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On the stratigraphical and palaeobiogeographical significance of *Borelis melo melo* (Fichtel & Moll, 1798) and *B. melo curdica* (Reichel, 1937) (Foraminifera, Miliolida, Alveolinidae)

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ABSTRACT – The stratigraphical and palaeobiogeographical significance of *Borelis melo melo* (Fichtel & Moll, 1798) and *B. melo curdica* (Reichel, 1937) is re-assessed in the light of a taxonomic review. *Borelis melo melo* ranges at least throughout the Miocene, whereas *B. melo curdica* is restricted to the late Early to Middle Miocene. Both sub-species occur only in the Indo-Pacific Province in the late Early Miocene ('early' Burdigalian), but in both the Indo-Pacific and Mediterranean provinces in the latest Early–early Middle Miocene ('middle' Burdigalian–Langhian), implying a marine (re-)connection between the two regions at this time. *J. Micropalaeontol*. **25**(2): 175–185, November 2006.

KEYWORDS: Borelis*, biostratigraphy, palaeobiogeography*

INTRODUCTION

The genus *Borelis* is a stratigraphically important constituent of the larger benthic foraminiferal (LBF) faunas of the Eocene–Holocene (see, for instance, Adams, 1970). It is represented in all of the low-latitude shallow-water palaeobiogeographical provinces of the period, namely the Mediterranean, Indo-Pacific and Caribbean provinces (Adams, 1967; Jones, 1999, and additional references cited therein), which latter two, incidentally, were contiguous prior to the formation of the Isthmus of Panama in the Pliocene. Modern LBF species live in areas with minimum sea-surface temperatures greater than 18 °C, and are essentially restricted to the tropics (Langer & Hottinger, 2000). They also host photosynthetic algal symbionts, and are restricted to the photic zone. A detailed ecological study in the Gulf of Aqaba revealed that *Borelis* hosts B-3 diatom symbionts and is restricted to depths of 5–65 m (Reiss & Hottinger, 1984).

At least sixteen nominal species and sub-species were considered by Samanta *et al*. (1990) or are considered by the present authors to be attributable to *Borelis* (note that, following Samanta *et al*. (1990) and other authors cited therein, a number of additional nominal species from the Upper Cretaceous and Lower Tertiary of the Caribbean Province have been excluded).

Unfortunately, the precise nature of the type species, *Nautilus melo* Fichtel & Moll, 1798, which was first described and illustrated, inadequately by modern standards, as long ago as the late eighteenth century, remained poorly known until comparatively recently, with the result that many nominal species described in the interim are candidate junior synonyms.

The purpose of this paper is to review the taxonomy of the sub-species *Borelis melo melo* and *B. melo curdica*, and, in the light of this review, to re-assess their stratigraphical and palaeobiogeographical significance.

SYSTEMATIC MICROPALAEONTOLOGY

Order **Miliolida** Calkins, 1909

Family **Alveolinidae** Ehrenberg, 1839

Diagnosis. Wall porcellaneous, imperforate. Test free, typically large (macroscopically visible), spherical to ellipsoidal depending upon degree of elongation along axis of coiling. Proloculus followed by spiral tube or flexostyle; later chambers initially irregularly coiled, at least in microspheric generation, later becoming planispiral. Chambers numerous, may be divided into one or more rows of chamberlets by means of secondary partitions or septula paralleling direction of coiling; those of upper (attic) row(s) smaller than those of lower row; septula of adjacent chambers either continuous or alternating. Basal layer thickening ('flosculinization') may be developed. External apertures generally arranged in one or more rows; apertural teeth present or absent.

Genus *Borelis* de Montfort, 1808

Type species. *Borelis melonoides* de Montfort, 1808=*Nautilus melo* Fichtel & Moll, 1798; original designation.

Synonym. *Neoalveolina* Silvestri, 1928 [*Alveolina bradyi* Silvestri, 1927=*Nautilus melo* Fichtel & Moll, 1798; subsequent designation (Bakx, 1932)].

Diagnosis. Chamberlets generally arranged in single row, but incipient attic chamberlets separated by Y-shaped septula developed in some forms; septula of adjacent chambers continuous. External apertures generally arranged in single row, but a second row of intercalar apertures developed in one form. Basal layer thickening ('flosculinization') not developed.

Stratigraphical distribution. Eocene to Holocene.

Palaeobiogeographical distribution. Mediterranean, Indo-Pacific and Caribbean provinces.

Remarks. As *Alveolina bradyi* Silvestri, 1927 is the type species by the subsequent designation of Bakx (1932) of the subgenus *Alveolina* (*Neoalveolina*) Silvestri, 1928, and *Nautilus melo* Fichtel & Moll, 1798 is the type species of the genus *Borelis* de Montfort, 1808, and as *bradyi* is a junior synonym of *melo*, *Neoalveolina* is consequently a junior synonym of *Borelis.*

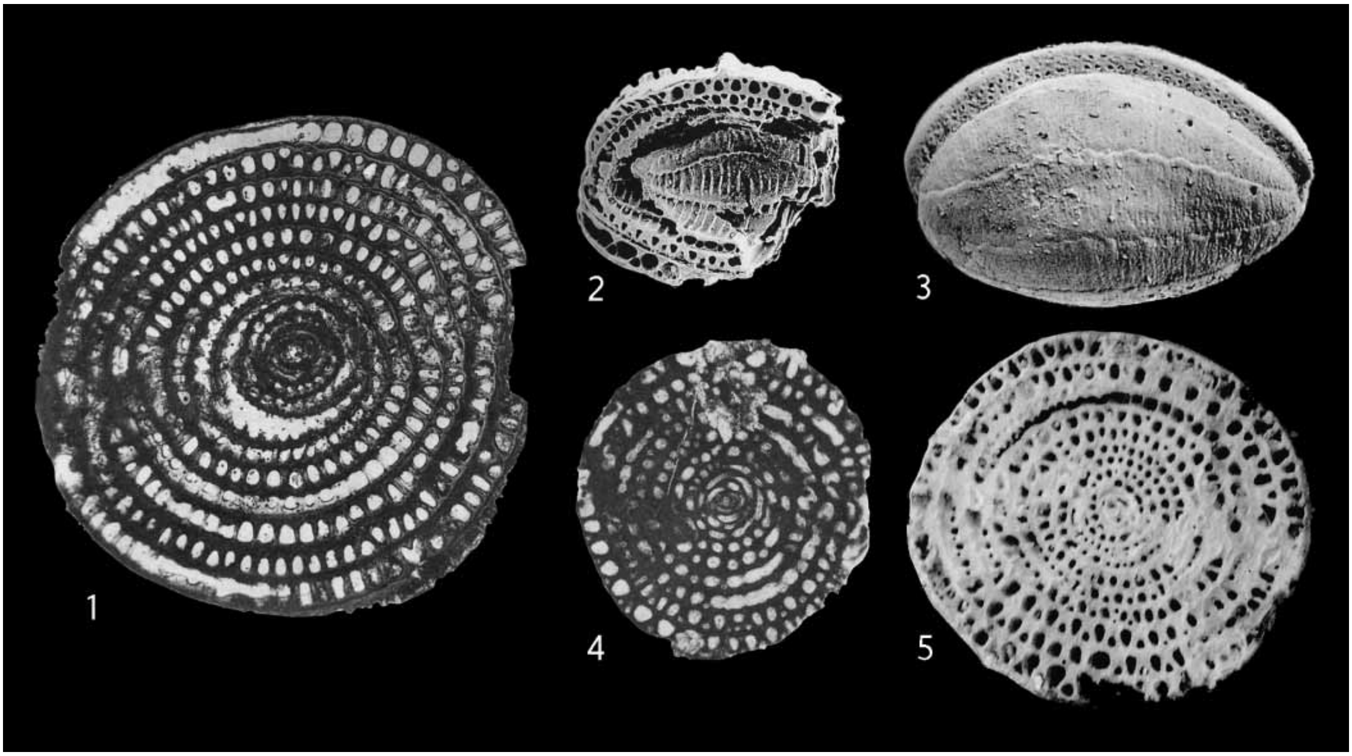

Plate 1.

Explanation of Plate 1. fig. 1. *Borelis melo melo* (Fichtel & Moll, 1798). Axial section, approximately ×22. Neotype designated by Smout (1963). Leithakalk ('Tortonien', in context probably early Middle Miocene, Badenian), Bujtur, Transylvania. Collection Schlumberger, La Sorbonne, Paris, No. 2405(3). After Reichel (1937). **figs 2, 3.** *Borelis melo haueri sensu* Cicha *et al.*, 1998 – external view of matrix-free specimen, approximately ×22 (after Cicha *et al.*, 1998): **2**, with outer whorls partially removed, showing internal structure, Early Badenian, Staropatica, Bulgaria (Naturhistorisches Museum, Wien); **3,** showing apertural face, Upper Lagenidae Zone, Badenian, Vienna Basin, Austria (d'Orbigny Collection, No. 102, Geologische Bundesanstalt, Wien). **figs 4, 5.** *Borelis melo* (Fichtel & Moll) *curdica* (Reichel, 1937), axial section, approximately ×22: **4**, syntype herein designated lectotype. Miocene, Garzan, Turkey (Institut de Géologie de l'Université de Bâle, Basel), after Reichel (1937); **5,** Badenian, Nussdorf/Steinfeld, Vienna Basin, Austria (D'Orbigny Collection, No. 101, Geologische Bundesanstalt, Wien), after Cicha *et al.* (1998).

Borelis melo melo (Fichtel & Moll, 1798)
(Pl. 1, fig. 1)

1798 *Nautilus melo* var. *alpha* Fichtel & Moll: 118; pl. 24, figs a–f (*non* var. *beta*).
1846 *Alveolina melo* d'Orbigny: 147, pl. 7, figs 15–16.
1928 *Alveolina melo* d'Orbigny (*sic*); Silvestri: pl. 1, figs 11–12.
1928 *Alveolina melo* Brady (*sic*); Silvestri: pl. 1, figs 13–16.
1937 *Neoalveolina melo* (Fichtel & Moll); Reichel: 105–108, pl. 10, figs 8–9; text-fig. 22 (pl. 10, fig. 8=neotype designated by Smout, 1963).
1957 *Borelis melo* (Fichtel & Moll); Cole: 766; pl. 240, fig. 2.
1962 *Borelis melo* (Fichtel & Moll); Eames *et al.*: pl. 7, fig. f.
1963 *Neoalveolina melo* (Fichtel & Moll); Souaya: 445–446, pl. 58, fig. 20.
1966 *Borelis melo melo* (Fichtel & Moll); Reiss & Gvirtzman: pl. 1, figs 1–7, pl. 2, fig. 2.
1966 *Neoalveolina* Saavedra: figs. 19A–B, 20.1.
1968 *Borelis melo* (Fichtel & Moll); Azema *et al.*: 447, pl. 27, figs 1–8.
1968 *Borelis melo* (Fichtel & Moll); Korecz-Laky: 96, pl. 6, fig. 6, pl. 7, fig. 4.
1975 *Borelis melo melo* (Fichtel & Moll); Ctyroky *et al.*: 40, text-figs 1–2, 5–6.
1978 *Borelis melo melo* (Fichtel & Moll); Karim: pl. 2, figs 2–4.
?1982 *Borelis melo* (Fichtel & Moll); Grasso *et al.*: pl. 2, fig. D (left centre).
1983 *Borelis melo* (Fichtel & Moll); Dullo *et al.*: pl. 1, fig. 5.
1983 *Borelis melo* (Fichtel & Moll); Gagic: figs 2–4.
1984 *Borelis melo* (Fichtel & Moll); Rögl & Hansen: 71–72, pl. 29, figs 5–6; pl. 30, figs 1–4 (pl. 30, figs 1–2=unnecessary neotype).
1985 *Borelis melo melo* (Fichtel & Moll); Al-Hashimi & Amer: pls 145, 148.
1985 *Alveolina melo* d'Orbigny (*sic*); Papp & Schmid (*pars*): 55–56, pl. 7, figs 1–2; pl. 47, figs 1, ?2, 3, 6.
1987 *Borelis melo* (Fichtel & Moll); Loeblich & Tappan (*pars*): pl. 374, figs 1–6 (not pl. 375, fig. 2).
1988 *Borelis melo* (Fichtel & Moll); Sartorio & Venturini: unnumbered plates (on p. 169).
1990 'Miliolid foraminifera'; Jenkyns *et al.*: fig. 69.
1993 *Borelis melo melo* (Fichtel & Moll); Buchbinder *et al.*: fig. 2E.
1997 *Borelis melo* (Fichtel & Moll); Betzler & Schmitz: 211–212, figs 3e–g.
1998 *Borelis melo melo* (Fichtel & Moll); Cicha *et al.*: 86, pl. 19, figs 10, 13, 15; pl. 20, figs 1–2.
1999 *Borelis melo* (Fichtel & Moll); Hughes *et al.*: fig. 22(a).
2000 *Borelis melo* (Fichtel & Moll); Hughes *et al.*: fig. 22.

Turkey	'Middle Miocene', Alexandretta	Authors' observations on material in the Iraq Petroleum Company (IPC) collection in the Natural History Museum (NHM), London, Slides PF54331, PF54332, PF54333 and PF54335). [No more refined stratigraphic interpretation possible].
	'Miocene'	Authors' observations on material in Caesar collection in the NHM). [No more refined stratigraphic interpretation possible].
Syria	'Middle Miocene', J. Terbol	Authors' observations on material in the IPC collection in the NHM, Slide PF54341). [No more refined stratigraphic interpretation possible].
Iran and Iraq	'Oligocene' (at least in part Miocene) to Miocene	Bozorgnia (1964), Sampò (1969), Kalantari (1976, 1986), Karim (1978) and Al-Hashimi & Amer (1985), as *Borelis* or *Neoalveolina haueri* or *B.* or *N. pygmaea*).
	Euphrates Formation	Tell Hamad, Al-Medlij, Western Desert (Ctyroky *et al*., 1975); also Abu Sfia and Al-Jazera, Western Desert, and Al-Fatha and near Mosul, North Iraq (Karim, 1978).
	Govanda Formation	Hillwa Nassara village, north of Amadiya, N. Iraq (Al-Hashimi & Amer, 1985). [Euphrates and Govanda formations in Western Desert Early Miocene, probably Burdigalian, on basis of occurrence of *Miogypsina globulina* (Ctyroky *et al*., 1975; Karim, 1978; Al-Hashimi & Amer, 1985). *Miogypsina globulina* Burdigalian (planktonic foraminiferal Zones N5–N6) in Aquitaine Basin in Western Tethys (Cahuzac, 1984; Cahuzac & Poignant, 1997). Euphrates elsewhere early Middle Miocene, Langhian, planktonic foraminiferal Zone N8 (Prazak, 1978), presumably on presence of *Praeorbulina* and absence of *Orbulina*].
	Jeribe Formation	Hatamia Village, near Al-Baghdadi, W. Iraq. [Jeribe at Dermanou no older than Middle Miocene, Langhian, planktonic foraminiferal Zone N9, on occurrence of *Orbulina* sp. (Karim, 1978; Prazak, 1978)].
	Wadi Hauran	Authors' observations on material in the IPC collection in the NHM, Slide PF54342). [No more refined stratigraphic interpretation possible].
Red Sea Coast, Saudi Arabia	Al Bad Formation	Midyan area, Red Sea coast, NW Saudi Arabia (Dullo *et al*., 1983). [Probably equivalent to Maqna Group of Hughes & Filatoff (1995) and Hughes *et al*. (1999)=early Middle Miocene, Langhian (see below)].
	Wadi Waqb Member, Jabal Kibrit Formation, Maqna Group	Red Sea coast, Saudi Arabia (Hughes *et al*., 1999, 2000). [Early Middle Miocene, Langhian, planktonic foraminiferal Zones N8–N9 on basis of occurrence of *Praeorbulina* (Hughes *et al*., 1999, 2000)].
Gulf Coast, Qatar	Dam Formation	Al-Saad & Ibrahim (2002) – questionable in view of poor quality of photograph. [Dam Formation in United Arab Emirates Early Miocene, Burdigalian, 18.9 Ma, on strontium isotope evidence (Peebles, 1999). Interpreted overall age-range for formation in Middle East late Early–early Middle Miocene, Burdigalian–Langhian, 16–19 Ma (Peebles, 1999). Based partly on terrestrial vertebrate evidence presented by Whybrow *et al*. (1987) from continental locality of Ad Dabtiyah in Saudi Arabia, indicating correlation to Orleanian land mammal stage of Europe, equivalent to Burdigalian–Langhian (see, for instance, Jones, 1999, and additional references cited therein)].
East Africa	'Burdigalian' (Tf_1) limestone	near Chanjani, Pemba Island, Zanzibar (Eames *et al*., 1962). ['Burdigalian' in this context implies Letter Stages Tf_1–Tf_2, i.e. Early–Middle Miocene, planktonic foraminiferal Zones N6–N12 (Boudagher-Fadel & Banner, 1999). No more refined stratigraphic interpretation possible].
	'Miocene' reef limestone	Dubar, Karin Anamayayeh, former British Somaliland (authors' observations on material in the Major J.A. Hunt Collection in the NHM, ex Slide P31557 and Slide P31558). [No more refined stratigraphic interpretation possible].
West Pacific	Tertiary e	1230–1248′, Core 3, Drill Hole F-1, Eniwetok Atoll (Cole, 1957). [In fact Upper Te on basis of associated microfauna (*Gypsina marianensis* and *Miogypsinoides dehaarti*), i.e. Early Miocene, Aquitanian–Burdigalian, planktonic foraminiferal Zones N4–N6 (Boudagher-Fadel & Banner, 1999)].

Table 1. Stratigraphical distribution of *Borelis melo melo* in the Indo-Pacific Province.

Paratethys	Badenian to 'early' Sarmatian	Styrian Basin, Baden, Brunn am Steinfeld (Brunn an der Schneebergbahn), Grinzing, Kalksburg (Leithakalk), Nussdorf, Theresienbad, 'limestone of the building of the Magdalena Chapel', Vienna (Leithakalk) and Voslau, Vienna Basin, Austria; Bulgaria; Moravia, former Czechoslovakia; Grusbach or Kroisbach (=Fertorakos, near Sopron) and other localities, Hungary; Duino, northwest of Trieste, Italy; Lapugia or Lapugiu de Sus or Lapugy, Bega Basin, Romania, Leithakalk, Bujtur, also Globukrajawa, Hunyad, Krasso-Szorenz and Pest, Peschtisch or Pestesu and Siebenburgen, Transylvanian Basin, Romania; Croatia, Serbia and Slovenia, former Yugoslavia (Fichtel & Moll, 1798; d'Orbigny, 1846; Reichel, 1937; Smout, 1963; Korecz-Laky, 1968; Ctyroky *et al.*, 1975; Gagic, 1983; Rögl & Hansen, 1984; Papp & Schmid, 1985; Cicha *et al.*, 1998; authors' observations on material in the F. Rögl Collection in the NHM).
	Konkian (late Badenian equivalent)	northern Caucasus and Crimea, former Soviet Union (Zhizhchenko, 1959, as *Borelis haueri*). [Middle Miocene, Langhian–Serravallian, calcareous nannoplankton Zones NN4?–?NN6 (Papp & Schmid, 1985; Jones & Simmons, 1996; Cicha *et al.*, 1998)].
Southern Europe	'Tortoniense'	Cabo de Gata, Almeria Province, SE Spain (Saavedra, 1966).
	Middle Miocene, 'Helvetian' (Serravallian)-Tortonian	eastern Betic Cordillera, SE Spain (Azema *et al.*, 1968). [No more refined stratigraphic interpretation possible].
	Siracusa Limestone Member, Monte Climiti Formation and Carlentini Formation, Sortino Group	Monte Carrubba, SE Sicily (Grasso *et al.*, 1982) – questionable in view of poor quality of photograph. [By correlation with dated section at Licodia Eubea, Carlentini Formation Late Miocene, Tortonian (*Globorotalia acostaensis* Zone). Monti Climiti Formation undated].
	'Middle Miocene'	S. Cesarea Terme, Apulia (Sartorio & Venturini, 1988). [No more refined stratigraphic interpretation possible].
	Middle Miocene or Late Miocene, Messinian	Porto Cristo, Mallorca (Jenkyns *et al.*, 1990; authors' observations on material presented by Miss A. Taylor in the NHM). [No more refined stratigraphic interpretation possible].
	Late Miocene, Cantera Member	Cabo de Gata, Almeria Province, SE Spain (Betzler & Schmitz, 1997). [Late Miocene, Tortonian–Messinian, planktonic foraminiferal Zones N16–N17 on basis of occurrence of sinistral *Neogloboquadrina acostaensis* (Betzler & Schmitz, 1997). Underlying volcanic rocks radiometrically dated to 8 Ma (Betzler & Schmitz, 1997)].
	'Miocene'	Ras Kala, Malta (authors' observations on material in the IPC Collection in the NHM, Slide PF54338). [No more refined stratigraphic interpretation possible].
North Africa	'Miocene medio'	'tra El-Abiar e Sidi-Mahius nella Cyrenaica' [Libya], also 'Esc-Scegga nella Marmarica' [Libya] (Silvestri, 1928). [No more refined stratigraphic interpretation possible].
	Zone of Neoalveolina melo, 'Vindobonian'	Gebel Gharra, Cairo–Suez Road, Egypt (Souaya, 1963). [Probably early Middle Miocene, Langhian. Overlies zonule of *Miogypsina cushmani*, restricted to Early Miocene, Burdigalian (planktonic foraminiferal N7) in Western Tethys (Cahuzac, 1984; Cahuzac & Poignant, 1997)].
	'Middle Miocene'	El Abyar, Libya (Sartorio & Venturini, 1988). [No more refined stratigraphic interpretation possible].
	Units II-IV, Marmarica Formation	El-Dabaa, NW Egypt (Ibrahim & Mansour, 2002). [Middle Miocene, Langhian–Serravallian, planktonic foraminiferal Zones N8–N13 on basis of occurrence of *Praeorbulina sicana*, *Orbulina* spp., *Globorotalia fohsi lobata* and *G. fohsi robusta*].
Israel	'Unit 4', Ziqlag Formation	Khirbet es Sura and Lakhish (Reiss & Gvirtzman, 1966). [Lower part of Ziqlag ('Unit 4a') Middle Miocene, Serravallian, planktonic foraminiferal Zones N12–N14 on basis of occurrence of *Globorotalia menardii* and *G. mayeri* in presumed equivalent basinal section].
	Ziqlag and Pattish formations	Ofaqim and other boreholes, coastal plain (Buchbinder *et al.*, 1993). [Late Miocene, Tortonian–Messinian, planktonic foraminiferal Zones N15–N17 (Buchbinder *et al.*, 1993, and additional references cited therein)].

Table 2. Stratigraphical distribution of *Borelis melo melo* in the Mediterranean Province.

Turkey	Miocene	2 km east of Garzan on the road between Djarbekir and Saist, Armenian Taurus, Turkey (Reichel, 1937).
	Miocene	Sivas Basin (Dizer, 1962) – questionable in view of poor quality of photograph. [No more refined stratigraphic interpretation possible].
Iraq	Euphrates Formation	Al-Qaim area, NW Iraq (Al-Saddiqui, 1972).
	Jeribe Formation	Type locality near Jaddala, also Dermanou, Erbil, Hilwa Nassara and Mawat, North Iraq, and Wadi Fuhaimi and W. Ukash, Western Desert (Karim, 1978).
	Jeribe Formation	Hatamia Village, near Al-Baghdadi, W. Iraq, also Qara Chaug Dagh, Kirkuk, N. Iraq (Al-Hashimi & Amer, 1985).
	Jeribe limestone	Palani (authors' observations on material in the IPC collection in the NHM, Slide PF54348). [Euphrates in Western Desert Early Miocene, probably Burdigalian, elsewhere early Middle Miocene, Langhian, planktonic foraminiferal Zone N8 (see above). Jeribe at Dermanou no older than Middle Miocene, Langhian, planktonic foraminiferal Zone N9 on occurrence of *Orbulina* sp. (Karim, 1978)].
	Lower or Middle Fars limestones	Kan-I-Shaitan section, Darband or Derbend-I-Bazian or Bezian, Kurdistan (authors' observations on material in the IPC collection in the NHM, including Slides PF54340 and PF54351). [No more refined stratigraphic interpretation possible].
Zagros Basin, Southern Iran	(Upper) Asmari Formation	Maidan-i-Naphtun [near Kuh-e-Asmari], Marun Field area, Tang-e-Haletuk and Tang-e-Mashemi, Khuzestan and Lurestan provinces.
	Razak Formation	Sarvestan, Interior Fars.
	Gachsaran Formation	Fars (Nicolesco, 1928; James & Wynd, 1965; Sampò, 1969; Kalantari, 1976; Rahaghi, 1984; Seyrafian & Hamedani, 1998; Seyrafian, 2000; authors' unpublished observations). [Upper Asmari in part late Early Miocene, Burdigalian, 19.3 Ma on strontium isotope stratigraphic evidence (authors' unpublished observations), in part early Middle Miocene, Serravallian, Zones N10–N12 on uncorroborated planktonic foraminiferal evidence (Adams, 1969; Jones, 1999). Razak, early Middle Miocene, Langhian, planktonic foraminiferal Zone N8 on presence of *Praeorbulina* and absence of *Orbulina* (James & Wynd, 1965). Gachsaran (in Abu Dhabi) late Early to early Middle Miocene, Burdigalian–Langhian, 20.1–16.3 Ma on strontium isotope stratigraphic evidence (Peebles, 1999)].

Table 3. Stratigraphical distribution of *Borelis melo curdica* in the Indo-Pacific Province.

?2002 *Borelis melo melo* (Fichtel & Moll); Al-Saad & Ibrahim: pl. 3b, fig. 21.

2002 *Borelis melo melo* (Fichtel & Moll); Ibrahim & Mansour: pl. 2, figs 8–9.

Diagnosis. Chamberlets of same chamber of equal or nearly equal size.

Variability. Degree of elongation along axis of coiling variable.

Stratigraphical distribution. Refer to Tables 1 and 2 (only records verifiable by reference to illustrations or material have been admitted).

Palaeobiogeographical distribution. Indo-Pacific Province (Early–Middle Miocene, Aquitanian–Langhian); Mediterranean Province (Middle–Late Miocene, Langhian–Messinian).

Remarks. The following nominal species differ from *Borelis melo melo* essentially only in their marginally greater axial elongation, and are regarded as at least possibly synonymous (as they appear to fall within the range of variation exhibited by *Borelis melo melo*):

- *Alveolina pulchra* d'Orbigny, 1839, originally described from the Recent of Cuba in the Caribbean, and also recorded in the Recent elsewhere in the equatorial Atlantic and in the Indo-Pacific, and in the Pleistocene and Miocene. Adams (1970) noted that *pulchra* 'may grade into *B. melo*'.
- *Alveolina melo sensu* Brady, 1884 (see also Jones, 1994) from the Recent of Ascension Island and Bermuda in the Atlantic. *Alveolina bradyi* Silvestri, 1927 was evidently intended by Silvestri (1927, 1928) as a new name for *A. melo sensu* Brady, 1884, which he interpreted as distinct from *melo sensu stricto.* However, Silvestri's species concept, as indicated by his synonymy and his plates, includes some specimens of undoubted *melo s.s.*, including some from the type locality, with the result that most subsequent authorities have synonymixed *bradyi* with *melo*.
- *Borelis primitivus* Cole, 1957, originally described from the Tertiary e (?Te_{1-4}, Late Oligocene) of Eniwetok Atoll in the West Pacific.

The following nominal species differ in their significantly greater axial elongation, and are regarded as probably distinct:

- *Neoalveolina pygmaea schlumbergeri* Reichel, 1937, originally described from the Recent of Mayotte, NW of Madagascar in

Central Paratethys	'Torton'	Devinska Kobyla and Sandberg, near Devinska Nova Mes, West Carpathians, Slovakia (Misik, 1966).
	Badenian-?'early' Sarmatian	Baden, Nussdorf and Steinfeld, Vienna Basin, Austria, Lapugia or Lapugy, Bega Basin, Romania, and Serbia, former Yugoslavia (Papp & Schmid, 1985; Cicha *et al.*, 1998; authors' observations on material in the F. Rögl collection in the NHM). [Middle Miocene, Langhian–?Serravallian, calcareous nannoplankton Zones NN4?–?NN6 (Cicha *et al.*, 1998). 'Early'–'middle' Badenian, probably Langhian only, where best dated in Serbia (Cicha *et al.*, 1998; fig. 49)].
Southern Europe		Leucas Island (Bornovas, 1964). [No stratigraphic interpretation possible].
	Middle Miocene	Kos, Greece (Bignot & Guernet, 1976). [Early Middle Miocene, Langhian, planktonic foraminiferal Zones N8–N9 on basis of occurrence of *Praeorbulina* and *Orbulina*].
	Late Early Miocene, 'middle'-'late' Burdigalian	Gulf of Saubrigues, SW France (Cahuzac & Poignant, 2004). [Planktonic foraminiferal zones N6 (pars)–N7; calcareous nannoplankton zones NN3–NN4].
North Africa	Miocene	Tripolitania (Lipparini, 1939) – questionable in view of poor quality of photograph. [No more refined stratigraphic interpretation possible].
	Middle Miocene	Sirtica, Libya (Haynes, 1981). [No more refined stratigraphic interpretation possible].
Israel	'Unit 4', Ziqlag Formation	Khirbet es Sura and Lakhish; also Horvat Zura, Shelefa Foothills and borehole, Helez (Reiss & Gvirtzman, 1966). [Middle Miocene, Serravallian, planktonic foraminiferal Zones N12–N14 on uncorroborated planktonic foraminiferal evidence, specifically on the occurrence of *Globorotalia menardii* and *G. mayeri* in the presumed equivalent basinal section. Could be as old as Middle Miocene, Langhian, Zone N8 if the purported *G. menardii* is actually misidentified *G. archaeomenardii*].
Qom or Qum Basin, Northern Iran	Qom or Qum Formation	Qom or Qum area (Bozorgnia, 1964; Rahaghi, 1980, 1984; Kalantari, 1986; authors' unpublished observations). [Where specified, f Member. Underlying e Member early Middle Miocene, Langhian, planktonic foraminiferal Zones N8–N9 on basis of occurrence of *Globigerinoides bisphericus* (Bozorgnia, 1965)].

Table 4. Stratigraphical distribution of *Borelis melo curdica* in the Mediterranean Province.

the Indian Ocean, and also recorded in the Recent elsewhere in the Indo-Pacific and in the Red Sea, and in the Pleistocene of Eniwetok Atoll in the West Pacific.

- *Borelis clarionensis* McCulloch, 1977, originally described from the Recent of the Pacific Ocean.

Borelis or *Neoalveolina haueri* and *B.* or *N. pygmaea*, under which names *B. melo melo* is interpreted here as having been identified by other authors (see below), are also regarded as distinct.

Unfortunately, the characters of *Alveolina haueri* d'Orbigny, 1846 *sensu stricto,* originally described from the Middle Miocene, Badenian, of Baden in the Vienna Basin, are not entirely clear from the type description (d'Orbigny, 1846, p. 148) and somewhat stylized type figures (d'Orbigny, 1846, pl. 7, figs 17–18). The specimen, again from the Badenian of Baden, described and figured by Cicha *et al*. (1998, p. 86, pl. 19, fig. 11) as *Borelis melo haueri*, and figured herein on Plate 1, fig. 2, exhibits an internal structure reminiscent of *B. melo curdica* (see below), with alternately large and small chamberlets, and the latter displaced towards the external periphery, resulting in the development of incipient attic chamberlets separated by Y-shaped septula. The specimen, yet again from the Badenian of Baden, described and figured by Papp & Schmid (1985, p. 56, pl. 47, figs 8, 12) as '*Borelis melo* (=*Alveolina haueri*)' and by Cicha *et al*. (1998, p. 86, pl. 19, fig. 12) as *Borelis melo haueri*, and figured herein on Plate 1, fig. 3, exhibits external apertures arranged in two, staggered, rows, rather than the one seemingly suggested by the original description of *Alveolina haueri* ('*une rangee longitudinale d'ouvertures ovales transverses*': d'Orbigny, 1846). In this respect, it is reminiscent of the genus *Flosculinella* Schubert *in* Richarz, 1910, differing essentially only in possessing one supplementary attic aperture per main aperture, rather than two.

Borelis (*Fasciolites*) *pygmaea* Hanzawa, 1930 *sensu stricto*, originally described from the Miocene of Indonesia, appears distinct in terms not only of its greater axial elongation, but also of its incipient polar flosculinization.

Borelis melo (Fichtel & Moll) *curdica* (Reichel, 1937)
(Pl. 1, figs 4–5)

1928 *Alveolina* cf. *melo*; Nicolesco: 1086, fig. 26.

1937 *Neoalveolina melo curdica* Reichel: 108–110, pl. 10, figs 4–7; pl. 11, fig. 6a (*N. melo* on caption); 103, text-fig. 20; 104, text-fig. 21; 122, text-fig. 26, no. 5. (pl. 10, fig. 4=syntype; herein designated lectotype).

?1939 *Neoalveolina melo curdica* Reichel; Lipparini: pl. 16, figs 1–7.

?1962 *Neoalveolina melo curdica* Reichel; Dizer: pl. 5, fig. 1.

1964 *Neoalveolina mello* (*sic*) *curdica* Reichel; Bornovas: pl. 16, fig. 2.

1964 *Neoalveolina melo curdica* Reichel; Bozorgnia: pl. 148, pl. 149, fig. 1; pl. 150, pl. 151, fig. 2; pl. 152, figs 1–2.
1964 *Borelis melo curdica* (Reichel); Loeblich & Tappan: fig. 394.2.
1965 *Neoalveolina melo curdica* Reichel; James & Wynd: fig. 78.
1966 *Borelis melo curdica* (Reichel); Misik: pl. 96, figs 1–2.
1966 *Borelis melo curdica* (Reichel); Reiss & Gvirtzman: pl. 1, fig. 8; pl. 2, fig. 1.
1969 *Neoalveolina melo curdica* Reichel; Sampò: pl. 104, figs 1–2; pl. 105, figs 9–19.
1972 *Borelis melo curdica* (Reichel); Al-Saddiqui: fig. 2.
1976 *Borelis curdica* (Reichel); Bignot & Guernet: 19, 21, pl. 2, figs 1–10.
1976 *Neoalveolina melo curdica* Reichel; Kalantari: pl. 47, fig. 21 (?); pl. 48, fig. 1.
1978 *Borelis melo curdica* (Reichel); Karim: pl. 1, fig. 3; pl. 2, fig. 1.
1980 *Neoalveolina melo curdica* Reichel; Rahaghi: 39–40, pl. 6, figs 1–10; pl. 7, fig. 1.
1981 *Borelis* sp. Haynes: pl. 13 (top fig.).
1984 *Neoalveolina melo curdica* Reichel; Rahaghi: 524, pl. 2, fig. 13. 1985 *Borelis melo curdica* (Reichel); Al-Hashimi & Amer: pls 145, 146.
1985 *Alveolina melo* d'Orbigny (*sic*); Papp & Schmid (*pars*): 55–56, pl. 47, figs ?2, 4–5.
1986 *Neoalveolina melo curdica* Reichel; Kalantari: pl. 132, figs 1–2; pl. 134, figs 1–2; pl. 135, figs 1–2; text-fig. 45, nos 1–4.
1987 *Borelis melo* (Fichtel & Moll) (*sic*); Loeblich & Tappan: pl. 375, fig. 2. 1993 *Borelis melo curdica* (Reichel); Buchbinder *et al.*: fig. 2F.
1998 *Borelis melo curdica* (Reichel); Cicha *et al.*: 86, pl. 19, figs 8–9, 14.
1998 *Borelis melo curdica* (Reichel); Seyrafian & Hamedani: fig. 7, nos 2, 4.
2000 *Borelis melo curdica* (Reichel); Seyrafian: fig. 5.
2004 *Borelis* cf. *curdica* (Reichel); Cahuzac & Poignant: pl. 2, fig. 3.

Stratigraphical distribution. Refer to Tables 3 and 4 (again, note that only records verifiable by reference to illustrations or material have been admitted).

Palaeobiogeographical distribution. Indo-Pacific Province (late Early–Middle Miocene, Burdigalian–Langhian, ?Serravallian); Mediterranean Province (latest Early–Middle Miocene, 'middle' Burdigalian–Langhian, ?Serravallian).

Diagnosis. Chamberlets of later chambers alternately large and small, the latter displaced towards the external periphery, resulting in the development of incipient attic chamberlets separated by Y-shaped septula; external apertures arranged in somewhat staggered row ('*alternativement larges et etroites et parfois jumelees*': Reichel, 1937).

Variability. Degree of elongation along axis of coiling variable. Ratio of lengths of polar to equatorial axes ranges from 1: 1 to up to at least 1.5: 1 (see, for instance, specimens illustrated by Reiss & Gvirtzman, 1966).

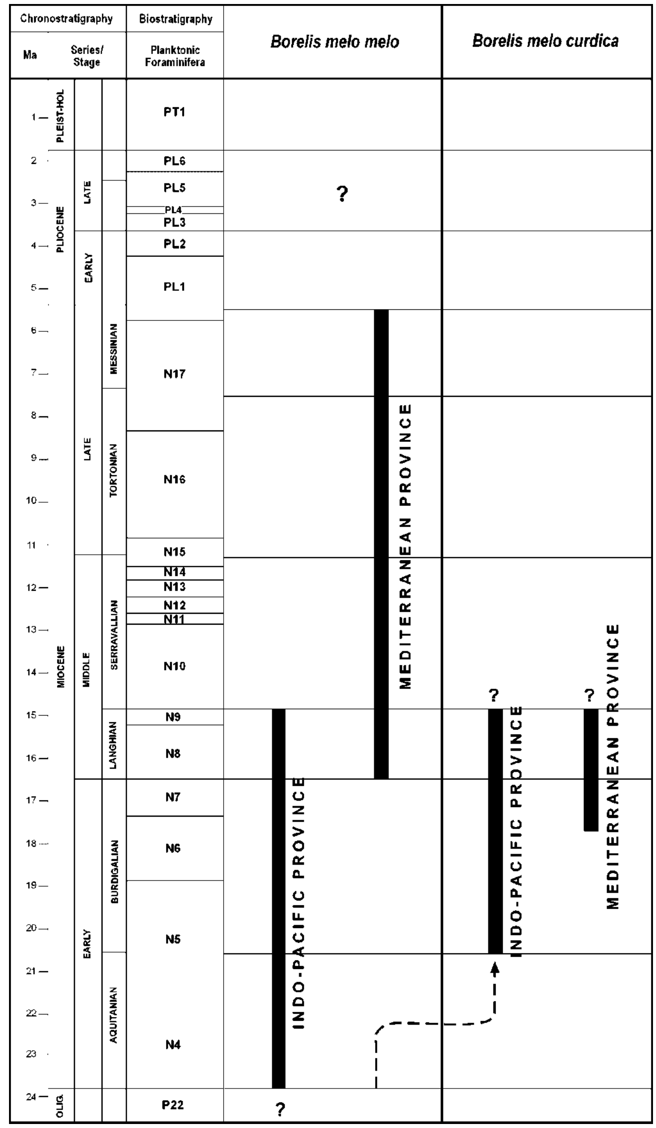

Fig. 1. Stratigraphical distribution of *Borelis melo melo* and *B. melo curdica*. Chronostratigraphy and biostratigraphy slightly modified after Berggren *et al.* (1995).

SUMMARY OF DISTRIBUTION DATA

The distributions of *Borelis melo melo* and *B. melo curdica*, as determined by records verifiable by reference to illustrations or material (see above), are listed below (see also Figures 1–2).

B. melo melo (Fichtel & Moll)

?Oligocene (*primitivus, haueri auctt., non* d'Orbigny, *pygmaea auctt., non* Hanzawa); Miocene; ?Pleistocene–Recent (*melo sensu* Brady, *pulchra*).

Indo-Pacific Province in Oligocene?, Early–Middle Miocene, Aquitanian?–Langhian; Mediterranean Province in Middle–Late Miocene, Langhian–Messinian; ?Atlantic/Caribbean Province in Pleistocene–Recent.

B. melo (Fichtel & Moll) *curdica* (Reichel)

Late Early–Middle Miocene, Burdigalian–Langhian, ?Serravallian.

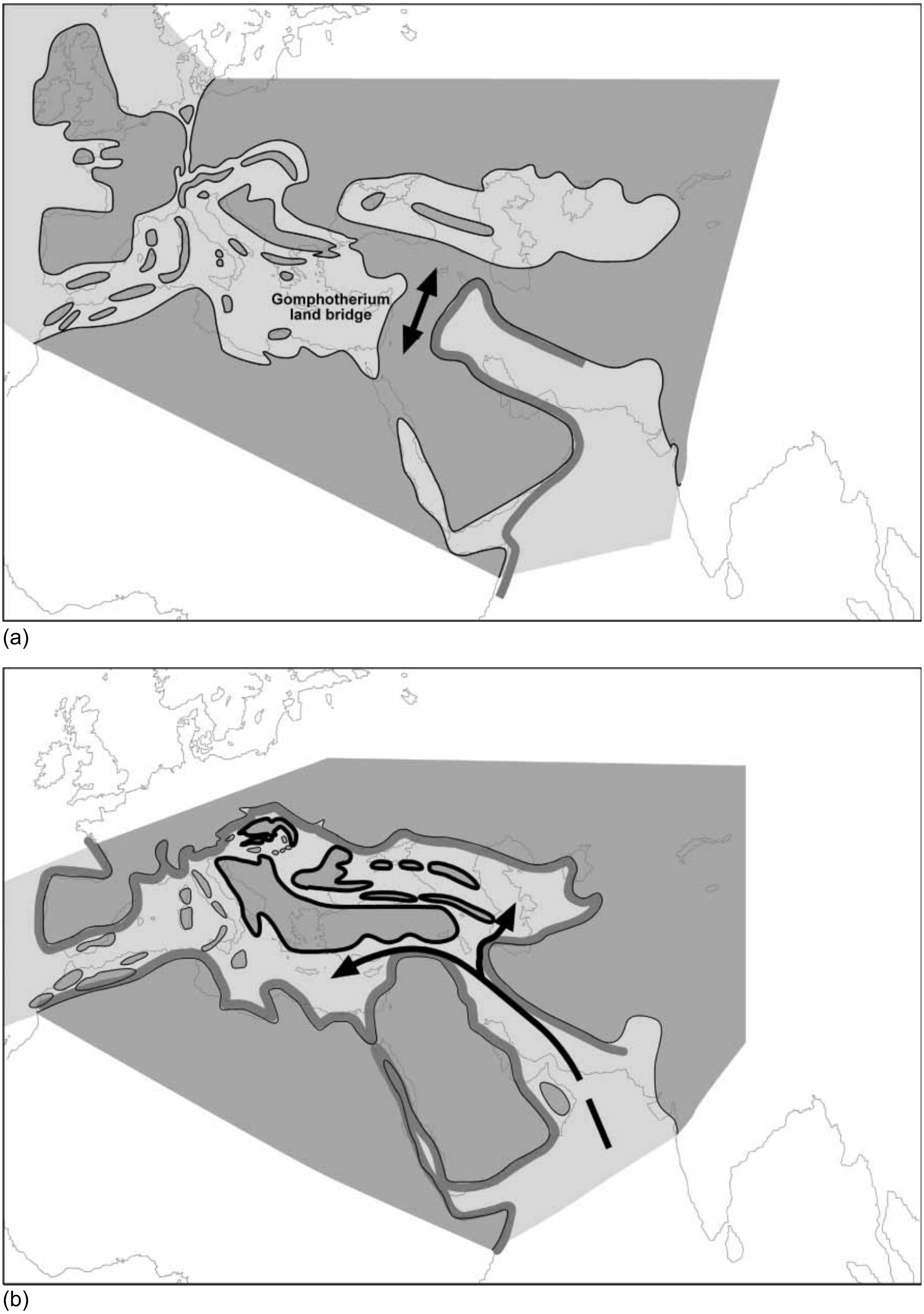

Fig. 2. Palaeobiogeographical distribution of *Borelis melo melo* and *B. melo curdica*: (**a**) late Early Miocene, 'early' Burdigalian; (**b**) latest Early–Early Middle Miocene, 'middle' Burdigalian–Langhian. Superimposed on the appropriate palinspastically restored base maps (Rögl, 1998, 1999a, b). Arrows indicate possible dispersal routes.

Indo-Pacific Province in late Early–Middle Miocene, Burdigalian–Langhian, ?Serravallian; Mediterranean Province in latest Early–Middle Miocene, 'middle' Burdigalian–Langhian, ?Serravallian.

DISCUSSION

Stratigraphical and evolutionary significance

These distribution data can be interpreted as indicating that *Borelis melo melo* evolved into *B. melo curdica*, with its 'more advanced' (certainly, more complex) structure of incipient attic chamberlets, Y-shaped septula and staggered row of external apertures, in the late Early Miocene, in the Indo-Pacific Province (Fig. 1).

Borelis melo curdica could conceivably have then evolved into *Flosculinella bontangensis*, with true attic chamberlets, in the Middle Miocene, in the Indo-Pacific Province. Importantly, *Flosculinella bontangensis* has been described (although unfortunately not illustrated) from the Middle Miocene of Fars Province in southeastern Iran, immediately post-dating *Borelis melo curdica* (James & Wynd, 1965).

Interestingly, *Flosculinella bontangensis* has been independently interpreted as having then in turn evolved into *Alveolinella praequoyi*, with an additional row of attic chamberlets, also in the Middle Miocene, in the Indo-Pacific Province (Wonders & Adams, 1991).

Palaeobiogeographical significance

The interpreted absences of *Borelis melo curdica* from the Indo-Pacific, and of *Flosculinella* from the Mediterranean, in the late Early Miocene, Burdigalian, were among the observations that led the late C. G. ('Geoff') Adams and his co-workers to suggest that the former Tethyan Sea connection between the two provinces had become interrupted by this time, by the formation of a land bridge between the converging Arabian and Eurasian Plates (Adams *et al*., 1983, 1999). Indeed, there is a wealth of terrestrial vertebrate evidence to indicate that there was a land bridge between Arabia and Eurasia in the late Early Miocene (Orleanian Land Mammal Age), which facilitated the dispersal not only of the primitive elephant *Gomphotherium* – after which it is colloquially known – but also of other less well-documented groups, such as fresh-water fish (see, for instance, Otero & Gayet, 2001). Corroborative evidence is provided by the existence of an emergence surface over much of Arabia (Adams, 1969). It is likely that the emergence surface and land bridge was generated by uplift of the Western Arabian Highlands by thermal doming associated with rifting in the Red Sea (Jones & Racey, 1994).

Fred Rögl and Fritz Steininger and their co-workers speculated, but were unable to prove to Adams' satisfaction, that there might have been a later reconnection between the Indo-Pacific and Mediterranean provinces, possibly in the early Middle Miocene, Langhian, prior to the final disconnection in the late Middle Miocene, Serravallian (see, for instance, Rögl, 1998, 1999a, b; see also Jones, 1999). Perhaps, significantly, this putative reconnection would have been coincident with a global climatic optimum and associated glacio-eustatic sea-level highstand.

The evidence outlined above of the occurrence of both *Borelis melo curdica* and *B. melo melo* only in the Indo-Pacific Province (at least in the Middle East) in the late Early Miocene, 'early' Burdigalian, supports Adams' interpretation of an interruption of the earlier marine connection between the Indo-Pacific and Mediterranean provinces at this time (Fig. 2a).

It is further submitted, however, that the occurrence of both sub-species, not only in the Indo-Pacific Province (in the Middle East) but also throughout the Mediterranean in the latest Early–early Middle Miocene, 'middle' Burdigalian–Langhian, supports Rögl & Steininger's interpretation of a (re-)connection, or at least a partial connection or filter, between the Indo-Pacific and Mediterranean provinces at this time (Fig. 2b).

CONCLUSIONS

1. *Borelis melo melo* and *B. melo curdica* are distinguishable from one another essentially on the basis of the level of development of their internal chamberlets and external apertures.
2. *Borelis melo melo* ranges at least throughout the Miocene. *B. melo curdica* is restricted to the late Early to Middle Miocene.
3. Both sub-species occur only in the Indo-Pacific Province in the late Early Miocene, 'early' Burdigalian, but in the Indo-Pacific and Mediterranean provinces in the latest Early–early Middle Miocene, 'middle' Burdigalian–Langhian. Their occurrence in both the Indo-Pacific and Mediterranean provinces in the latest Early–early Middle Miocene points to a marine (re-) connection between the two provinces at this time.

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