

Integrated Jurassic biostratigraphy: A closer look at nannofossil and ammonite evidences from the Indian subcontinent

Sreepat Jain

Old and outdated use of ammonite and nannofossil literature indicates that nannofossils are better in defining the Bathonian–Callovian boundary in the Jurassic sediments of Jaisalmer basin, western India. However, globally and with an updated biozonation from more recent literature, it is the other way round. This paradox is an example where standardization is urgently needed. In light of new nannofossil data, age assignments based on nannofossil records are critically assessed and a globally updated composite Bajocian–Callovian biozonation of ammonites and marker nannofossil species is given to encourage use of more updated literature.

Keywords: Ammonites, Bathonian–Callovian boundary, Indian subcontinent, nannofossils.

NANNOFOSSILS, owing to their small size, widespread distribution in short intervals of time and the fact that a large number of individual coccoliths can be analysed from a fraction of sediment, make them good time markers and valuable tools for biostratigraphic analyses. However, smaller size and resistance to mechanical breakdown also result in their reworking, and increasing their potential for sample contamination. Association with condensed horizons (hardgrounds) further dilutes their biostratigraphic relevance and hence age interpretations¹. This is corroborated by recent alleged time diagnostic nannofossil occurrences from a Middle Jurassic exposure along the Masurdi River in the Kuldhar section (western Rajasthan, India; Figure 1a). The samples locality is marked by the presence of multiple hardgrounds that show evidence of increasing maturity, recording a protracted period of non-sedimentation at the seafloor^{2,3} (Figure 2, iiC). Common association of complex cross-cutting *Thalassinoides* networks, cemented and bored upper layers with irregular, pitted, glauconite-impregnated surfaces, oyster encrustations, bored body fossils and pebbles and disarticulated shells of bivalves (*Nanogyra nana*, *Plicatula* and *Oysters*) are seen (Figure 2)².

A recent study from this locality, from the basal sediments of the Kuldhar Member, recovered a moderately preserved and numerically low assemblage of long-ranging Jurassic nannofossils taxa such as *Watznaueria barnesae*, *W. britannica*, *W. ovata* and *Cyclagelosphaera margerelii*⁴. Here, very rare occurrence of *Ansulasmaera helvetica* and *Stephanolithion speciosum* in sample nos KDI

and KD2, and rare and very rare presence of *Stephanolithion hexum* and *Stephanolithion bigotii* in sample nos KD2A and KD5 have been used to identify both the *Ansulasmaera helvetica* Zone (NJ12; KD1, KD2) as well as the *Stephanolithion bigotii bigotii* Zone (NJ13; KD2A, KD5) and correspondingly assigned to Early Callovian age⁴. Furthermore, the LO (last occurrence) of *S. speciosum* and FO (first occurrence) of *Watznaueria manivittae* and *Cyclagelosphaera perforata* in the lower part of the section have also been used to define the base of Zone NJ13. The LO of *Stephanolithion octum* close to the top of the section has been employed to restrict the age of the studied section to Early Callovian⁴.

Interestingly, globally, the FO of *A. helvetica*, which marks the base of the nannofossil Zone NJ12 in NW Europe, is much older in the Portuguese sections⁵ (Table 1). Bown⁶ also showed the FO of *S. hexum* near the base of this nannofossil zone, and correlated it with the Late Bathonian Retrocostatum Zone (Table 1). In Portugal, the lowest occurrence of *S. hexum* falls within the same ammonite zone⁵ (Table 1). Recent investigations^{7,5} of sections in Portugal, SE France and northern France demonstrate the usefulness of genus *Stephanolithion* in providing a more refined biostratigraphic framework for the Callovian⁸ (Table 1). This biozonation is defined by the succession of: (1) LO of *S. speciosum*; (2) FO of *S. bigotii* ssp. *bigotii*; (3) LO of *S. hexum*; and (4) FO of *S. bigotii* ssp. *maximum*. Higher up, the LO of *A. helvetica* is roughly coincident to the FO of *S. bigotii* ssp. *maximum* and both events have been correlated to the Lamberti Zone in NW Europe^{6,9,10} and SE France⁵. Noteworthy is the conspicuous absence of nannofossil datums for the Earliest Callovian (Bullatimorphites bullatus Zone) and the preceding Latest Bathonian Discus Zone⁸ (Table 1).

Sreepat Jain is in the Department of Paleobiology, National Museum of Natural History, Smithsonian Institution, 10th Street and Constitution Avenue, Washington DC 20560, USA. e-mail: jains@si.edu



Figure 1. *a*, Geological map of Jaisalmer basin (modified after Dave and Chatterjee¹⁹). *b*, Jurassic outcrops of the Kachhh basin.

Table 1. Intrabasinal correlation of Bajocian–Callovian nannofossil and ammonite zones (after De Kaenel *et al.*⁵). Note that each nannofossil event has been measured as percentage within each ammonite zone/subzone. Nannofossil abbreviations used are: *L. crucicentralis*, *Lotharingius crucicentralis*; *S. hexum*, *Stephanolithion hexum*; *S. bigotti max.*, *Stephanolithion bigotti ssp. maximum*; *S. bigotti big.*, *Stephanolithion bigotti ssp. bigotti*; *S. speciosum*, *Stephanolithion speciosum*; *S. speciosum spec.*, *Stephanolithion speciosum ssp. speciosum*; *T. expansum*, *Triscutum expansum*; *A. helvetica*, *Ansulaspheera helvetica*; *T. shawensis*, *Tetrapodorhabdus shawensis*; *P. enigma*, *Pseudocomus enigma*; *A. rahla*, *Axopodorhabdus rahla*; *A. harrisonii*, *Anfractus harrisonii*; *H. cuvielleri*, *Hexapodorhabdus cuvielleri*; *O. decussatus*, *Octopodorhabdus decussatus*; *F. multicolumnatus*, *Favicomus multicolumnatus*; *M. quadratus*, *Microstaurus quadratus*; *D. constans*, *Diductus constans*; *T. sullivani*, *Triscutum sullivani*; *T. tiziense*, *Triscutum tiziense*; *P. grassei*, *Podorhabdus grassei*; *C. margerelli*, *Cyclagellosphaera margerelli*; *C. margharensis*, *Carinolithus margharensis*; *C. superbus*, *Carinolithus superbus*; *W. barnesae*, *Watznaueria barnesae*; *E. Britannica*, *Ellipsagelosphaera britannica*; *B. striatum*, *Biscutum striatum*. Ammonite Zone/Subzone abbreviations used are: BOR, Boreal; JAS, Jason; E, Enodatum; CALL, Calloviense; KO, Koenigii; KA, Kamptus; ASP, Aspidoceras; HOD, Hodsoni and TEN, Tenuiplicatus

STAGE		AMMONITES ZONES		NANNOFOSSIL SUCCESSION	NORTHWESTERN EUROPE BOREAL / SUBBOREAL		SOUTHWESTERN EUROPE / NW AFRICA TETHYAN / SUBMEDITERRANEAN																												
		TETHYAN	BOR.		EUROPEAN BASIN		GREAT BRITAIN / GERMANY NORTH FRANCE		NORTH SWITZERLAND / PORTUGAL		SOUTH / CENTRAL ITALY / SE FRANCE																								
CALLOVIAN	L	LAMBERTI		S. bigotii max.	A. hevetica	NJ14	S. bigotii max.	A. hevetica	A. hevetica	S. bigotii max.	A. hevetica																								
		ATHLETA																																	
		CORONATUM																																	
		M	ANCEPTS									JAS.	S. hexum	NJ13	S. hexum	S. hexum	S. hexum	S. hexum																	
			E.																																
	E	GRACILIS	CALLO- VINSE	CALL.	S. bigotii big.	NJ12b	S. bigotii big.	L. velatus	S. bigotii big.	L. velatus	S. bigotii big.																								
		KO.	KA.	S. speciosum spec.								NJ12a	S. speciosum spec.	T. expansum	P. enigma	S. speciosum spec.	S. speciosum octum	S. speciosum spec.																	
		MACROCEPHALUS																	T. expansum	NJ12a	A. rahla	T. shawensis	S. hexum	V. stradhneri A. rahla O. decussatus A. harrisonii H. cuvieri	C. loquatus	S. speciosum									
		BATHONIAN	L																								DISCUS	S. hexum	NJ11	A. hevetica	T. shawensis	S. hexum	V. stradhneri A. rahla O. decussatus A. harrisonii H. cuvieri	C. loquatus	S. speciosum
																											RETROCO- STATUM								
BREMERI	HOD.				S. hexum	NJ11	A. hevetica	T. shawensis	S. hexum	V. stradhneri A. rahla O. decussatus A. harrisonii H. cuvieri	C. loquatus																S. speciosum								
MORBI				S. hexum								NJ11	A. hevetica	T. shawensis	S. hexum	V. stradhneri A. rahla O. decussatus A. harrisonii H. cuvieri	C. loquatus	S. speciosum																	
SUBCONTRACTUS		S. hexum	NJ11																A. hevetica	T. shawensis	S. hexum	V. stradhneri A. rahla O. decussatus A. harrisonii H. cuvieri	C. loquatus	S. speciosum											
PROGRACILIS																									S. hexum	NJ11		A. hevetica	T. shawensis	S. hexum	V. stradhneri A. rahla O. decussatus A. harrisonii H. cuvieri	C. loquatus	S. speciosum		
E	ZIGZAG				S. hexum	NJ11	A. hevetica	T. shawensis	S. hexum	V. stradhneri A. rahla O. decussatus A. harrisonii H. cuvieri	C. loquatus																S. speciosum								
				S. hexum								NJ11	A. hevetica	T. shawensis	S. hexum	V. stradhneri A. rahla O. decussatus A. harrisonii H. cuvieri	C. loquatus	S. speciosum																	
			S. hexum																NJ11	A. hevetica	T. shawensis	S. hexum	V. stradhneri A. rahla O. decussatus A. harrisonii H. cuvieri	C. loquatus										S. speciosum	
																									S. hexum	NJ11		A. hevetica	T. shawensis	S. hexum	V. stradhneri A. rahla O. decussatus A. harrisonii H. cuvieri	C. loquatus	S. speciosum		
																																			S. hexum
		S. hexum			NJ11	A. hevetica	T. shawensis	S. hexum	V. stradhneri A. rahla O. decussatus A. harrisonii H. cuvieri	C. loquatus	S. speciosum																								

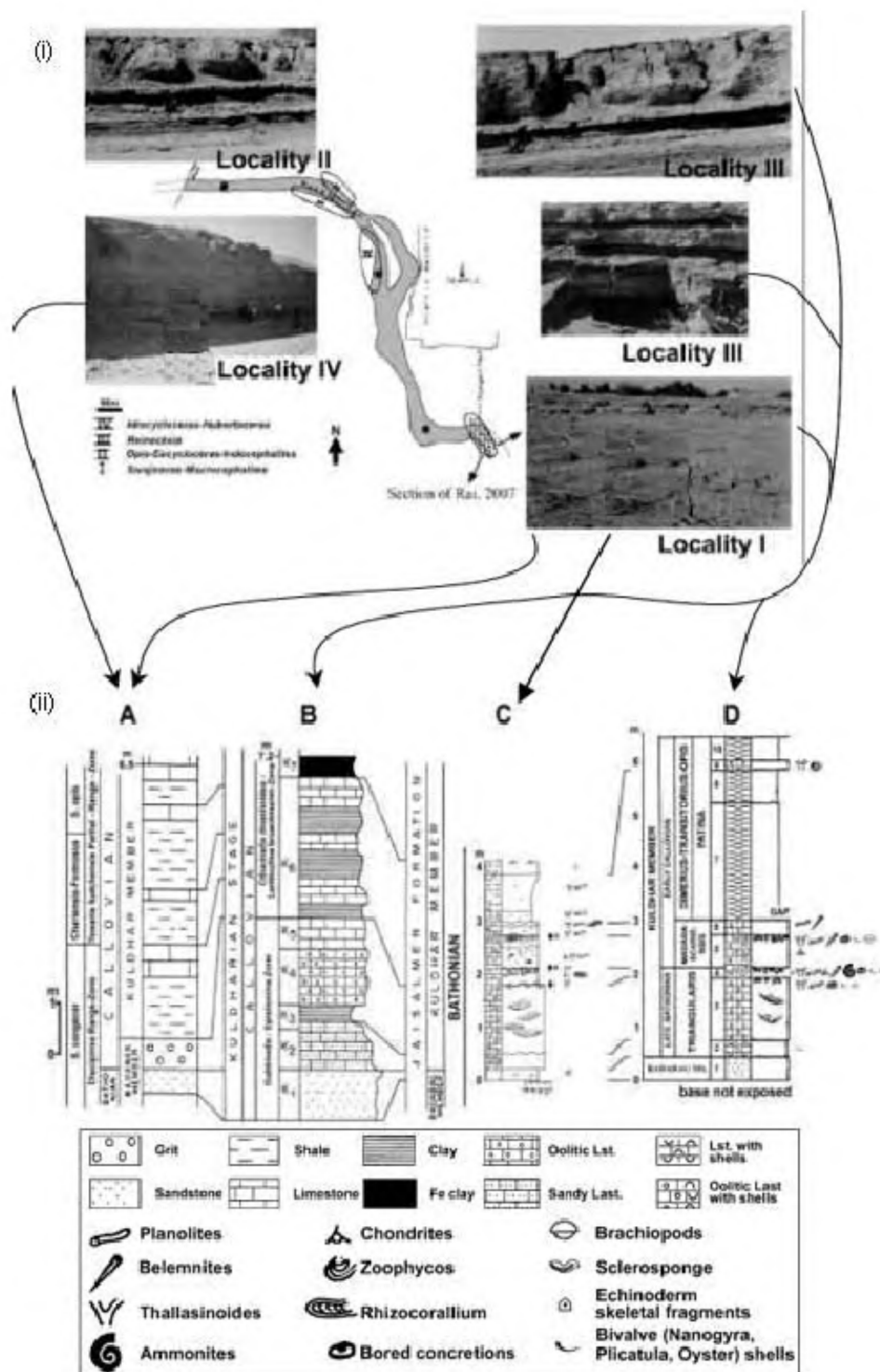


Figure 2. Correlation of Kuldhar Member beds. (i) Locality map of beds exposed along the Masurdi River, Kuldhar village. (ii) Correlation of identified sections at various localities by different authors. All sections have the same scale of 1 m. (A) Modified after Dave and Chatterjee¹⁹. (B) Modified after Kalia and Chowdhury³⁰. (C) Modified after Fürsich *et al.*². (D) Present work. Bold arrow marks in (iiC) indicate the presence of hardgrounds. Note that the figure illustrates yet another aspect of complexity generated by partial sections measured by different workers from diverse locations (localities), but referred to as their 'the Kuldhar section' *sensu stricto*. Also note that section A is most likely a combination of sections from localities I and IV, B of I and III, C of I, and D of I and III. The Bathonian–Callovian boundary sediments lie only at locality I and on the eastern flank of the river bed marked by an elliptical area with hatched symbols (limestone). Note that most likely the section by Rai and Garg⁴ is from the western flank of the river bed that overlies bed nos 5 and 6 of present work (D).

Additionally, both *S. bigotii* ssp. *bigotii* and *S. hexum* are rare and delicate species, and have been noted to yield truncated ranges in sections where coccoliths preservation is moderate or poor¹. Additionally, there are conflicting data on the total age range of *S. hexum*. Medd¹¹ reported it in beds as young as the Middle Callovian (Caronatum Zone). Different age ranges of *S. hexum* are also given by Barnard and Hay¹² (Early to Late Callovian) and by Hamilton (Bathonian to Callovian)¹³. Thus, the total range of *S. hexum* needs to be documented fully; reworking, palaeoecological factors and preservation seem to play an important role in its distribution¹.

Contextually, from the Kuldhar section, contrary to claims by Rai and Garg⁴ who employed old nannofossil biostratigraphic datum^{6,10}, age misrepresentation (Early Callovian instead of Late Bathonian) is inevitable. Age demarcation based on old and generalized ammonite occurrences¹⁴ only exacerbates the otherwise well-defined Bathonian–Callovian age boundary for the same section^{3,15} (for a review of the fauna in the adjoining Kachchh basin, see Callomon¹⁶).

Recently, the occurrence of a distinctly Bathonian genus *Clydoniceras* Blake from the sandy limestone of the base of Bada Bag Member, Jaisalmer Formation, on which the Kuldhar Member overlies in the Jaisalmer basin (western Rajasthan) has been documented¹⁵. Additionally, the base of the Kuldhar Member beds exposed at Kuldhar (the nannofossil collection locality; Figures 1 and 2) has also yielded the more cosmopolitan, age diagnostic and Late Bathonian association of *Sivajiceras congener* (Waagen, M/♀) and *Macrocephalites traingularis*³ (Waagen, M/♀; Figure 3). This association in the adjoining Kachchh basin^{3,16–18} marks the Latest Bathonian interval. The record of similar *S. congener* and *M. traingularis* association from the basal beds of the Kuldhar Member not only reaffirms that ammonites are by far the best available datum globally for the Middle Jurassic, more so for sediments straddling the Bathonian–Callovian boundary and the succeeding Earliest Callovian interval⁸. Needless to emphasize that moderately to poorly preserved nannofossils collected from areas with the predominance of hardgrounds² should be viewed with great caution. Often the use of endemic species, preference of references used, along with the use of outdated and old biostratigraphic datum result in overlooking of better preserved and more common basin-wide body fossils. This is made all the more complicated when benthic foraminifers are also incorporated as age diagnostic taxa^{4,19}. Surprisingly, benthic foraminifera are known for their longevity²⁰. Hence, such correlative analyses are not only erroneous, but also undermine the usefulness provided by other body fossils (such as ammonites, bivalves, echinoids and brachiopods) or microfossils that have far shorter ranges and rapid evolutionary histories²¹.

Thus, for future endeavours, an updated and extended Bajocian–Callovian ammonite and nannofossil zonation⁸

is provided (Table 2), which should be used as a guide until benthic foraminiferal biozonation overtakes the body fossils biochronostratigraphically or globally, and sections yield more constrained Bajocian–Callovian datum⁸. Similar boundary demarcations based on the occurrence of *A. helvetica* from the Kachchh basin (date as latest Early Callovian)²² (Figure 1) and from the eastern Karakorum block where the association of *A. helvetica* and *Cyclagelosphaera wiedmannii* with five fragmentary samples of *Choffatia furcula* and *Grossouvria* sp. has curiously been dated to indicate Late Bathonian–Early Callovian age²³, should be viewed with caution.

At the Karakorum block, the poorly preserved and low diversity nannofossil assemblage consists of *A. helvetica*, *Watznaueria barnesae*, *W. biporta*, *W. britannica*, *W. communis*, *W. fossacincta*, *W. ovata*, *W. manivatae*, *Lotharingius crucicentralis*, *Crepidolithus* sp., *C. margerelii*, *C. wiedmannii*, *Discorhabdus striatus* and *Schizosphaerella* sp.²³. Note that the delicate species of *Stephanolithon* which proliferate the Bathonian–Callovian interval are absent, attributed by the authors²³ to poor preservation. Interestingly, globally, the last occurrence of *D. striatus* is used to date Mid–Late Bajocian sediments (Table 2). Similar nannofossil assemblages dominated by genus *Watz-*

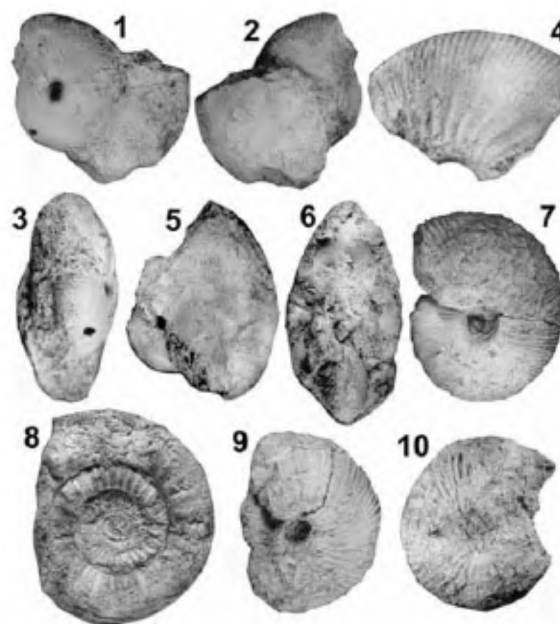


Figure 3. Specimens in (1–9) are from bed no. 4, locality I, Triangularis Zone and (10) from the same locality, Madagascariensis Zone. All magnifications are 0.5×, except for specimen (8) (0.4×). 1–3, *Macrocephalites formosus* (Sowerby) [M], sp. no. SJK/4/3; 1, Lateral view; 2, Opposite lateral view; 3, Apertural view. 4, *Macrocephalites* cf. *madagascariensis* (Sowerby) [M], sp. no. SJK/4/4, lateral view. 5, 6, *Macrocephalites traingularis* Spath [M], sp. no. SJK/4/1; 5, Lateral view; 6, Apertural view. 7 and 9, *Macrocephalites lamellosus* (Waagen) [m], sp. no. SJK/4/2, lateral view. 8, *Sivajiceras congener* (Waagen) [M], sp. no. SJK/4/5, lateral view. 10, *Macrocephalites* cf. *subcompressus* (Waagen) [m], sp. no. SJK/5/2.

Table 2. Standard and globally recognized nannofossil and ammonite zones used in the present study. The age model is after Gradstein *et al.*⁸. Columns A and B are stage and substage discussed in the text. Nannofossils, because of their rapid rate of evolution and wide geographic distribution, are excellent guide fossils for the Jurassic. Globally, their first (FO) and last occurrence (LO) datums usually occur at the same horizon and hence can date sediments to accuracies of one million years or less. Data in column C are globally recognized Tethyan ammonites zones, a standard reference often compared and correlated with Kachchh biozones. Data for columns D and E are from a compilation of several studies based on FOs and LOs of nannofossil taxa summarized in Gradstein *et al.*⁸. Column D gives the stratigraphic position of globally recognized FOs and LOs of Jurassic nannofossil zone markers. Column E is a global standard FO and LO of all tropical nannofossil datums, nannofossils proliferating in the warm ocean water palaeolatitudes. Note the stark scarcity of nannofossil datums for the Jurassic Bathonian

Age	A	B	C	D	E
	Stage	Substage	Tethyan Ammonite Zones	Jurassic Zone Marker	All Tropical Nanno Datums Combined
161					
162		Late Callovian	Quenstedtoceras lamberti	Stephanolithion bigotii maximum	Stephanolithion bigotii maximum
			Peltoceras athleta	Ansulaspheera helvetica	Ansulaspheera helvetica
163	Callovian	Middle Callovian	Erymnoceras coronatum	Stephanolithion hexum	Stephanolithion hexum
			Reineckeia anceps		
164		Early Callovian	Macrocephalites gracilis	Stephanolithion bigotii bigotii	Stephanolithion bigotii bigotii
			Bullatimorphites bullatus	Crepidolithus perforata	Crepidolithus perforata
			Clydoniceras discus	Triscutum expansus	Triscutum expansus
165		Late Bathonian	Hecticoceras retrocostatum	Stephanolithion hexum	Stephanolithion hexum
			Cadomites bremeri	Axopodorhabdus rahla	Axopodorhabdus rahla
166	Bathonian	Middle Bathonian	Morrisiceras morrisi		
			Tulites subcontractus		
167		Early Bathonian	Procerites progracilis		
			Procerites aurigerus		
168			Zigzagiceras zigzag	Stephanolithion speciosum octum	Stephanolithion speciosum octum
		Late Bajocian	Parkinsonia parkinsoni	Ansulaspheera helvetica	Ansulaspheera helvetica
169			Garantiana garantiana	Discorhabdus striatus (acme)	Discorhabdus striatus (acme)
			Strenoceras niortense	Carinolithus superbus	Carinolithus superbus
170	Bajocian		Stephanoceras humphriesianum	Biscutum constans	Biscutum constans
		Early Bajocian	Sonninia propinquans	Triscutum sullivanii	Triscutum sullivanii
171			Witchellia laeviscula	Triscutum tiziense	Triscutum tiziense
			Hyperlioceras discites		

naueria, with occurrences of *D. striatus* and *Schizophaerella* spp. have also been recorded from the lower portion of Zone NJ10, straddling the Early–Late Bajocian interval (Table 2)²⁴. Globally, the last occurrence of *Discorhabdus striatus* is slightly above the first occurrence of *A. helvetica* from Late Bajocian sediments (Table 2). In Europe, the stratigraphic range of *C. wiedmanni* was originally dated as Callovian²⁵. However, recent studies have noted that the first occurrence of *C. wiedmanni* is close to the Middle/Late Bathonian boundary^{24–27}. Interestingly, the oldest occurrence of genus *Choffatia* Siemiradzki [that includes microconch perisphinctid genera of *Subgrossouvria*, *Grossouvria*, *Homeoplanulites* and *Parachoffatia*] has also been extended to Middle Bathonian sediments^{27,28}. Hence, based on sparse and poorly preserved nannofossil and ammonite evidences, the most likely age of the Karakorum block sediment is at least Middle Bathonian, if not lower. However, if nannofossil

evidences are to be considered, then a more robust dataset is needed for any conclusive age designation as both diachroneity and dissolution are a widespread phenomenon in the Jurassic nannofossil record^{5,29} (Table 1).

In summary, the above discussion amply demonstrates that: (a) major age designations or boundary demarcations based on sparse, poorly preserved and low-diversity nannofossil datasets are not only perilous, but also flawed when only part of the section is measured and the age is extrapolated for the entire section. (b) Age assignment should incorporate recent references from all faunal groups that are irrespectively in favour or against the available data in the manuscript. (c) Faunal/sediment locality (or localities) should be clearly marked and compared with previous records for future follow-up micro and macrofossils collections. Lack of all or any of the above three parameters will always result in incomplete age assignments and incorrect biostratigraphic correla-

tions, thus strongly undermining the usefulness provided by other microfossils or macrofossils (such as ammonites, bivalves, echinoids and brachiopods).

- Roth, P. H., Medd, A. W. and Watkins, D. K., Jurassic calcareous nannofossil zonation, new evidence from deep sea drilling project site 534. In *Initial Reports DSDP* (eds Sheridan, R. E. et al.), 1983, vol. 76, pp. 573–589.
- Fürsich, F. T., Oschmann, W., Singh, I. B. and Jaitly, A. K., Hardgrounds, reworked concretion levels and condensed horizons in the Jurassic of western India: Their significance for basin analysis. *J. Geol. Soc. London*, 1992, **149**, 313–331.
- Jain, S., The Bathonian–Callovian boundary in the middle Jurassic sediments of Jaisalmer Basin, Western Rajasthan (India). *J. Geol. Soc. India*, 2007, **69**, 79–89.
- Rai, J. and Garg, R., Early Callovian nannofossils from the Kuldhar section, Jaisalmer, Rajasthan. *Curr. Sci.*, 2007, **92**, 816–820.
- De Kaenel, E., Bergen, J. A. and von Salis Perch Nielsen, K., Jurassic calcareous nannofossil biostratigraphy of western Europe. Compilation of recent studies and calibration of bioevents. *Bull. Soc. Geol.*, 1996, **167**, 15–28.
- Bown, P. R., Cooper, M. K. E. and Lord, A. R., A calcareous nannofossil biozonation scheme for the early to mid Mesozoic. *Newsl. Stratigr.*, 1988, **20**, 91–114.
- Bergen, J. A. and Gardin, S., Tethyan late Bathonian to Tithonian nannofossil biostratigraphic events from SE France and DSDP Site 534: Emphasis on Callovian events and regional correlation (Portugal and northwest Europe). In 5th INA Conference, Salamanca (eds Young, J. R. and Bown, P. R.), Abstr., INA Newsl., 1993, vol. 15, p. 54.
- Gradstein, F. M. et al., *A Geologic Time Scale*, Cambridge University Press, Cambridge, 2004, pp. 1–589.
- Bown, P. R. and Cooper, M. K. E., New calcareous nannofossils from the Jurassic. *J. Micropalaeontol.*, 1989, **8**, 91–96.
- Bown, P. R. and Cooper, M. K. E., Jurassic. In *Calcareous Nannofossil Biostratigraphy* (ed. Bown, P. R.), Chapman and Hall, London, 1998, pp. 34–85.
- Medd, A. W., Nannofossil zonation of the English Middle and Upper Jurassic. *Mar. Micropaleontol.*, 1982, **7**, 73–95.
- Barnard, T. and Hay, W. W., On Jurassic coccoliths: A tentative zonation of the Jurassic of Southern England and North France. *Eclogae Geol. Helv.*, 1974, **67**, 563–585.
- Hamilton, G. B., Early Jurassic calcareous nannofossils from Portugal and their biostratigraphic use. *Eclogae Geol. Helv.*, 1977, **70**, 575–597.
- Krishna, J., An overview of the mesozoic stratigraphy of Kachchh and Jaisalmer basins. *J. Palaeontol. Soc. India*, 1987, **32**, 136–149.
- Prasad, S., Jain, R. L. and Srivastava, M. S., Record of Middle Jurassic (Bathonian) Ammonite Genus *Clydoniceras* Blake from Jaisalmer Basin, Western Rajasthan. *J. Geol. Soc. India*, 2007, **69**, 1–8.
- Callomon, J. H., On *Perisphinctes congener* Waagen, 1875, and the age of the Patcham Limestone in the Middle Jurassic of Jumara, Kutch, India. *Geol. Bl. NO-Bayern*, 1993, **43**, 227–246.
- Jain, S., Callomon, J. H. and Pandey, D. K., On the earliest known occurrence of the Middle Jurassic ammonite genus *Reineckeia* in the Upper Bathonian of Jumara, Kachchh, Western India. *Palaeontol. Z.*, 1996, **70**, 129–143.
- Krishna, J. and Ojha, J. R., The intrabasinal correlation in the Middle Jurassic Callovian Stage of Kachchh (Gujarat) and Ammonoid-foraminifer integration. *Geophytology*, 2000, **28**, 101–120.
- Dave, A. and Chatterjee, T. K., Integrated foraminiferal and ammonoid biostratigraphy of Jurassic sediments in Jaisalmer Basin, Rajasthan. *J. Geol. Soc. India*, 1996, **47**, 1–477.
- Buzas, M. A. and Culver, S. J., Biogeographic and evolutionary patterns of continental margin benthic foraminifera. *Paleobiology*, 1989, **15**, 11–19.
- Murray, J. W., *Ecology and Applications of Benthic Foraminifera*, Cambridge University Press, Cambridge, 2006.
- Rai, J., Early Callovian nannofossils from Jara Dome, Kachchh, western India. *J. Geol. Soc. India*, 2002, **61**, 283–294.
- Upadhyay, R., Rai, J. and Sinha, A., New record of Bathonian–Callovian calcareous nannofossils in the eastern Karakoram block: A possible clue to understanding the dextral offset along the Karakoram Fault. *Terra Nova*, 2005, **17**, 149–157.
- Chiari, M., Cobianchi, M. and Picotti, V., Integrated stratigraphy (radiolarians and calcareous nannofossils) of the Middle to Upper Jurassic Alpine radiolarites (Lombardian Basin, Italy): Constraints to their genetic interpretation. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2007, **249**, 233–270.
- Reale, V. and Monechi, S., *Cyclagelosphaera wiedmannii* new species, a marker for the Callovian. *J. Nannoplankton Res.*, 1994, **16**, 117–119.
- Bartolini, A., Baumgartner, P. O., Mattioli, E., Middle and Late Jurassic Radiolarian Biostratigraphy of the Colle Bertone and Terminilletto sections (Umbria–Marche–Sabina Apennines, Central Italy): An integrated stratigraphical approach. *Mem. Geol. Lausanne*, 1995, **23**, 817–832.
- Hall, R. L., New, biostratigraphically significant ammonites from the Jurassic Fernie Formation, southern Canadian Rocky Mountains. *Can. J. Earth Sci.*, 2006, **43**, 555–570.
- Roy, P., Bardhan, S., Mitra, A. and Jana, S. K., New Bathonian (Middle Jurassic) ammonite assemblages from Kutch, India. *J. Asian Earth Sci.*, 2007, **30**, 629–651.
- Lees, J. A., Bown, P. R. and Mattioli, E., Problems with proxies? Cautionary tale of calcareous nannofossil paleoenvironmental indicators. *Micropaleontology*, 2005, **51**, 333–343.
- Kalia, P. and Chowdhury, S., Foraminiferal biostratigraphy, biogeography, and environment of the Callovian Sequence, Rajasthan, Northwestern India. *Micropaleontology*, 1983, **29**, 223–254.

Received 26 October 2007; revised accepted 11 June 2008