spath 1931; Krishna and Westermann 1987; Datta et al. 1996; Jain 2014). Dietl et al. (2021) noted its similarities with *M. jacquoti* and aptly stated that '*M. triangularis* is not identical with *M. jacquoti* [and] its subtriangular whorl section and narrow venter distinguish *triangularis* from Quenstedt's "*compressus*" with its subparallel flanks and a comparatively wide and rounded outline'.

Macrocephalites aff. triangularis Spath (M) from eastern Crimea

Gulyaev and Ippolitov (2023) recorded two fragmentary specimens assigned to *Macrocephalites* aff. *triangularis* Spath from the middle Bathonian of eastern Crimea (see Figure 6A–D). The specimens were recorded from strata immediately underlying the Bremeri Zone (i.e. ~3 m below the Fortecostatum Subzone, the lower part of the Bremeri Zone) (Gulyaev and Ippolitov 2023, p. 47, fig. 2). Interestingly, these specimens present two distinct morphologies: one is characterised by a broadly rounded venter, gently arched flanks and moderately coarse ribbing (Gulyaev and Ippolitov 2023, p. 48, fig. 1a-b; refigured here as Figure 6A–B) and the other with a compressed shell, subparallel flanks and a narrowly rounded venter (p. 49, fig. 3a-b; refigured here as Figure 6C–D). These specimens lack the characteristics features of *M. traingularis*, of persistent triangular whorl section, fine and dense ribbing and an acutely narrow triangular venter, noted even at 250 mm shell diameter (see Jain 2014, p. 127, fig. 27). The eastern Crimean specimens also possess a somewhat more flexuous ribbing pattern, contrary to a somewhat straighter one in typical *M. traingularis* (see also Datta et al. 1996).

It is very interesting to note that forms with similar morphology such as broadly rounded venter with gently arched flanks and moderately coarse ribbing pattern (as noted in one of the specimens illustrated by Gulyaev and Ippolitov 2023, p. 48, fig. 1a–b) strongly resembles with *Macrocephalites* cf. *triangularis* Spath (M) specimens recorded from the upper Bathonian sediments of the Jumara (refigured here as Figure 6E–F and 6G; after Krishna and Westermann 1987, figs. 3 and 2, respectively; bed A8 of present work) and *M.* aff. *triangularis* Spath (M) from the Mouwana dome (Bela Island, Kachchh) and refigured here as Figures 6H–I and 6J–K (after Singh et al. 1979, p. 180, pl. 4, fig. 1, and pl. 2, fig. 1, respectively). This *Macrocephalites*-bearing bed at the Mouwana Dome, lithostratigraphically and faunastically, has been correlated with the upper Bathonian Raimalro Limestone Member, Pachchham Island and also with the Sponge Limestone Member, Mainland Kachchh (= beds A6-A8 of present work) (see Figure 2; see also Agrawal and Kacker 1980; Fürsich et al. 2001, 2023). Interestingly, all the aforementioned forms also resemble *Macrocephalites madagascariensis* Spath that spans from the upper Bathonian to the lower Callovian sediments (see Krishna and Westermann 1987; Datta et al. 1996; Jain 2014). These east Crimean and Kachchh examples (Figure 6) are morphologically intermediate forms with a ribbing pattern close to that of *M. triangularis* and a whorl section of *M. madagascariensis*. The Kachchh data do suggest that although both *M. triangularis* and *M. madagascariensis* are morphologically distinct, but the smaller, more involute and compressed forms show intergrading characteristics with in-between *M.* aff. *triangularis* forms. However, it must also be kept in mind that the inner whorls of both *M. triangularis* and *M. madagascariensis* are not very well known.

Thus, based on available data, it is plausible that both Kachchh (Jumara and Mouwana) and eastern Crimean forms are new species that persisted up to the upper Bathonian (like *M. triangularis* s.st.) and that the 'macrocephalitic appearance' as noted by Gulyaev and Ippolitov (2023), was already well established in the early middle Bathonian. In Kachchh, however, such forms are not known in middle Bathonian sediments.

Conclusion and way forward

This review clearly demonstrates broad ages from different groups for the same strata, Yellow Bed (bed A4), as inferred by assemblages of ammonites (early middle Bathonian), and calcareous nannofossil (early to early middle Bathonian) and magnetostratigraphy (early Bathonian) (Figure 5). It is true that calcareous nannofossils suffer from diachronous occurrences, but it is equally true that their FO and LO are robust markers. The available magnetostratigraphic data is of very low resolution and judging by its constant polarity, it is quite likely a case of re-magnetisation. However, having said that, and taking all the available evidences together, an early middle Bathonian age is safe to assume for the Yellow Bed, as previously suggested (Jain and Pandey 2000; Jain 2014, 2020).

It must also be kept in mind that the Kachchh Basin epitomises a distinct marine palaeobiogeographic province, and, hence, necessitates an independent regional chronostratigraphy. It is true that some levels are indeed marked by age-diagnostic cosmopolitan species enabling global correlations, but, it is premature to assign coeval ages based on European and Submediterranean counterparts to all Kachchh ammonite occurrences, especially those belonging to the Bathonian rocks, considering their much earlier records in the southern Tethys (Kachchh Basin, western India and Sula Island, Indonesia); those from Madagascar are still patchy.

In this regard, it must also be noted that the Kachchh early middle Bathonian Arkelli Zone assemblage already displays well-established 'macrocephalitic appearance' as noted by Gulyaev and Ippolitov (2023) for his middle Bathonian pre-Fortecostatum Subzone *Macrocephalites*-bearing eastern Crimean forms. This 'macrocephalitic appearance' means that the Crimean middle Bathonian macrocephalitids look like the classic representatives of the family, and not like some transitional forms, such as the Sphaeroceratids s.l. (personal communication, Denis Gulyaev,

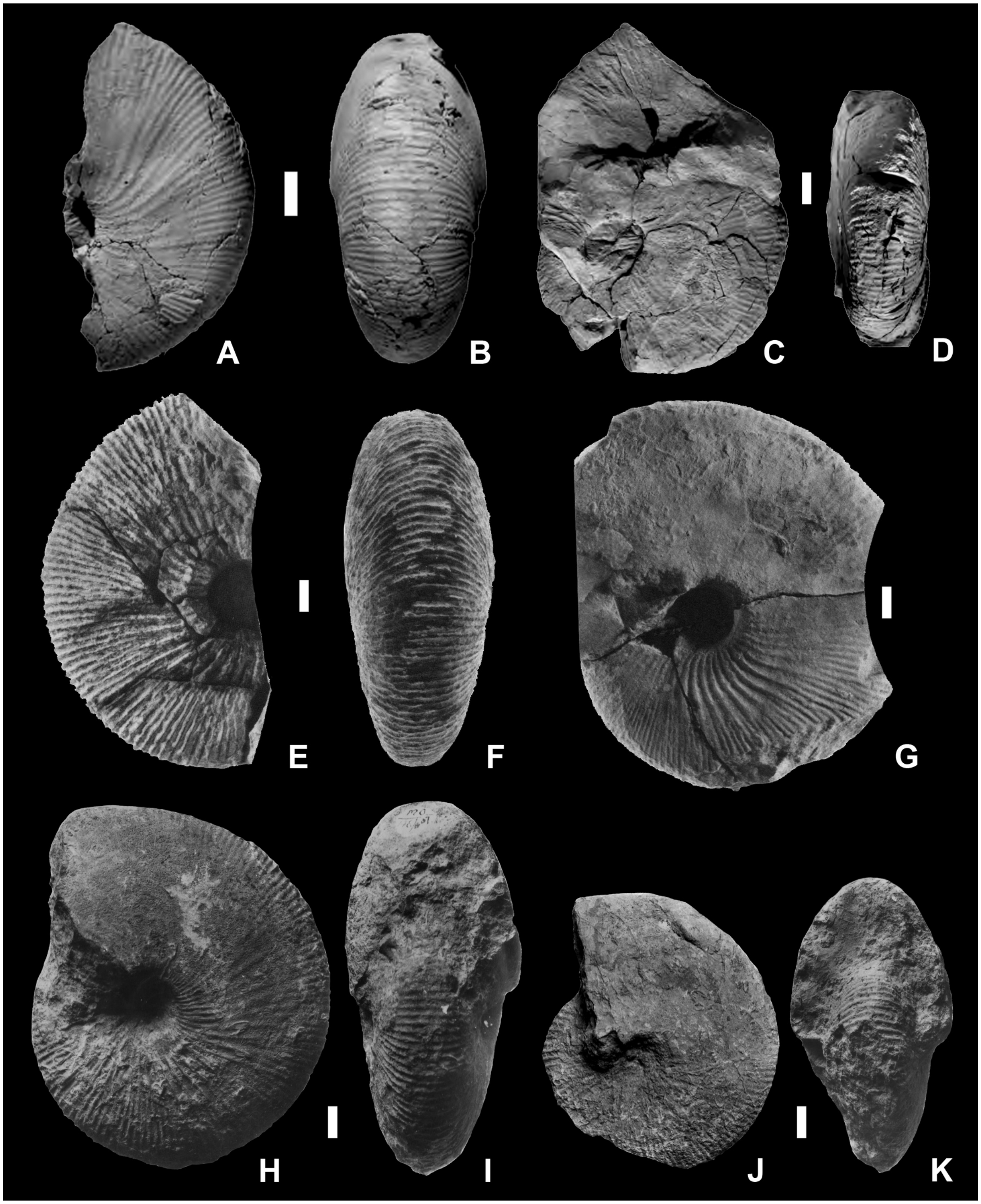

Figure 6. *Macrocephalites* aff. *triangularis* Spath (M). A–D: *macrocephalites* aff. *triangularis* Spath, middle bathonian, from a strata underlying the fortecostatum subzone, Bremeri Zone, eastern Crimea, refiguredfrom Gulyaev and Ippolitov (2023). A–B: p. 48, fig. 1a-b. C–D: p. 49, fig. 3a–b. E–G: *macrocephalites* cf. *triangularis* Spath (M), Jumara Dome, from Rajnath's bed no. 22–25 (= beds A5–A8 of present work). Septate specimens refigured from (Krishna and Westermann 1987), p. 1573, fig. 2–3. E–F: specimen no. BHU 10,002, fig. 3a-b. G: specimen no. BHU 10,001, fig. 2. H–K: *M.* aff. *triangularis* Spath (M), Mouwana Dome (Bela Island; see fig. 1), Raimalro Limestone member (= sponge Limestone Member; bed A8 of present work). Septate specimens refigured from Singh et al. (1979). H–I: specimen no. MO/146/807, p. 180, pl. 4, fig. 1a-b. J–K: specimen no. MO/146/805, p. 176, pl. 2, fig. 1a-b.

February 2024). This suggests, as earlier proposed by Jain (2014), an even earlier age for genus *Macrocephalites* in the Kachchh Basin (western India), as suggested both by the calcareous nannofossil assemblage and on lithostratigraphic grounds (see Fürsich et al., 2023). However, more integrated analyses and closely spaced sampling are needed from the Jhura and Nara domes within the Kachchh Basin to corroborate this earlier age.

Westermann and Callomon (1988) assigned the age to their earliest *Macrocephalites* (= *Macrocephalites bifurcatus* associations) based on the premise that *Cadomites* cf. *rectelobatus* 'in Europe is typical of the late Middle Bathonian' age. Galácz (1994) noted that the lectotype of *Cadomites rectelobatus* most likely originated from the base of the middle Bathonian, the Progracilis Zone; this is also the age of the Kachchh Basin Arkelli Zone as proposed by Jain

(2014, 2020). It must be kept in mind that in the Sula Island, the *Macrocephalites bifurcatus* Association contains both *Cadomites* and *Satoceras* (Assemblage 1b) and is dated to lie between early and middle Bathonian (see Westermann and Callomon 1988, p. 9). Additionally, the earliest *Gracilisphinctes* in Kachchh are dated as early middle Bathonian Progracilis Zone (see Pandey and Callomon 1995; Jain 2014, 2020), and the earliest *Macrocephalites* (*M*. cf. *etheridgei*) specimn occurs ~40 m below the *Gracilisphinctes* occurrence, at the Jhura Dome, Kachchh (see Roy et al. 2007) (see Figure 4D).

The report by Dietl et al. (2021) of a lower Callovian *Macrocephalites triangularis* Spath needs re-evaluation. It is not only heavily encrusted (and thus most likely transported/redeposited) but also occurs close to the Bathonian-Callovian boundary, where it probably came from; *M. triangularis* Spath does not occur in lower Callovian deposits.

Finally, it must be kept in mind that eastern Crimea and western India are located at the two eastern extremities of the Tethys, the first one in the north and the second one in the south (Figure 5). *M*. cf. *etheridgei* (Spath), the oldest species of genus *Macrocephalites* in the southern margin of the Tethys (SW Somali, Kachchh and Sula Island) is not known in the eastern end of the northern margin, for now (Figure 5). However, in Kachchh (Jain 2014, 2020), and corroborated by Crimea occurrences by Gulyaev and Ippolitov (2023), genus *Macrocephalites* Zittel was well established even in the early middle Bathonian, if not earlier. Hence, a relook/resampling with an integrated approach involving other groups such as calcareous nannofossils or radiometric dating of ammonite-bearing rocks for the southern Tethyan margin localities such as from Madagascar and Sula Island is urgently needed.

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