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Article

Occurrences, age and paleobiogeography of rare genera *Phlycticeras* and *Pachyerymnoceras* from South Tethys

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With 24 figures

Abstract: New data on two rare genera (*Phlycticeras* and *Pachyerymnoceras*) from the Callovian (Middle Jurassic) sediments of Kachchh, western India are presented with an update on their South Tethyan occurrences. This paper documents the earliest occurrence of the genus *Phlycticeras* from the entire south of Tethys (*P. polygonium* var. *polygonium* [M]) from latest Early Callovian sediments (= Proximum Subzone, Gracilis Zone). Further, in light of the new taxonomic data, the previously recorded early Middle Callovian *P.* gr. *pustulatum* [M] is reevaluated as also all other *Phlycticeras* occurrences from the Indian subcontinent. Data suggests that in Kachchh, *Phlycticeras* has a long range from the latest Early to Late Callovian interval. Additionally, two new macroconch species of *Pachyerymnoceras* are also described and illustrated from Late Callovian sediments. A critical review of previous records suggests that in Kachchh, *Pachyerymnoceras* is restricted to the Submediterranean interval of the Collotiformis-Poculum subzones of the Athleta Zone. A note on the paleobiogeography and probable migratory routes of these two genera to India and elsewhere is also suggested.

Key words: Kachchh, Middle Jurassic, Late Callovian, *Pachyerymnoceras*, *Phlycticeras*.

1. Introduction

Kachchh (Fig. 1) is a prolific Jurassic ammonite area in the Indo-Madagascan faunal Province (South Tethys) which has been extensively studied for its taxonomic, biochronostratigraphic and paleobiogeographic significance (Waagen 1873-1875; Rajnath 1932, 1934, 1942; Spath 1927-1933; Cariou & Krishna 1988; Krishna & Cariou 1990, 1993; Krishna & Ojha 1996, 2000; Jain 1995, 1997, 1998, 2002, 2014; Jain et al. 1996; Jain & Pandey 1997, 2000; Shome & Bardhan 2005; Bardhan et al. 2010; Pandey & Pathak 2015). The Callovian sediments (~370 m thick), best exposed at Jumara (Fig. 2) are dominated by perisphinctids (44%), macrocephalitids (37%), and reineckeiids (4%), besides others (15%) (see Jain 1995). However, in spite of the huge literature on Callovian ammonites from the Indian subcontinent, stratigraphically precise data is scarce both for Pachyceratidae Buckman (Waagen 1873-1875; Buckman 1909-1930; Spath 1927-1933; Krishna & Thierry 1987; Shome & Bardhan 2005) and Phlycticeratinae Spath (Waagen 1873-1875; Spath 1927-1933; Jain 1997; Bardhan et al. 2010).

Of the six widely known western Tethyan genera of Pachyceratidae (Callomon in Donovan et al. 1981), only three – *Erymnoceras*, *Pachyerymnoceras* and *Pachyceras* have so far been described from the Indian Subcontinent. *Erymnoceras* comes from Middle Callovian sediments (Krishna & Thierry 1987; Shome & Bardhan 2005) and both *Pachyerymnoceras* (Kachchh: Waagen 1875 in 1873-1875; Spath 1927-1933 and Central Nepal: Cariou & Enay 1999) and *Pachyceras* (Kachchh: Waagen 1873-1875; Spath 1927-1933; Thierry 1980) from Late Callovian sediments.

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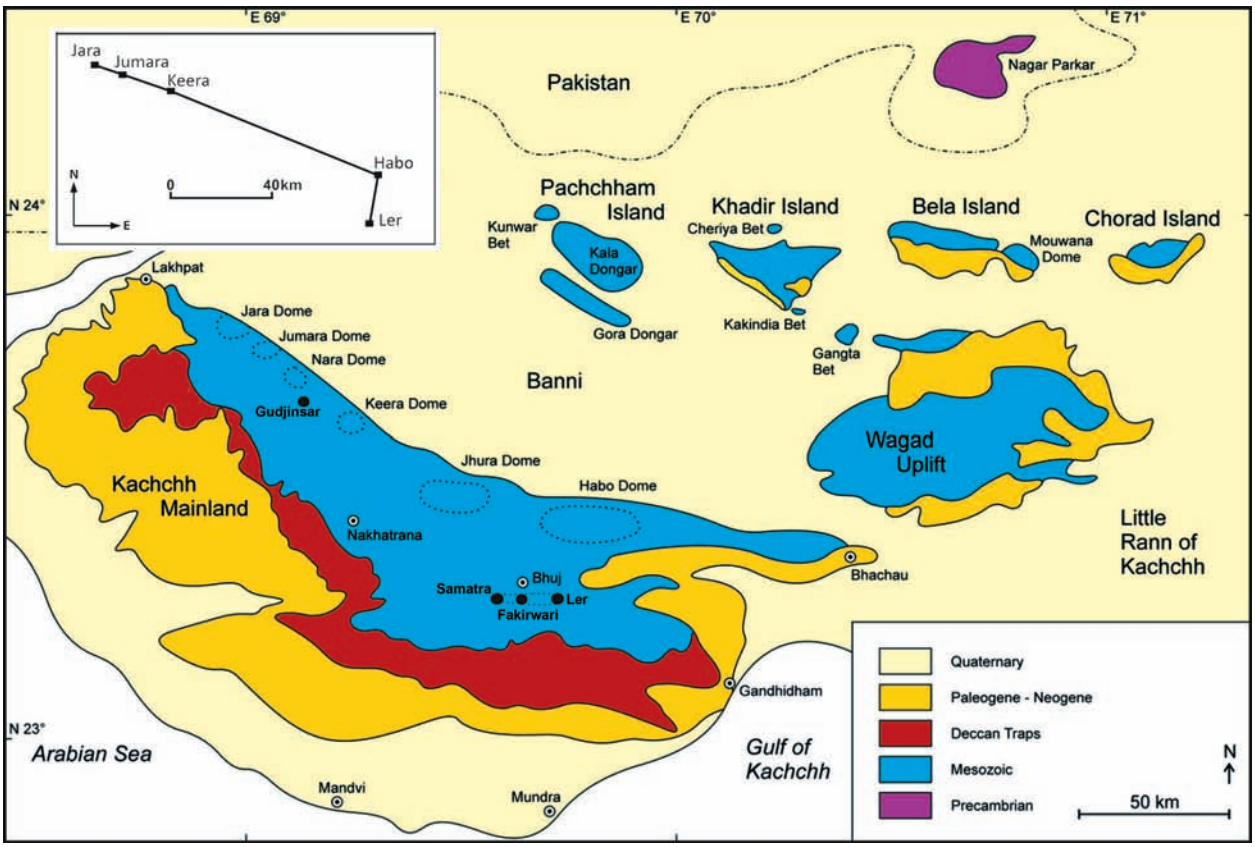

Fig. 1. Important Middle Jurassic outcrops in Kachchh (modified from Fürsich et al. 2013). Inset: Distances of major localities discussed in the text.

However, elsewhere Pachyceratidae ranges from the Middle Callovian to the Middle Oxfordian (Callomon in Donovan et. al. 1981).

The earliest occurrence of *Phlycticeras*, and in fact from the entire southern Tethys, is now being recorded here from latest Early Callovian sediments of Jumara (Kachchh; illustrated and described here as *Phlycticeras polygonium* var. *polygonium* [M]). *Phlycticeras* occurrences have been mostly noted in passing (Prasad & Kanjilal 1985; Krishna & Ojha 1996; Prasad 1998; Krishna et al. 2000), with very few illustrated records (Waagen 1873-1875; Spath 1927-1933; Jain 1997; Bardhan et al. 2010).

The present contribution, thus, attempts to:
(a) describe and illustrate two new species of the genus *Pachyerymnoceras* from Jumara and Ler sections (Kachchh, western India),
(b) provide a probable migratory route of *Pachyerymnoceras* and *Phlycticeras* to Kachchh and elsewhere,
(c) review the occurrences of the genus *Phlycticeras* in Kachchh based on new high resolution bed-by-bed am-

Fig. 2. Correlation of profiles of the Jumara, Jara and Ler Dome sections. The Jumara biozones are correlated with the original zones identified for the Kachchh Basin (Spath 1927-1933), with the bed numbers of Rajnath (1932, 1934, 1942) as well as with the biozones of the Jara and Ler sections. For the Jumara section, bed numbers are recorded as A-E from bottom to top. Distribution of specimens discussed in the text is also marked for the three domal outcrops. Shaded portion represents the extent of the Athleta Zone in the recorded sections. *Zoophycos* symbol denotes Zoophycos beds I and II.

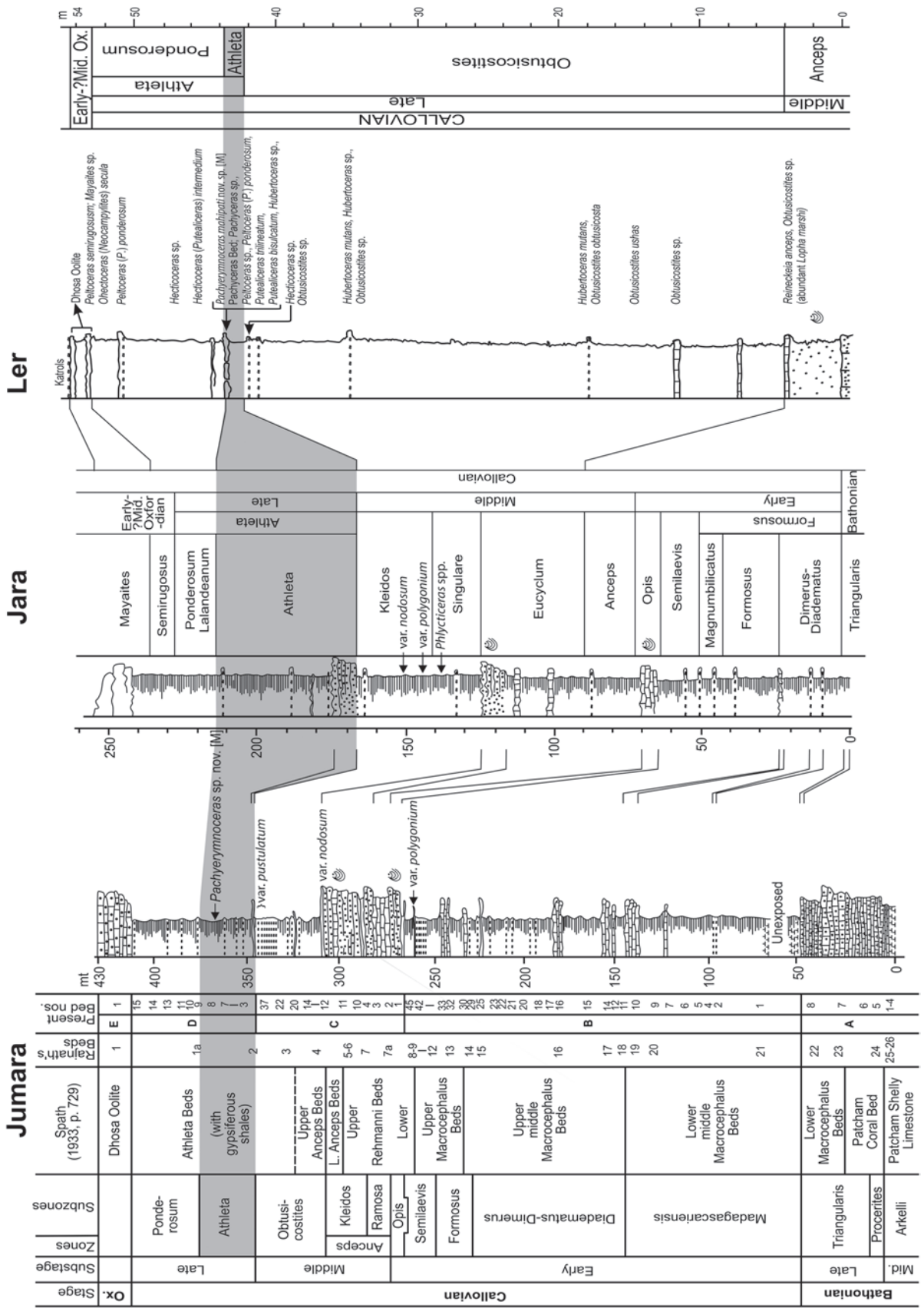
Jumara
Ler
Jara
Stage
Substage
Zones
Subzones
Spath (1933, p. 729)
Rajnath's Beds
Present Bed nos.
Ox.
Callovian
Bathonian
Late
Middle
Early
Mid.
Ponderosum
Athleta
Obtusicostites
Anceps
Dhosa Oolite
Athleta Beds (with gypsiferous shales)
Upper Anceps Beds
L. Anceps Beds
Upper Rehmanni Beds
Lower
Upper Macrocephalus Beds
Upper middle Macrocephalus Beds
Lower middle Macrocephalus Beds
Lower Macrocephalus Beds
Patcham Coral Bed
Patcham Shelly Limestone
Kleidos
Ramosa
Opis
Semilaevis
Formosus
Diadematus-Dimerus
Madagascariensis
Triangularis
Procerites
Arkelli
Pachyerymnoceras sp. nov. [M]
var. pustulatum
var. nodosum
var. polygonium
Unexposed
Katrols
Dhosa Oolite
Peltoceras seminugosum; Mayaites sp.
Olnectoceras (Neocampylites) secula
Peltoceras (P.) ponderosum
Hecticoceras sp.
Hecticoceras (Putealiceras) intermedium
Pachyerymnoceras mahiparti nov. sp. [M]
Pachyceras Bed; Pachyceras sp.
Peltoceras sp., Peltoceras (P.) ponderosum,
Putealiceras milineatum,
Putealiceras bisulcatum, Hubertoceras sp.,
Hecticoceras sp.
Obtusicostites sp.
Hubertoceras mutans, Hubertoceras sp.,
Obtusicostites sp.
Hubertoceras mutans,
Obtusicostites obtusicosta
Obtusicostites ushas
Obtusicostites sp.
Reineckeia anceps, Obtusicostites sp.
(abundant Lopha marshi)
Mayaites
Semirugosus
Ponderosum
Lalandeanum
Kleidos
var. nodosum
var. polygonium
Phlycticeras spp.
Singulare
Eucyclum
Anceps
Opis
Semilaevis
Magnumbilicatus
Formosus
Dimerus-Diadematus
Triangularis
Early-?Mid. Oxfor-dian
Early-?Mid. Ox.
CALLOVIAN
Middle
Late
Early
Formosus
Bathonian
mt
m

Fig. 2.

<table>
<tr><th colspan="2">Keera</th><th colspan="2">Jumara</th><th>Jara</th><th colspan="2">Jara</th><th colspan="3" rowspan="2">Age</th></tr>
<tr><td colspan="2">Krishna & Ojha, 1996, 2000</td><td colspan="3">This study</td><td colspan="2">Prasad, 1998</td></tr>
<tr><td rowspan="3">Athleta</td><td>Ponderosum</td><td rowspan="3">Athleta</td><td>Ponderosum</td><td>Ponderosum</td><td rowspan="3">Athleta</td><td>Lalandeaneum</td><td>L</td><td rowspan="2">Late</td><td rowspan="9">Callovian</td></tr>
<tr><td>Depressum</td><td rowspan="2">Athleta</td><td rowspan="2">Athleta</td><td rowspan="2">Athleta</td></tr>
<tr><td>Pseudorion</td><td>Athleta</td><td>E</td></tr>
<tr><td rowspan="2">Obtusicosta</td><td>Catillus</td><td colspan="2" rowspan="2">Obtusicostites</td><td>Kleidos</td><td rowspan="4">Anceps</td><td>Kleidos</td><td rowspan="2">L</td><td rowspan="4">Middle</td></tr>
<tr><td>Obtusicosta</td><td rowspan="2">Singulare</td><td>Singulare</td></tr>
<tr><td rowspan="3">Anceps</td><td>Paramorphum</td><td rowspan="3">Anceps</td><td rowspan="2">Kleidos</td><td rowspan="2">Eucyclum</td><td rowspan="2">Eucyclum</td><td>M</td></tr>
<tr><td>Kleidos</td></tr>
<tr><td>Ramosa</td><td>Ramosa</td><td>Anceps</td><td>Anceps</td><td>E</td></tr>
<tr><td rowspan="2">Semilaevis</td><td>Opis</td><td colspan="2">Opis</td><td>Opis</td><td rowspan="6">Formosus</td><td colspan="2">Semilaevis</td><td rowspan="3">L</td><td rowspan="6">Early</td></tr>
<tr><td>Semilaevis</td><td colspan="2">Semilaevis</td><td>Semilaevis</td><td colspan="2" rowspan="3">Diadematus</td></tr>
<tr><td colspan="2">Formosus</td><td colspan="2">Formosus</td><td>Magnumbilicatus</td></tr>
<tr><td rowspan="3">Chrysoo
-lithicus</td><td>Diadematus</td><td colspan="2" rowspan="3">Dimerus-
Diadematus</td><td rowspan="3">Diadematus-
Dimerus</td><td>Formosus</td><td rowspan="3">M</td></tr>
<tr><td>Chrysoolithicus</td></tr>
<tr><td>Transitorius</td></tr>
<tr><td colspan="2">Madagascariensis</td><td colspan="2">Madagascariensis</td><td>Madagascariensis</td><td colspan="2">Madagascariensis</td><td>E</td></tr>
</table>

Fig. 3. Correlation of Callovian Kachchh biozones recorded from Jara, Jumara and Keera sections.

monite collections from Jumara and Jara Domes, and (d) describe and illustrate the earliest occurrence of the genus *Phlycticeras* (*Phlycticeras polygonium* var. *polygonium* [M]) from the entire south of Tethys in latest Early Callovian sediments of Jumara.

All occurrences are further correlated within the Kachchh Basin (Fig. 3) as well as with the standard Submediterranean and European biozones (Fig. 4).

2. The sections

2.1. Jumara

The Jumara Dome, besides being a reference area of the Indo-Madagascan Province (Waagen 1873-1875; Spath 1927-1933; Jain et al. 1996) also exhibits the most expanded Callovian section within the peri-Gondwana, South of Tethys (Fig. 2a). Hence, it is not surprising that the Kachchh Callovian biozones are widely based on the fossil occurrences recorded from this section (Waagen 1875 in 1873-1875; Spath 1927-1933; Krishna & Westermann 1987; Callomon 1993; Jain & Pandey 2000; Jain 2014). However, a spatial distribution of the dominant fossil occurrences within this important domal section is still unavailable and most zones / assemblages based on them are either constructed without precise bed numbers or are based on outdated bed numbers of Rajnath (Rajnath 1932, 1934, 1942; Cariou & Krishna 1988; Krishna & Westermann 1987; Bhaumik et al. 1993; Jana et al. 2005). Precise correlation and bed-by-bed comparison of Middle Bathonian-Early Callovian beds exposed in this section have already been outlined (Jain 1995, 1998, 2002, 2014; Jain et al. 1996; Jain & Pandey 2000). Hence, this paper focuses on Middle-Late Callovian sediments (Fig. 2a). A detailed spatial occurrence of the most dominant ammonite taxa is given for this important domal outcrop (including the occurrences of present records; see Fig. 5), along with a detailed ammonite content for the studied interval from Jumara (Fig. 6; see also Jain 1995).

Fig. 4. Correlation of Callovian biozones of the Subboreal and the Submediterranean provinces with those of Kachchh (after Cariou 1980, 1984).

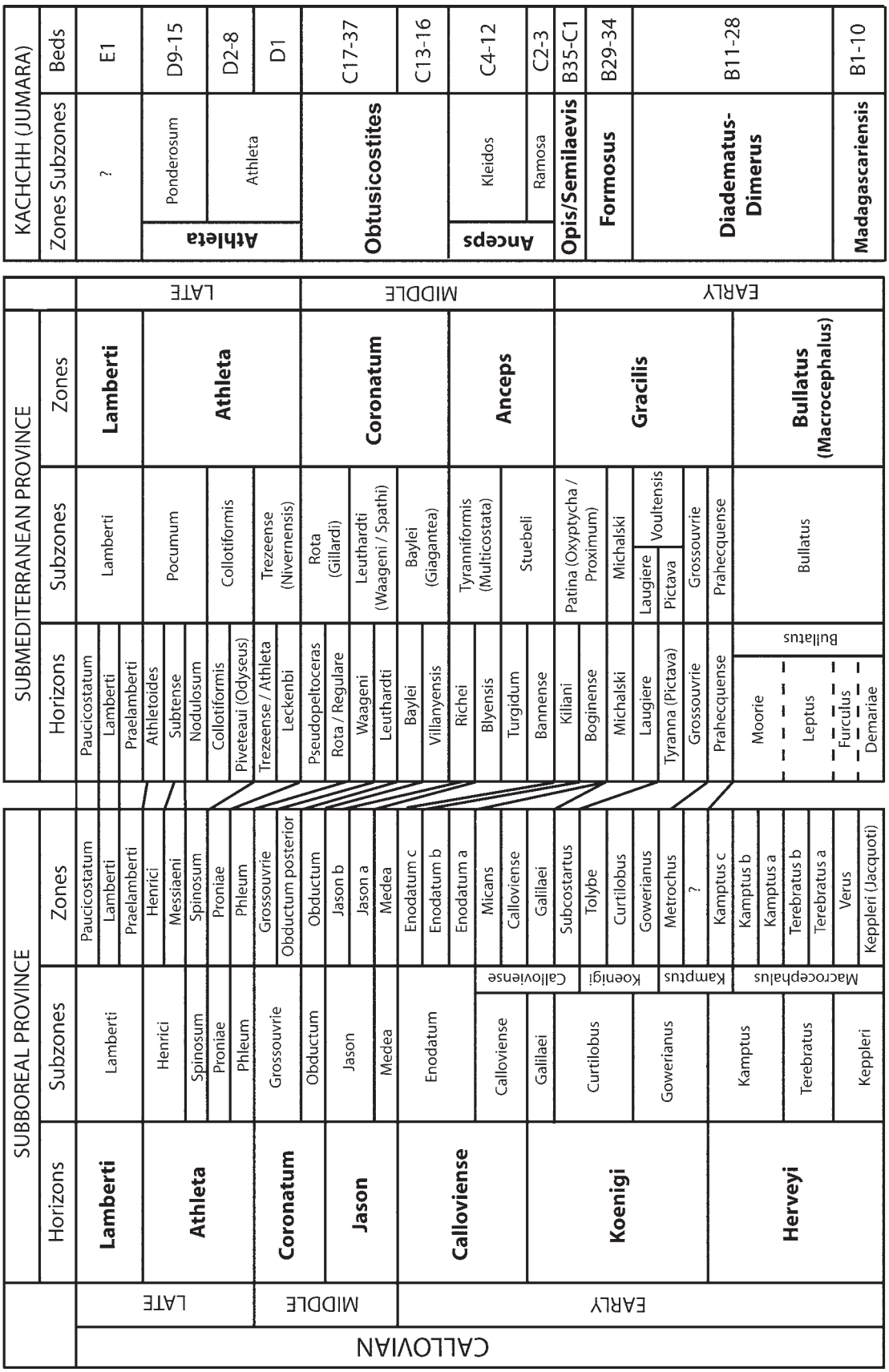
CALLOVIAN
LATE
MIDDLE
EARLY
SUBBOREAL PROVINCE
Horizons
Subzones
Zones
Lamberti
Athleta
Coronatum
Jason
Calloviense
Koenigi
Herveyi
Paucicostatum
Lamberti
Praelamberti
Henrici
Messiaeni
Spinosum
Proniae
Phleum
Grossouvrie
Obductum posterior
Obductum
Jason b
Jason a
Medea
Enodatum c
Enodatum b
Enodatum a
Micans
Calloviense
Galilaei
Subcostartus
Tolybe
Curtilobus
Gowerianus
Metrochus
?
Kamptus c
Kamptus b
Kamptus a
Terebratus b
Terebratus a
Verus
Keppleri (Jacquoti)
Lamberti
Henrici
Spinosum
Proniae
Phleum
Grossouvrie
Obductum
Jason
Medea
Enodatum
Calloviense
Galilaei
Curtilobus
Gowerianus
Kamptus
Terebratus
Keppleri
Calloviense
Koenigi
Kamptus
Macrocephalus
SUBMEDITERRANEAN PROVINCE
Horizons
Subzones
Zones
Lamberti
Athleta
Coronatum
Anceps
Gracilis
Bullatus (Macrocephalus)
Paucicostatum
Lamberti
Praelamberti
Athletoides
Subtense
Nodulosum
Collotiformis
Piveteaui (Odyseus)
Trezeense / Athleta
Leckenbi
Pseudopeltoceras
Rota / Regulare
Waageni
Leuthardti
Baylei
Villanyensis
Richei
Blyensis
Turgidum
Bannense
Kiliani
Boginense
Michalski
Laugiere
Tyranna (Pictava)
Grossouvrie
Prahecquense
Moorie
Leptus
Furculus
Demariae
Bullatus
Lamberti
Pocumum
Collotiformis
Trezeense (Nivernensis)
Rota (Gillardi)
Leuthardti (Waageni / Spathi)
Baylei (Giagantea)
Tyranniformis (Multicostata)
Stuebeli
Patina (Oxyptycha / Proximum)
Michalski
Laugiere
Voultensis
Pictava
Grossouvrie
Prahecquense
Bullatus
KACHCHH (JUMARA)
Zones Subzones
Beds
?
E1
Ponderosum
Athleta
D9-15
D2-8
D1
Obtusicostites
C17-37
C13-16
Kleidos
Ramosa
C4-12
C2-3
Opis/Semilaevis
B35-C1
Formosus
B29-34
Diadematus-Dimerus
B11-28
Madagascariensis
B1-10

Fig. 4.

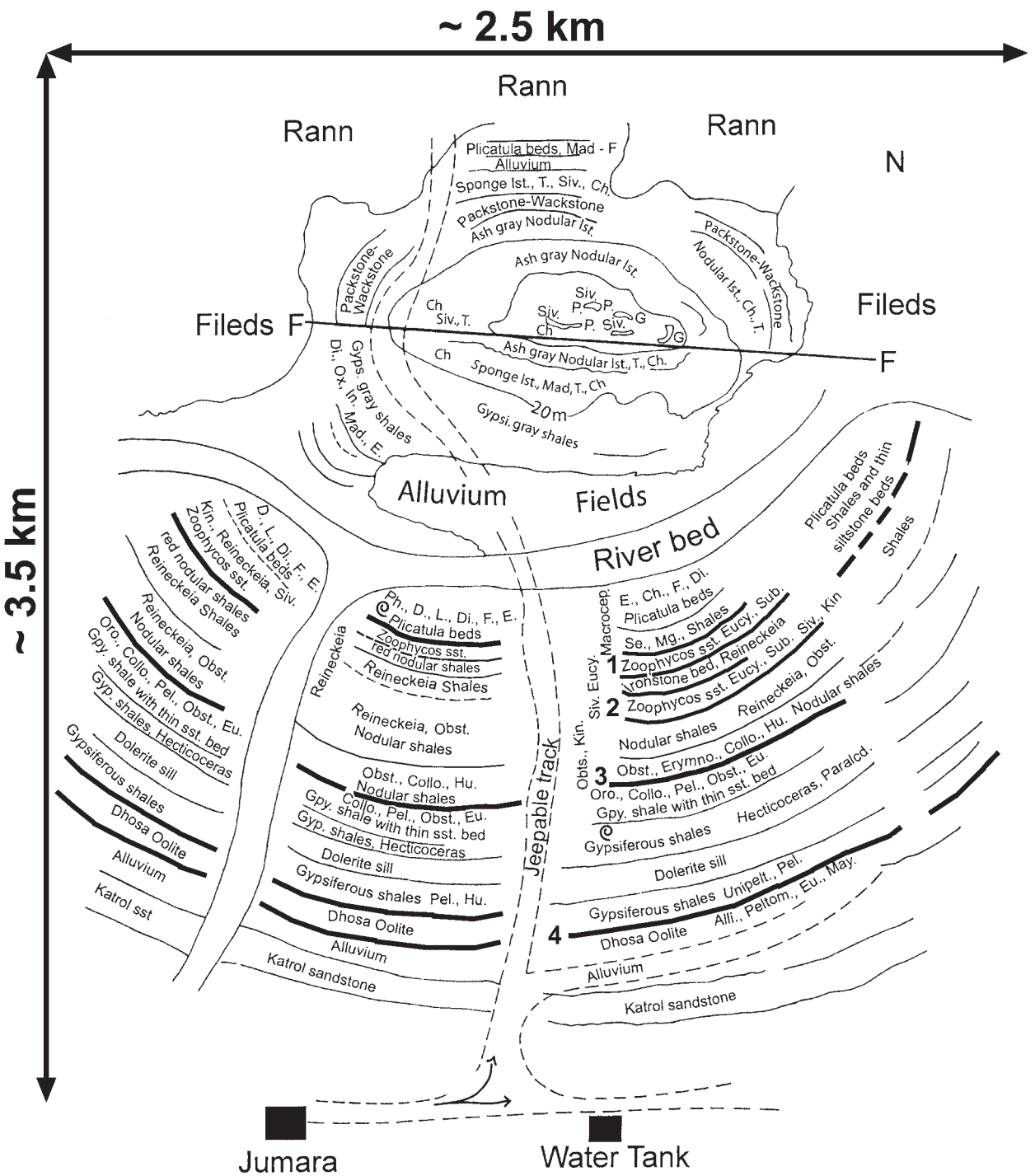

Fig. 5. Spatial overview of the Jumara Dome section. This map is not to scale, however, broad distances for the extent of the dome is given. Marker beds (as first noted by Fürsich et al. 2001) are numbered as 1: Zoophycos bed - I, 2: Zoophycos bed - II; 3: Bed D1 (Purple sandstone of Fürsich et al. 2001), and 4: Dhosa Oolite. The ammonite symbol between marker beds 3 and 4 on the right, represents the site of *Pachyerymnoceras* sp. A and that on the left, close to marker bed 1 (Plicatula beds) is from where *Phlycticeras polygonium* var. *polygonium* [M] was recorded.
Abbreviations used: G: This includes all fauna that is described in this contribution (except one from bed A2a; see Fig. 4a) and comes from the Yellow Bed (bed A4); T: *Macrocephalites triangularis;* Mad.: *M. madagascariensis*; Siv.: *Sivajiceras congener*; Ch: *Choffatia*; P: *Procerites*; Mad.-F: *M. madagascariensis* to *M. formosus* Zone fauna (for details see Jain & Pandey 2000); Di: *M. dimerus*; Ox: *Oxycerites*; E: *M. elephantinus*; Ph: *Phlycticeras*; F: *M. formosus*; D: *M. diadematus*; L: *M. inflata* and *M. habyensis*; Se.: *M. semilaevis*; Mg.: *M. magnumbilicatus*; In.: *Indosphinctes*; Kin.: *Kinkiliniceras*; Si: *Sivajiceras kleidos*; R: *Reineckeiids*; Su: *Subkossmatia*; Collo.: *Collotia*; Obst.: *Obtusicostites*; Erymno.: *Erymnoceras*; Oro.: *Orionoides*; Pe: *Peltoceras*; Hu.: *Hubertoceras*; Eu.: *Euaspidoceras*; Paraccl.: *Paralcidia*; Unipelt.: *Unipeltoceras*; Alli.: *Alligaticeras*; Peltom.: *Peltomorphites*; May.: *Mayaites*; Gyp: Gypsiferous; lst.: Limestone; sst.: Sandstone.

Age	Middle Callovian																			Late Callovian												Oxfordian
Zones	Anceps						Obtusicostites													Athleta												
Subzones	Ramosa		Kleidos																	Athleta									Ponderosum			
Beds	C2	C3	C4	C5	C11	C12	C13	C15	C16	C17	C22	C24	C29	C30	C31	C32	C34	C35	C37	D1	D2	D3	D4	D5	D6	D7	D8	D9	D11	D14	D15	E1
Species							Eucycloceras-Reineckeia-Hubertoceras			Obtusicostites-Hecticoceras-Collotia																						
Reineckeia (Reineckeia) anceps	R																															
Subkossmatia cogni - browni	R																															
Subkossmatia opis	C																															
Subkossmatia sp.	C	R																														
Rehmannia (Loczyceras) reissi	R						R																									
Reineckeia (Reineckeia) crispa	R					R	C	C																								
Reineckeia (Reineckeia) waageni	C				A		C											R														
Subgrossouvria gudjinsirensis var. *tenius*	C	R	C				C						C		C												C					
Reineckeia (Reineckeia) stuebeli		R																														
Subkossmatia cf. *ramosa*		C	C		R																											
Eucycloceras eucyclum		R					R																									
Choffatia shakuntala			C																													
Sivajiceras kleidos			C																													
Sivajiceras aff. *kleidos*			A	R	C																											
Putealiceras bisulcatum			R		C		A																									
Sivajiceras sp.				C		C																										
Collotia (Reineckeia) octagona					C		C																									
Subkossmatia ramosa					R	R																										
Reineckeia (Reineckeia) tyranniformis					C																											
Eucycloceras pilgrimi					C		C	R																								
Kinkiliniceras sp.					C						C										R											
Kinkiliniceras aff. *subwaageni*					C	C																										
Kinkiliniceras discoideum					A	A																										
Obtusicostites sp.						R		C	R	C	C		R														R					
Phlycticeras (*P.*) var. *pustulatum*						R																										
Paralcidia khengari						R																										
Reineckeia (Reineckeia) stuebeli							R																									
Rehmannia (Loczyceras) rudis							R																									
Hubertoceras mutans var. *evolutum*							C				R																					
Huberstoceras omphalodes							A	C	C		C		C					R	C	C		C			C	C	C					
Collotia gigantea							R		R																							
Reineckeia sp.								R																								
Hubertoceras sp.									R																							
Kinkiliniceras aff. *varuna*											R																					
Obtusicostites buckmani											R	R			C			R									R					
Obtusicostites ushas											C	R		R	R																	
Subgrossouvria intermedia												C			C																	
Obtusicostites ushas var. *compressa*													R		R																	
Hubertoceras hubertus var. *densicostatum*															C																	
Erymnoceras coronatum																R		R														
Obtusicostites aff. *waageni*																	R	R														
Erymnoceras jumariensis																		R														
Hecticoceras (S.) lariense var. *plana*																		C		C		C										
Collotia fraasi																		C					C	R								
Lytoceras sp.																			R	R												
Orionoides anguinus																				R												
Orionoides purpurus																				R												
Peltoceras (Peltoceras) metamorphicum																				R	C										C	
Euspidoceras (Euspidoceras) sp.																				R										R		R
Peltoceras (Peltoceras) athleta																					R						C					
Peltoceras (Peltoceras) kachchhense																					R						R	R			R	
Peltoceras (Peltoceras) sp.																							R					C			C	
Hecticoceras (Sublunuloceras) dynastese																								R								
Hecticoceras (Sublunuloceras) sp.																								C								
Hecticoceras sp.																								R								
Collotia kachchhense																								R								
Collotia sp.																								R								
Paralcidia aff. *obsoleta*																									R							
Hubertoceras mutans																											C				C	
Metapeltoceras sp.																													R			
Unipeltoceras sp.																														R		
Peltoceras (Peltoceras) ponderosum																														R		
Peltoceras (Peltoceras) solidum																															R	
Peltoceras (Peltoceras) aff. *vijaya*																															R	
Peltoceras (Peltoceras) kumagunense																															R	
Alligaticeras aff. *polymorphum*																																C
Alligaticeras sp.																																R
Peltoceratoides (Peltomorphites) cf. *propinquis*																																C
Properisphinctes sp.																																C
Dichomosphinctes sp.																																R

Fig. 6. Ammonite content for Middle-Late Callovian sediments at Jumara.

2.2. Jara

Biozonation for Jara remains general and broad despite the presence of a well-developed Callovian sequence (Waagen 1873-1875; Spath 1927-1933; Prasad & Kanjilal 1985; Prasad 1998). In a reinvestigation of this important locality, which is 12 km west of the Jumara Dome (Fig. 1, inset), 11 zones and 5 subzones are recorded (Fig. 2b). Major lithostratigraphical units, such as the Zoophycos beds I and II, the Athleta sandstone bed (= Purple sandstone of Fürsich et al. 2001), and the Dhosa Oolite have been mapped (Fig. 7) and the

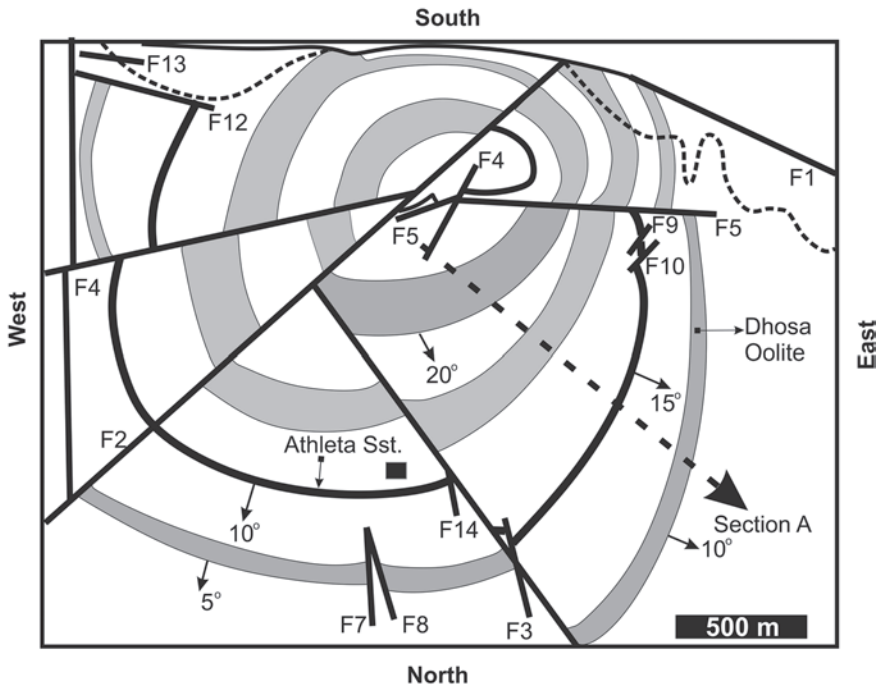

Fig. 7. Structural map of the Jara Dome showing the recorded section (dashed arrow; Section A; for Fig. 2b). Faults are numbered from F1-14 (modified after Prasad 1998).

litho-units are correlated with the adjoining Jumara and Keera sections (Fig. 8) as well as the biozones contained in them (Fig. 3). The measured section for Jara (see Section A in Fig. 7; dotted arrow) is given in Fig. 2b. A more detailed bed-by-bed description of the ammonite content and the contained lithology will be presented elsewhere.

2.3. Ler

The Ler section (Figs. 1, 2.c) records a new species of *Pachyerymnoceras*. Faunal content is provided in Fig 2c with biozones.

3. Distribution of *Phlycticeras* Hyatt in the Indian Subcontinent

Globally, *Phlycticeras* ranges from the Late Bajocian to Late Callovian (Schweigert & Dietze 1998); the early species (Bajocian-Bathonian) are largely restricted to western Tethys (see also Fernández-López 2001; Fernández-López et al. 2009) but during the ?Late Bathonian-Early Callovian, they spread to Mexico (*Phlycticeras* sp.; Sandoval et al. 1990) and Chile (Fernández-López et al. 1994, pl. 1, fig. 3, figured a specimen of this genus from the Upper Bathonian Steinmanni Biozone), occurring in the upper part of the Late Bathonian *Lilloettia* Association, Steinmanni Zone and the Early Callovian *Frickites* Association, Bondenbenderi Zone (Fig. 9). Thereafter, occurrences of the genus *Phlycticeras* Hyatt within the Indo-Madagascan Province (of *P. polygonium*, P. *pustulatum*, *P. waageni* and *P. schaumburgi*) have been noted (see Arkell et al. 1957; Waagen 1875; Spath 1928 in 1927-1933; Jain 1997; Bardhan et al. 2010). In Kachchh (western India), the genus was first recorded as *Amaltheus pustulatus* (Reinecke) (= *Phlycticeras waageni* Buckman; see Spath, 1928 in 1927-1933: 90, pl. 13, fig. 14) from Gudjinsar (near Ler; Fig. 1) along with *P. schaumburgi* (see Waagen 1873 in 1873-1875: 41, pl. 9, fig. la-c = *P. waageni* Buckman; see Schweigert & Dietze 1998: 19) from Samatra (near Nara; Fig. 1) in Late Callovian "Athleta beds" associated with the Late Callovian zonal index *Peltoceras* (*Peltoceras*) *athleta* Phillips (Spath 1928 in 1927-1933: 90).

A recent update by Bardhan et al. (2010) on the genus *Phlycticeras* from Kachchh and the stratigraphy that followed for several *Phlycticeras* occurrences by

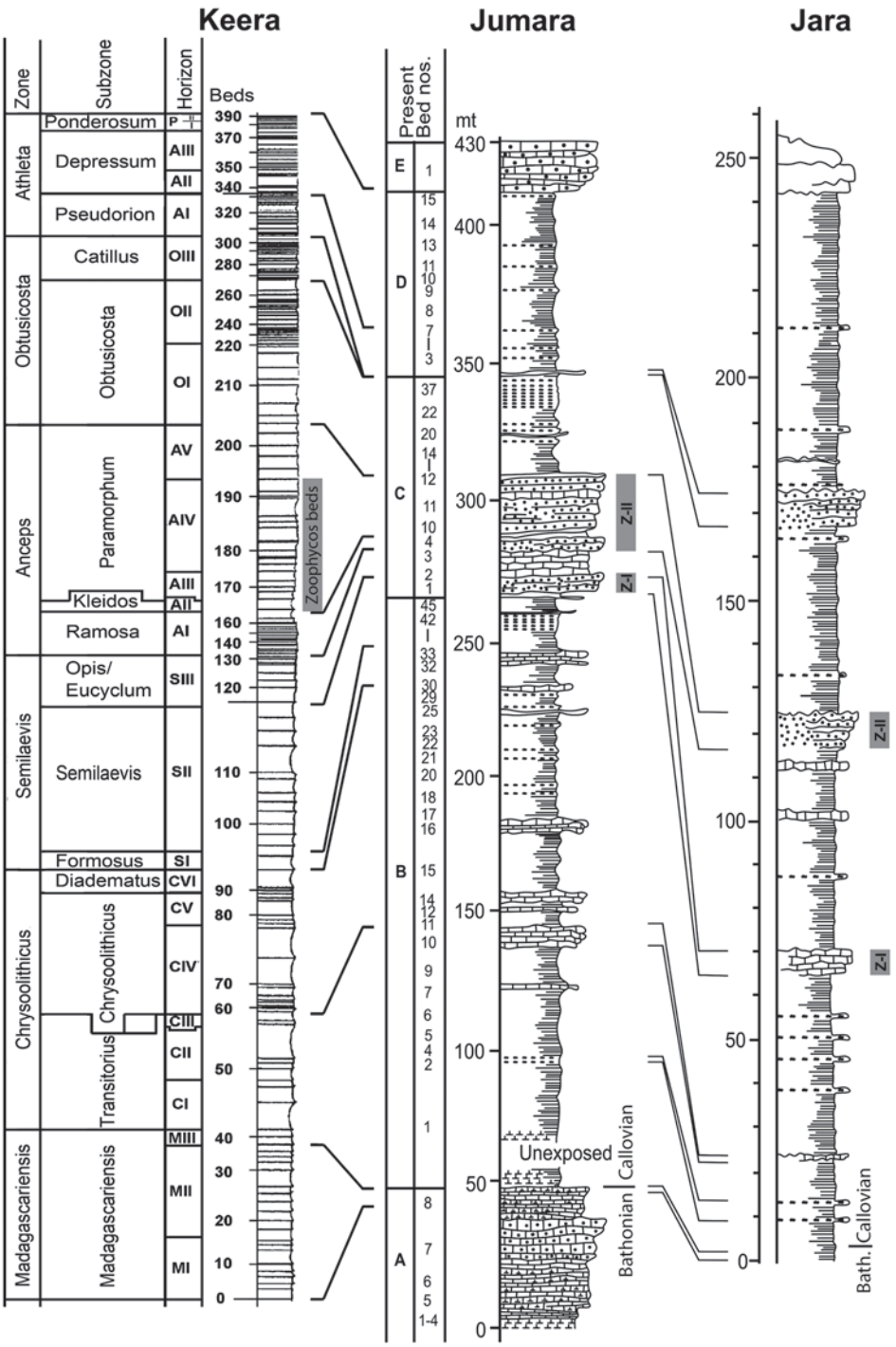

Fig. 8. Lithological correlation between Keera, Jumara and Jara sections. Major marker beds (Zoophycos beds) are indicated. The Keera section follows Krishna & Ojha (1996).

them from their three beds and three localities (Jara, Jumara and Keera) is extremely broad and generalized, lacking stratigraphic precision (Fig. 10). The alleged three beds are depicted to possess the same lithology (sandstone and shale) and are of equal thickness across vast distances, from Jara to Keera (Fig. 1b). This lithological evenness, in Kachchh, is a rarity and not noted by any other worker, for any recorded beds, so

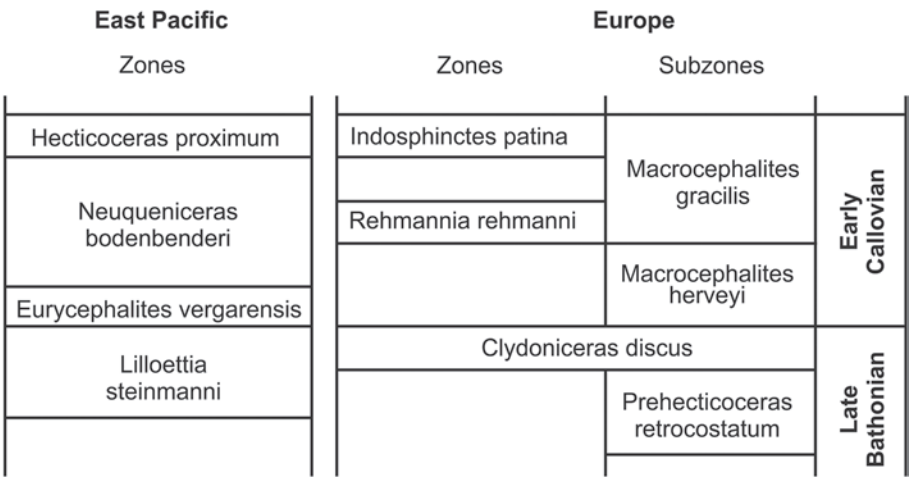

Fig. 9. Standard zonation around the Bathonian-Callovian boundary in Europe and the Eastern Pacific (from Jain et al. 1996).

far (see also Fürsich et al. 2001; Pandey et al. 2012; Jain 2014). Additionally, the thickness of the alleged Middle Callovian units at Jumara, a standard reference locality, by Bardhan et al. (2010; their beds nos. 8, 9 and 10; see Fig. 10) measures 28 m, whereas others agree with 54.6 m (Jain 1995) and 53 m (Fürsich et al. 2001; Albert et al. 2011). Additionally, Bardhan et al. sampled three lithounits transcends several biozones and subzones from Early Callovian Opis Zone to the Middle Callovian Kleidos Subzone, Anceps Zone (see Figs. 3, 10). Thus, species of *Phlycticeras* recorded by Bardhan et al. (2010) are stratigraphically clubbed, and then, inferred. Similar questions have also been pointed by Pandey et al. (2012) for their review on Kachchh *Perisphinctes* (Roy et al. 2012). Additionally, Bardhan et al. (2010) recorded *P. polygonium* from their bed no. 9 at Jara (Fig. 4n-q), however, in their cited reference (Jana et al. 2005), Jara has only 6 beds; the 6th bed is the Early-Middle Oxfordian Dhosa Oolite, a condensed bed (Fig. 2).

Hence, a detailed stratigraphy is urgently needed for these three localities (Jara, Jumara and Keera) specifying sampled locations properly. This is now done for Jara and Jumara (Fig. 2); the stratigraphy for Keera has been well established by Krishna & Ojha (1996) and is correlated with Jara and Jumara, also (Fig. 8). Additionally, owning largely due to lack of precise stratigraphy and clubbed sampling by Bardhan et al. (2010), a brief discussion on the distribution and age of various *Phlycticeras* species recorded from Kachchh is imperative and is summarized below. All whorl sections and the suture line of *Phlycticeras polygonium* var. *polygonium* [M] is given in Fig. 11. All relevant specimens are re-illustrated for ready reference (Figs. 12-14).

(a) *Phlycticeras polygonium* var. *nodosum* [M]
From the southern flank of Jumara Dome, Jain (1997) had recorded the earliest occurrence of *Phlycticeras* [*P.* gr. *pustulatum* (Reinecke) = re-described and re-illustrated here as *Phlycticeras polygonium* (Zieten) *nodosum* (Quenstedt) [M]] from bed C12 (see Figs. 2a, 12a-d), within the Kleidos Subzone, Anceps Zone of early Middle Callovian age (Jain & Pandey 2000) (Fig. 2c). The species occurs associated with *Sivajiceras kleidos*, *Subkossmatia ramosa*, *Eucycloceras pilgrimi*, *E. eucyclum*, *Reineckeia* (*R.*) *tyranniformis*, *Collotia* (*Reineckeia*) *octagona*, *R.* (*R.*) *waageni*, *Subgrossouvria gudjinsirensis* var. *tenuis*, *Paralcidia khengari*, *Kinkiliniceras discoideum* (large forms), *K.* cf. *subwaageni* and *Putealiceras bisulcatum* (Fig. 6). Bed C12 is correlated with the Tyranniformis Subzone, Anceps Zone of the Submediterranean Province and the Jason Zone of the Subboreal Realm (Jain & Pandey 2000) (Fig. 4). In Jara, var. *nodosum* has been recorded from the late Middle Callovian Kleidos Zone (Fig. 2b). The Kleidos Zone at Jara is stratigraphically higher and equivalent to the upper part of the Obtusicostites Zone at Jumara (= Coronatum Zone of the Submediterranean Province; Fig. 3). In Kachchh, faunal abundances are patchy such that one species dominates in one dome but

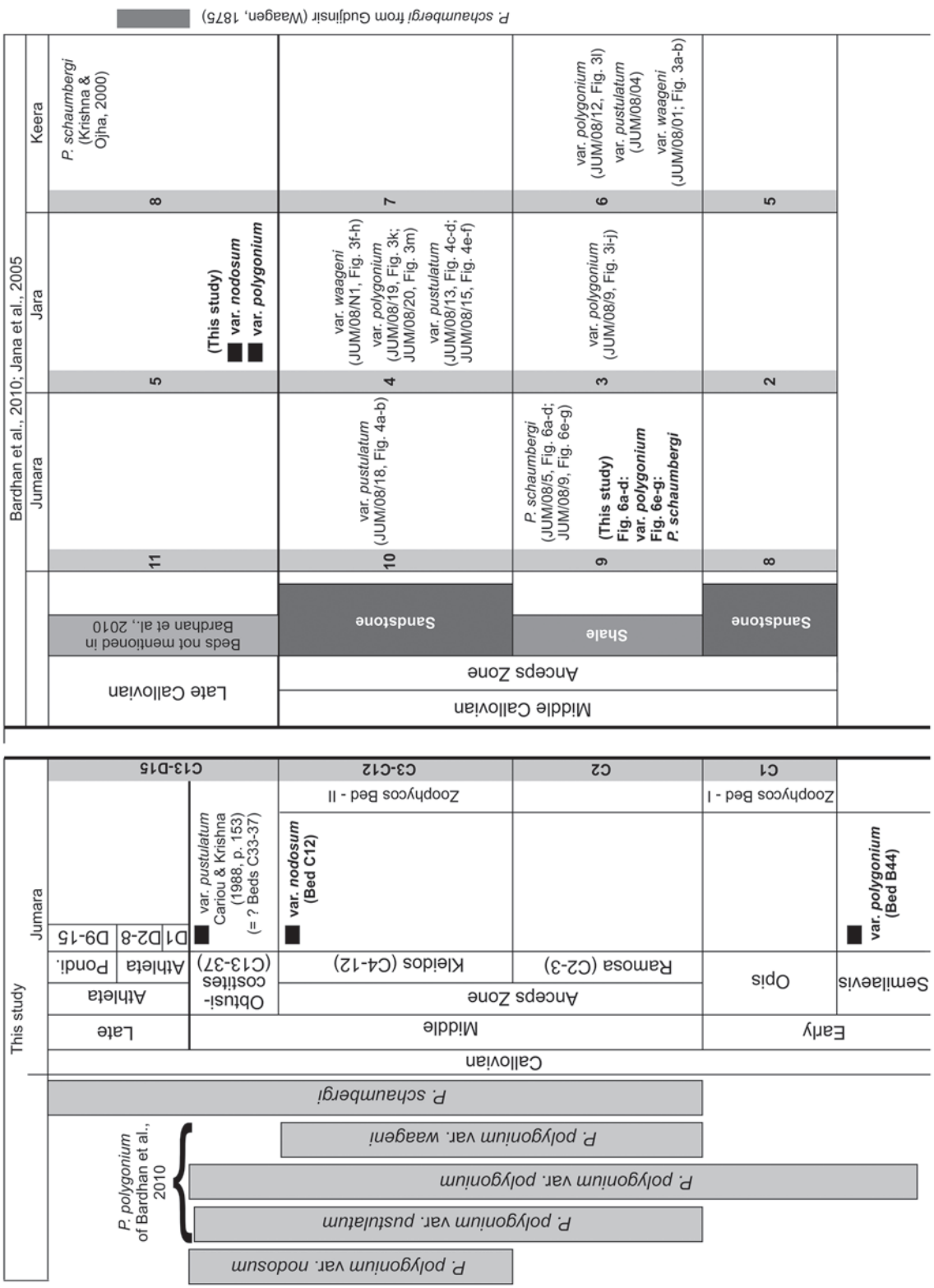

Fig. 10. Correlation and occurrences of *Phlycticeras* species as recorded by Bardhan et al. (2010) with their bed numbers (right panel). Those on the left panel (and also in bold) are from present study with current interpretation of the stratigraphic ranges of various species/varieties discussed in the text.

at coeval time interval, in a nearby dome, some other will; this patchiness is very pronounced between Jara and Jumara domes (Fig. 15), though, they are barely 12 km apart (Fig. 1 inset)!

Schweigert & Dietze (1998) noted close similarity between *P. polygonium* var. *nodosum* (Fig. 12a-d) and var. *pustulatum* (Figs. 12e-m, 16a). In Kachchh, based on revised stratigraphy, var. *pustulatum* appears stratigraphically earlier and continues a little longer (Fig. 10). However, morphologically both varieties possess a similar length phragmocone (95 mm; Jain 1997; Bardhan et al. 2010), stronger umbilicate tubercles, bifurcating ribs, and strong and dense striations, along the venter (Fig. 12). Morphometrically also, they form a somewhat uniform population (Fig. 16a). However, pending finds of more specimens of var. *nodosum*, and following Schweigert & Dietze (1998), both var. *nodosum* and var. *pustulatum* are considered separate species (Fig. 12).

(b) *Phlycticeras polygonium* var. *pustulatum* [M]
Cariou & Krishna (1988: 153) mentioned *P. pustulatum* (Reinecke) from top of Rajnath's bed no. 3 (= approx. Beds C33-C37; Fig. 2a) from Jumara, in association with "*Pseudopeltoceras*, bituberculate reineckeiids, *Subgrossouvria*, *Hubertoceras*, *Obtusicostites* and Hecticoceratins". This association represents late Middle Callovian in Kachchh (see also Jain & Pandey 2000; Krishna & Ojha 2000). Bardhan et al. (2010) recorded var. *pustulatum* (Fig. 12e-m) from a slightly younger horizon, within the Anceps Zone (see Fig. 10). They considered var. *pustulatum*, var. *polygonium* and var. *waageni* as variants of *P. polygonium* (see discussion above and Fig. 10). Thus, in Kachchh, *P. pustulatum* (Reinecke) [M] (Fig. 12e-m), has a somewhat broader stratigraphic range (Fig. 17), unlike its restricted occurrence in Europe, i.e. within late Middle Callovian sediments (Schweigert & Dietze 1998; Schweigert et al. 2003) (Fig. 17).

(c) *Phlycticeras polygonium* var. *polygonium* [M]
This study records the earliest occurrence of var. *polygonium* from late Early Callovian Semilaevis Zone from Jumara (see Figs. 2a, 10) associated with the zonal index *Macrocephalites semilaevis*, *M. magnumbilicatus*, *M. subcompressus*, *Rehmannia* (*Loczyceras*) *reissi* and *Indosphinctes urbanus*. This Zone is correlated with the interval between the Proximum Horizon and the Kiliani Horizon, Proximum Subzone of the Gracilis Zone of the Submediterranean Province (Jain & Pandey 2000; see also Fig. 4). At Jara, var. *polygonium* records by Bardhan et al. (2010) (Fig. 13) exclusively comes from the Middle Callovian Kleidos Subzone (Anceps Zone) (see also Figs. 2a, 10).

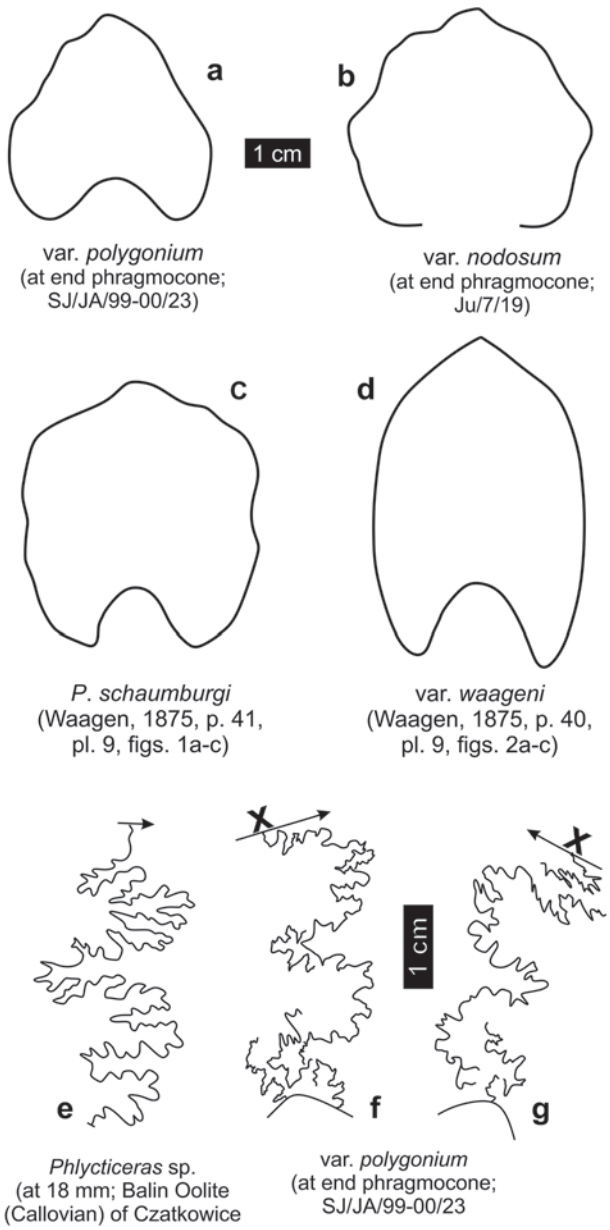

Fig. 11. Whorl section of the *Phlycticeras* specimens measured on the body chamber. **a** – var. *polygonium* [M], figured in Fig. 13j-h; **b** – var. *nodosum* [M], figured in Fig. 12a-d; **c** – *P. schaumburgi* [M], figured as Fig. 14n-p, d. *P. waageni* [M], figured in Fig. 14c-e.

Var. *polygonium* (Fig. 13) is characterized by the near absence of tuberculation (at least in its outer

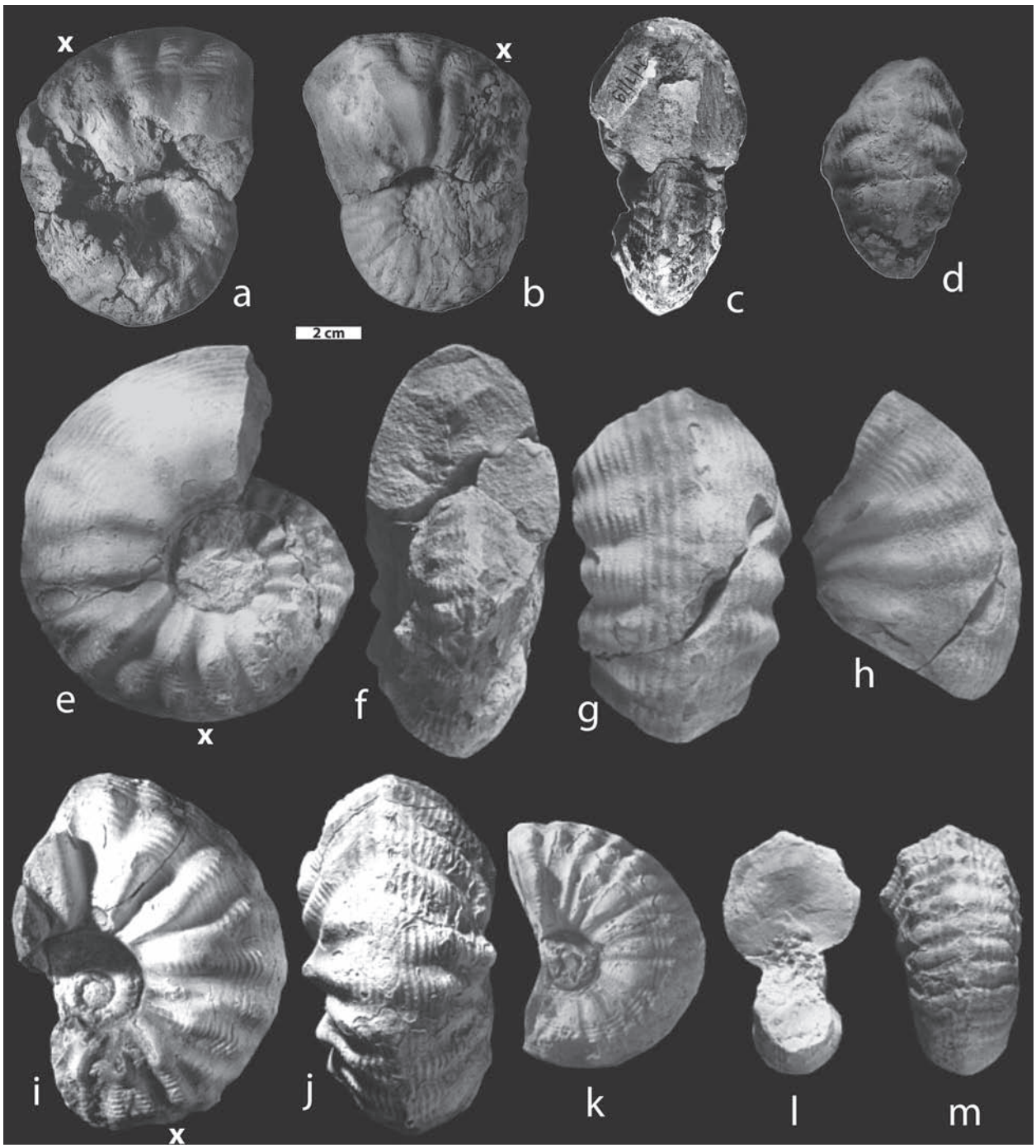

Fig. 12. *Phlycticeras polygonium* (Zieten) [M]. **a-d** – var. *nodosum* [M] (present study), specimen no. Ju/7/9, a nearly complete specimen. a. lateral view, b. opposite lateral view, c. ventral view, d. apertural view. **e-m** – var. *pustulatum* [M] (refigured from Bardhan et al. 2010). e-f: lateral and apertural views, specimen no. JUM/08/18, bed 10, Jumara; g-h: ventral and apertural views of body whorl fragment, specimen no. JUM/08/13, bed 4, Jara; i-j: lateral and ventral views of adult specimen, specimen no. JUM/08/15, bed 4, Jara. See Fig. 10 for the stratigraphic position of Bardhan et al.'s bed numbers mentioned here. Cross indicates the beginning of the body chamber.

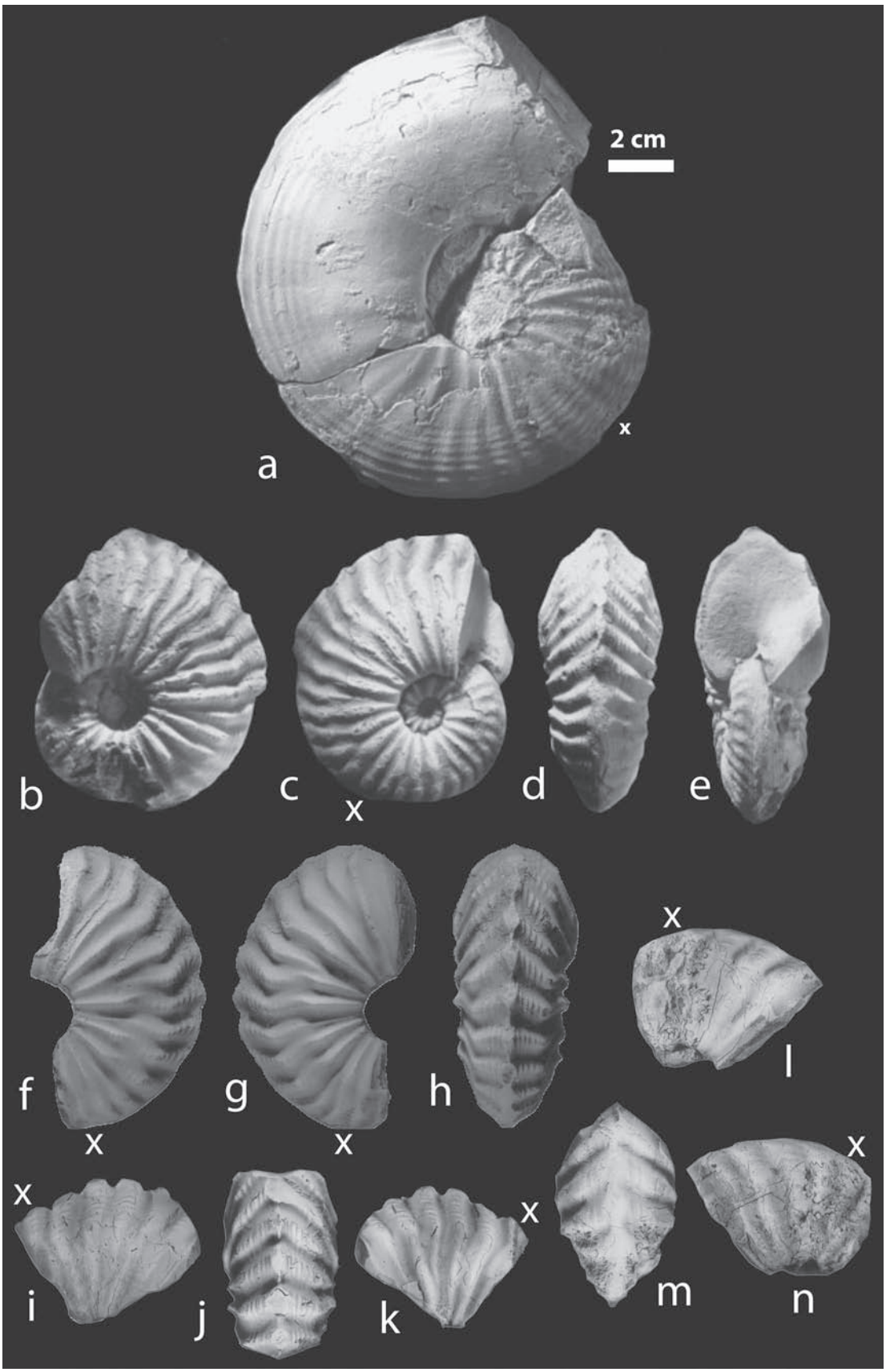

Fig. 13.

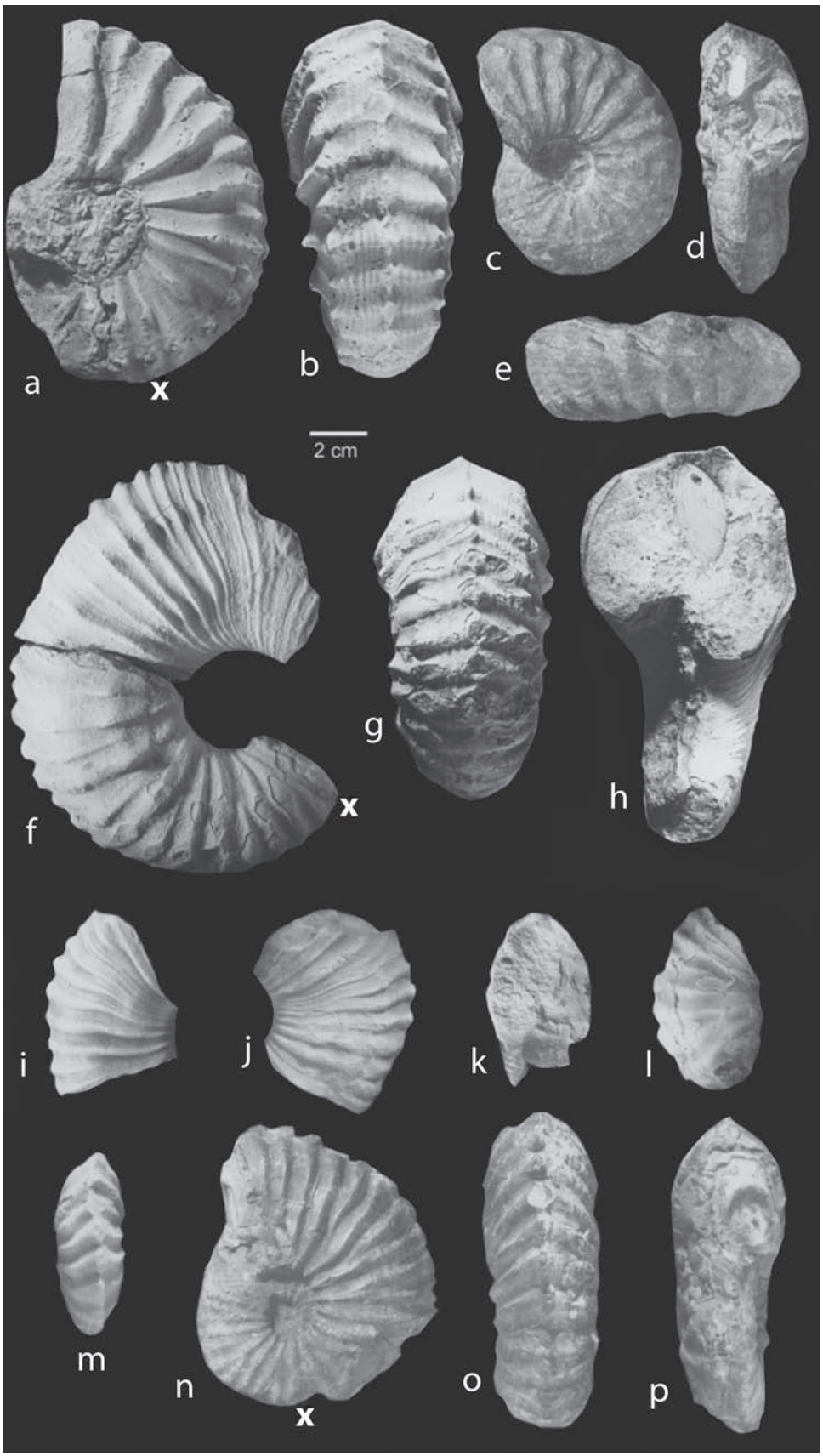

Fig. 14.

whorls), rectiradiate solitary ribs at least up until the phragmocone, thence bifurcating and showing sign to moderate to strong attenuation (Fig. 13b-c, f-g). Shell is compressed. Var. *polygonium* (Fig. 13) resembles var. *schaumburgi* (Fig. 14i-p) with which it shares the "rooster-like" raised mid-ventral keel (Fig. 13d, h, j) and stratigraphic horizon (early part of the Anceps Zone; see Fig. 10). However, there are differences also; var. *schaumburgi* is a smaller form (D = 103 mm; as compared to var. *polygonium*, D = 148). Additionally, var. *schaumburgi* has somewhat straighter ribs at the phragmocone and beyond, with less pronounced rib attenuation (compare 13b-c, f-g with Fig. 14n). Bardhan et al. (2010) recorded two specimens of var. *schaumburgi* from their bed no. 9 from Jumara (their fig. 10). However, one of the specimen, their Fig. 6a-d (refigured here as Fig. 13b-e) closely resembles var. *polygonium*, a variety also recorded from the same locality but stratigraphically much earlier in late Early Callovian sediments; the former is considered here as var. *polygonium*. Hence, as compared to that in Europe, var. *polygonium* has a much earlier occurrence (see Fig. 17).

(d) *Phlycticeras polygonium* var. *waageni* [M]
Amaltheus pustulatus (Reinecke) (Waagen 1875 in 1873-1875: 40, pl. 9, fig. 2a-c) was recorded from Late Callovian "Early Athleta beds" of Gudjinsar (Kachchh; Fig. 1) and occurs associated with the Athleta Zone index *Peltoceras* (*Peltoceras*) *athleta* Phillips. This species was revised by Spath (1928 in 1927-1933: 91) as *Phlycticeras waageni* Buckman (M) (see also Schweigert & Dietze 1998) (Fig. 14a-h). Thus, *P. waageni* Buckman, in its wider interpretation, occurs typically within the Athleta Zone (of early Late Callovian age).

Var. *waageni* (Fig. 14a-h) is moderately inflated, broadly ventered, and strongly ribbed, possessing dominantly bifurcating ribs, often with short strong intercalatories; it is bituberculate (both at mid-flank and ventrolateral margin). However, both var. *waageni* and var. *polygonium* share a common character – in that the venter is fastigate with prominent discontinuous keel connected by lateral ribs (compare Fig. 13d, h and j with Fig. 14b and g).

(e) *Phlycticeras schaumburgi* [M]
Waagen (1875 in 1873-1875: 41, pl. 9, fig. 1a-c; refigured in Fig. 14n-p) recorded this species from the "Athleta beds of Gadjinsar" [Waagen 1875 in 1873-1875: 41; = "Early athleta beds (fraasi zone)" of Spath 1928 in 1927-1933: 92, pl. 13, fig. 15] (see Fig. 1). Krishna & Ojha (1996) mentioned this species from their AII Horizon (Depressum Subzone, Athleta Zone) in Keera (Fig. 8). Earlier, Schweigert & Dietze (1998) had synonymized this species with var. *waageni* Buckman (Fig. 14a-h), which is similarly upheld here.

Thus, lack of precise stratigraphic sampling and inconsistent data (much of Bardhan et al.'s table 1 data is given as *P. polygonium* plexus and not differentiated

last doublepage

Fig. 13. *Phlycticeras polygonium* (Zieten) [M]. **a-n** – var. *polygonium* [M]. a-e: refigured from Bardhan et al. (2010). a: lateral view of specimen no. JUM/08/14, Jara (bed unspecified), a near complete form with three-fourths of the outer whorl occupied by body chamber. Note the disappearance of radial ribs with strigations that persists until the end (this specimen is considered a possible dimorph with Fig. 13f-h); b-e: specimen no. JUM/08/5, bed 9, Jumara, b-c: left and right lateral views; d-e: ventral and apertural views; f-h (this study; possible microconch to Fig. 13a; speculative; see text for explanation): specimen no. Ju/B44/1, Bed B44, 2 m below the Ist Zoophycos bed (see Fig. 2a), northwest of the village of Jumara; i-n: two fragmentary specimens with part of a body chamber from Jara Dome, Kleidos Subzone, Anceps Zone (see Fig. 2b for exact stratigraphic position), i-k: specimen. no. SJ/JA/99-00/23, l-n: specimen. no. SJ/JA/99-00/25. Note the sudden appearance of "rooster"-like raised keel at the body chamber in Figs. b-c and f-g. See Fig. 10 for the stratigraphic position of Bardhan et al.'s bed numbers mentioned here. Cross indicates the beginning of the body chamber.

Fig. 14. *Phlycticeras polygonium* (Zieten) [M] (all refigured from Bardhan et al., 2010). **a-h** – var. *waageni* [M]. a-b: specimen no. JUM/08/1, bed 6 of Keera, a: lateral and b: ventral views; c-e: Holotype, GSI (Geological Survey of India) Type no. 1915, from Athleta beds, north-east of Gudjinsir (Waagen 1875 in 1873-1875; see Fig. 1 for locality); c: lateral, d: apertural and e: ventral views of a fully septate specimen; f-h: specimen no. JUM/08/N1, bed 4, Jara, a specimen with near complete body chamber, f: indicating mature modification, g: ventral and h: apertural views of the early part of the body chamber. **i-p** – *Phlycticeras schaumburgi*. i-k: specimen no. JUM/08/9, bed 9, Jumara, body whorl fragment, i: left lateral, j: right lateral and k: apertural views; l-m: specimen no. JUM/08/E6, bed 11, Jumara, body whorl fragment, l: lateral and m: ventral views; n-p, Holotype, GSI type no. 1914, Athleta beds, Gudjinsir (Waagen 1875 in 1873-1875), n: lateral, o: ventral and p: apertural views. See Fig. 10 for the stratigraphic position of Bardhan et al.'s bed numbers mentioned here. Cross indicates the beginning of the body chamber.

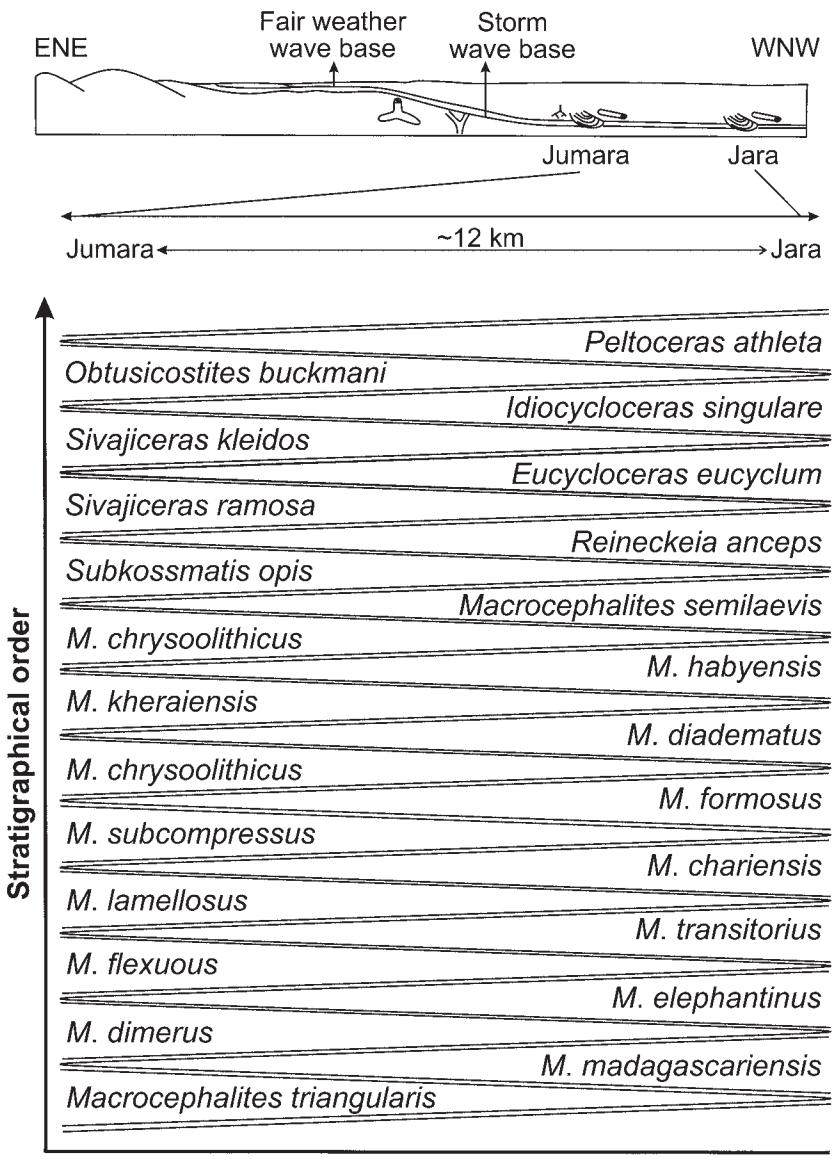

Fig. 15. Relative abundances of ammonite species. Note that in Kachchh faunal abundances are patchy such that one species dominates in one dome but at coeval time interval, in a nearby dome, some other will; this patchiness is very pronounced between the Jara and Jumara domes, though they are barely 12 km apart (see Fig. 1 inset).

into varieties, as discussed in the text) makes inferences only conjectural. However, although scarce, the available morphometric (Fig. 16c) and morphological data (Figs. 12-14) enables few broad inferences:

1. There is merit in Bardhan et al.'s suggestion that all varieties co-occur, at least in the Kleidos Subzone (the later part of the Anceps Zone) (Figs. 4, 10).

2. Sample evidence is still patchy (few and far in-between) to conclusively prove that var. *polygonium*, var. *pustulatum* and var. *waageni* can be safely clubbed under the broader *P. polygonium*. Thus, pending more finds with precise stratigraphic sampling, all are retained here as distinct species.

3. Bardhan et al.'s suggestion that a dimorphic relationship exists between *P. polygonium* [M] and *P. schaumburgi* [m] is contentious, although, both forms do share common stratigraphic space within the Ramosa Subzone, Anceps Zone (Fig. 10). Alternatively, there seems to be dimorphic pairing within var. *polygonium* itself! In fact, Bardhan et al.'s var. *polygonium* speci-

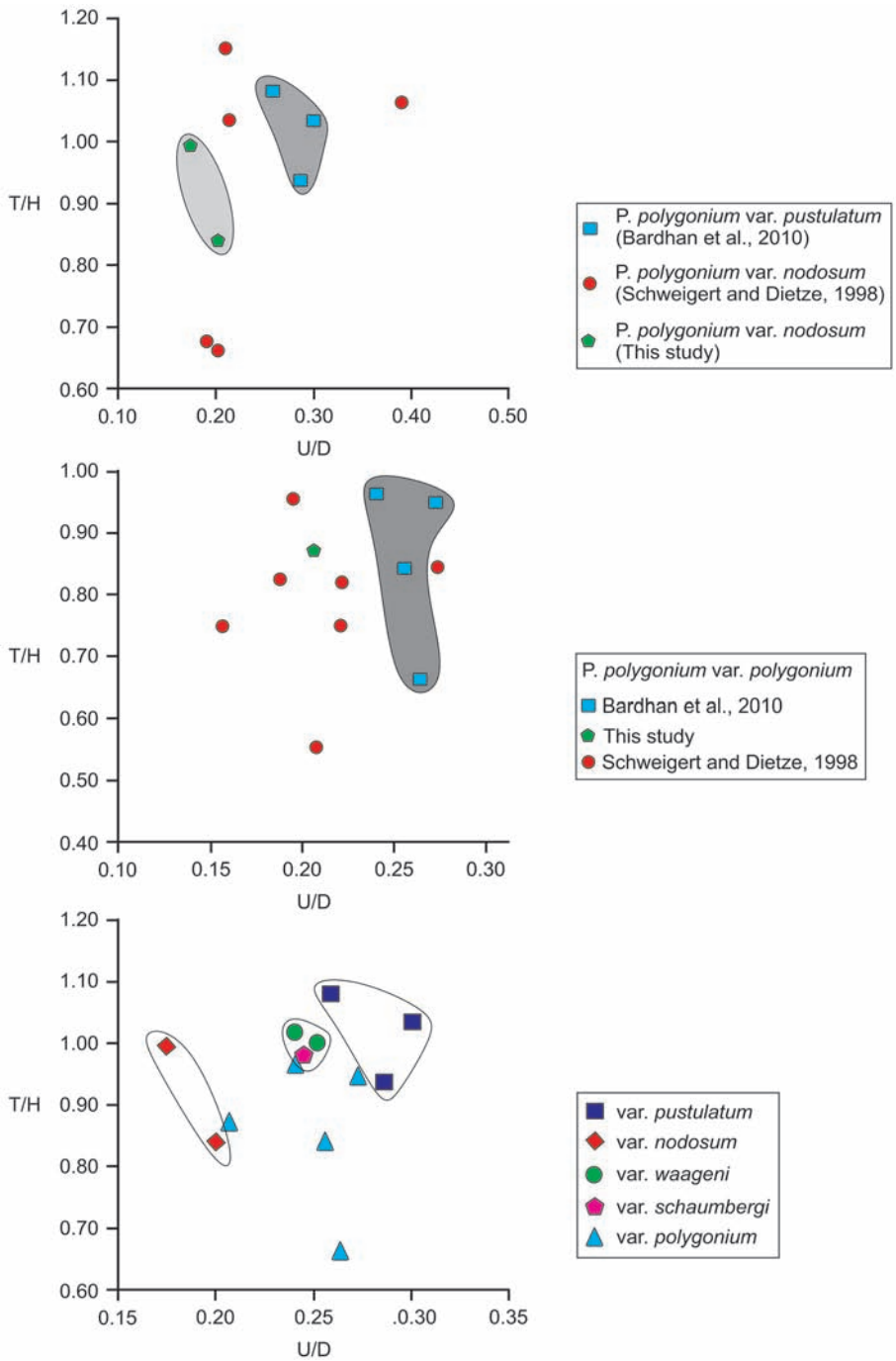

Fig. 16. Whorl thickness (T/H) versus Coiling ratio (U/D) of *Phlycticeras*. **a** – var. *pustulatum* versus var. *nodosum*. **b** – *Phlycticeras polygonium* var. *polygonium*. **c** – Spread of all varieties of *Phlycticeras* from Kachchh. Fig. 16a, b: specimens of Bardhan et al. (2010) fall in a very distinct and somewhat different pattern, contrary to those from the present study. Except var. *nodosum*, Bardhan et al. (2010) considered all the rest as part of one *Phlycticeras polygonium* plexus. However, meagre the data is, the plot suggests distinctness for all *Phlycticeras* varieties/species.

men (no. JUM/08/14; refigured here as Fig. 13a) from Jara from an unspecified stratigraphic horizon seems to be a good dimorphic pair with the newly recorded latest Early Callovian Jumara specimen of var. *polygonium* (Fig. 13f-h) (for more discussion see under the Systematic Paleontology section), and

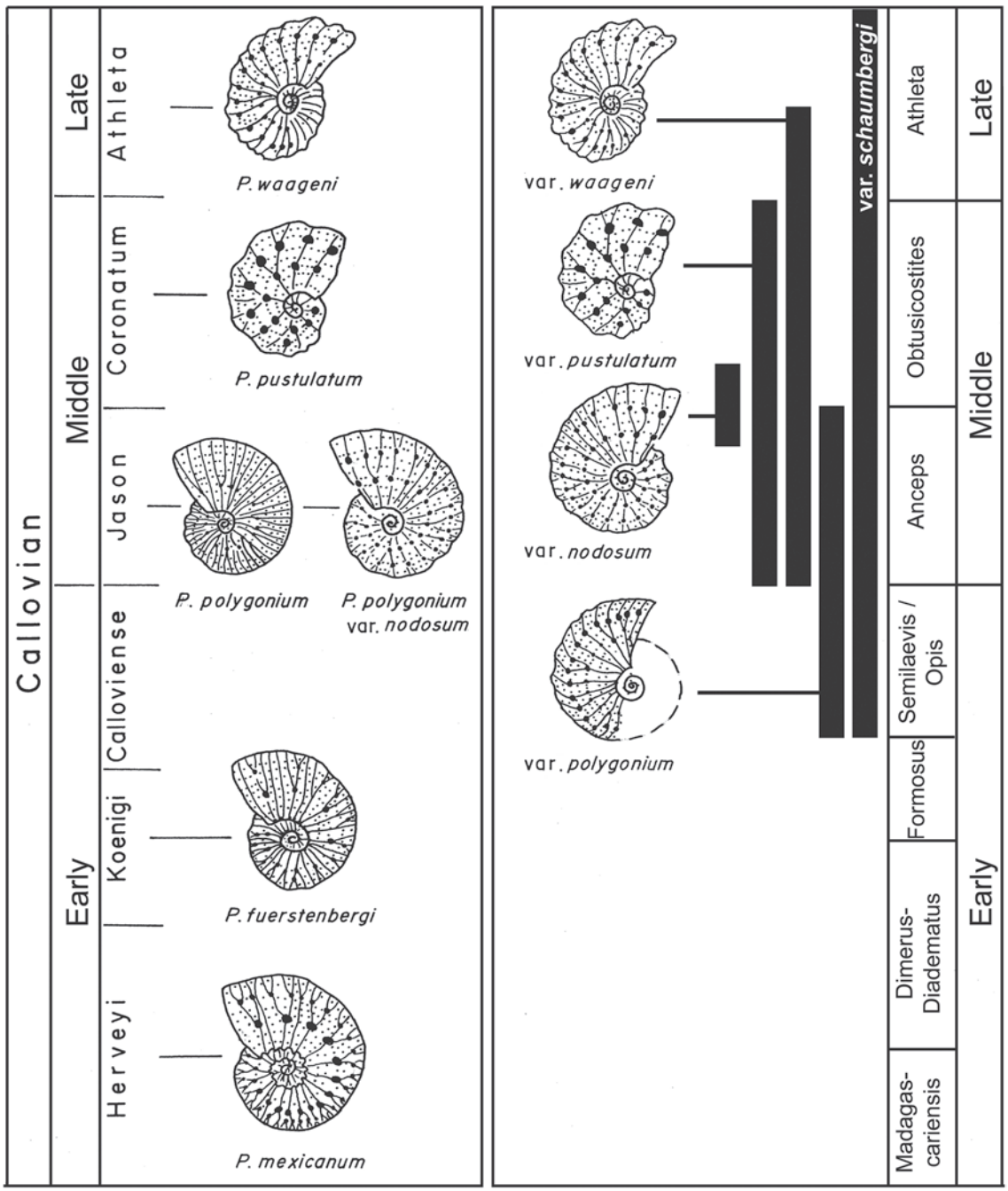

Fig. 17. Summary of the stratigraphic distribution of all *Phlycticeras* varieties/species discussed in the text.

4. *Phlycticeras* has a much longer range in Kachchh (both as a genus and for respective varieties/species), spanning from the late Early Callovian Semilaevis Zone to the Late Callovian Athleta Zone (see Figs. 10, 17).

4. Probable migratory routes

Globally, the earliest record of the genus *Pachyerymnoceras* is from the Middle Callovian Coronatum Zone (Enay et al. 1987; Mangold 1988) (Figs. 18, 19). In

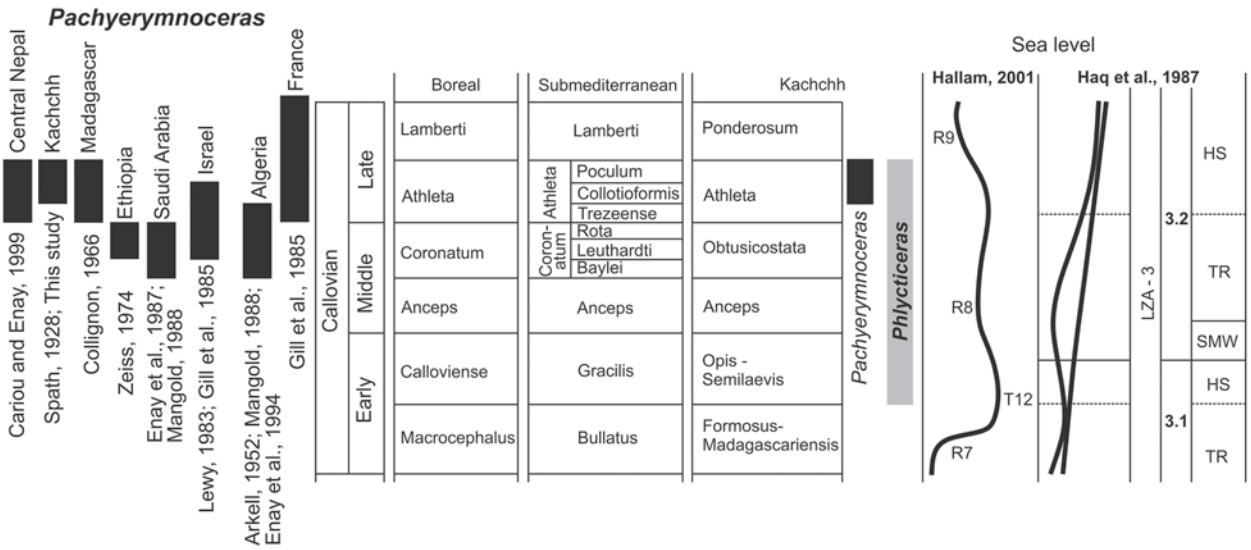

Fig. 18. Stratigraphic distribution of *Pachyerymnoceras* and sea level during the studied interval.

Kachchh, the earliest occurrence is from the Collotiformis Subzone, Athleta Zone of Late Callovian age (Fig. 18). The other occurrence within the Indian subcontinent is from Central Nepal of *Pachyerymnoceras leave* also from the Athleta Zone and associated with *Collotia fraasi* (Cariou & Enay 1999: 705). Thus, it appears, the genus *Pachyerymnoceras* first appeared in the Ethiopian Province (Saudi Arabia or Western Algeria) and migrated to Kachchh and elsewhere (Fig. 19) in early to mid-Late Callovian times (between Trezeense-Collotiformis subzones, Athleta Zone), aided by a global Highstand (Fig. 18), also recorded within the Kachchh Basin (Fürsich et al. 2001).

The entry of the genus *Phlycticeras* in Kachchh, was also probably facilitated by an earlier and similar transgressive phase (T12; Fig. 18), taking the same route along the continental margin, from Europe, through the Ethiopian Province and into Kachchh in late Early Callovian times and on the other hand (and somewhat a bit earlier) to Mexico and Chile (through the Hispanic Corridor) in Late Bathonian-earliest Callovian times (see Figs. 18-19).

5. Systematic paleontology

Repository: The present study specimens (Ler/1999/1; Ju/2/2, Ju/B44/1, SJ/Ja/99-00/23 and 25 and Ju/7/19) are lodged at the Invertebrate Palaeontology Laboratory, Department of Geology, University of Rajasthan, Jaipur (India) and form part of the author's dissertation (Jain 1995).

Superfamily Haploceratoidea Zittel, 1884
Family Strigoceratidae Buckman, 1924
Subfamily Phlycticeratinae Spath, 1925

Genus Phlycticeras Hyatt, 1900 [M]
Syn.: *Lophoceras* Parona & Bonarelli, 1895, *Melendezia* Fernández-López, 1985

Type species: *Nautilus pustulatus* Reinecke, 1818, p. 84, pl. 7, figs. 63-64.

Phlycticeras polygonium var. *nodosum* [M]
Figs. 11b, 12a-d

1847 *Ammonites pustulatus* Haan. – D'Orbigny, pl. 154, figs. 1-2 (non fig. 3).
1995 *Phlycticeras waageni* (Buckman). – Jain, p. 98, fig. 1a-b.
1997 *Phlycticeras* gr. *pustulatum* (Reinecke). – Jain, p. 75, fig. 2 (refigured in Fig. 12a-d).
1998 *Phlycticeras polygonium* (Zieten) var. *nodosum* Quenstedt. – Schweigert & Dietze, p. 16, pl. 7, fig. 5; pl. 8, figs. 1-4, 6-8.

For a detailed synonymy see Schweigert & Dietze (1998: 16).

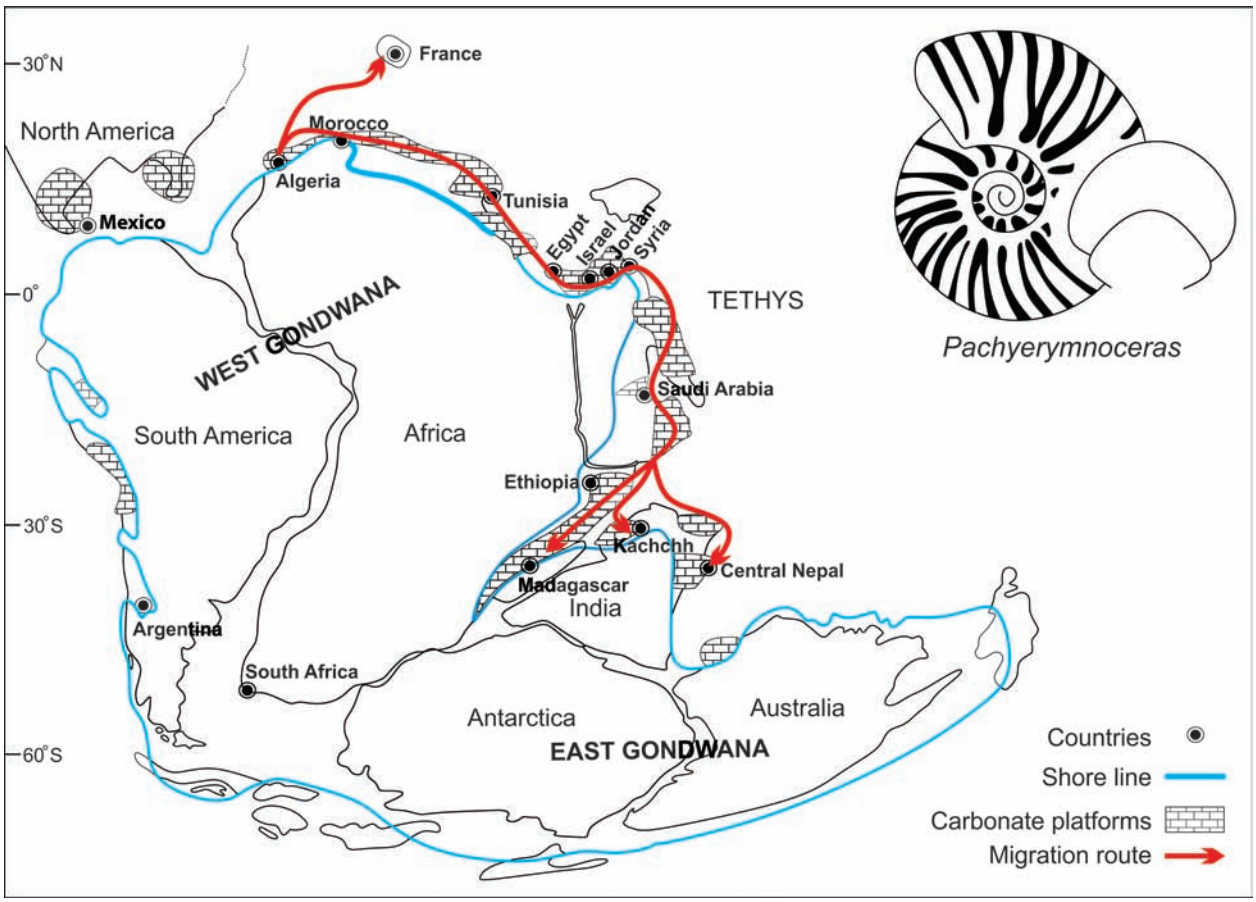

Fig. 19. Probable migratory route for *Pachyerymnoceras* and *Phlycticeras*. *Pachyerymnoceras* first appeared in the Ethiopian Province (Western Algeria or Saudi Arabia) and migrated to Kachchh and elsewhere in early to mid-Late Callovian times (between Trezeense and Collotiformis subzones, Athleta Zone), aided by a global highstand (see Fig. 18) also recorded within the Kachchh Basin. The entry of *Phlycticeras* in Kachchh was probably also facilitated by an earlier and similar transgressive phase (T12; see Fig. 18), taking the same route along the continental margin, from Europe, through the Ethiopian Province and into Kachchh in late Early Callovian times and, on the other hand (and somewhat little earlier), to Mexico and Chile (through the Hispanic Corridor) in Late Bathonian-earliest Callovian times (map modified from Andreu et al. 2012).

Material: One specimen, nearly complete (Ju/7/19).

Horizon and locality: (a) Jumara Dome: One fragmentary specimens from Bed C12 (top bed 5 of Rajnath), Kleidos Subzone, Anceps Zone of Jain & Pandey (2000; Fig. 2a).

Description (phragmocone): Phragmocone measures 95 mm with a maximum estimated shell diameter of 145-150 mm. Shell is large, moderately evolute and opening up. At 60 mm, the flanks are arched and strongly convex at the end of the phragmocone. Venter is narrow and distinctly keeled. Striations are absent in umbilical region and thereafter are strong and restricted to the outer third of flank height. Umbilicus is deep, occupying 1/5 of whorl height. Shell becomes more evolute from the end of the phragmocone with body chamber occupying ¾ of the outer whorl, judging by the remains of the umbilical seam. Umbilical wall is high and vertical with a rounded umbilical edge. Primaries which arise from below the umbilical edge, are initially low, but increase in height, forming a prominent lateral tubercle at the lower third of flank height. Thereafter, the primaries branch into two or three blunt secondaries, which at the ventrolateral edge also possess tubercles. The lateral tubercles are more prominent and stronger than the ventrolateral ones. At the ventrolateral margin, the striations are much stronger. The tubercles increase in size from being sharp at 30-40 mm, high and rounded at 50-60 mm to mammilliform at 90 mm. Single primaries with two rows of tubercles are also present as intercalated ribs. Whorl section at the body chamber is sub-hexagonal (Fig. 11b). Suture line poorly preserved.

Remarks: The dimensional proportions of the present specimen are in the range of *P. polygonium* (Zieten) var. *nodosum* (Quenstedt) [M] (Fig. 16a), according to data from European

specimens (Schweigert & Dietze 1998: 17). The U/D ratio against shell diameter represents an upward trend indicating opening of the shell at around 80 mm (see also Fig. 12a).

The present specimen closely resembles European *P. polygonium* var. *pustulatum* (Fig. 12e-m) in possessing the characteristic crenulated keel, striations and the lateral and ventrolateral tubercles of unequal height. In spite of morphological closeness, the present specimen, at comparable diameters, is less evolute and possesses a higher T/D ratio (49 as compared to 31 at 65 mm in *P. pustulatum*). Primaries number 14 per whorl with two tubercles to a primary as compared to 17-18 primaries in var. *pustulatum*.

P. polygonium var. *waageni* (Fig. 14a-h) and *P. schaumburgi* (Fig. 14i-p) are large forms with dense ribs that are often single.

P. mexicanum (Sandoval et al. 1990: 121, pl. 4, figs. 2, 3a-b, 4a-b, text-fig. 9d; refigured in Schweigert & Dietze 1998: 12, pl. 3, figs. 5-6; pl. 4, figs. 1-4) is a densely ribbed and compressed form with characteristic row of umbilical nodes, absent in Kachchh forms.

Thus, *P.* gr. *pustulatum* (Reinecke) (Jain 1997: 75, fig. 2) is here considered a variant of *P. polygonium* var. *nodosum* [M] (refigured in Fig. 12a-d).

Assemblage and age: *P. polygonium* var. *nodosum* [M] from bed C12 (see Fig. 2a) is associated with *Sivajiceras kleidos*, *Subkossmatia ramosa*, *Eucycloceras pilgrimi*, *E. eucyclum*, *Reineckeia* (*R.*) *tyranniformis*, *Reineckeia* (*R.*) *revili*, *Collotia* (*Reineckeia*) *octagona*, *R.* (*R.*) *waageni*, *S. gudjinsirensis* var. *tenius*, *Paralcidia khengari*, *Kinkiliniceras discoideum* (large forms), *K.* cf. *subwaageni* and *Putealiceras bisulcatum* (see also Fig. 6). This bed is correlated with the Tyranniformis Subzone, upper part of the Anceps Zone of the Submediterranean Province and the Jason Zone of the Subboreal Realm (Jain & Pandey 2000; see Fig. 4). *Collotia gigantea* and *Rehmannia* (*Loczyceras*) *rudis* have been recorded from the superjacent bed C13 (Fig. 2). The association of *C. gigantea* with *R.* (*L.*) *rudis* is typical of the base of the Coronatum Zone in Europe (Cariou 1980, 1984; Cariou & Krishna 1988).

Phlycticeras polygonium var. *polygonium* [M]
Figs. 11a, 13f-h, 13i-n

1833 *Ammonites polygonius nobis* Zieten in Zieten 1830-1834, p. 21, pl. 15, fig. 6.
1875 *Amaltheus schaumburgi* Waagen in 1873-1875, p. 41, pl. 9, fig. 1
1998 *Phlycticeras polygonium* (Zieten). – Schweigert & Dietze, p. 15, pl. 5, figs. 1-3; pl. 6, figs. 2-4; pl. 7, figs. 1-4.
2010 *Phlycticeras polygonium* var. *polygonium*. – Bardhan et al., p. 271, figs. 3i-m, 4j-q, 6a-d.
2010 *Phlycticeras schaumburgi*. – Bardhan et al., p. 276, fig. 6a-d.

For a detailed synonymy see Schweigert & Dietze (1998: 15).

Material: 3 specimens; a) Jumara Dome: specimen no. Ju/B44/1 (with part of body chamber), North West of the village of Jumara, Kachchh (Fig. 13f-h), b) Jara Dome: specimen. no. SJ/JA/99-00/23 and 25 (part of a body chamber), two fragmentary specimens (Fig. 13i-n).

Horizon: (a) Jumara Dome: Bed B44; 2 m below the Ist *Zoophycos* sandstone body (see Fig. 2a), Semilaevis Zone, latest Early Callovian, (b) Jara Dome: two fragmentary specimens from gypsiferous shales with marls and ironstone, 28 m below the Athleta sandstone and assigned to late Middle Callovian age (= Kleidos Subzone, Anceps Zone; see Fig. 2b).

Description (body chamber): Shell is moderately evolute, compressed, septate till 80 mm with a maximum estimated diameter of 120 mm. Flanks are strongly arched with maximum inflation at the inner third of flank height. Umbilicus is deep, measuring 1/5 of shell diameter with vertical umbilical walls and a rounded umbilical edge. Shell is strongly ribbed with 10 primaries per half whorl. Primaries are radial in nature, arising at the umbilical seam, from below the umbilical shoulder. Primaries continue as a single rib or irregularly branch into 2 prorsiradiate secondaries. Lateral tubercles are strong, placed at the lower third of flank height. At the ventrolateral edge, another row of moderately prominent tubercles exists, from where the secondaries become strongly prorsiradiate, terminating at the acutely keeled venter as sharp nodes, making the keel strongly serrated. The ventrolateral tubercles are stronger than the lateral tubercles at the lower third of the flank height. Entire shell is moderately striated until the second row of tubercles. Whorl section is sub-pentagonal (Fig. 11a).

The suture line is given in Fig. 11f-g and compares well with a specimen of *Phlycticeras* sp. (Fig. 11e) from the Callovian Balin Oolite of Czatkowice, Cracow, Poland (Myczynski 1970). This Polish form is similar to Quenstedt's pl. 86, fig. 17), which was considered as a junior synonymy of var. *polygonium* by Schweigert & Dietze (1998: 15).

Remarks: The present specimen closely resembles the small macroconchiate holotype of *Phlycticeras polygonium* Zieten (Zieten 1833 in 1830-1834: 21, pl. 15, fig. 6; Schweigert & Dietze 1998: 15, pl. 5, fig. 3a-c = *P. polygonium* var. *polygonium*), common in the European Middle Callovian Jason Zone (= Blyensis to Villanyensis horizons; pars. Anceps to Coronatum Zones) (see Figs. 4, 17). The present specimen in dimensional proportions falls well within the range of other specimens of var. *polygonium* (Figs. 13, 16b).
The characteristically distinctly keeled venter of the present specimens also closely matches with the illustrated macroconch specimens of *P. polygonium* (Schweigert & Dietze 1998). However, the sudden prorsiradiate nature of the ribs at the ventrolateral margin (= attenuation; Fig. 13f-g, i, k) is more pronounced in Kachchh specimens as compared to any of the forms described and illustrated elsewhere (Schweigert & Dietze 1998: 15, pl. 5, figs. 1-3; pl. 6, figs. 2-4; pl. 7, figs. 1-4).

Bardhan et al. (2010) had suggested that a dimorphic relationship exists between *P. polygonium* [M] (Fig. 13) and *P. schaumburgi* [m] (Fig. 14i–p). Based on recent stratigraphic revision, both forms do share common stratigraphic

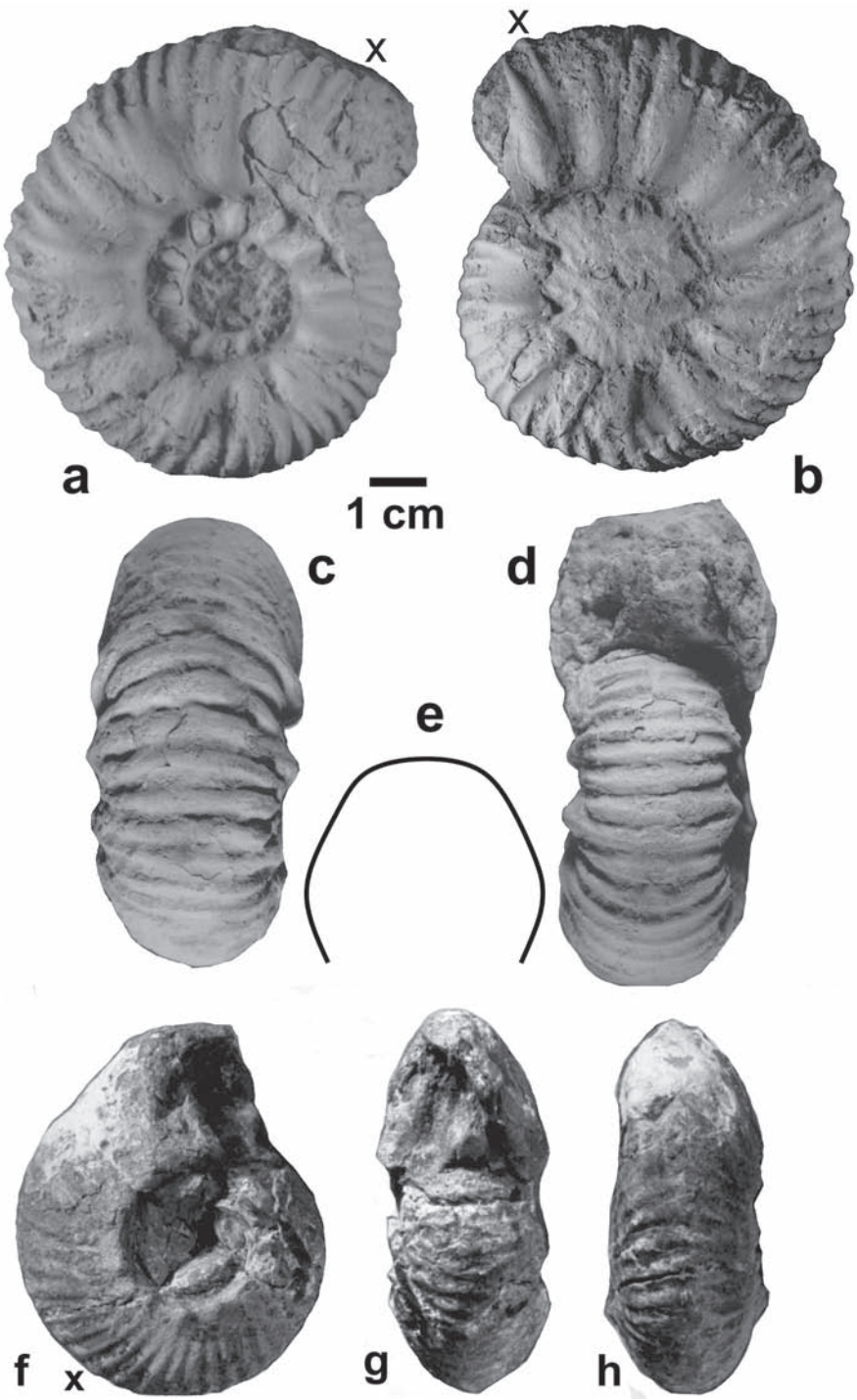

Fig. 20. *Pachyerymnoceras mahipati* nov. sp. [M], Ler, Kachchh, western India, Sp. no. Ju/Ler/I, 1999, a: lateral, b: ventral, c: opposite lateral, and d: apertural views; f-h: *Erymnoceras dorothae* SPATH (type specimen from the "Lower Athleta Bed" in Fakirwadi (see Fig. 1), about 10 km south of Bhuj), f: lateral, g: apertural and h: ventral views. *E. dorothae* SPATH appears to be a young *Pachyerymnoceras* (pers. comm. JACQUES THIERRY, 1999). Cross indicates beginning of the body chamber.

space also within the Ramosa Subzone, Anceps Zone (Fig. 10). However, alternatively, as with other genera, there may be a possibility for dimorphic pairing within var. *polygonium* itself! BARDHAN et al.'s var. *polygonium* specimen (no. JUM/08/14; refigured here as Fig. 13a; D = 148 mm; phragmocone = 95 mm) from Jara from an unspecified strati-

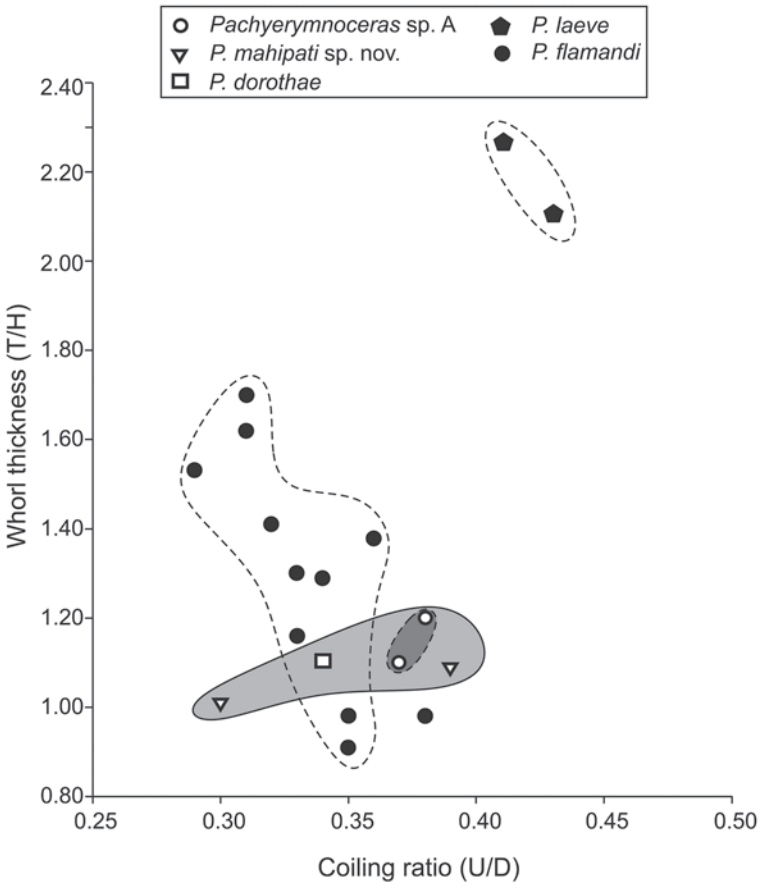

Fig. 21. Relationship of *Pachyerymnoceras mahipati* nov. sp. [M] and *Pachyerymnoceras* sp. A to closely comparable forms (see text for discussion).

graphic horizon seems to be a good dimorphic pair with the present specimen (Fig. 13f-h; D = ~120 mm; phragmocone = 80 mm). This is speculative for now, pending collection of more var. *polygonium* specimens.

Phlycticeras waageni Buckman (Spath 1928 in 1927-1933: 90, pl. 13, fig. 14) (= var. *waageni*) closely resembles the present form, though, the former (Fig. 14a-h), is a much larger form at 180 mm diameter as compared to 120 mm of the present specimen (see also Schweigert & Dietze 1998). At comparable diameters, var. *waageni* is similarly evolute but less densely ribbed (15-16 primaries per whorl as compared to 20 in the present specimen) (see also Fig. 14a-h).

P. polygonium (Zieten) var. *nodosum* (Quenstedt) [M] (= var. *nodosum*) possess coarser ornamentation and prominent nodes at the point of rib furcation at comparable diameters (Fig. 12a-d).

Assemblage and age: Jumara Dome: *P. polygonium* var. *polygonium* [M] is associated with a transgressive *Nanogyra* shell bed (bed no. B44; Fig. 2a). The fauna includes *Macrocephalites semilaevis* (the zonal index), *M. magnumbilicatus*, *M. subcompressus*, *Rehmannia* (*Loczyceras*) *reissi* and *Indosphinctes urbanus*. Occurrence of *Hecticoceras proximum* Elmi, from the subjacent Formosus Zone suggests the correlation of the Semilaevis Zone with the interval between the Proximum Horizon and the Kiliani Horizon, Proximum Subzone of the Gracilis Zone of the Submediterranean Province and the Enodatum Subzone, Calloviense Zone of the Subboreal Britain (Jain & Pandey 2000; see also Fig. 4). Jara Dome: Two fragmentary species occur in association with *Sivajiceras kleidos* (the zonal index), Kleidos Subzone, Anceps Zone, late Middle Callovian.

Superfamily Perisphinctoidea Steinmann, 1890
Family Pachyceratidae Buckman, 1918

Genus *Pachyerymnoceras* Breistroffer, 1947

Type species: *Pachyceras jarryi* Douvillé, 1912. For a detailed synonymy the readers are referred to Mangold (1988: 574).

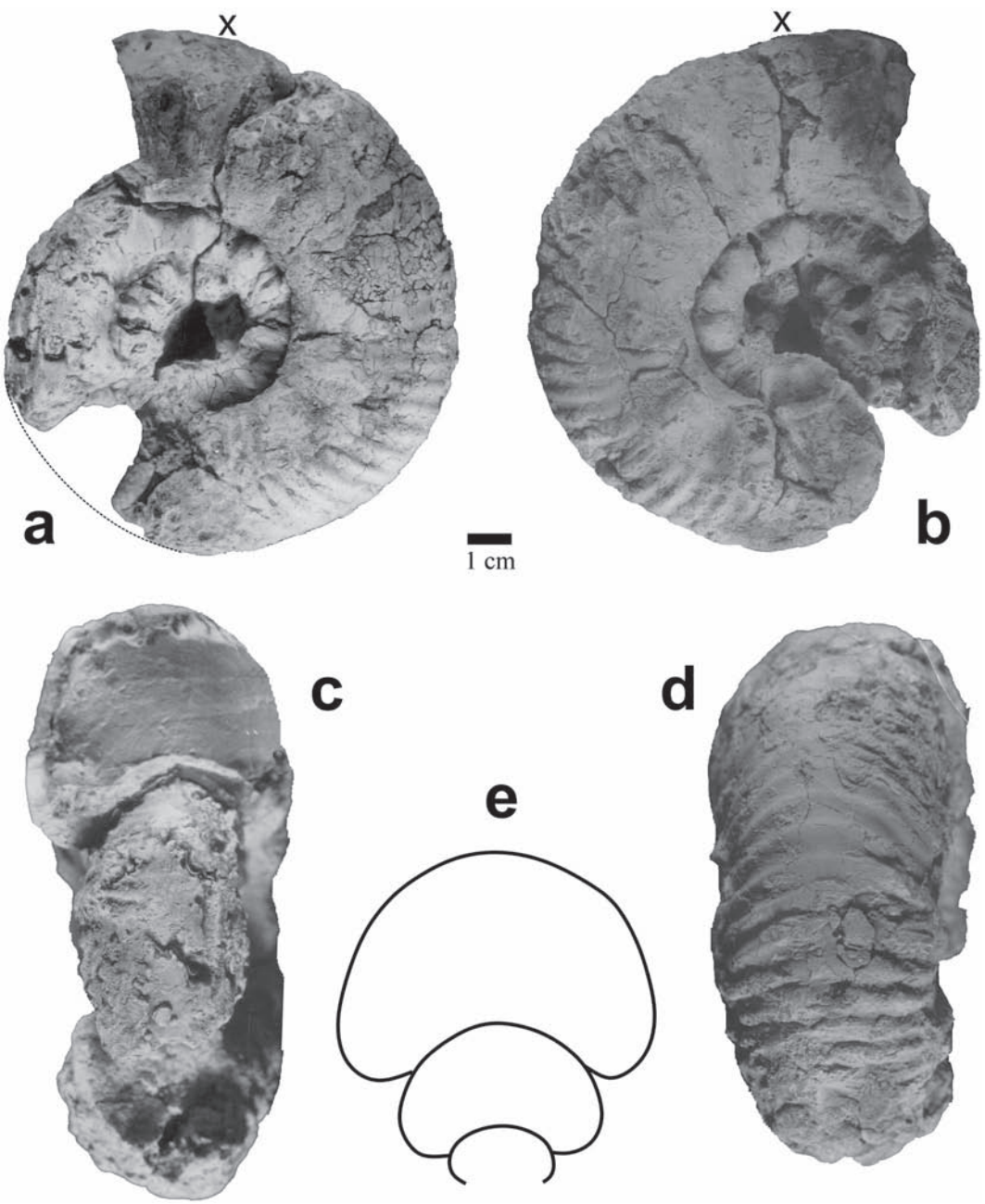

Fig. 22. *Pachyerymnoceras* sp. A [M], Jumara, Kachchh, specimen no. Ju/2/2, a: lateral, b: ventral, c: opposite lateral, and d: apertural views, e: whorl section. Cross indicates beginning of the body chamber. Cross indicates beginning of the body chamber.

Pachyerymnoceras mahipati nov. sp. [M]
Fig. 20a-e

Etymology: Named after the author's late father Mahipat Singh Jain.

Holotype: Specimen no. Ler/1999/1.

Type locality: Ler Dome section, East of Ler, Kachchh, western India (see Fig. 2c).

Type horizon: 6.5 m below the marker Early-Middle Oxfordian Dhosa Oolite bed, in a 15 cm thick, cream colored micritic concretion layer (Fig. 2c), Athleta Zone.

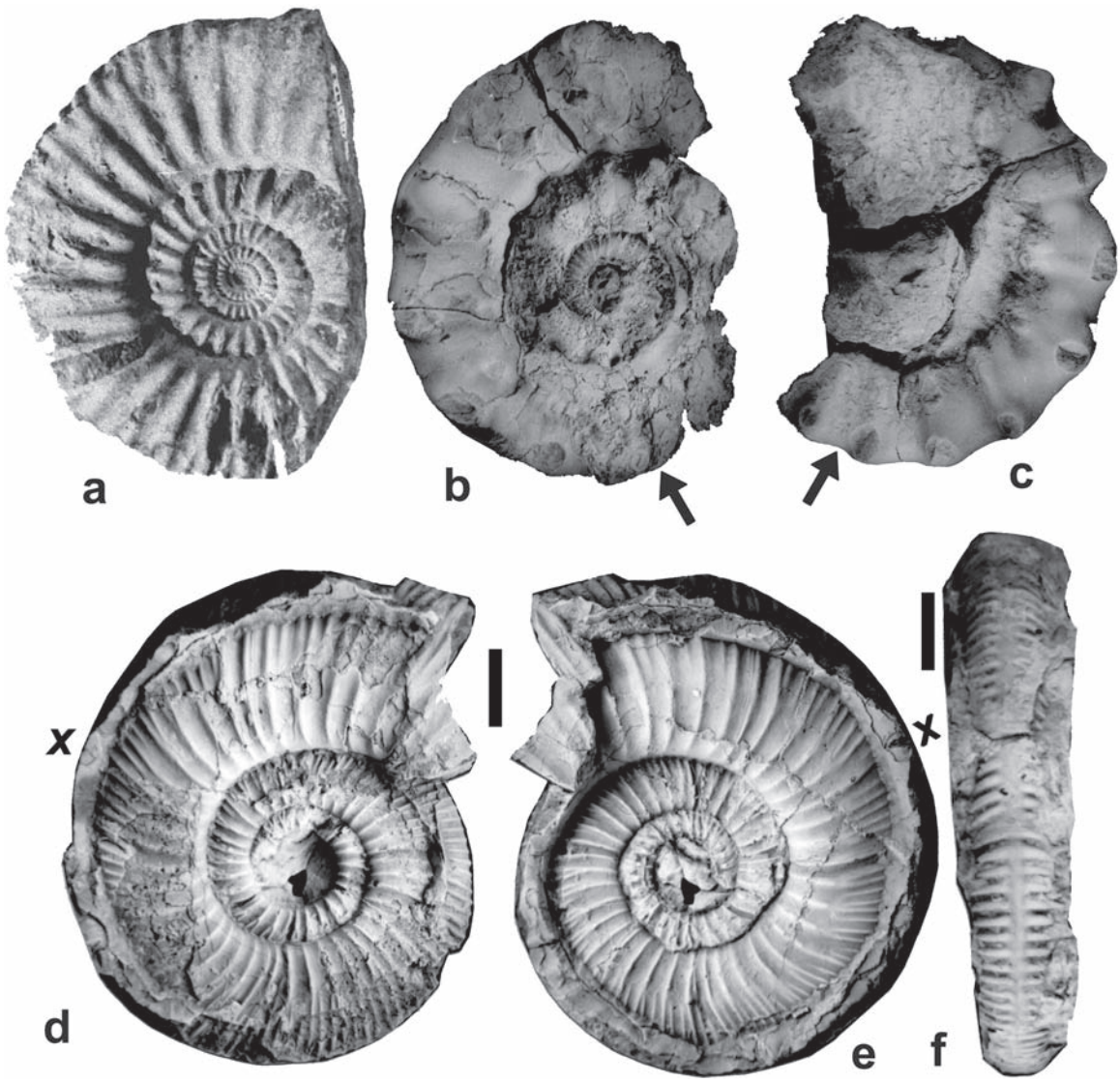

Fig. 23. a – *Orionoides anguinus* Spath (bed D1; Jumara), **b-c** – *Peltoceras* (*P.*) *athleta* (Phillips) (bed D1; Jumara), **d-f** – *Collotia fraasi* (Oppel) from the Jara Dome at 190 m (see Fig. 2b). Cross indicates beginning of the body chamber.

Diagnosis: Shell small, highly coronate, compressed and evolute. Primaries moderately long, strong and blunt with bullae near the umbilical shoulder, dividing the primaries at the lower third to middle of flank height into three slightly prorsiradiate secondaries with rare single intercalatory. Whorl section subcircular with 14 primaries and 46 secondaries per whorl at 80 mm shell diameter. Body chamber partly preserved with an estimated maximum shell diameter of 120 mm. Phragmocone measures 81 mm.

General morphology: Shell small, compressed, coronate and evolute (Fig. 21). Inner whorls coronate. Spirally placed primaries are short, strong and blunt forming bullae near the umbilical margin. Primaries arise from below the umbilical edge and divide at lower third to mid of flank height into three slightly prorsiradiate secondaries that cross the broadly rounded venter with a slight forward ventral sinus; they are moderately long. Rare single intercalatories are also present. Umbilical wall is vertical at early whorls and sloping on the body chamber. Umbilical edge remains rounded throughout. There are 14 primaries and 46 secondaries per whorl at 80 mm diameter. Body chamber is partly preserved. Suture line is not visible. The remains of the umbilical seam indicate a maximum diameter of 120 mm.

Remarks: The closest comparison of the present specimen is with *Erymnoceras dorothae* (Spath 1928 in 1927-1933: 220, pl. 18, fig. 4a; from the 'Lower Athleta Bed' in Fakirwari,

Species names	Specimen no.	Description	D	H	T	U	T/H	U/D	Bed	Locality	Author
Phlycticeras											
var. pustulatum	JUM/08/15	Body chamber	120,0	58,0	60,0	36,0	1,03	0,30	4	Jara	Bardhan et al., 2010
var. pustulatum	JUM/08/13	fragmentary							4	Jara	Bardhan et al., 2010
var. pustulatum	JUM/08/18	Phragmocone	119,0	55,0	51,5	34,0	0,94	0,29	10	Jumara	Bardhan et al., 2010
var. pustulatum	JUM/08/04	Body chamber	85,0	42,5	46,0	22,0	1,08	0,26	6	Keera	Bardhan et al., 2010
var. nodosum	Ju/7/19		62,8	30,8	30,7	11	1,00	0,18	C12	Jumara	This study (see text)
var. nodosum	Ju/7/19	at	94,5	50	42	18,9	0,84	0,20	C12	Jumara	This study (see text)
var. nodosum	SMNS 63452/1		78	39,5	42	30,5	1,06	0,39	Schweigert & Dietze, 1998		
var. nodosum	SMNS 62408/1		57	39,3	26	11,5	0,66	0,20			
var. nodosum	SMNS 62408/2		52,3	35,5	24	10	0,68	0,19			
var. nodosum	SMNS 63453/1		30,3	15,2	17,5	6,4	1,15	0,21			
var. nodosum	SMNS 63453/2		29	15	15,5	6,2	1,03	0,21			
P. schaumbergi	GSI Type 1915	Phragmocone	90,0	45,0	44,0	22,0	0,98	0,24		NE Gajinsar	Holotype
var. waageni	JUM/08/N1	Body chamber	129,0	61,0	62,0	31,0	1,02	0,24	4	Jara	Bardhan et al., 2010
var. waageni	JUM/08/01	Body chamber	127,0	63,0	63,0	32,0	1,00	0,25	6	Keera	Bardhan et al., 2010
var. polygonium	JUM/08/14	Body chamber	148,0	68,0	45,0	39,0	0,66	0,26		Jara	Bardhan et al., 2010
var. polygonium	Specimen no. 7								4	Jara	Bardhan et al., 2010
var. polygonium	JUM/08/12								6		Bardhan et al., 2010
var. polygonium	JUM/08/N2	Phragmocone	79,0	42,5	41,0	19,0	0,96	0,24	9	Jara	Bardhan et al., 2010
var. polygonium	JUM/08/19	Phragmocone	77,0	38,0	36,0	21,0	0,95	0,27	3	Jara	Bardhan et al., 2010
P. schaumbergi (= var. polygonium)	JUM/08/05	Body chamber	86,0	44,0	37,0	22,0	0,84	0,26	9	Jumara	Bardhan et al., 2010
var. polygonium	Ju/B44/1	Phragmocone	82,4	41,3	36,0	17,0	0,87	0,21	B44	Jumara	This study (see text)
var. polygonium	SJ/JA/99-00/23			21,4	17,9		0,84		see text	Jara	This study (see text)
var. polygonium	SJ/JA/99-00/25			19,1	18,2		0,95		see text	Jara	This study (see text)
var. polygonium	Holotype		28,2	14,8	14,2	5,5	0,96	0,20	Schweigert & Dietze, 1998		
var. polygonium	SMNS 63510		220,0	102,0	77,0	48,5	0,75	0,22			
var. polygonium	SMNS 63510		130,0	65,0	36,0	27,0	0,55	0,21			
var. polygonium	SMNS 63451/1		111,5	49,5	42,0	30,5	0,85	0,27			
var. polygonium	SMNS 62408/9		61,0	32,0	26,3	13,5	0,82	0,22			
var. polygonium	SMNS 62408/3		44,8	23,3	19,3	8,4	0,83	0,19			
var. polygonium	SMNS 63453/2		32,0	17,7	13,3	5,0	0,75	0,16			
Unspecified varieties											
P. polygonium (Zieten)	JUM/08/07	Young specimen		38,0	31,0		0,82		not specified	Jara	Bardhan et al., 2010
P. polygonium (Zieten)	JUM/08/16	Body chamber	85,0	42,0	42,0	26,0	1,00	0,31		Jumara	Bardhan et al., 2010
P. polygonium (Zieten)	JUM/08/17	–		64,0	53,0		0,83			Jumara	Bardhan et al., 2010
P. polygonium (Zieten)	JUM/08/11	Phragmocone	62,0	31,0	32,5	16,0	1,05	0,26		Jumara	Bardhan et al., 2010
P. polygonium (Zieten)	JUM/08/08	Phragmocone	75,0	25,0	24,0	20,0	0,96	0,27		Jumara	Bardhan et al., 2010
P. polygonium (Zieten)	JUM/08/10	Body chamber	100,5	57,0	48,0	30,5	0,84	0,30		Jara	Bardhan et al., 2010
Pachyerymnoceras											
Spath, p. 220	P. dorothae	at	65,0	26,0	28,0	22,1	1,1	34,0	see text	Fakirwari	Spath
Ju/2/2	Pachyerymnoceras sp. A	end of phrag.	125,0	48,7	55,0	46,0	1,1	36,8	D8	Jumara	This study
Ju/2/2	Pachyerymnoceras sp. A	at	116,0	40,0	46,0	44,0	1,2	37,9	D8	Jumara	This study
Ju/2/2	Pachyerymnoceras sp. A	at	85,0	26,0	34,0	28,3	1,3	33,3	D8	Jumara	This study
Ler/1999/1	Pachyerymnoceras mahipati	at	81,5	33,0	36,0	31,4	1,1	38,5	see text	Ler	This study
Ler/1999/1	Pachyerymnoceras mahipati	at	72,5	22,6	22,8	21,4	1,0	29,5	see text	Ler	This study

Fig. 24. Dimensions used in the text. The measurements of the figured specimens are taken on the internal mold (estimated if test preserved) in millimeters. D = diameter; H = whorl height at the given diameter from the umbilical seam to the venter in the plane of the coiling; T = whorl width at the given diameter perpendicular to the plane of the coiling; U = umbilical width at the given diameter; T/H = ratio of whorl width and whorl height; U/D = ratio of width of the umbilicus and the diameter; P/2 = Primaries per half whorl, S/2 = Secondaries per half whorl. Ratios are in percentages.

about 10 km south of Bhuj; Fig. 1) (refigured here in Fig. 20f-h) in its pattern of ornamentation, shell dimensions and similar stratigraphic occurrence (Figs. 2c, 20, 21). However, at comparable diameters, *E. dorothae* (Fig. 20f-h) is less strongly ribbed (with 11 primaries at 65 mm as compared to 14 in the present specimen). The present specimen is also easily distinguished by its coarse primaries as compared to the somewhat subdued ribbing in *E. dorothae* (Spath). Additionally, the present specimen has more tabulate flanks and rounded venter (Fig. 20). The Ler specimen has no other comparable morphological forms and hence, has been assigned to a new species.

Assemblage and age: *Pachyerymnoceras mahipati* nov. sp. [M] occurs in association with *Pachyceras* sp., *Peltoceras* sp., *Peltoceras* (*P.*) *ponderosum*, *Putealiceras trilineatum*, *Putealiceras bisulcatum* and *Hubertoceras* sp. (Fig. 2c), characteristics of the Submediterranean Poculum Subzone,

Athleta Zone (Jain & Pandey 2000) (Fig. 4). In the adjoining Keera Dome, coeval sediments (PII Horizon, Ponderosum Zone; see Fig. 8) have yielded *Poculisphinctes* cf. *poculum*, *Pachyceras lalandeanum* and *Properisphinctes manialensis* (Krishna & Ojha 1996, 2000). At Jara, Prasad (1998) recorded *Pachyceras lalandeanum*, *Peltoceras* (*P.*) *ponderosum*, *P.* (*P.*) *kachchhense*, *Unipeltoceras* sp., *Pseudopeltoceras* sp. and *Phlycticeras* spp. characterizing the Poculum Subzone. *P. lalandeanum* has now been recorded by the author from the same section (Fig. 2b). Thus, the co-occurrence of *P. lalandeanum* in Keera and Jara along with common *Peltoceras* (*P.*) *ponderosum* at Ler, Jara, Jumara and Keera (Fig. 1) enables correlation of the horizon with *P. mahipati* [M] with the Poculum Subzone (Athleta Zone) of the Submediterranean Province.

Pachyerymnoceras sp. A [M]
Fig. 22

Locality and horizon: North of the village of Jumara in the southern flank of the Jumara Dome (Kachchh, western India; marked by an ammonite symbol in Fig. 5). Gypsiferous red nodular shales; bed D8; pars. "Upper Athleta beds" of Spath (1927-1935) (Fig. 2a).

Diagnosis: Shell evolute, compressed with a wide and shallow umbilicus. Primaries are short and blunt; branching at the lower third of flank into 3-4 secondaries with a single intercalatory. Phragmocone measures 125 mm with 7 primaries and 30 secondaries per half whorl. Maximum shell diameter is 160 mm. Whorl section is cadiconic. Suture line is poorly preserved.

General morphology (phragmocone): Shell is evolute and compressed. Umbilicus is shallow and wide. Primaries, arising from the umbilical edge are short and blunt, branching into 3-4 strong prorsiradiate secondaries with a single intercalatory. At the point of branching of the primaries, which is at the lower third of the flank height, a bulla is present. At the end of the phragmocone stage, at 125 mm shell diameter, there are 7 primaries and 30 secondaries per half whorl. Coarse secondaries cross the broadly rounded venter with a slight forward convexity (sinus). Umbilical wall is vertical at 85 mm, but with increasing diameter, near the end of the phragmocone (at 125 mm) becomes slightly slanting and is still coronate. At 85 mm shell diameter the whorl section is cadiconic in nature, while at 125 mm, it becomes somewhat rounded though retaining the depressed cadiconic nature (Fig. 22e). Maximum estimated shell diameter is 160 mm. Suture line is poorly preserved.

Remarks: The closest comparison of the present specimen is with *Pachyerymnoceras flamandi* [M] (Fig. 21) recorded from the Trezeense Subzone, Athleta Zone, in Algeria (Mangold 1988, pl. 5, figs. 1, 2). However, the Jumara specimen is more evolute, and compressed at comparable diameters (see Fig. 21). *P. philbyi* from coeval Late Callovian sediments of Israel is an equally large form with a similar whorl section (Lewy 1983, fig. 4e) and coarse ornamentation. However, *P. philbyi* is a much more depressed form (T/H = 1.5) as opposed to the Jumara specimen (T/H = 1.15) (see Fig. 21). *P. leave* (Cariou & Enay 1999, fig. 9.2a-b), from the Athleta Zone of Central Nepal is smaller (complete at 65 mm) with a more cadiconic whorl section and is twice as depressed (at 45 mm: T/H = 2-26; at 61 mm: T/H = 2-15) (Fig. 21). No other forms are comparable to the present form.

Assemblage and age: Bed D8 is 39 m below the marker Early-Middle Oxfordian Dhosa Oolite (bed E1 of present work; Fig. 2a) and 15 m above the Purple sandstone (bed D1 of present work; Fig. 2a). The specimen is associated with *Peltoceras* (*P.*) *athleta* (zonal index; Fig. 23b-c), *P.* (*P.*) *metamorphicum*, *Paralcidia* cf. *obsoleta*, *Hubertoceras omphalodes*, *Obtusicostites* sp. and *Subgrossouvria gudjinsirensis* var. *tenius* (Fig. 6). Bed D8 is correlated with the Collotiformis Subzone, Athleta Zone of the Submediterranean Province (Fig. 2), thus assigning an early Late Callovian age to *Pachyerymnoceras mahipati* nov. sp. [M].

Beds D2-D7 (Fig. 2a) has yielded *Peltoceras* (*Peltoceras*) *kachchhense*, *Collotia fraasi* (Fig. 23d-f) and *Hecticoceras* (*Sublunuloceras*) *lariense* var. *plana*. The presence of common *Collotia fraasi*, *Paralcidia* sp. and *Peltoceras* sp. help in correlating these beds (D2-D8) with the Collotiformis Subzone, Athleta Zone of the Submediterranean Province (Figs. 2, 4, 6).

Bed no. D1 has yielded *P.* (*P.*) *athleta* (Fig. 23b-c), the index of the Athleta Zone and occurs associated with the earliest occurrence of *Orionoides* (*O. anguinus*: Jain & Pandey 1999, Fig. 23a; and *O. purpurus*: Rajnath, 1942) (see also Fig. 6).

Hence, in Kachchh, the genus *Pachyerymnoceras* is restricted to the Athleta Subzone (Athleta Zone) correlated with the Submediterranean interval from the Collotiformis to the Poculum subzones of the Athleta Zone (Fig. 4).

All data used in the present study are given in Fig. 24.

4. Conclusions

The genus *Pachyerymnoceras* in Kachchh as well as in the Indian Subcontinent ranges from the Collotiformis to Poculum subzones (Athleta Zone) of the Submediterranean Province. Its entry in the Indian subcontinent is facilitated by the earliest Late Callovian global transgression.

Genus *Phlycticeras* in Kachchh and in the Indian subcontinent ranges from the latest Early Callovian (Jumara: Semilaevis Zone = Submediterranean Patina Subzone) to the earliest Late Callovian (Keera: Depressum Subzone, Athleta Zone = Submediterranean Collotiformis Subzone, Athleta Zone). The present record of *Phlycticeras polygonium* var. *polygonium* from the Semilaevis Zone (Jumara) is the earliest record from the entire southern Tethys.

There is a possibility for a dimorphic pairing within var. *polygonium* itself. Bardhan et al.'s var. *polygonium*

specimen (Fig. 13a; D = 148 mm) from Jara may be a good dimorphic pair with the present specimen (Fig. 13f-h; D = 120 mm). But this is speculative for now, pending collection of more var. *polygonium* specimens.

Alternatively, as also identified here (all macroconchs), Dr Guenter Schweigert (Stuttgart, Germany), in a personal communication while reviewing the early draft of the manuscript noted "...that these are not micro- and macroconchs but all macroconchs that became adult at very different stages. Similar phenomena can be seen in aspidoceratids. The males are the small-sized *Oecoptychius*, which share the strigation when the shell is preserved and which have the same suture line in the early stages. It seems that the Kachchh Basin was not favourable for the males (hence they are extremely rare, but not absent) and that they met elsewhere, or the macroconchs were mostly empty shells that drifted into this basin by currents" (see also Schweigert & Dietze 1998; Schweigert et al. 2003).

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