Stratigraphic and taxonomic considerations on the Late Cretaceous rudist fauna of Aksai Chin (Western Tibet, China) from the De Filippi Collection

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Abstract: The rudist fauna collected in western Tibet in the Aksai Chin area by the De Filippi expedition in 1914 has been reprised and redescribed. This fauna is composed of *Radiolites* cf. *lusitanicus*, *Radiolites* sp., *Gorjanovicia* cf. *endrissi*, ? *Sauvagesia* sp., *Sphaerulites* sp., *Durania* sp., and *Gyropleura* sp. The rudist-bearing beds belong to the Tielongtan Group of the Tianshuihai terrane. The Turonian-? Coniacian Xiloqzung Formation (Fm.) bear the older rudists (*Radiolites* cf. *lusitanicus*, *Radiolites* sp., *Sphaerulites* sp., *Durania* sp.), whereas younger ages have been determined through microfossil analysis which, compared with the western Neotethys records, suggests an early-mid Campanian age. This allowed to ascribe the younger rudists of the collection (*Gorjanovicia* cf. *endrissi*, ? *Sauvagesia* sp., *Gyropleura* sp., *Radiolites* sp.) to the Dongloqzung Formation. Our data confirm that rudist-bearing facies in the Tielongtan Group extend at least up to the middle Campanian. The Aksai Chin rudist assemblage should belong to the Southwestern Asian assemblage of the Eastern Mediterranean Sub-province.

Key-words:

* Hippuritida;
* Tethysian biostratigraphy;
* Upper Cretaceous of Tibet;
* paleobiogeography;
* museum collection

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Résumé : *Considérations stratigraphiques et taxonomiques sur la faune de rudistes du Crétacé supérieur d'Aksai Chin (Tibet occidental, Chine) appartenant à la Collection DE FILIPPI.-* La faune de rudistes récoltée dans la région d'Aksai Chin dans l'ouest du Tibet par l'expédition DE FILIPPI en 1914 est réexaminée et redécrite. Cette faune est composée de *Radiolites* cf. *lusitanicus*, *Radiolites* sp., *Gorjanovicia* cf. *endrissi*, ? *Sauvagesia* sp., *Sphaerulites* sp., *Durania* sp. et *Gyropleura* sp. Les couches à rudistes appartiennent au Groupe Tielongtan du terrane de Tianshuihai. La Formation Xiloqzung du Turonien - ? Coniacien recèle les rudistes les plus anciens (*Radiolites* cf. *lusitanicus*, *Radiolites* sp., *Sphaerulites* sp., *Durania* sp.), tandis que l'analyse du contenu microfossilifère par comparaison avec celui de la Néotéthys occidentale suggère un âge Campanien inférieur à moyen pour les rudistes les plus jeunes. Ceci permet d'attribuer les rudistes les plus jeunes appartenant à la collection (*Gorjanovicia* cf. *endrissi*, ? *Sauvagesia* sp., *Gyropleura* sp. et *Radiolites* sp.) à la Formation de Dongloqzung. Nos données confirment que les faciès à rudistes du Groupe Tielongtan sont présents au moins jusqu'au Campanien moyen. L'association de rudistes de l'Aksai Chin devrait être rattachée à l'association du sud-ouest asiatique au sein de la Sous-Province méditerranéenne orientale.

Mots-clefs :

• Hippuritida ;
• biostratigraphie de la Téthys ;
• Crétacé supérieur du Tibet ;
• paléobiogéographie ;
• collection de musée

Introduction

The Aksai Chin is a remote region at the western termination of the Tibetan Plateau (China), extending at its westernmost point to the Karakorum Pass (Fig. 1.a). It is essentially a wide system of plateaus, partly occupied by salt lakes (*e.g.*, Aksai Chin Lake), the average elevation of which is greater than 4800 m. Northward, it is bordered by and separated from the Tarim Basin by the Kunlun Range, a mountain chain that exceeds 7000 m asl. The Upper Karakash River, which is one of the main tributaries of the Tarim River, flows in the western part of the Aksai Chin, along a deeply incised valley. In the central sector of the region a high mountain ridge exceeding 6400 m asl, is known as Western Loqzung Mountains/Luokezongshan (Fig. 1.b).

Aksai Chin is almost uninhabited and very difficult for researchers to investigate because–the average altitude is more than 4800 m asl, with a frigid climate and reduced oxygen levels, which result in a wide desert land. Furthermore, travelling is extremely difficult across the region with a single, wide, long road (G219) (Fig. 1.c) built at the end of 20th century.

Because of such issues, the geology of Aksai Chin was sporadically investigated through time and, with few exceptions, most of the significant expeditions in the area were made in the first half of 20th century (HEDIN, 1909; DE TERRA, 1932; NORIN, 1946). After such pioneering explorations this remote area was almost forgotten by geologists until the '80s of the 20th century, when it was investigated by the "Comprehensive Scientific Expedition to the Tibetan Plateau" in the years 1987-1990 (Chinese Academy of Sciences, 1998, 2000). Also it was only marginally the object of studies of the huge Sino-English "geotraverse of Tibet" (CHANG *et al.*, 1986, 1989; Sino-UK Geological Expedition Team, 1990), and subsequently of the Sino-French expedition, which followed the route of the G219 Highway (MATTE *et al.*, 1996; GAETANI, 2011). Regarding the area east of the Karakorum Pass, and in particular between the Upper Karakash Valley and the Thaldàt Basin

(*i.e.*, Loqzung Mts./Luokezongshan subregion – Chinese Academy of Sciences, 2000), the first scientific data known to date are those collected by the Italian DE FILIPPI Expedition made in 1913-1914 (DE FILIPPI, 1915; DAINELLI, 1934; reviewed by GAETANI, 2011). This expedition crossed the Western Loqzung Mts., through the Kizil Pass and reached the Thaldàt Basin and the Aksai Chin Lake (Fig. 1.c). Later data was collected by the "Comprehensive Scientific Expedition to the Tibetan Plateau" (Chinese Academy of Sciences, 1998, 2000). During the DE FILIPPI expedition, which crossed the Himalayan Range from Kashmir to Baltistan and Xinjiang and lasted for about two years, almost one month was spent in the Aksai Chin Region (DAINELLI, 1934). The ~1000 rock and fossil samples collected during the expedition are stored at the *Natural History Museum of Florence University* (Italy), and represent still today one of the most complete geological archives of the area (GAETANI, 2011).

The first goal of this paper is to re-evaluate in modern terms the taxonomy of this remarkable rudist collection from the DE FILIPPI expedition in order to refine the Upper Cretaceous stratigraphy. The second goal is to place this area into a wider paleobiogeographic framework by comparing it with more recently published research (WEN, 1998; WEN *et al.*, 1998; Chinese Academy of Sciences, 2000).

Geological setting

The geological setting of the study area is complex because of the superimposition of multiple orogenic phases (*e.g.*, MOLNAR & TAPPONNIER, 1975; SENGOR *et al.*, 1988; DECELLES *et al.*, 2002; YIN & HARRISON, 2000; MATTERN & SCHNEIDER, 2000). The subsequent accretion of crustal blocks at the southern margin of the Siberian Craton or paleo-Asia (Fig. 2) persisted from Paleozoic to Cenozoic times (DEWEY *et al.*, 1988; WINDLEY, 1988; CHANG *et al.*, 1989; GAETANI, 1997; ZANCHI & GAETANI, 2011; ANGIOLINI *et al.*, 2013; FAISAL *et al.*, 2014). The northernmost of these crustal blocks is represented by the western Kunlun Range, a Paleozoic orogen rejuvenated during the

Figure 1: (a) and (b) Location and geographical setting of the study area (basemap retrieved from Google Earth). (c) close-up of the study area, the dashed line is the route of the DE FILIPPI expedition through the W-Loqzung Mts., yellow stars indicate sampling localities.

early Cenozoic collisional stage of the Himalaya-Karakorum-Tibet orogenic system (TAPPONNIER & MOLNAR, 1977; CHANG *et al.*, 1986, 1989; YONGUN & HSU, 1994; MATTE *et al.*, 1996; Chinese Academy of Sciences, 2000; XIAO *et al.*, 2005; ZHANG *et al.*, 2019). The southern boundary of the western Kunlun range is represented by the regional scale Altyn Tagh – Karakash strike-slip fault or Kunlun-Maqe Fault (Fig. 2 ; MATTE *et al.*, 1996; SHA & FÜRSICH, 1999; XIAO *et al.*, 2005; SHA *et al.*, 2004; ZANCHI & GAETANI, 2011).

A complex system of terranes south of the Kunlun block, drifted northward after the fragmentation of the northern margin of Gondwana (SENGOR *et al.*, 1988). It was accreted during the late Middle-Late Permian to the Eocene (Fig. 2), and includes the Songpan-Ganzi-Hoxhil terrane, the Qiantang composite terrane, the Tianshuihai terrane, the Lhasa terrane, and the Himalaya terrane (MOLNAR & TAPPONNIER, 1975; HUANG & CHEN, 1987; DEWEY *et al.*, 1988; WINDLEY, 1988; CHANG *et al.*, 1989; GAETANI *et al.*, 1990; MATTE *et al.*,

Figure 2: Tectonic framework of the study area. The yellow star indicates the study area. TST=Tianshuihai terrane, S-G-H=Songpan-Ganzi-Hoxhil terrane; Modified after YIN & HARRISON, 2000 (basemap retrieved from Google Earth).

1996; SHA & FÜRSICH, 1999; SHA, 1998; YIN & HARRISON, 2000; SHA *et al.*, 2004; ZANCHI & GAETANI, 2011; SHA, 2018).

Most of the Aksai Chin Region belongs to the Tianshuihai terrane (PAN *et al.*, 1992; MATTE *et al.*, 1996; Chinese Academy of Sciences, 2000; WITTLINGER *et al.*, 2004; XIAO *et al.*, 2005) or Kara-Kunlun and Uygur terranes (MATTERN *et al.*, 1996; MATTERN & SCHNEIDER, 2000). The Tianshuihai terrane is a small crustal block interposed between the larger Kunlun, Pamir, Songpan-Ganzi-Hoxhil, and Qiantang terranes (Fig. 2). It was interpreted as an accretionary wedge produced by the northward subduction of the Paleotethys oceanic crust beneath the Kunlun block (MATTERN & SCHNEIDER, 2000; XIAO *et al.*, 2005). The general stratigraphy of the Tianshuihai terrane (Fig. 3) is characterized by a thick (>> 6000 m) ? Carboniferous to Permian succession consisting of fusulinid limestones (marbles), green schists and brachiopod-bearing marbles that overly poorly known early Paleozoic rocks (MATTE *et al.*, 1996). These are overlain by Permo-Triassic dark grey slates and barely metamorphic flyschoid sandstones (CHANG *et al.*, 1989; MATTE *et al.*, 1996; MATTERN *et al.*, 1996). The stratigraphic succession was strongly deformed during the Triassic - ? Early Jurassic (Cimmerian) orogeny (MATTERN & SCHNEIDER, 2000; SENGOR *et al.*, 1988). Arc magmatism affected the Tianshuihai accretionary wedge, with batholiths intruding the sedimentary succession trending parallel to the orogen (MATTERN & SCHNEIDER, 2000). The 215

and 171 Ma ages of the plutonic rocks (mostly granitoid) were determined using various radiometric methods (^{40}Ar/^{39}Ar, K/Ar, U/Pb) (MATTE *et al.*, 1996; MATTERN & SCHNEIDER, 2000). This magmatic activity ceased in the Middle Jurassic (MATTERN & SCHNEIDER, 2000).

Unconformably covering the Paleozoic-Triassic deformed rocks is a marine sedimentary succession consisting of a few hundred (?) meters of Jurassic black shales, sandstones and limestones (Fig. 3). This is, in turn, covered by a thick Cretaceous stratigraphic succession made of conglomerates, sandstones and limestones, containing macrofossils such as ammonites, echinoids, bivalves (including rudists), corals among others (PARONA, 1928; STEFANINI, 1928; DAINELLI, 1933-1934; WEN *et al.*, 1998, 2000a, 2000b). The Jurassic-Cretaceous sedimentary successions of the Aksai Chin are poorly investigated, but since the end of the last century, a general stratigraphic subdivision was established by WEN *et al.* (1998, 2000a, 2000b) based on paleontology and superposition. In this paper we contribute to the knowledge of the Cretaceous stratigraphy of the area through the analysis of rudists collected in the surroundings of the Kizil Pass by the Italian scientists Giotto DAINELLI and Olinto MARINELLI in 1914. These fossils are from the Tielongtan Group (see below), which crops out, strongly deformed, in the Western Loqzung Mts. (DAINELLI, 1933-1934; MATTE *et al.*, 1996; WEN *et al.*, 2000a, 2000b).

Figure 3: Sketch of the general stratigraphy of the W-Loqzung Mts. (modified after MATTE *et al.*, 1996; WEN *et al.*, 2000a, 2000b).
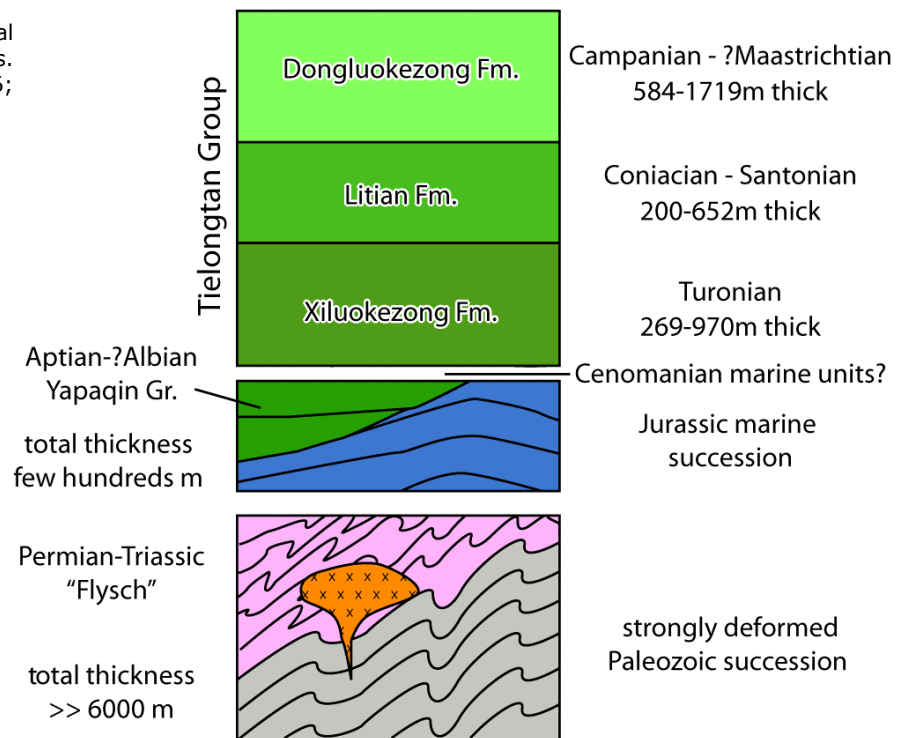
The Cretaceous of Aksai Chin

Stratigraphy

A discontinuous stratigraphic succession crops out in the Aksai Chin, characterizing the Loqzung Mts./Luokezongshan stratigraphic subregion (WEN *et al.*, 1998, 2000a, 2000b), previously studied by pioneers such as HEDIN (1909), PARONA (1917; 1928), STEFANINI (1917), DOUVILLÉ (1926) and DAINELLI (1933-1934). The Lower Cretaceous includes both continental and marine units: the Aptian-? Albian Yapaqin Group (Fig. 3) is made of interbedded marine (limestone) and non-marine facies (SUN & ZHANG, 1983; WEN *et al.*, 2000a); this unit likely corresponds to the possibly Albian crinoid red limestone and underlying conglomerates, described by PARONA (1928) and DAINELLI (1933-1934), and to the Albian limestones inferred by MATTE *et al.* (1996). The occurrence of Barremian limestone with *Choffatella* sp. and orbitolinids described by DOUVILLÉ (1916, 1926) in samples collected by HEDIN (1909) is considered not reliable.

The Lower Cretaceous is disconformably covered by marls and limestones belonging to the Tielongtan Group (Fig. 3), which marks a regional transgression considered it to be Cenomanian (SUN & ZHANG, 1983; XI *et al.*, 2019) or Turonian (WEN *et al.*, 2000a, 2000b). Elsewhere it directly overlies the Upper Jurassic (*e.g.*, SUN & ZHANG, 1983). The Tielongtan Gp. is a very thick (up to >3300 m) stratigraphic unit. It is subdivided into the Xiloqzung/Xiluokezong (269-970 m thick), Litian (200-652 m thick) and Donglokzung/Dongluokezong (584-1719 m thick) formations. Its age was suggested as being late Turonian to Campanian (even to early Maastrichtian) based on rudists and gastropods (WEN *et al.*, 1998, 2000a, 2000b). Recently, some authors inferred the range of Tielongtan Group to be early Cenomanian to late Maastrichtian (*e.g.*, XI *et al.*, 2019), although they do not provide any good evidence.

Palaeontology

The fossil assemblages that are the object of this study, led PARONA (1917, 1928) to subdivide the Upper Cretaceous succession in two parts: **1.** A Cenomanian - ? "Senonian" limestone and marly limestone with abundant macrofossils such as ammonoids in the lowermost part, with rudist bivalves, echinoids and miliolids (PARONA, 1917, 1928; DAINELLI, 1933-1934); **2.** An ? "upper Senonian" limestone with bivalves (including rudists), bryozoans, brachiopods, and possibly orbitoids (PARONA, 1928; DAINELLI, 1933-1934). This subdivision was obviously only tentative, and they did not reconstruct a reliable stratigraphy, but the stratigraphic succession seems roughly to correspond to the Tielongtan Gp., which is composed of interbedded brown calcareous sandstones, marls, red conglomerates, gray massive bioclastic limestones, and brown sandstones, also bearing bioclastic limestones in the upper part (YANG *et al.*, 2014). This group yields, in fact, abundant marine bivalves, in particular, rudists, which are abundant along the eastern slopes of Western Loqzung Mts. (WEN *et al.*, 2000a, 2000b). According to WEN *et al.* (2000b) the Xiloqzung/Xiluokezong Formation yields a rich rudist assemblage with *Rhedensia*, *Vaccinites*, *Bournonia*, *Medeella*, *Biradiolites*, *Praeradiolites*, *Sauvagesia*, and *Durania*. The Litian Formation yields *Lapeirousia*, *Distefanella*, *Hippurites*, and *Gorjanovicia*. The Dongloqzung/Dongluokezong Formation yields Lapeirousinae, *Praeradiolites*, *Bournonia*, *Gorjanovicia*, and Hippuritidae (Table 1). Some of these determinations should be reviewed and are not considered here.

Table 1: Stratigraphic chart of rudist taxa of the Aksai Chin region cited in the literature and notes.

Chronostrat.		PARONA, 1917, 1928	DOUVILLÉ, 1916	KLINGHARDT, 1934
'Senonian'	Maastrichtian			
	Campanian			
	Santonian			
	Coniacian			
Turonian		*Radiolites* cf. *peroni* *Radiolites indicus* (*R. radiosus* gr.) *Durania mutabilis* (previously described as *Durania* f. ind.* cf. *D. arnaudi*) *Gyropleura cenomanensis*		*Sauvagesia garjanica* *Hippurites* aff. *requieni*
Cenomanian			*Eoradiolites hedini*	
Albian				
Notes:		The Rudist fauna was ascribed to the uppermost Cenomanian - lowermost Turonian, but the occurrence of younger ('Senonian') beds was inferred by the anlaysis of non-rudistid fossils. * 'f. ind.' means 'forma indeterminata' in Italian, it is equivalent to 'sp. ind.'	The stratigraphic distribution of *E. hedini* is not well-constrained. This occurrence is placed in the Turonian Xiloqzung Fm. by WEN *et al.* (2000b).	The stratigraphic distribution of *S. garjanica* is not well-constrained, whereas *H. requieni* is a Turonian taxon. These occurrences are placed in the Turonian Xiloqzung Fm. by WEN *et al.* (2000b).

Material and methods

This is a study of rudist-bearing samples stored in the Natural History Museum of the University of Florence (Table 2), from the Aksai Chin area (Fig. 1). Sampling was carried out by unconventional methods, and it is very difficult to refer each specimen to a precise locality. PARONA (1917, 1928) and DAINELLI (1934) erroneously said that the samples were from the "Lingzi-Thang area", which is actually the Western Loqzung Mts. The actual collection area is marked by well-developed rudist banks, with specimens collected in the surroundings of Kizil Pass, "*along the valley descending from the pass toward NE in the left riverside*" and "*beyond Kizil II camp site*" (PARONA, 1917). In addition, we have tried our best to refer each specimen to a formation, following the stratigraphic nomenclature established by WEN *et al.* (1998, 2000a, 2000b).

Unfortunately, most of the nearly 100 specimens of the collection are broken isolated fragments or fragmental in whole rock. The list of specimens in the collection, with register numbers (Table 2), includes several specimens that are grouped under the same register number.

Ten samples have been cut to check the shell structure and for general microfacies analysis, resulting in 20 thin sections. Due to limitations of the preservation of fossil material and that only a few specimens were sectioned, only gross descriptions of the main features of the rudists have been perfomed. Shell shape and structure description follows DECHASEAUX *et al.* (1969), PONS & VICENS (2008), PONS *et al.* (2012), and SKELTON (2013).

Abbreviations: AB=Anterior Band; PB=Posterior Band; L= Ligament ridge; CA= Cardinal apparatus; IGF = Register number.

MATTE *et al.*, 1996	WEN *et al.*, 1998, 2000a, 2000b	Present paper	Stratigraphy (after WEN *et al.*, 2000b)
	Lapeirousinae, *Praeradilolites*, *Bournonia*, *Gorjanovicia*, Hippuritidae	*Gyropleura* sp. *Radiolites* sp. ?*Sauvagesia* sp. *Gorjanovicia* cf. *endrissi*	Dongloqzung Fm.
	Lapeirousia, *Distefanella*, *Hippurites*, *Gorjanovicia*	*Radiolites* sp. ?	Litian Fm.
	Rhedensia, *Vaccinites*, *Bournonia*, *Medeella*, *Biradiolites*, *Praeradiolites*, *Sauvagesia*, *Durania*	*Radiolites* cf. *lusitanicus* *Radiolites* sp. *Sphaerulites* sp. *Durania* sp.	Xiloqzung Fm.
			?
Auroradiolites gilgitensis			Apaqin Gr.
Noticed, but not figured	*Rhedensia* is an invalid genus, whereas *Distefanella* is endemic to W-Tethys. Only generic determinations prevent any further consideration about the age and paleogeographic significance of these faunas.	Rudists studied in the present paper belong to the Xiloqzung and Dongloqzung formations. Nevertheless, several specimens of *Radiolites* sp. have been collected randomly in the field and it cannot be excluded that some of them could belong to the Litian Fm.	Cenomanian marine beds possibly occur but their study is beyond the scope of this paper.

Paleontological note

The rudist bivalves (Order HIPPURITIDA NEWELL, 1965) of the DE FILIPPI fossil collection were originally determined by PARONA (1917, 1928), who recognized three (or possibly more) species of radiolitids and one of monopleurids: *Radiolites indicus* (STOLICZKA) (*Radiolites radiosus* ORB. group); *Radiolites* cf. *peroni* (CHOFFAT); *Radiolites* sp.; *Durania* f. ind. (cf. *D. arnaudi* (CHOFF.)), then identified as *Durania mutabilis* and *Gyropleura cenomanensis* (ORB.).

Family Radiolitidae ORBIGNY, 1847

Original determination (PARONA, 1928): *Radiolites* cf. *peroni* (CHOFFAT)

Radiolites cf. *lusitanicus* (BAYLE, 1857)

(Fig. 4.a-g)

Material: 5 quite well-preserved right valves and 7 fragments (IGF 103258, 103260, 103261, 103262, 103263).

Locality: beyond Kizil 2 (Fig. 1)

Inferred formation: Xiloqzung Fm.

Age: ? Turonian-? Coniacian

Table 2: Aksai Chin Rudist collection stored at the Natural History Museum of Florence University (Italy). A catalogue number can include one or more specimens.

IGF	Description	N.	Order	Family	Genus	Species	Locality	Nation	Epoch	Age	Year	Collectors
103252	Fragments with rudists and matrix	7	Hippuritoida	Monopleuridae	-	*Gyropleura cenomanensis*	Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103253	Fragments with rudists and matrix	3	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103254	Fragments with rudists and matrix	11	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103255	Fragments with rudists and matrix	3	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103256	Fragments with rudists and matrix	3	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103257	Fragments with rudists and matrix	8	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103258	Single specimen	1	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* cf. *peroni*	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103259	Broken specimens	7	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	Aksai Chin	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103260	Fragments	2	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* cf. *peroni*	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103261	Fragments	3	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* cf. *peroni*	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103262	Fragments	2	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* cf. *peroni*	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103263	Fragments	3	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* cf. *peroni*	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103264	Fragments	4	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103265	Fragments	7	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103266	Fragments	3	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103267	Fragments	15	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	Aksai Chin	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103268	Single specimen	1	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites indicus*	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103269	Fragments	15	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103270	Two specimens	2	Hippuritoida	Radiolitidae	-	*Durania mutabilis*	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103942	Fragments with rudists and matrix	1	Hippuritoida	Monopleuridae	*Gyropleura*	*Gyropleura cenomanensis*	Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103943	Fragments with rudists and matrix	1	Hippuritoida	Monopleuridae	*Gyropleura*	*Gyropleura cenomanensis*	Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103944	Fragments with rudists and matrix	1	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103945	Fragments with rudists and matrix	1	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103946	Fragments with rudists and matrix	1	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI
103947	Fragments with rudists and matrix	1	Hippuritoida	Radiolitidae	*Radiolites*	*Radiolites* sp.	beyond Kizil 2	CHINA	Upper Cretaceous	Turonian	1914	DAINELLI & MARINELLI

Description: Elongate shell, subcylindrical, up to >90 mm high showing slightly inclined growth lamellae sets and dominant normal cellular shell structure (Fig. 4.a, g, g'). In transverse sections the cardinal apparatus is well developed (Fig. 4.f). On the external side, well impressed growth cycles are present with robust non-protruding costae (Fig. 4.a-b, d). Growth cycles are well impressed also interiorly, in the inner shell of elongated specimens, from which the outer shell layer has spalled away (Fig. 4.e). The radial bands are on indented folds producing smooth sinuses (Fig. 4.a-b, g). The ligament ridge is well marked and projected towards the ventral side (Fig. 4.e-g).

Discussion: This fossil material was described as *Radiolites* cf. *peroni* by PARONA (1917, 1928). *Radiolites peroni* was considered as a distinct species but only differs from *Radiolites lusitanicus* by the number of folds in the interband, which is variable and not a distinctive character (STEUBER, 1999). For this reason and the common occurrence of both species in the same stratigraphic interval (PEJOVIC, 1957; BERTHOU, 1973; STEUBER, 1999) led STEUBER (1999) to consider *R. peroni* a junior synonym of *R. lusitanicus.* More fossil material close to the type locality in Portugal has been recently described, with a shell structure marked by well differentiated lamellar sets interiorly inclined with regular, well developed, small costae, externally barely visible radial bands and normal cells passing locally to very elongate cells from the inner towards the external part of the outer shell layer (TROYA-GARCÍA, 2016).

Due to the poorly preserved morphostructural features of the studied material, a definite attribution of this fossil material to this species is not possible due to: (a) the notable presence of compact structure together with the normal cellular structure of growth lamellae sets (Fig. 4, inset g'), (b) the ligament ridge that is more projected toward the inner cavity in our material with respect to the material described by TROYA-GARCÍA (2016), and (c) the unclear organization of radial bands. Despite this, we have no sufficient data to refute the original determination by PARONA, thus we stand on its attribution, updated to modern taxonomy (*e.g.*, STEUBER, 1999).

R. lusitanicus has a broad geographical distribution, being reported from both the southern and northern margins of Neotethys, and from Portugal to the Mediterranean area, Middle-East, Afghanistan and western Tibet (*e.g.*, CHOFFAT, 1886; DOUVILLÉ, 1910; PARONA, 1917, 1928; STEUBER, 1999; STEUBER & LÖSER, 2000; EL HEDENY, 2007). Originally described as a Turonian species, its stratigraphic range is between the late Cenomanian and the Coniacian (STEUBER, 1999; EL HEDENY, 2007; ZAKHERA, 2011).

Original determination (PARONA, 1928): *Radiolites* sp.

Several specimens, mainly fragments, in the collection were described by PARONA (1928) as *Radiolites* sp. (Table 2). Most of the material shows no diagnostic characters, and its determination is thus left as *Radiolites* sp. *sensu* PARONA (1928). But some distinction is made between two groups of specimens that show different characters. Note that register numbers can be repeated because different taxa can be found in the same polished slab.

Radiolites sp. 1

(Fig. 5.a-e)

Material: Several poorly preserved right valves and fragments (IGF 103253, 103254, 103255, 103256, 103257, 103259, 103264, 103265, 103266, 103267, 103269, 103944, 103946, 103947).

Locality: Kizil 2; beyond Kizil 2.

Inferred formation: Xiloqzung/Litian/Dongloqzung Fm.

Age: ? Turonian to ? Campanian

Description: Only right valves, commonly in the form of inner shell fragments, from which the outer shell layer has spalled away, have been studied. Shape is conical to low cylindrical, with well-developed growth cycles (Fig. 5.a-b). Shell is marked by growth lamellar sets with both compact and normal cellular structure (Fig. 5.c-d), with this last more developed on the dorsal side.

Discussion: This material differs from other specimens by its elongate cylindrical shape and the dominant compact structure (Fig. 5.e), which contrasts to the cellular structure of *Radiolites* sp. 2.
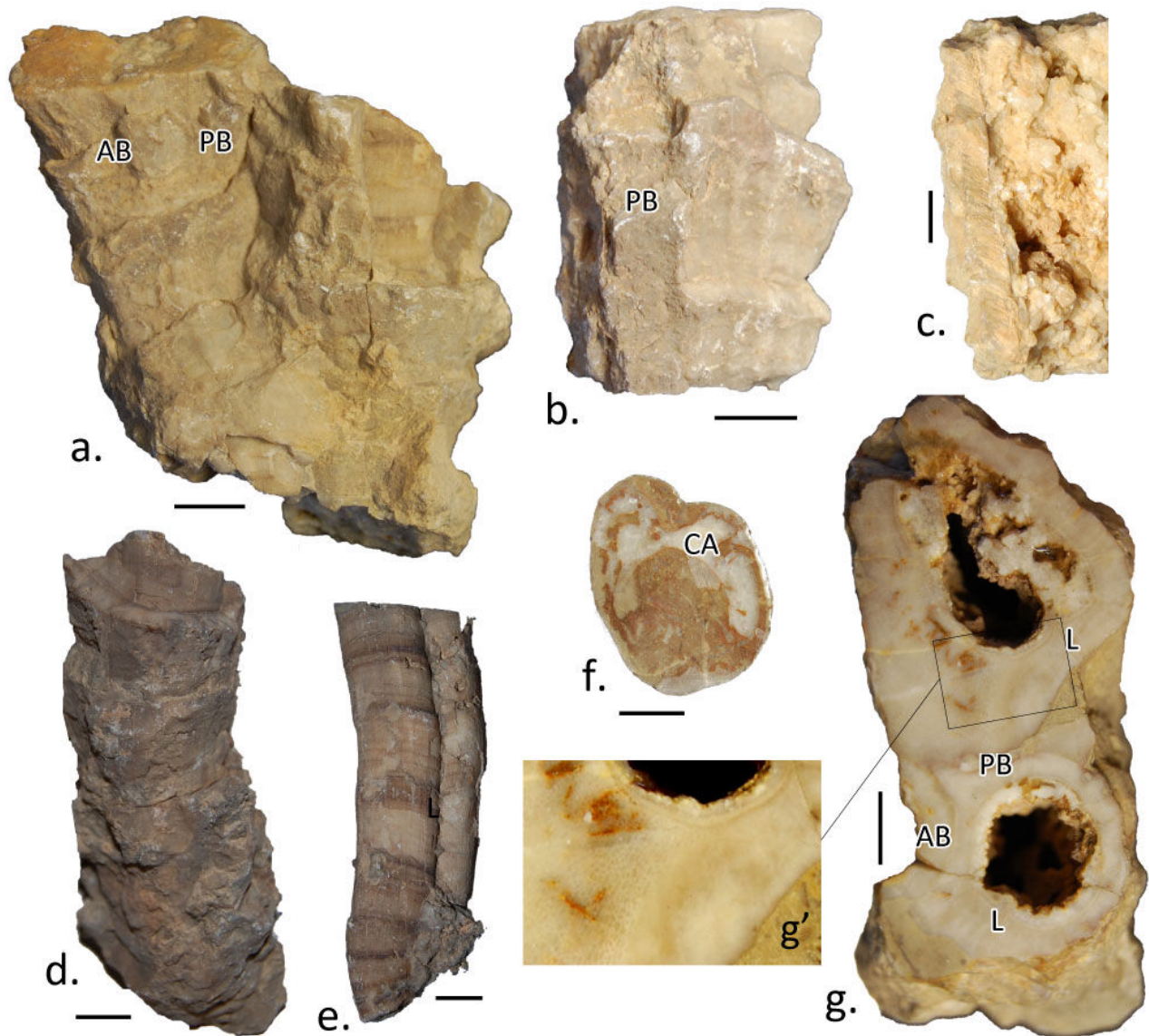
Radiolites sp. 2

(Fig. 5.f-g)

Material: Few poorly preserved right valves and fragments (IGF 103253, 103254, 103254B, 103267).

Locality: Kizil 2; beyond Kizil 2.

Inferred formation: Litian/Dongloqzung Fm.

Age: ? Campanian

Description: Only right valves have been studied; shell form is conical to low cylindrical, structure of growth lamellar sets is normal cellular with large cells more developed in the thicker dorsal side with short ligament ridge (Fig. 5, inset f'), whereas it is compact in the thinner antero-ventral side, where the radial structures are marked by slightly developed folds (as in 103267, Fig. 5.f-g).

Figure 4: *Radiolites* aff. *lusitanicus* (ex cf. *peroni* in PARONA, 1928). (a) IGF103260 (figured as *R*. cf. *peroni* by PARONA, 1928, Pl. 16, fig. 2), two joined specimens in lateral view. (b, c) IGF 103261, lateral dorsal view and longitudinal section (showing slightly inclined growth lamellae sets) of right valve, respectively. (d) IGF103260, lateral dorsal view of right valve. (e) IGF 103263, dorsal view of right valve, only a thin layer of inner shell preserved, with well impressed growth cycles and invaginated ligament ridge. (f) IGF 103261, transverse section of right valve. (g, g') IGF 103258, transverse section of two right valves with detail of the outer shell layer with normal cellular (left) and compact (right) structure in inset f'. Scale bars = 1 cm.

Discussion: This material differs from the other group by its cylindro-conical shape, the dominant normal cellular structure (Fig. 5.f-g) and radial band organization.

Besides these two groups, other material originally described as *Radiolites* sp. has been tentatively assigned to different taxa.

Gorjanovicia cf. *endrissi* (BOEHM, 1927)

(Fig. 6.a)

Material: IGF 103945, 103947

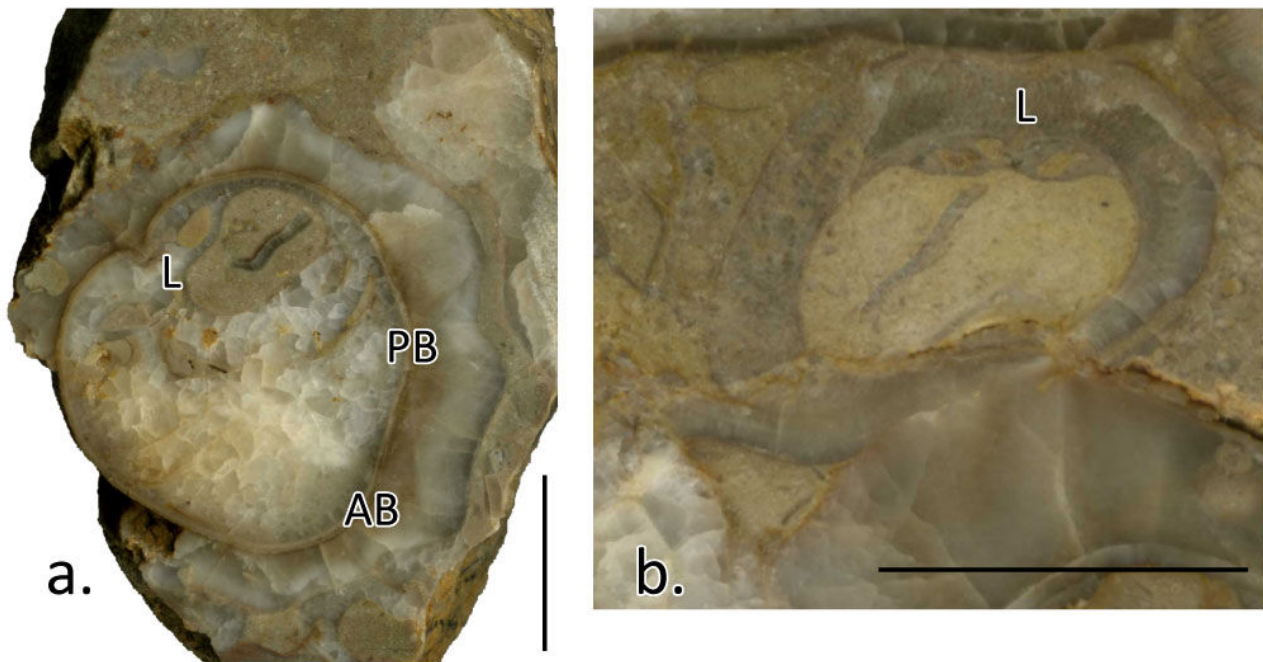Locality: beyond Kizil 2

Inferred formation: Dongloqzung Fm.

Age: Campanian

Description: Two transverse sections of right valves are characterized by a thick compact outer shell layer; radial bands are marked by slightly developed folds with a slight external central indentation of the AB, which is separated from the PB by a narrow interband; a thin triangular ligamentary infolding is also present (Fig. 6.a).

Discussion: The radial bands organization, the thick compact outer shell and the ligamentary infolding suggest a similarity of our specimens to *Gorjanovicia endrissi* as described by FENERCI-MASSE *et al.* (2011). The lack of any well-preserved material only allows an uncertain attribution to *Gorjanovicia* cf. *endrissi*.
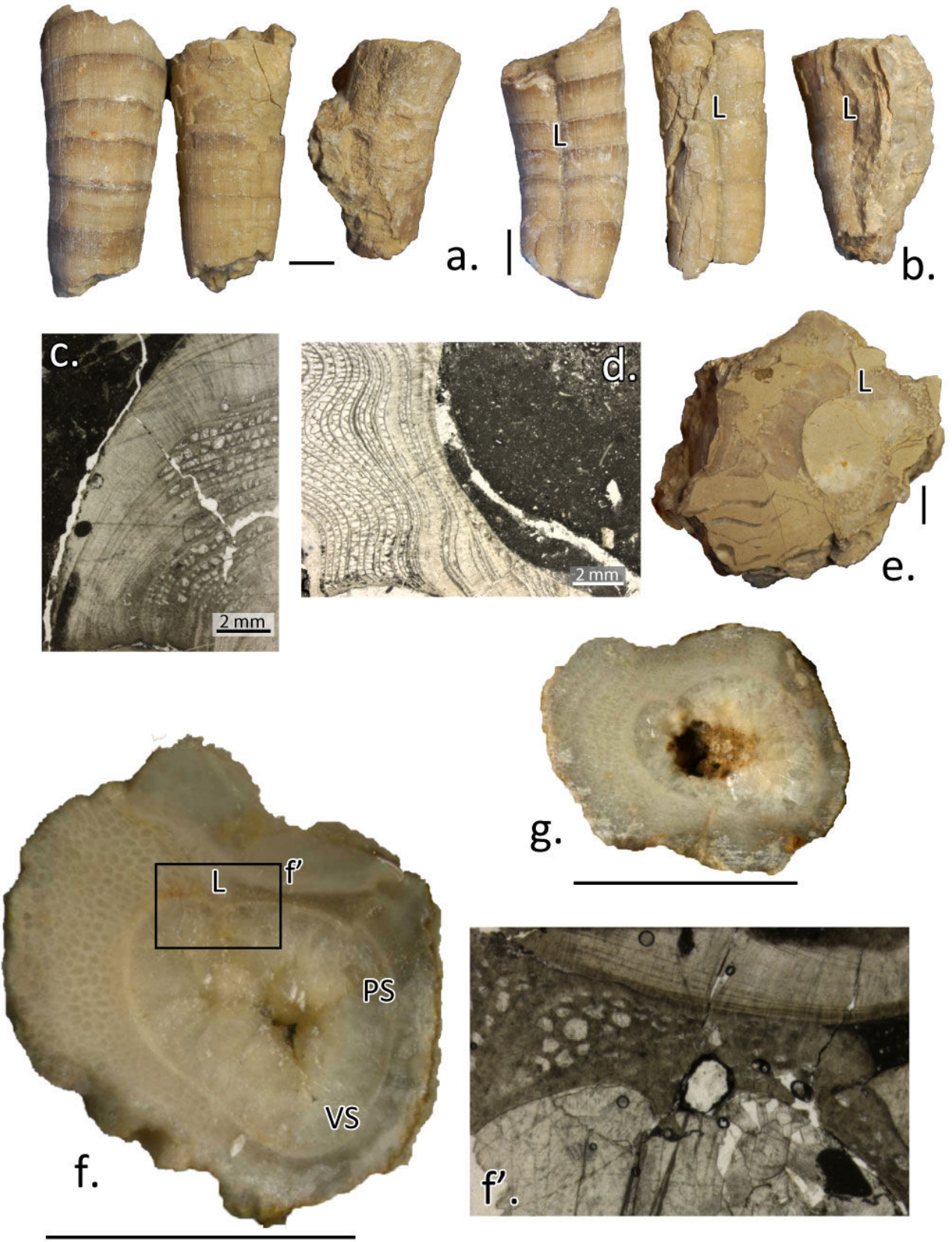
Figure 5: *Radiolites* sp. (a, b) IGF103265, ventral and dorsal views, respectively of elongate specimens, only a very thin layer of the inner shell is preserved, with well impressed growth cycles and invaginated ligament ridge. (c, d) IGF103267 and IGF 103269 respectively, thin sections of the outer shell showing growth lamellar sets with both compact and normal cellular structures. (e) IGF103267, transverse section of the right valve showing dominant compact structure. (f, g) IGF103267, transverse sections of right valves showing normal cellular with well-developed cells in the dorsal side and short ligament ridge (inset f'). Scale bars = 1 cm.

Figure 6: (a) IGF103267, Transverse section of the right valve of *Gorjanovicia* cf. *endrissi*. (b) IGF 103947, transverse section of the right valve, juvenile stage, of ? *Sauvagesia* sp. Scale bars = 1 cm.

? *Sauvagesia* sp.

(Fig. 6.b)

Material: IGF 103947

Locality: beyond Kizil 2

Inferred formation: Dongloqzung Fm.

Age: Campanian

Description: Another taxon previously assigned to *Radiolites* sp. is a single specimen cut in a polished section from a rock slab (IGF 103947). The transverse section of the lower (right) valve, juvenile stage, shows a sub-rounded external perimeter and thick outer shell layer composed of growth lamellar sets with normal cellular structure. Ligament ridge is present and delimiting an undeveloped cardinal apparatus, at the edge of the dorsal side (Fig. 6.b).

Discussion: Although determined by a well-preserved single specimen, the polished slab reveals a shape and structure that could be possibly assigned to *Sauvagesia* sp. by the characteristic small cells of the cellular shell structure.

Original determination (Parona, 1917): *Radiolites indicus* (Stoliczka)

Sphaerulites sp.

(Fig. 7.a-d)

Material: 1 right valve (IGF 103268)

Locality: beyond Kizil 2

Inferred formation: Xiloqzung Fm.

Age: ? Turonian-? Coniacian (for its occurrence in association with *R.* cf. *lusitanicus*).

Description: This single specimen of the collection consists of a large right valve (up to 200 mm in diameter) partly deformed and broken on the ventral side (Fig. 7.a). The shell is cylindro-conical, at least 35 cm high, the right (lower) valve is very thick in the antero-dorsal side (up to 80 mm) with a wide radial, down-and-outward fold separating two badly preserved radial structures (Fig. 7.a). Shell is composed of growth lamellar sets with normal cellular structure and cells commonly are elongate in the outer part, where lamellar sets are downfolded (Fig. 7.a, c-d) giving rise to a foliaceous aspect. Growth cones cannot be observed in the outer surface as it is eroded and badly preserved. Ligament ridge is robust at the base (Fig. 7.b), presumably with a long pedicle. Left valve is absent.

Discussion: The specimen was assigned to *Radiolites indicus* by Parona (1917), but the few preserved features suggest a different assignment to the genus *Sphaerulites*. The shell structure is marked by growth lamellar sets with normal cellular structure composed of elongate cells. The radial bands, although not clearly visible, are separated by a typical main fold in between them. The cellular structure differs slightly from the radial, essentially discontinuous ridges of the cellular structure typical of *Sphaerulites* (*e.g.*, Troya-García, 2016). The poorly preserved features and the scarcity of material do not allow a specific assignment, but we consider invalid the generic emendation by Parona, due to the analyzed characters, which led us to assign this specimen to *Sphaerulites*, rather than to *Radiolites*.
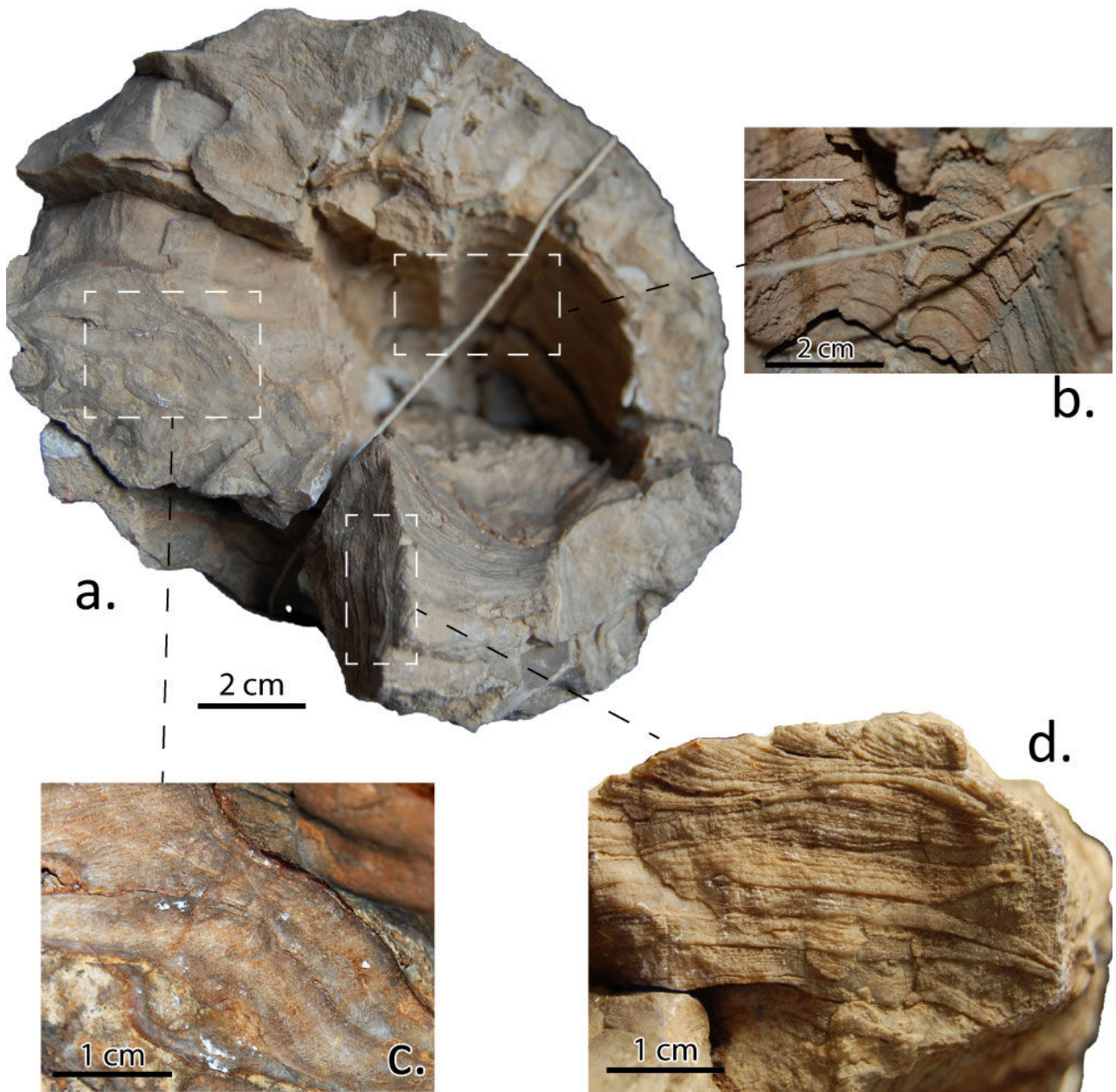
Figure 7: *Sphaerulites* sp. (a) IGF103268, conical shaped specimen seen from above showing thick ligament ridge; in the ventral side the presumably position of the radial bands is separated by an upward fold. (b) IGF103268, internal view of growth cycles and robust ligament ridge. (c) IGF103268, growth lamellar sets with normal cellular structure characterized by elongated cells. (d) IGF103268, side view of sub-horizontal and downfolded lamellae sets projecting laterally in grain-supported sediment.

Sphaerulites indicus is a species not commonly reported in the scientific literature. It was established by STOLIZCKA (1871) from specimens in Upper Cretaceous brownish marly limestone at Odium (NW from Ottakkovil) south-east India. DOUVILLÉ (1910) suggested that *S. indicus* was similar to *R. peroni*, but he did not emend the taxon, and he noted that the figures by STOLIZCKA and the quality of the material was poor. *S. indicus* was then described as *Radiolites indicus* by PARONA (1917) and listed in KÜHN (1932) and SANCHEZ (1981). Our unique specimen and the sectioning limitations do not allow a better taxonomic redescription that could result in a definite specific determination. Only few species are currently assigned to genus *Sphaerulites*, and *S. indicus* is not included (as in TROYA-GARCÍA, 2016). Due to the scarce reports and poor quality of the mate-

rial, *S. indicus* would be possibly an invalid taxon. In addition, the hypothetical geographical distribution of the species should oddly be limited only to southeastern India and, eventually, the Aksai Chin area. These issues led us to consider, that if the species is valid, its actual occurrence in the Himalayan area is very dubious, and thus we assign our specimen to *Sphaerulites* sp.
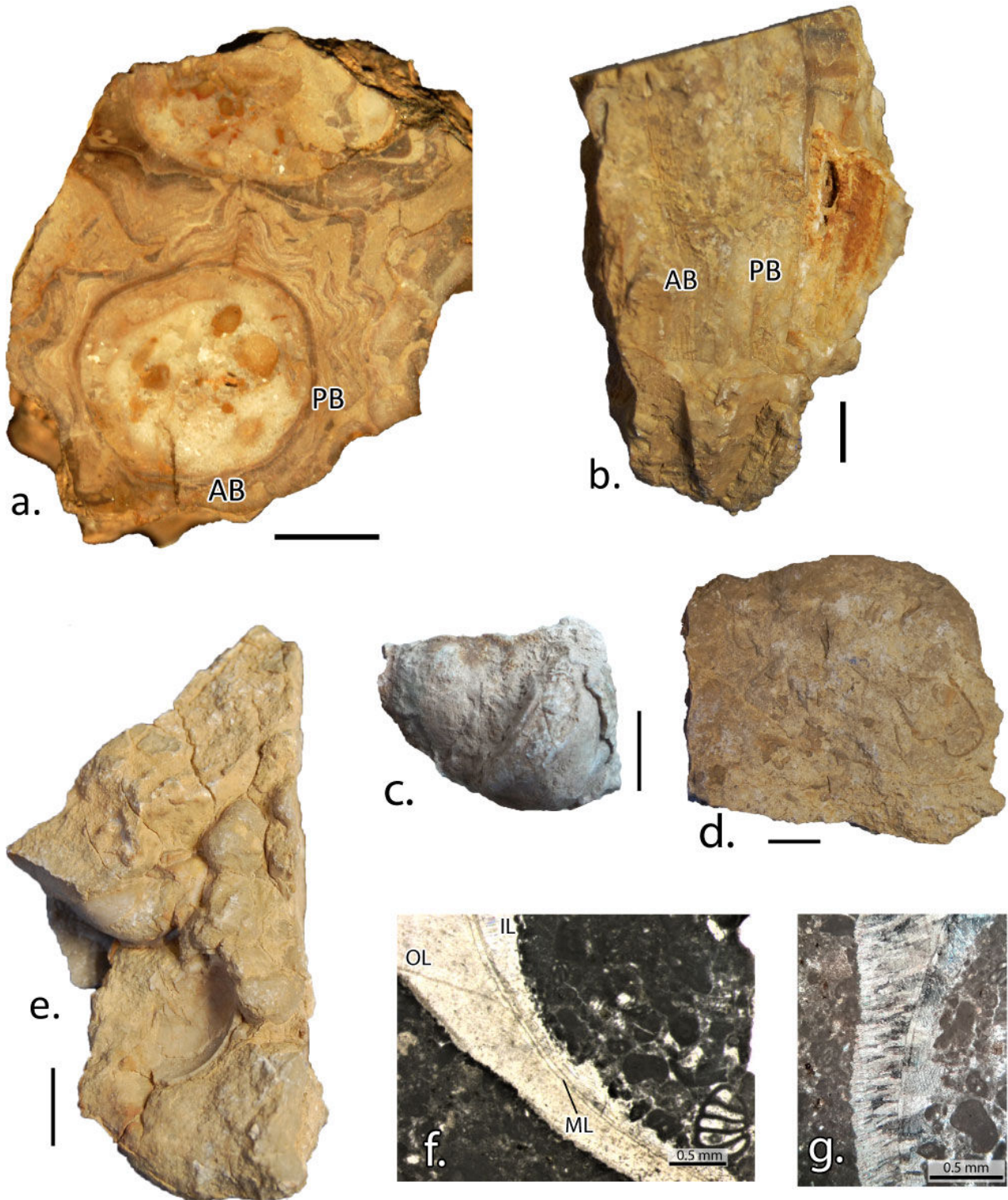
Original determination (PARONA, 1928): *Durania mutabilis* (STOL.)

Durania sp.

(Fig. 8.a-b)

Material: 1 almost complete right valve, 1 broken and weathered right valve, 1 fragment of right valve (IGF 103256, 103270).

Locality: beyond Kizil 2

Figure 8: (a, b) *Durania* sp., IGF103270, (a) transverse section of right valve showing well developed folds and radial bands ; (b) ventral view of a right valve of *Durania* sp. showing ribs corresponding to the radial bands (figured by PARONA, 1917, p. 135). IGF103270. (c-g) *Gyropleura* sp., (c) IGF 103943, ventral view of a single spirogyrate valve; (d) IGF 103942, fragments of made of compact calcite structure, embedded in grain-supported limestone; (e) IGF 103252, bouquet of several spirogyrate valves of *Gyropleura* sp.; (f) IGF103942, thin section of a shell fragment: outer shell layer (OL) is made of compact calcite lamellar sets, a very thin middle shell layer (ML) separate it from the inner shell layer (IL) made of white neomorphic calcite substituting the original aragonite. Scale bars 1 cm. (g.) IGF103942, same shell fragment shown in (f) with crossed polars, showing calcite crystals oriented perpendicular to the growth lines, typical of rudists.

Inferred formation: Xiloqzung

Age: ? Turonian-? Coniacian (for its occurrence in association with *R.* cf. *lusitanicus*)

Description. Although the material is not well preserved, the few specimens have an elongate cylindrical shape (Fig. 8.b) and well-developed

growth laminar sets with normal cellular structure (Fig. 8.a). The radial bands have growth laminar sets that are concave in radial section and they are marked externally by a dozen thin costellae (Fig. 8.b) separated by a protruding main inter-band fold. Well-developed folds form external costae; no ligament ridge has been detected.

Discussion. The studied material was first described as *Durania* f. ind. (cf. *D. arnaudi* (CHOFF.)) by PARONA (1917) and then as *Durania mutabilis* (STOL.) by PARONA (1928), who erroneously placed *Radiolites mutabilis* STOLICZKA in "*Durania mutabilis*". However later *R. mutabilis* was reassigned to *Bournonia mutabilis* by DOU-VILLÉ (1910), which is reported in the Maastrichtian Ottakkovil Fm. of southern India (MOHANTI & PONS, 1999; DIHMAN *et al.*, 2019). Except for the papers by PARONA, "*D. mutabilis*" was no longer cited in the palaeontological literature (with the only exception of a paper by MORRIS & SKELTON (1995), who considered *D. mutabilis* as a senior synonym of *D. gaensis*), and is considered the result of an erroneous taxonomic attribution by PARONA. The described specimens can be, therefore, determined only at the generic rank, as *Durania* sp.

Family Monopleuridae
(MUNIER-CHALMAS, 1873)

Gyropleura sp. (Fig. 8.c-g)

Material: 4 rock samples with several specimens embedded in limestone matrix, some thin section has been performed (IGF 103252, 103942, 103943)

Locality: Kizil 2

Inferred formation: Dongloqzung Fm.

Age: Campanian

Description: Small (< 20 mm) spirogyrate valves (Fig. 8.c, e), difficult to study in terms of shell structures and morphostructural analysis. A thin section performed on the whole rock has shown shell fragments made of plano-parallel growth laminar sets with compact calcite in the outer shell layer and the inner layer made of neo-morphic calcite, in some case showing the middle layer, aragonitic in origin (Fig. 8.f-g).

Discussion: *Gyropleura* is a monopleurid rudist represented by few samples in the studied collection. The specimens described as *Gyropleura cenomanensis* by PARONA (1917) are difficult to determine at specific rank, being small and embedded in the rock (Fig. 8.d-e) and not showing any distinctive character. For this reason, nothing can be added in a paleontological point of view. It is worth noting that when morphostructural analyses can be performed only with difficulty, specific attribution is easily erroneous. Similar spirogyrate rudists occur beginning in the Aptian and up to the end of the Cretaceous (STEUBER *et al.*, 2016). The studied specimens are associated with a Campanian microfossil assemblage and are considered as *Gyropleura* sp.

Age and stratigraphic considerations

Rudists

Comparing the original sedimentological description of the succession, which yielded the studied material (as said, collected more than one century ago in an inaccessible area, DAINELLI, 1933-1934), with the recently assessed stratigraphic setting of the area (WEN *et al.*, 2000a, 2000b), we infer that the rudist beds represented in the collection belong to the Tielongtan Group.

The lower part of the Tielongtan Gp. (Xiloqzung Formation) is Turonian-Coniacian *p.p.* according to WEN *et al.* (2000a, 2000b). The older rudists determined at generic rank by WEN *et al.* (1998, 2000a, 2000b) in the Xiloqzung Fm. were considered as Turonian, by the occurrence of *Vaccinites*, *Bournonia* and other taxa (Table 1), which ruled out the hypothesis of a Cenomanian age.

Cenomanian and Turonian beds bearing *Eoradiolites hedini*, *Sauvagesia garianica* and *Hippurites* aff. *requieni* were noted by DOUVILLÉ (1916) and KLINGHARDT (1934), who studied samples collected by S. HEDIN and H. DE TERRA (Table 1), respectively. Nevertheless, the stratigraphic range of *E. hedini* and *Sauvagesia garianica* being not well constrained, and *H. requeni* definitely a Turonian taxon, these occurrences have to be considered as most likely Turonian.

As we have already discussed, age determinations by PARONA (1917, 1928), who ascribed the studied rudist fauna to the upper Cenomanian-Turonian, are not reliable. The age of the older rudist assemblage of our material (*R.* cf. *lusitanicus*, *Durania* sp., *Sphaerulites* sp., *Radiolites* sp. 1) is not well-constrained as well, but the occurrence of *Radiolites* cf. *lusitanicus*, which is a Cenomanian-Coniacian taxon (STEUBER, 1999), is significant, whereas other taxa only determined at generic rank do not provide any additional information, being *Durania* and *Radiolites* Albian-Maastrichtian genera, and *Sphaerulites* a Cenomanian-Campanian genus (STEUBER *et al.*, 2016).

The Turonian-Coniacian *p.p.* age of the Xiloqzung Fm. is fully consistent with the stratigraphic distribution of *Radiolites lusitanicus* and is thus inferred for the rudist-bearing beds of the succession characterized by its occurrence, which should belong to the Xiloqzung Fm.

Ages younger than the Coniacian were inferred in the literature and confirmed by analyzing the studied material. The rudist assemblages of the Litian Formation, composed of *Lapeirousia*, *Hippurites*, *etc.* determined by WEN *et al.* (1998, 2000a), were considered as being approximately Santonian but the lack of specific determinations does not allow a greater precision of stratigraphic attribution. Our material provided no additional data regarding this unit.
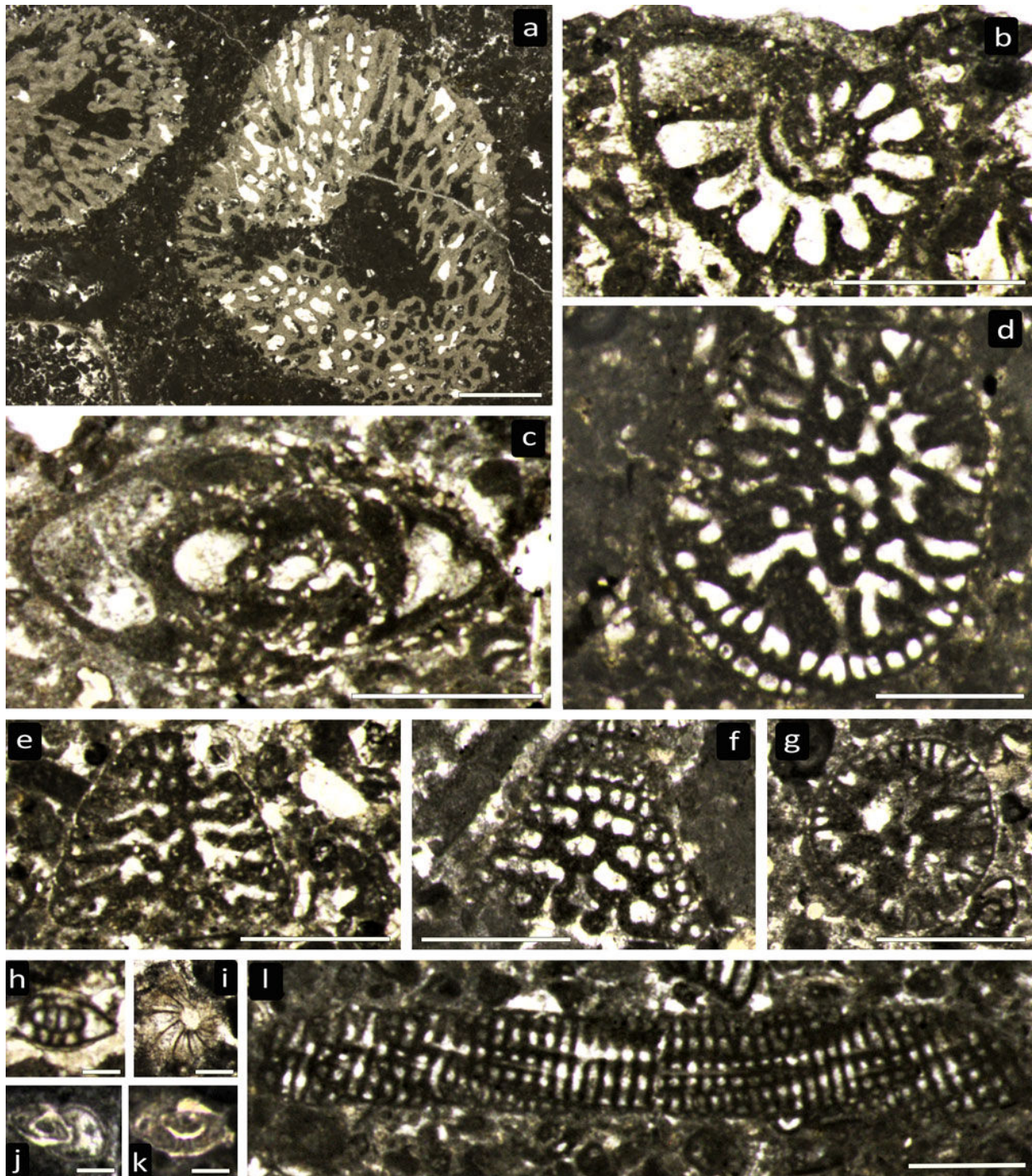
Figure 9: Chronostratigraphically important benthic Foraminifera and stromatoporoids recovered from the matrix of the rudist specimens. (a) IGF 103944, *Sarmentofascis zamparelliae* SCHLAGINTWEIT *et al.*. Scale bar 2 mm. (b) IGF 103269, *Nezzazatinella* sp. Scale bar 0.5 mm. (c) IGF 103264, *Navarella* sp. CIRY & RAT. Scale bar 0.5 mm. (d, f) IGF 103942 and 103946, *Calveziconus lecalvezae* CAUS, basal and longitudinal sections respectively. Scale bar 0.5 mm. (e, g) IGF 103264 and 103946, Orbitolinidae gen. ind. Scale bar 0.5 mm. (h, i) IGF 103269, *Murgeina apula* (LUPERTO SINNI). Scale bar 0.1 mm. (j, k) IGF 103942, *Cibicidoides* sp. Scale bar 0.1 mm. (l) IGF 103942, *Dicyclina schlumbergeri* MUNIER-CHALMAS. Scale bar 0.5 mm.

The upper part of the Tielongtan Gp. is represented by the the Dongloqzung Fm.; the occurrence of Lapeirousinae, which did not appear until Santonian, and *Praeradiolites*, *Bournonia*, *etc.* (Table 1), which appeared slightly earlier but extended into Maastrichtian, led WEN *et al.* (1998, 2000a, 2000b) to infer a mainly Campanian or possibly Maastrichtian age.

Some of the studied rudists have been referred to this unit (*Gorjanovicia* cf. *endrissi*, ? *Sauvagesia* sp., *Radiolites* sp., *Gyropleura* sp.) with the only exception of *G.* cf. *endrissi*, which is essentially a Campanian taxon (FENERCI-MASSE *et al.*, 2011), other taxa do not provide any additional information, but their age has been constrained based on micropaleontological analysis (see below).

Benthic Foraminifera

Along with the study of rudist assemblages, micropaleontological analyses performed through thin sections on the rock matrix embedding the rudist specimens revealed the occurrence of some stratigraphically relevant foraminifers, which provide important information on the temporal position of the samples.

The carbonate matrix embedding *Radiolites* sp. is represented by a bioclastic packstone-wackestone and subordinate floatstone (Figs. 9.a, 10.k), with *Dicyclina schlumbergeri* MUNIER-CHALMAS (Fig. 9.l), possible *Murgeina apula* (LUPERTO SINNI) (Fig. 9.h-i), possible *Navarella* CIRY & RAT (Fig. 9.c), a possible *Nezzazatinella* sp. (Fig. 9.b), and a probable specimen structurally close to a macrospheric ? *Keramosphaerina* STACHE (Fig. 10.i). We have observed three features supporting the identification of *Navarella* (Fig. 9.c): 1) the microgranular shell texture; 2) the accumulation of coarse carbonate grains over the outer shell surface, and 3) the streptospiral arrangement typical of *Navarella*. The geometry of chambers over the central area of the cross section suggests a degree of involution rather than a perfectly symmetrical disposition of lumens that, in a planispiral geometry, should appear on both sides. Regarding ? *Keramosphaerina* sp. (Fig. 10.i), another possible identification may be a microspheric *Hellenalveolina* (HOTTINGER *et al.*, 1989). That species, however, has more distinctly streptospiral chambers than our specimen. Furthermore, the proloculus size is substantially smaller than that of a megalospheric *Hellenalveolina*. Moreover, *Hellenalveolina* seems geographically restricted into the Upper Cretaceous of Europe. Having a look at the initial chambers of *Keramosphaerina* in DEVOTO (1964) we have found a close match. Anyway, due to the scarcity of material at our disposal we prefer keeping this identification under open nomenclature. The identification of *Murgeina apula* (see CHIOCCHINI *et al.*, 2012) is supported by the thickly calcified umbos on both sides of the test. *Nezzazatinella* sp. can be linked to the Santonian taxon figured by CHIOCCHINI *et al.* (2012) as *N. picardi*, but a more specific taxonomic designation is hampered by the lack of diagnostic sections.

This western Tibetan foraminiferal assemblage is also known in the western Neotethys where it ranges from upper Santonian to at least middle Campanian (RADOIČIĆ *et al.*, 2010; FRIJIA *et al.*, 2015; CONSORTI *et al.*, 2017); this age is attributed to the Litian and Donglozung formations.

The packstone matrix embedding *Gyropleura* sp. contains, along with other abundant undetermined microfossils, the stromatoporoid *Sarmentofascis zamparelliae* SCHLAGINTWEIT, FRIJIA & PARENTE (Figs. 9.a, 10.k), *Calveziconus lecalvezae* CAUS (Figs. 9.d, f, 10.a, d), a small and high-conical agglutinated foraminifer closely resembling the Orbitolinidae gen. ind. in LUPERTO SINNI & RICCHETTI (1978: Pl. 43, figs. 3, 7), *Cuneolina* sp., (Fig. 10.e) and *Cibicidoides* sp. (Fig. 9.j-k). In particular, the identification of *Calveziconus lecalvezae* is supported by its subepidermal network formed by two orders of beams and rafters, and by radial undulated septula. Orbitolinidae gen. ind. (Figs. 9.e, g, 10.b) lacks the second order of beams. Their occurrence in such levels is justified by LUPERTO SINNI & RICCHETTI (1978) as well, who found some strictly comparable forms in the Upper Cretaceous carbonates of southern Italy, and in co-assemblage with *Calveziconus*. Their identification should be accompanied by a close taxonomical analysis, likely resulting in the description of a new taxon, which falls beyond the scope of the present contribution. This foraminiferal assemblage, if correlated with the European records, suggests an age ranging between the lower and the middle Campanian. This age of the European assemblage is firmly constrained by the Strontium Isotope Stratigraphy studies made through the levels bearing *Calveziconus lecalvezae* (STEUBER *et al.*, 2005; FRIJIA *et al.*, 2015; VILLALONGA *et al.*, 2019) and *Sarmentofascis zamparelliae* (SCHLAGINTWEIT *et al.*, 2016). *Cibicidoides* sp. is commonly recorded in the Maastrichtian (CONSORTI & RASHIDI, 2019) and the lower Paleocene (see *Gavelinellidae* indet. in SERRA-KIEL *et al.*, 2020), but its stratigraphic range would widen into older or younger levels, thus limiting its biostratigraphic potential. Besides giving critical and more detailed stratigraphic information on the Tibetan rudists, this assemblage allows us to definitely consider that the rudist-bearing facies of the Tielongtan Gp. extends up to, at least, the middle Campanian.

Comparison of the Aksai Chin fauna with other Neotethys faunas

Rudist faunas from the Himalaya-Karakorum-Tibet range and the Tarim basin are known from the late Aptian and are well-developed into the Maastrichtian (LAN & WEI, 1995; WEN *et al.*, 1998; SCOTT *et al.*, 2010; RAO *et al.*, 2015, 2017, 2020; SHA & CESTARI, 2016; RAO, 2019).

SCOTT *et al.* (2010) reported 36 genera and 44 species occurring in the region in the Albian-Maastrichtian interval. Most of the taxa were considered endemic and only 10 species were considered as being cosmopolitan.

In particular, the uppermost Lower Cretaceous Langshan Formation and the Upper Cretaceous Tielongtan Group of Lhasa, Qiantang and Tianshuiai terranes and the Tarim basin, yielded rich rudist faunas (WEN, 1998; WEN *et al.*, 1998; SCOTT *et al.*, 2010). The genera determined from the Langshan Fm. include *Monopleura*, *Auroradiolites*, *Eoradiolites*, *Requienia*, *Magallanesia*, *Sellaea*, and *Toucasia* (SCOTT *et al.*, 2010; RAO *et al.*, 2015, 2017). Differently, the Upper Cretaceous Tielongtan Group yielded a fauna dominated by warm, shallow-water Tethysian rudists, such as *Hippurites*, *Vaccinites*, *Praeradiolites*, *Biradiolites*, *Durania*, *Sauvagesia*, *Distefanella*, and *Lapeirousia*, among others. They are more abundant and diverse than rudists of the Himalaya, Shiqunhe-
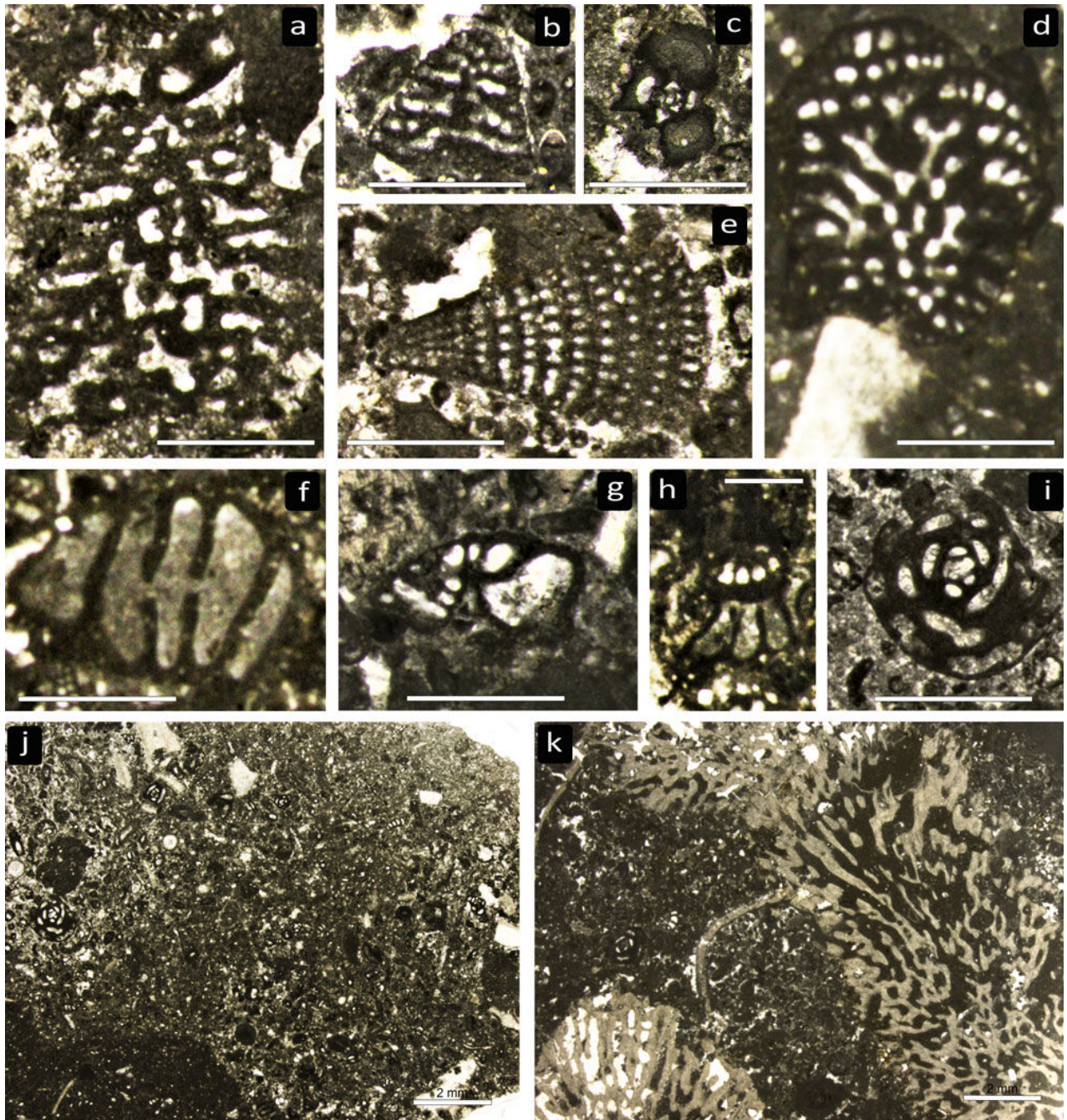
Figure 10: Benthic Foraminifera and facies of the matrix of rudist specimens. (a, d) IGF 103269; 103943, *Calveziconus lecalvezae* CAUS. Scale bar 0.5 mm. (b) IGF 103269, Orbitolinidae gen. ind. Scale bar 0.5 mm. (c) IGF 103264, Thick-shelled undetermined miliolid. Scale bar 0.5 mm. (e) IGF 103269, *Cuneolina* sp. Scale bar 0.5 mm. (f, g) IGF 103942; 103946, *Nezzazatinella* sp. Scale bar 0.5 mm. (h) IGF 103942, *Nezzazatinella* sp. scale bar 0.25 mm. (i) IGF103254, megalospheric ? *Keramosphaerina* sp. Scale bar 1 mm. (j) IGF 103254, Packstone facies rich in miliolid foraminifers. Scale bar 2 mm. (k) IGF 103944, floatstone with *Sarmetofascis zamparelliae*. Scale bar 2 mm.

Xainza (Southeastern Tethys) and southwestern margin of the Tarim Basin (Northeastern Tethys) (WEN, 1999; SCOTT *et al.*, 2010). In the Kunlun terrane and Tarim Basin, Late Cretaceous rudists are *Biradiolites*, *Gyropleura*, *Lapeirousella*, *Osculigera*, and *Sauvagesia* (LAN & WEI, 1995; WEN, 1999; RAO, 2019).

The rudist fauna of the Aksai Chin in the Tielongtan Group is not rich and has low variability compared with published data. In addition, it is similar in terms of age with the Western Tarim fauna (Yigeziya and Wuyitake formations) described by LAN & WEI (1995) such as the Campanian age of *Gyropleura* beds.

The taxa described in this paper should be considered cosmopolitan; in particular *Radiolites lusitanicus* and *Gorjanovicia endrissi* are known from most of the Tethysian realm (Fig. 11).

Radiolites indicus (sensu PARONA*)*, as said, is considered an invalid taxon and is useless for paleogeographic considerations. *Gyropleura* sp., *Praeradiolites* sp., *Sphaerulites* sp., *Sauvagesia* sp., *Durania* sp., and *Radiolites* sp. provide no further information on their distribution pattern,
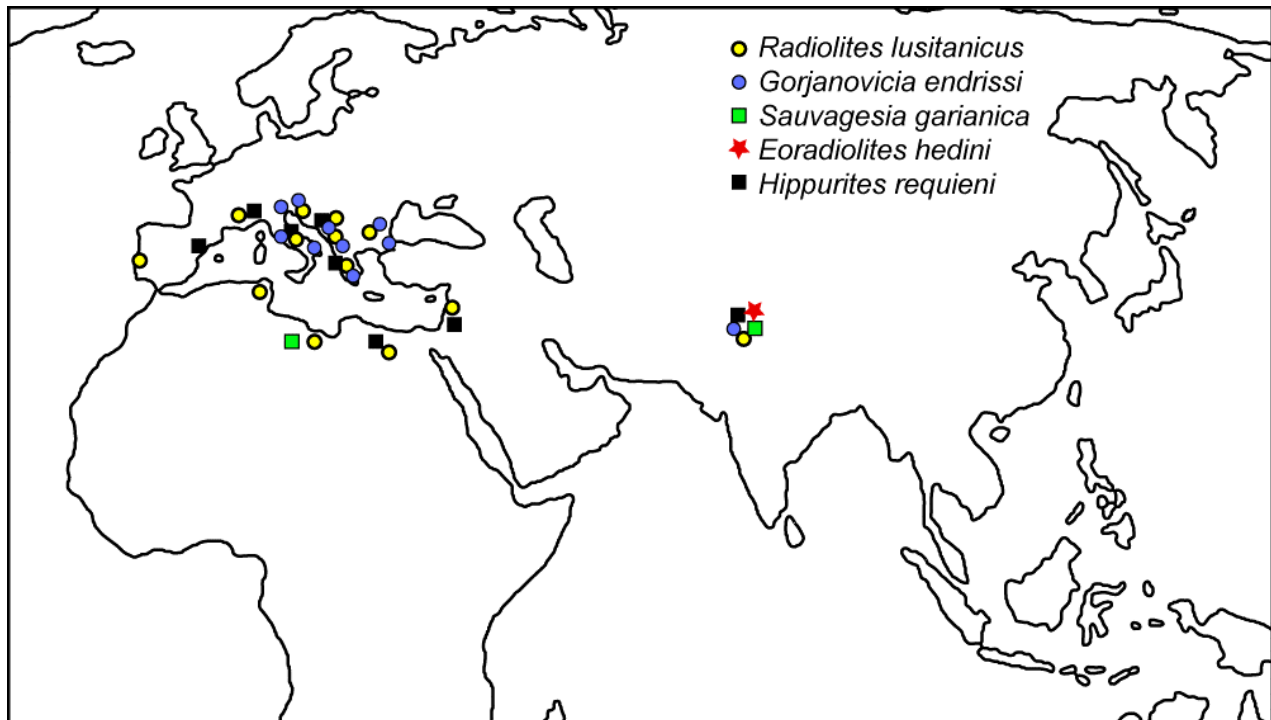
Figure 11: Geographical distribution of the rudist species from the Western Loqzung Mountains discussed in this paper.

not being determined at specific rank. Along with the described rudists, also the Turonian *Sauvagesia garianica* and *Hippurites* aff. *requieni* described by KLINGHARDT (1934) are considered as cosmopolitan taxa, the first having been found in the Aksai Chin, Lybia and Tunisia (PARONA, 1921; BUSSON, 1967), and the second being a common taxon of both the northern and southern margins of Neotethys (*e.g.*, CESTARI & SARTORIO, 1995; STEUBER & LÖSER, 2000).

In contrast, the Albian - Cenomanian rudists *Auroradiolites gilgitensis* (= *Eoradiolites gilgitensis*) and *Eoradiolites hedini* (= *Praeradiolites hedini*) described by MATTE *et al.* (1996) and DOUVILLÉ (1916) are considered as endemic taxa (RAO *et al.*, 2015), being only known from the northeastern margin of the Neotethys (Fig. 11).

No further paleobiogeographic consideration can be done regarding the rudist assemblages described by WEN *et al.* (1998, 2000a, 2000b), being only generic determinations of cosmopolitan genera, except for *Rhedensia*, which is not a valid genus according to STEUBER *et al.* (2016) and *Distefanella*, which is a radiolitid with an extremely elongate shell whose occurrence is limited to the central Mediterranean Tethys (CESTARI *et al.*, 2018).

The Aksai Chin rudist assemblage should belong to the Southwestern Asian assemblage of the Eastern Mediterranean subprovince, as defined by KAUFFMAN (1973) and SCOTT *et al.* (2010).

Concerning benthic foraminifers and Demospongiae, the specimens identified in the studied microfacies show strong affinities with that known in the shallow-water deposits of central-western Neotethys including the central and southern Apennines (Italy: FRIJIA *et al.*, 2015; SCHLAGINTWEIT *et al.*, 2016; CONSORTI *et al.*, 2017), Dinarides (Croatia: STEUBER *et al.*, 2005), Apulian platform (Italy: LUPERTO SINNI & RICCHETTI, 1978) and southeastern Pyrenees (northeast Spain: VILLALONGA *et al.*, 2019, among others). It is thus affirmed that during the Campanian a biogeographic connection, represented by foraminifers and Demospongiae, was established between the Tibetan and Mediterranean areas. The confidence in the age assignment is provided by a direct correlation with the European fauna, which stratigraphic age is calibrated by means of Strontium Isotope (*e.g.*, STEUBER *et al.*, 2005; FRIJIA *et al.*, 2015; VILLALONGA *et al.*, 2019). However, we cannot exclude the presence of a biogeographic effect, likely due to faunal dispersal, which may slightly affect such age-correlation. Like other shallow-water taxa, large Upper Cretaceous agglutinating and porcelaneous foraminifera were possibly subject to provincialism and periodic populations diversification (*e.g.*, HOTTINGER *et al.*, 1989; GOLDBECK & LANGER, 2009). This is the reason why *Navarella* from Tibet would not exactly match with the European forms. Even in Europe, the specific diversity (or the occurrence of different varieties) may be higher than the expected, as MAYNC (1954) demonstrates. In the Tibetan samples, in fact, there are certain morphotypes such as *Nezzazatinella* sp. and ? *Keramosphaerina* sp., or the Orbitolinidae gen. ind., that cannot be assigned to any species so far known. These are likely new taxa, but their detailed systematic placing is hampered by the lack of additional material.

Conclusions

The rudist fauna of the DE FILIPPI collection from western Tibet has been reprised and redescribed. The previous taxonomic attribution of this fauna has been mostly considered inaccurate, with the only exception of *R.* cf. *lusitanicus*, which has been renamed after the recent emendation of the taxon *R. peroni*. Regarding the other specimens no definitely specific attributions have been possible due to the poor quality of the material. The fauna is mostly composed of radiolitids, *R.* cf. *lusitanicus*, two more species of *Radiolites*, *Gorjanovicia* cf. *endrissi*, a possible ? *Sauvagesia* sp., a *Durania* and a specimen, which was previously described as *Radiolites indicus* but is most likely a *Sphaerulites*. The only non-radiolitid taxon which was determined in the studied rudist assemblage is the monopleurid *Gyropleura* sp. (previously erroneously determined as *G. cenomanensis*).

The rudists have been collected in beds belonging to the Tielongtan Group The oldest rudists belong to the Xiloqzung Formation and their age is Turonian-? Coniacian. Younger ages have been determined through the analysis of the carbonate matrix embedding the rudists, which, compared with the western Neotethys records suggest a lower-middle Campanian age, allowing to ascribe such specimens to the Litian Formation and Dongloqzung Formation. Our data confirm that rudist-bearing facies in the Tielongtan Gp. extends at least up to the middle Campanian.

The described rudist fauna shows some similarity with the Western Tarim fauna and is composed of cosmopolitan taxa *Radiolites lusitanicus* and *Gorjanovicia* cf. *endrissi*, which are in fact known from most of the Tethysian realm.

Benthic Foraminifers and Demospongiae in the Dongloqzung Formation and associated with the younger rudists of the studied fauna (*Gorjanovicia* cf. *endrissi*, ? *Sauvagesia* sp., *Gyropleura* sp., *Radiolites* sp.) suggest that during the Campanian a biogeographic connection existed between the Tibetan and Mediterranean areas. However, it cannot be excluded that an effect due to faunal dispersal may slightly affect the age-correlation and the evolution of possibly endemic taxa. The Aksai Chin rudist assemblage should belong to the Southwestern Asian assemblage of the Eastern Mediterranean Subprovince.

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