

Late Permian to Miocene bivalve assemblages from Hohxil, Qinghai-Xizang Plateau, China.

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Nine fossil bivalve assemblages have been recognized in the Hohxil desert area of western Qinghai, China: Wuchiapingian *Netschajewia jiangsuensis* assemblage, Smithian – Spathian *Bakevella costata* – *Leptochondria virgalensis* – *Entolium microtis* assemblage, Carnian *Halobia austriaca* – *Halobia yunnanensis* – *Halobia convexa* assemblage, Norian *Halobia yandongensis* – *Halobia* aff. *dilatata* assemblage, Carnian-Norian *Trigonodus carniolicus* – *Unionites?* *rhomboidalis* assemblage, Bathonian – Kimmeridgian *Radulopecten pamirensis* – *Protocardia stricklandi* assemblage, Late Jurassic *Pseudolimea* – *Opis* assemblage, Early Cretaceous *Eokoreanaia qinghaiensis* assemblage, and Miocene *Sphaerium nitidum* assemblage.

The marine bivalves, except for the cosmopolitan *Halobia*, are Tethyan and characterised mainly the northern margin of the Tethys. Non-marine taxa are restricted Asian forms. These assemblages are very significant in studying the biostratigraphy, paleobiogeography and tectonic history of the Qinghai – Xizang Plateau. In the Early Cretaceous marine connections were broken and the area has experienced since then only terrestrial conditions.

Keywords: Bivalve assemblages, biostratigraphy, paleobiogeography, north Tethys, Hohxil, Qinghai-Xizang Plateau, western China, Permian, Triassic, Jurassic, Cretaceous, Miocene, marine, non-marine.

INTRODUCTION

Hohxil is a depopulated zone at an average of more than 5000 metres above sea level, so is frigid, with reduced oxygen levels, and is short of fresh water. It lies in Qinghai, Xizang (Tibet) and Xinjiang provinces, but mainly in western Qinghai between the Kunlun and Tanggula (Dangla) Mountains, bordered by the Qinghai – Xizang Highway in the east and the Xinjiang and Xizang provincial boundaries in the west (Fig. 1) (Sha 1991a, 1992a, 1995). Geologically, it lies in the central part of the Paleotethys suture zone of western China. This suture zone is bordered by the Kunlun-Maqen Fault (Fig. 2) through Bukadaban in the north and by the Wulanwulaco-Gangqiqu Fault in the south (Fig. 1). The principal part of the suture zone is the Longmoco-Yushu Fault passing through Xijinwulanco and Gouluco and is interpreted as the boundary between the Kunlun and Qiangtang terranes and the northern border of the Tethys before collision between Gondwana and Eurasia. Another fault parallels these along the Leixiewudanco-Hohxilco-Zhuonaico line (Fig. 1) (Huang & Chen 1987; Zhang 1991, 1993; Sha 1995; Sha et al. 1992). The source of the Yangtze River, Geladandong, is on the southern margin of Hohxil (Fig. 1).

The Hohxil area is a difficult zone for human settlement (Sha 1991a, 1992a), but a critical area for understanding the geology of Asia, including the evolution of Tethys and the Qinghai – Xizang Plateau.

During their investigation, the 1990 Chinese Comprehensive Scientific Expedition to

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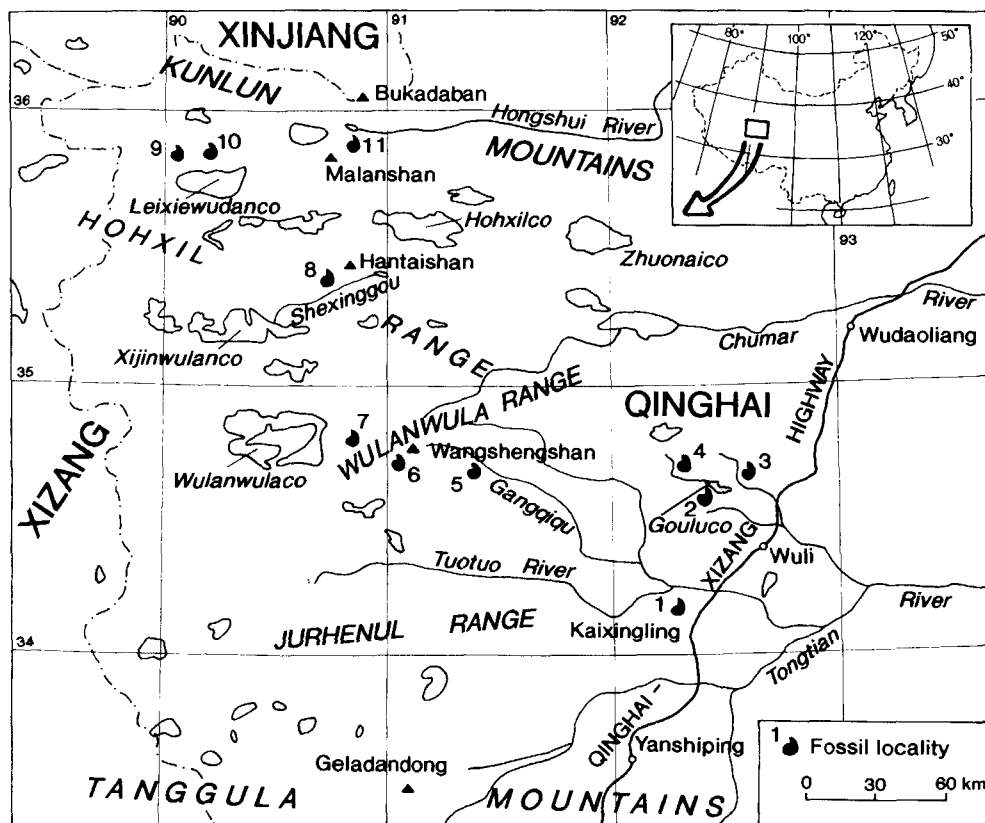


Fig. 1 Map showing the geographic position and Late Permian – Miocene bivalve localities of Hohxil, western Qinghai, China. Shaded areas are lakes (“-co” = lake).

Qinghai Hohxil, including the senior author, found that in the Hohxil area, which includes the Hohxil and Xijinwulan regions and the slopes of the Kunlun and Tanggula Mountains (Table 1), the oldest exposed strata are Carboniferous. A rift valley or ocean basin occupied the area from the Early Carboniferous, closing or disappearing by the beginning of the Late Permian. In most areas there is a lacuna in the Early and Middle Triassic, but extensive marine Late Triassic, including both deep anoxic and littoral facies, are present. Marine Jurassic is limited to the Wulanwula Range (Wulanwulashan) and the area to the south of it, and lacks the Lower and part of the Middle Jurassic. Over the whole area there are no marine deposits of post-Jurassic age. Cretaceous and Cenozoic successions include widely distributed red beds of lacustrine or fluvial origin. Quaternary red beds are mostly distributed close to the shores and banks of modern lakes and rivers, and near the snouts of glaciers. In addition, Cenozoic volcanic rocks are particularly well developed (Sha 1995; Sha et al. 1992).

The stratigraphy varies from the flanks of the Kunlun Mountains in the north to the Tanggula Mountains in the south, and is particularly marked in the pre-Jurassic sequences (Zhang & Sha 1995) (Table 1). Apart from the Kunlun and Tanggula Mountains, the Hohxil area can be subdivided into two regions along the line of the Leixiewudanco – Hohxilco – Zhuonaico: i.e. the Hohxil region in the north, and the Xijinwulan region in the south. In ascending order, the stratigraphic sequences in Hohxil and Xijinwulan can be summarized as follows.

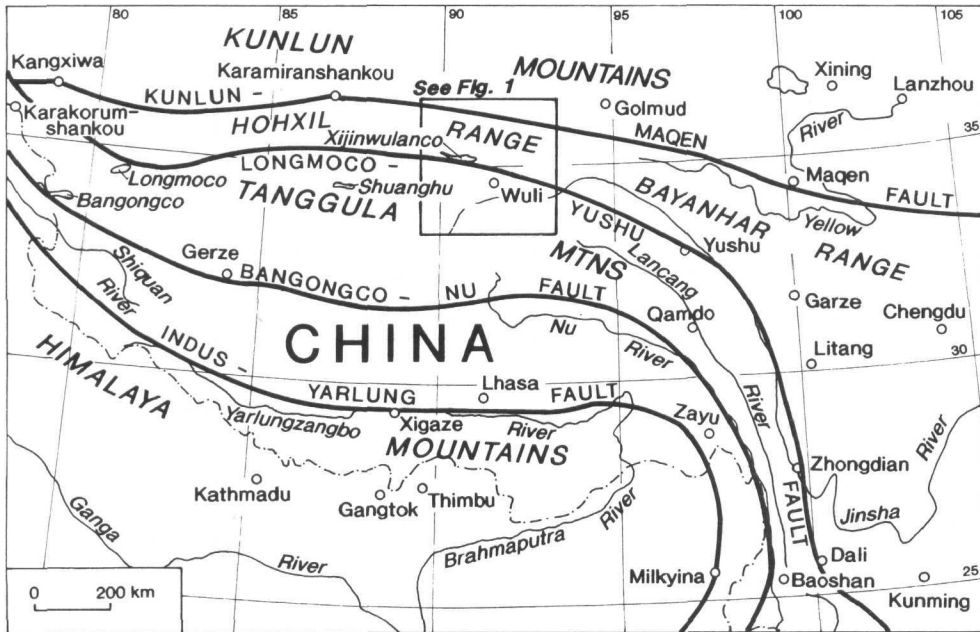


Fig. 2 Map showing the tectonic setting of Hohxil.

Carboniferous

Xijinwulan Group (lower part): clastic rocks, volcanics, radiolarian chert; up to c. 1900 m thick.

Early Permian

Yesanggang Group: clastic rocks and limestone with intercalated volcanic rocks; more than 2500 m thick.

Xijinwulan Group (upper part): lithology as for the lower part of the unit; up to c.800 m thick.

Late Permian

Wuli Group: (lower) coal and carbonaceous clastic unit; (upper) carbonate rock; together up to 640 m thick.

Late Permian – Early Triassic

Hantaishan Group: clastic rocks, limestone, with basal conglomerate; up to 1800 m thick.

Middle Triassic

Gande Formation: sandstone intercalated with slates; c. 3000 m thick.

Late Triassic

Bayanhar Group: (lower) slate intercalated with sandstone, c. 3780 m; (upper) sandstone intercalated with slate, c. 2000 m; distributed in the Hohxil region. Southwards, in the Xijinwulan region, the Late Triassic can be subdivided into two formations, i.e.

Early Late Triassic Batang Formation consisting of clastic rocks and volcanics intercalated with limestone; up to 2800 m thick.

SYSTEM		EAST KUNLUN		HOHXIL		XIJINWULAN		TANGGULA	
QUATERNARY	HOLOCENE	Lacustrine sediments, aeolian sands, fluvioglacial debris						Lacustrine sediments	
	UPPER PLEISTOCENE	alluvium, glaciogene deposits							
	MIDDLE PLEISTOCENE	Glacial deposits							
	LOWER PLEISTOCENE	Lacustrine sediments							
	PLEISTOCENE	hiatus							
NEO-GENE	PLIOCENE	hiatus		Lacustrine carbonates, lava					
	MIOCENE	hiatus		Lacustrine carbonates, lava					
PALEO-GENE	OLIGOCENE	Red lacustrine sandstone, mudstone, evaporite							
	EOCENE	hiatus		hiatus					
	PALEOCENE	hiatus		hiatus					
CRETACEOUS		hiatus		Fenghuoshan Gr.					
JURASSIC	UPPER	hiatus		hiatus		Jiri Gr.			
	MIDDLE	Lacustrine coal-bearing clastic rocks with basal conglomerate		hiatus		Yanshiping Gr.			
	LOWER	hiatus		hiatus		hiatus			
TRIASSIC	UPPER	Babaoshan Fm.	?	Bayanhar Gr.	Sandstone with slate	Goulushankeco Fm.	Jiza Gr.		
	MIDDLE	Naochangjiangou Fm.			Slate with sandstone	Batang Fm.	hiatus		
	LOWER	Hongshuishuan Fm.	Qamalong Fm.		Gande Fm.	?	hiatus		
PERMIAN	UPPER	?		?	Hantai-shan Gr.	?	Wuli Gr.	Carbonates	
	LOWER	Bioclastic limestone	Buqinshan Gr.	Yesanggang Gr.	Xijinwulan Gr.	Kaxingling Gr.		Coal, carbonaceous clastics	
CARBONIFEROUS	UPPER	unexposed		Carbonates					
	LOWER	unexposed		Carbonates					
DEVONIAN	UPPER	Volcanic rocks		Carbonates					
	MIDDLE	hiatus		Clastics, volcanics					
	LOWER	hiatus		Carbonates					
LOWER PALEOZOIC		Najitai Gr.		?					
MIDDLE AND UPPER PROTEROZOIC		Wanbaogou Gr.		(unexposed)					
LOWER PROTEROZOIC		Jinshuikou Gr.							

Table 1 Stratigraphic correlation chart of Hohxil and environs (after Zhang & Sha 1995). Sawtooth lines denote unconformities; dashed lines imply imprecise dating of contacts or that the contact is unseen or poorly located; Fm = Formation.

Late Late Triassic Goulushankeco Formation consisting of slate and sandstone; up to 1200 m thick.

Middle Jurassic

Yanshiping Group: purplish red clastic rocks with bioclastic limestone and variegated deposits in the middle and upper parts; up to c. 2000 m thick.

Late Jurassic

Jiri Group: red clastic rocks with bioclastic limestone in the basal and upper parts; up to 1900 m thick.

No Jurassic strata have yet been found in the Hohxil region.

Cretaceous

Fenghuoshan Group: red clastic lacustrine rocks intercalated with copper-bearing sandstone; up to c. 6000 m thick.

Oligocene

Red lacustrine sandstone and mudstone bearing gypsiferous salt and rock-salt layers; up to 1200 m thick.

Neogene

Lacustrine carbonate and terrestrial high-alkali intermediate lava; up to 350 m thick.

Early Pleistocene

Lacustrine deposits; c. 380 m.

Middle Pleistocene

Glacial deposits; up to 200 m thick.

Late Pleistocene

Fluviolacustrine deposits; up to 80 m thick.

Holocene

Lacustrine sedimentation, aeolian sands and fluvio-glacial deposits; up to 20 m thick.

The Expedition collected significant fossils of Carboniferous to Quaternary age. Bivalves are abundant, widespread, and of different facies. They hence play an important role in dating and in paleoenvironmental and paleobiogeographic analysis. They were found only in the Late Permian of Kaixingling (loc. 1, Fig. 1), the Early Triassic of Shexinggou, south of Hantaishan (loc. 8, Fig. 1), the Late Triassic of north and northwest Leixiewudanco (loc. 9, 10, Fig. 1), northeast of Malanshan (loc. 11, Fig. 1), and north of Gouluco (loc. 3,4, Fig. 1), the Middle – Late Jurassic of southwest Wangshengshan (loc. 6, Fig. 1) and east of Wulanwulaco (Ulanulco) (loc. 7, Fig. 1), the Early Cretaceous of southwest Gangqiqu (loc. 5, Fig. 1), and the Neogene of south Gouluco (loc. 2, Fig. 1) (Sha 1991a, 1992a, 1995). The oldest bivalve-bearing sequence is Late Permian and in the Xijingwulan area overlies Carboniferous-Early Permian ophiolites and radiolarian cherts.

This study complements that of Sha (1995) and shows the bivalve faunas to be distinctly varied in both age and environment of deposition. Except for species with good dispersive potential and a wide or global distribution, such as the opportunist *Halobia*, the broad geographic distribution of bivalve assemblages found in Hohxil did not change much during the Permian – Jurassic. They are distributed mainly along the Tethyan margins, west and central Europe, plus some on the northwest margin of the Pacific Realm. Since the Early Cretaceous, the Hohxil region has been above sea-level, and marine bivalves have been replaced by non-marine taxa of restricted Asian distribution.

All collections dealt with in this study are housed in the collections department of the Nanjing Institute of Geology and Paleontology, Academic Sinica, Nanjing, and individual specimens are registered in the catalogue of that institution by numbers with the prefix RN.

BIVALVE ASSEMBLAGES

Bivalves from Hohxil can be subdivided into 9 temporally arranged assemblages (Table 2).

Late Permian bivalve assemblages

1. Wuchiapingian *Netschajewia jiangsuensis* assemblage

This assemblage, mainly consisting of *Netschajewia jiangsuensis* (Liu), *N. cf. modioliformis* (King), *Pernopecten* sp. and a few Palaeotaxodonta, associated with very small (1–5 mm high) gastropods (*Polygyrina*, *Holopea*, *Rhabdotocochlis* etc.), brachiopods and plant debris, has been found only in argillite within a coal-bearing, dominantly carbonaceous argillite unit of littoral-deltaic facies origin, in the lower Wuli Group. The sequence extends northwestwards from Kaixingling to Gangqiqu and Hantaishan. It underlies the Changxingian *Palaeofusulina*-bearing limestone of the upper Wuli Group in the Kaixingling area (loc. 1, Fig. 1).

Netschajewia is common and easy to recognize in this fauna. *N. jiangsuensis* (Fig. 3 A) is small (up to 25 mm long) transversely elongate, subtrapezoid in outline, with its anterior margin narrowly rounded, posterior margin subtruncated, and the ventral margin almost straight and subparallel to the very slightly convex dorsal margin. The umbo is obtuse, anterodorsally placed, and only very slightly projecting above the hinge line. The valve is moderately inflated, with a smooth surface except for fine, closely spaced commarginal growth lines. Cardinal teeth are poorly developed, two in the left valve, one in the right; one divided posterior lateral tooth occurs in the left valve and two in the right. The anterior adductor scar is placed near the anterior end, is fairly strong, vertically oval in outline and has a well developed buttress.

N. cf. modioliformis (Fig. 3 B) is very small (c. 5 mm long), narrowing anteriorly and broadening posteriorly. The anterior margin is narrowly rounded, posterodorsal margin arched, posteroventral corner roundly angular, ventral margin gently curved and dorsal margin straight. The shell is rather modioliform in outline and somewhat inflated, but more flattened posteriorly. The umbo is obtuse, placed near the anterior extremity of the dorsal margin and barely projects above the hinge line.

These two species have also been found in the Wuchiapingian Longtan Formation of south Jiangsu in east China, and the Xuanwei Formation of Panxian in Guizhou, south central China (e.g. Gu et al. 1976). To the northwest, the former species extends into Russia (Chavan 1969) and relatives of the latter have been recorded from the Permian of England (King 1850).

Both the Longtan and Xuanwei Formations are coal-bearing units and widely distributed in south, east, south central and southwest China. Their age has been confirmed as Wuchiapingian by fusulines and ammonoids (e.g. Sheng et al. 1982). The Changxingian *Palaeofusulina* fauna (Zhang 1995) overlying the *Netschajewia jiangsuensis* assemblage-bearing bed in Kaixingling also indicates that the *Netschajewia* assemblage is likely to be Wuchiapingian in age.

Early Triassic bivalve assemblages

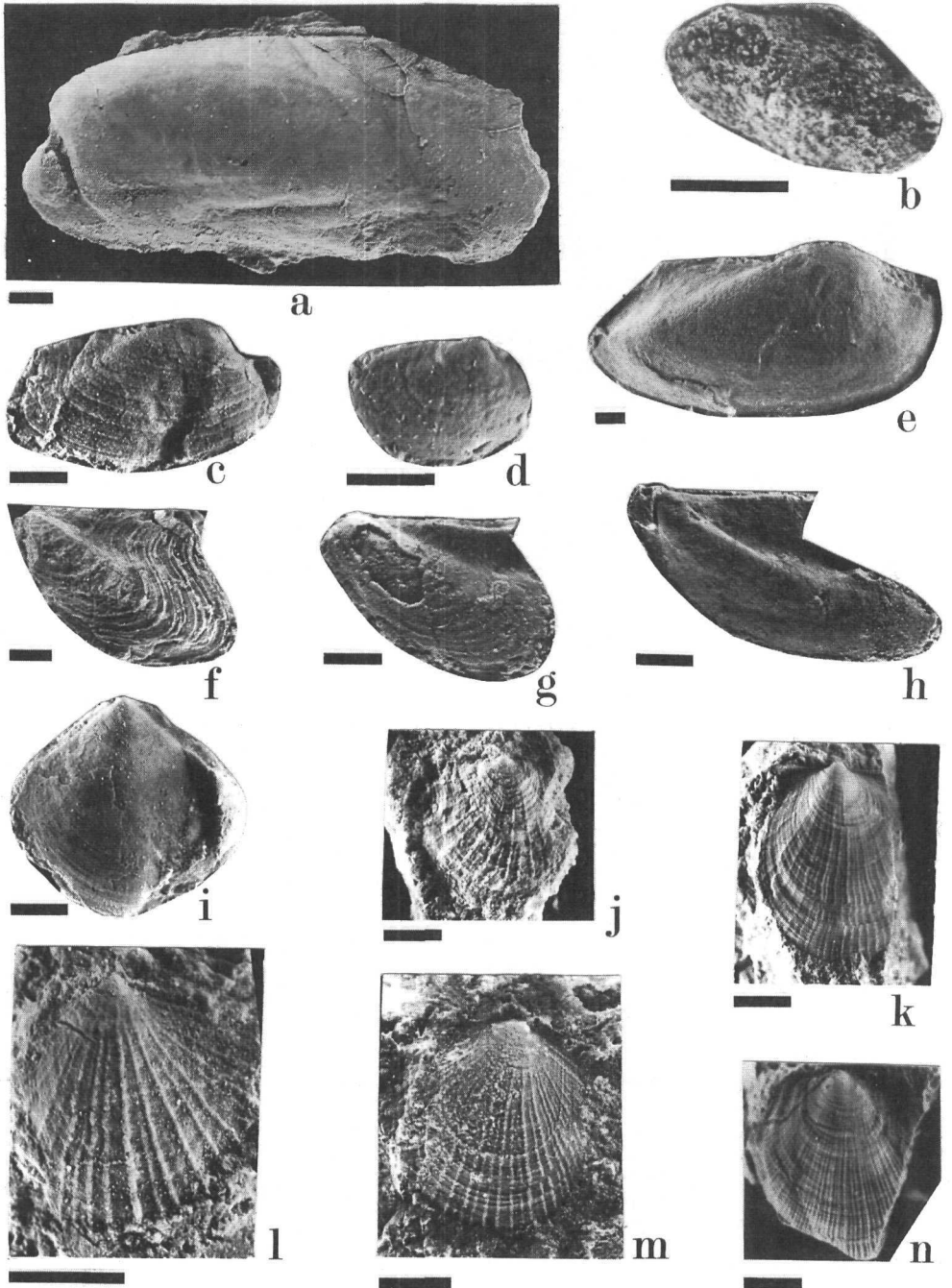
2. Smithian – Spathian *Bakevellia costata* – *Leptochondria virgalensis* – *Entolium microtis* assemblage

This assemblage (Table 3) is found in the lower Limestone Member of the Hantaishan Group of Shexinggou, south Hantaishan (loc. 8, Fig. 1). These bivalves are associated with conodonts (see below), gastropods (including *Neritaria*, *Natiria*, *Naticopsis*, *Guizhouspira*, *Worthenia*, *Wortheniopsis*, *Scurriopsis*, *Solariconulus*), brachiopods and echinoderm debris.

Ecologically, there are 3 distinct features to this bivalve fauna. (1) All forms are small, commonly <15 mm and rarely up to 26 mm long. (2) It is dominated by epi-byssate suspension

SYSTEM	SERIES	STAGE	BIVALVE ASSEMBLAGE	
QUAT-ERNARY	HOLOCENE			
	PLEIST-OCENE	UPPER		
		MIDDLE		
LOWER				
NEOGENE	PLIO-CENE	UPPER	Piacenzian	
		LOWER	Zanclean	
	MIO-CENE	UPPER	Messinian	<i>Sphaerium nitidum</i>
			Tortonian	
		MIDDLE	Serravallian	
			Langhian	
		LOWER	Burdigalian	
	Aquitanian			
PALEOGENE	OLIGOCENE	Chattian		
		Rupelian	Stampian	
		Priabonian	Latdorfian	
	EOCENE	Bartonian		
		Lutetian		
		Ypresian		
		Thanetian	Selandian	
	PALEOCENE	Danian		
	CRETACEOUS	UPPER	Maastrichtian	
Campanian				
Santonian				
Coniacian				
Turonian				
Cenomanian				
LOWER		Albian		
		Aptian		
		Barremian		
		Hauterivian		
		Valanginian		
		Berriasian		
JURASSIC	UPPER	Tithonian	Volgian	
		Kimmeridgian		
		Oxfordian		
	MIDDLE	Callovian		
		Bathonian		
		Bajocian		
		Aalenian		
	LOWER	Toarcian		
		Pliensbachian		
		Sinemurian		
		Hettangian		
	TRIASSIC	UPPER	Rhaetian	Norian
			Norian	
Carnian				
MIDDLE		Ladinian		
		Anisian		
LOWER		Olenekian	Spathian	
			Smithian	
		Induan	Dienerian	
			Griesbachian	
PERMIAN	UPPER	Changhsingian	Changhsingian	
		Wuchiapingian	Capitanian	
		Maokouan	Wordian	
	LOWER		Roadian	
		Chihnsian	Artinskian	<i>Netschajewia jiangsuensis</i>
			Sakmarian	
			Asselian	

Table 2 Bivalve assemblages of Hohxil.



feeders (e.g. *Parallelodon*, *Mytilus*, *Arcavicula*, *Gervillia*, *Eumorphotis*, *Leptochondria*, *Parachlamys*) and free-living forms capable of swimming in the adult stage (e.g. *Entolium*); these total approximately 90%. (3) Epifaunal cemented suspension feeders (e.g. *Placunopsis*), and infaunal mobile suspension (e.g. *Unionites*) and detritus (e.g. *Palaeoneilo*) feeders are very rare, amounting to only 3.5%. These ecologic features appear to demonstrate that this bivalve assemblage inhabited a relatively turbulent substrate with abundant hard debris (inorganic and organic) in a shallow sea or open bay.

This fauna, particularly the index species *Bakevellia costata*, *Leptochondria virgalensis* and *Entolium microtis*, but also *Bakevellia exprorecta* and *Leptochondria albertii*, has a wide distribution in the Qinghai – Xizang Plateau except for south Xizang (e.g. Fan et al. 1962; Gu et al. 1976; Zhang & Lu 1979; Chen 1982, 1983; Yang et al. 1983; Lu & Chen 1986; Sha 1995; Sha et al. 1990). To the northwest, this fauna extends through Afghanistan, Iran and Turkey as far as Italy, Germany and Poland (e.g. Wittenburg 1908; Diener 1925; Leonardi 1935; Herb 1957; Allasinaz 1972; Farsan 1972; Chen 1980, 1983). Southeastwards, this fauna spreads to Vietnam (e.g. Vu Khuc et al. 1965, 1991) through Qamdo, Yunnan and Guizhou (e.g. Chen 1983; Chen et al. 1974; Gu et al. 1976). Some species or relatives of this fauna were distributed northeastwards through southeast and south central China (e.g. Hsü 1937; Gu 1948; Chen 1950; Gu et al. 1976) and possibly Japan, e.g. *Entolium discites* (a group including *E. microtis*) and *Leptochondria virgalensis* (e.g. Nakazawa 1961; Kambe 1963; Hayami 1975) into Wusuli and Siberia, e.g. *Leptochondria albertii*, *L. minima* and *Entolium discites* (Kiparisova 1938; Chen 1983; Dagys & Kurushin 1985).

Bakevellia exprorecta and *Entolium microtis* also occur in the *Eumorphotis inaequicostata*

Table 3 Bivalves of the *Bakevellia costata*-*Leptochondria virgalensis* – *Entolium microtis* assemblage.

<i>Palaeoneilo</i> cf. <i>oviformis</i> (Eck)	<i>L. albertii</i> (Goldfuss)
<i>Parallelodon</i> cf. <i>beyrichii</i> (Strombeck)	<i>L. cf. albertii</i> (Goldf.)
<i>P. xijinwulanensis</i> Sha	<i>L. sp. aff. illyrica</i> (Bittner)
<i>Mytilus praecursor</i> (Frech)	<i>L. minima</i> (Kiparisova)
<i>Pteria?</i> sp.	<i>L.?</i> <i>xijinwulanensis</i> Sha
<i>Arcavicula hohxilensis</i> Sha	<i>Leptochondria</i> spp.
<i>Bakevellia costata</i> (Schlotheim)	<i>Entolium microtis</i> (Bittner)
<i>B. exprorecta</i> (Lepsius)	<i>Entolium?</i> sp.
<i>B. sp. aff. taelei</i> (Cox)	<i>Praechlamys</i> sp.
<i>B. cf. pannonica</i> (Bittner)	<i>P.?</i> <i>hohxilensis</i> Sha
<i>Gervillia</i> sp.	<i>Placunopsis</i> cf. <i>plana</i> Giebel
<i>Eumorphotis huancangensis</i> Chen?	<i>Unionites</i> sp. ex gr. <i>canalensis</i> (Cattullo)
<i>Leptochondria virgalensis</i> Wittenburg	

◀ **Fig. 3** Index bivalves of the Wuchiapingian lower Wuli Group from Kaixingling (loc. 1, Fig. 1) (A – B) and the Smithian – Spathian lower limestone member of the Hantaishan Group (C – N) of Shexinggou, south Hantaishan (loc. 8). **A.** *Netschajewia jiangsuensis* (Liu), internal mould of left valve (RN118483). **B.** *Netschajewia* cf. *modioliformis* (King), internal mould of left valve (RN118486). **C, E.** *Parallelodon xijinwulanensis* Sha, internal mould of right valve; **C** (RN118302); **E** (RN118303). **D.** *Palaeoneilo* cf. *oviformis* (Eck), internal mould of right valve (RN118300). **F.** *Bakevellia costata* (Schlotheim), left valve (RN118323). **G.** *Bakevellia exprorecta* (Lepsius), left valve (RN118327). **H.** *Arcavicula hohxilensis* Sha, internal mould of left valve (RN118307). **I.** *Entolium microtis* (Bittner), internal mould of left valve (RN118365). **J.** *Leptochondria?* *xijinwulanensis* Sha, internal mould of left valve (RN118351). **K.** *Leptochondria* aff. *illyrica* (Bittner), internal mould of left valve (RN118356). **L.** *Leptochondria* cf. *albertii* (Goldfuss), internal mould of right valve (RN118353). **M.** *Leptochondria albertii* (Goldfuss), internal mould of left valve (RN118355). **N.** *Leptochondria virgalensis* Wittenburg, left valve (RN118354). Scale bars = 2 mm.

– *Pteria* cf. *murchisoni* assemblage which is equivalent to the *Tirolites* Beds of the European Alps (Chen 1980). Furthermore, conodonts associated with the bivalve fauna, *Neospathodus waageni* Sweet, *N. timorensis* (Nogami) and *N. cf. jubata* Sweet, are also Smithian – Spathian (Xu 1995). Consequently, this assemblage is Early Triassic, mainly late Early Triassic in age (e.g. Gu et al. 1976; Chen 1980, 1982, 1983; Chen et al. 1974; Yang et al. 1983; Vu Khuc et al. 1991).

The critical species of the *Bakevellia* – *Leptochondria* – *Entolium* assemblage are easily recognised.

Bakevellia costata (Fig. 3 F) is small (10–13 mm long), rhomboidal, distinctly prosocline, and with an obliquity angle of c. 30°. The umbo is anteriorly placed, the surface of the left valve bears commarginal growth lamellae, the posterior wing is large and its posterodorsal end pointed. Compared with *B. costata*, *B. exporrecta* (Fig. 3 G) has a distinct boundary between posterior wing and flank, and its surface has commarginal growth lines rather than lamellae.

Leptochondria virgalensis (Fig. 3 N) is small (c. 6.5 mm long) and subcircular in outline. Its umbo is small, placed near the centre of the straight dorsal margin, and the beak projects slightly above the hinge line. Both anterior and posterior auricles are distinct, obtusely triangular and of almost equal size. The shell is moderately inflated, with ornamentation of elegant, intercalated radial ribs of three orders which quickly become of equal strength. Commarginal growth lines are fine, regularly and closely spaced, and commarginal undulations are rare but distinct.

The *Leptochondria albertii* group (Fig. 3 L – M) resembles *L. virgalensis* but has fewer, stronger, rounded radial ribs and commarginal growth lines.

Entolium microtis (Fig. 3 I) is small (up to 13 mm long) and oval in outline, both anterior and posterior auricles are obtusely triangular and very small, the dorsal margin is very short, less than one-third of shell length, and the shell surface is smooth.

There are some other readily identifiable forms in this assemblage, e.g. the suboval *Palaeoneilo* cf. *oviformis* (Fig. 3 D), quadrilaterally elongate *Parallelodon xijinwulanensis* (Fig. 3 C, E), wing-like *Arcavicula hohxilensis* (Fig. 3 H), the vertically oval *Leptochondria* cf. *illyrica* (Fig. 3 K), and the subquadrate *Leptochondria?* *xijinwulanensis* (Fig. 3 J).

Late Triassic bivalve assemblages

The Late Triassic bivalves in Hohxil include two ecotypes, one consisting of equivalved, flat, thin-shelled epibyssate forms with a pseudoplanktonic or pendant mode of life and some capable of free swimming; they were suspension feeders and opportunists capable of inhabiting deep and possibly anoxic environments: the *Halobia* fauna. The second consists of inflated, thick-shelled and strong-hinged mobile infaunal suspension feeders of marine – brackish water: the *Trigonodus* and *Unionites* faunas which inhabited littoral facies.

3. Carnian *Halobia austriaca* – *Halobia yunnanensis* – *Halobia convexa* assemblage

This assemblage is found in dark or greenish sandy slates of the flysch facies in the lower and middle parts of the lower unit (slate with sandstone) of the Bayanhar Group, of northwest Leixiwudanco (loc. 9) and northeast Malanshan (loc. 11, Fig. 1). This assemblage consists of only 3 genera and 8 species of bivalve (Table 4), plus occasional gastropods (*Euomphalus*) and stems of crinoids. The fauna is often clustered on bedding planes.

Palaeoneilo and *Myophoriopsis* are very rare, with fewer than 5 specimens of each species collected. It is therefore obvious that this fauna, having a very

Table 4 Bivalves of the *Halobia austriaca* – *H. yunnanensis* – *H. convexa* assemblage.

<i>Palaeoneilo elliptica</i> Goldfuss
<i>Halobia austriaca</i> Mojsisovics
<i>H. yunnanensis</i> Reed
<i>H. convexa</i> Chen
<i>H. banmaensis</i> Chen & Lu
<i>H. cf. yandongensis</i> Chen
<i>Halobia</i> sp.
<i>Myophoriopsis guizhouensis</i> Chen

simple generic make-up, is dominated in both specific diversity and abundance of individuals by *Halobia*. Such a bivalve fauna possibly represents deep water and/or relatively anoxic bottom conditions that would have been unfavourable to most benthic creatures except those such as Palaeotaxodonta that could bear the anoxic stress. The environment of the Bayanhar Group has previously been interpreted as typical deep water with trough-filling flysch sedimentation (Huang & Chen 1987; Zhang 1991).

There are minor inconsistencies concerning the exact age of *Halobia austriaca*. Gruber (1976) thought this species to be Late Carnian – Early Norian, an age allocation accepted by Chonglakmani & Grant-Mackie (1993) and Campbell (1994), but it was rather common in the Carnian of Alaska (Smith 1927), and both Ganev (1974) and Muthac & Preda (1974) regarded this species as Carnian. On the basis of the *Halobia* sequence of Isparta, Turkey, this globally distributed species was regarded as Late Carnian by Allasinaz et al. (1974) but more recently the Isparta Clay has been dated as Norian (De Wever et al. 1979). Vozin & Tikhomirova (1964) put it in the Late Carnian *Carnites* – *Tropites* zone. Unfortunately, there are no well preserved ammonoids associated with the Hohxil *Halobia* assemblages. *H. yunnanensis* and *H. convexa* are common in the Carnian in China (Reed 1927; Chen 1964; Chen et al. 1974; Gu et al. 1976; Ma et al. 1976; Sha 1995; Sha et al. 1990). This Hohxil *Halobia* assemblage thus here is regarded as Carnian in age.

Halobia austriaca has a global distribution. It occurs from the European Alps (Italy, Yugoslavia, Romania, Bulgaria) and Austria (e.g. Mojsisovics 1874; Kittl 1903, 1912; de Capoa Bonardi 1970; Muthac & Preda 1974; Ganev 1974; Gruber 1976; Cafiero & de Capoa Bonardi 1982), through Turkey (e.g. Allasinaz et al. 1974; Gruber 1976) to Himalaya (e.g. Bittner 1899), the Qinghai – Xizang Plateau (e.g. Zhang & Lu 1979; Sha 1995; Sha et al. 1990), south China (Reed 1927; Chen 1964; Gu et al. 1976; Ma et al. 1976), Thailand (see Chonglakmani & Grant-Mackie 1993), Laos and Vietnam (e.g. Vu Khuc et al. 1965, 1991), Malaysia (see Chonglakmani & Grant-Mackie 1993), south into Timor (e.g. Krumbeck 1924) and New Zealand (Campbell 1994), and possibly from southeast China northeast into Japan (e.g. Ichikawa 1954; Nakazawa 1955; Hayami 1975) and Siberia (e.g. Vozin & Tikhomirova 1964; Bychkov et al. 1976) and into western North America (e.g. Smith 1927).

However, the mobile infaunal bivalve *Palaoneilo elliptica* is distributed only in the European Alps – south China area (e.g. Goldfuss 1838; Bittner 1895; Vozin & Tikhomirova 1964; Gu et al. 1976), and the *Myophoriopsis guizhouensis* group is limited to the Qinghai – Xizang Plateau and southwest China (e.g. Chen et al. 1974; Gu et al. 1976; Lu 1981; Sha 1995; Sha et al. 1990).

Halobia austriaca (Fig 4 A – B) is characterised by small to medium size (8–10 mm long), ovate or subcircular outline more or less longer than high. Its umbo is placed somewhat anteriorly, with large broad auricles commonly separated from the flank. Radial ribs are moderately broad, nearly straight, dividing 2–4 times, and have narrow interstitial furrows.

Halobia yunnanensis (Fig. 4 F – G) is a member of the *H. austriaca* group (Gu et al. 1976), but its shell is elongate (up to 26 mm long), semi-elliptical in outline. The anterior auricle is narrow. Radial ribs are narrow, flat and straight anteriorly, but very broad and separated by faint narrow furrows in mid flank, and relatively narrower and bundled posteriorly.

Halobia convexa (Fig. 4 C – D) is obliquely oval, 14–15 mm long, and rather inflated, with the anterior auricle narrow and separated from the flank by a deep groove. Radial ribs in the middle part of the flank are commonly bifurcated, occasionally trifurcated, and anterior ribs are broader but irregularly branched.

Palaoneilo elliptica (Fig. 4 E) is small, 7–17 mm long, and ellipsoidal with a tapered posterior, and is readily recognized.

4. Norian *Halobia yandongensis* – *Halobia* aff. *dilatata* assemblage

This assemblage is composed only of *Halobia*: *H. yandongensis* Chen, *H.* aff. *yunnanensis* Reed, *H.* aff. *dilatata* Kittl and *H.* sp. It has only been found in the flysch facies dark sandy

slates in the upper part of the lower unit of the Bayanhar Group of north Leixiwudanco (loc. 10).

This fauna consists only of opportunists, and this clearly implies an unusual environment resembling that of the Carnian *Halobia* assemblage, under deep water and/or anoxic conditions. Its distribution is the same as that of the older *Halobia* assemblage.

Halobia yandongensis, a member of the *Halobia hoernesii* group, is widely distributed in the Norian of south Yunnan and south Qinghai (Gu et al. 1976; Ma et al. 1976; Zhang & Lu 1979; Sha 1995; Sha et al. 1990) and *Halobia* aff. *dilatata* is also known from the Late Triassic of Qinghai (Zhang & Lu 1979). *Halobia dilatata* is Norian in such areas as Austria (Kittl 1912; Cox 1969), Bulgaria (Ganev 1974), and North America (e.g. Alaska – Smith 1927). Furthermore, this assemblage in Hohxil occurs in strata above the Carnian *H. austriaca* – *H. yunnanensis* – *H. convexa* assemblage, and is thus considered Norian, and probably Early Norian in age.

Halobia yandongensis (Fig. 5 A – B), 26–41 mm long, is characterized by its oval shape, slightly longer than high, its convex anterior auricle, and its subequal mostly bifurcated radial ribs.

Halobia aff. *dilatata* (Fig. 5 C) is large (>45 mm long), transversely oval, much longer than high, with the surface ornamented with distinctly branched radial ribs and commarginal wrinkles or undulations, particularly umbonally.

Compared with *Halobia yunnanensis*, *H. aff. yunnanensis* (Fig. 5 D) is smaller (up to 29 mm long), has relatively narrower ribs both anteriorly and posteriorly, they bifurcate earlier in mid disc, and the furrows between ribs are deeper.

5. Carnian – Norian *Trigonodus carniolicus* – *Unionites? rhomboidalis* assemblage

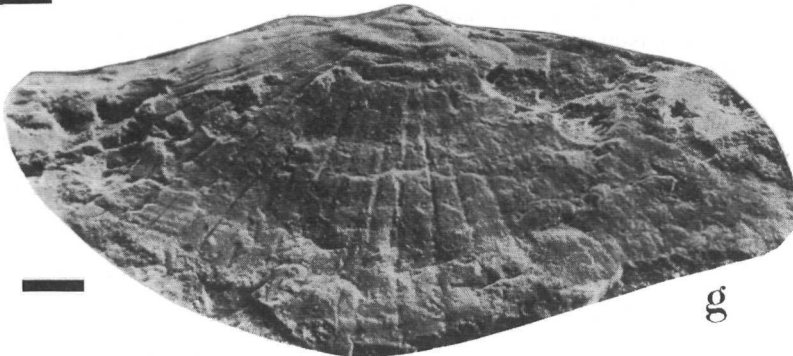
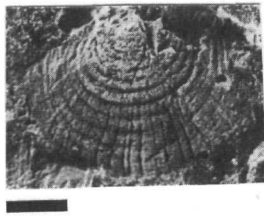
This bivalve assemblage consists of Pachycardiidae and Myophoricardiidae, dominated by *Trigonodus* and *Unionites* (Table 5) and is associated with the gastropods *Trachynerita* and *Neritaria*. It comes from the Goulushankeco Formation of north Gouluco (loc. 3,4). This assemblage very probably represents the fauna of a mud-sand substrate typical of a littoral environment with an influx of freshwater.

Elements of this assemblage, *Trigonodus carniolicus* and *Pseudocorbula nuculiformis*, have been reported from the European Carnian (e.g. Waagen 1907; Assmann 1937; Allasinaz 1966; Cox 1969), but in south Qinghai they are found in the upper Middle – Upper Triassic (Sha et al. 1990); *Unionites griesbachi* occurs in the middle Upper Triassic of Xizang (Bittner 1899; Gu et al. 1976; Wen et al. 1976). *Unionites? rhomboidalis* is a common Norian or Late Triassic bivalve in southwest China and Xizang (e.g. Chen et al. 1974; Zhang & Lu 1979). *Unionites griesbachi* is also known in the Late Triassic of Vietnam (Vu Khuc et al. 1991) and Misool, Indonesia (Hasibuan 1990); a closely related species is reported in Thailand (Chonglakmani & Grant-Mackie, in prep.).

This assemblage and the *Halobia* assemblages discussed above are likely to be at least partly contemporaneous but of different facies. This assemblage is certainly Late Triassic but more detailed field work is required to determine its precise age, viz. Carnian, Norian, or Carnian – Norian.

All members of this fauna are widely distributed in the Qinghai – Xizang Plateau and southwest China. Northwestwards, it is distributed as far as the European Alps, and to the southeast, it extends into Vietnam.

Fig. 4 Carnian index bivalves from the lower and middle parts of the lower unit of the Bayanhar Group. **A – B.** *Halobia austriaca* Mojsisovics; **A**, internal mould of articulated valves (RN118383), northwest Leixiwudanco (loc. 9, Fig. 1); **B**, internal mould of left valve (RN118382), northeast Malanshan (loc. 11). **C – D.** *Halobia convexa* Chen, internal mould of right valve; **C**, (RN118371); **D**, (RN118373). **E.** *Palaoneilo elliptica* (Goldfuss), internal mould of right valve (RN118298), northeast Malanshan. **F – G.** *Halobia yunnanensis* Reed, internal mould of left valve (RN118385, 118387), northeast Malanshan. Scale bars = 2 mm.



The index of the assemblage, *Trigonodus carniolicus* (Fig. 5 H–J), is of medium to large size (up to 60 mm long), oval to trapeziform in outline, and strongly inequilateral; the anterior margin is obtusely rounded, the posterior narrowly rounded or subtruncated; the umbo lies at the anterior one-fourth to one-fifth of shell length, the posterior umbonal ridge is obtusely rounded and moderately inflated, and the shell surface is smooth except for weak commarginal growth lines.

Unionites? rhomboidalis (Fig. 5 E–G) is very small (4–8 mm long), moderately inflated, and trapeziform in outline, with an angled posteroventral margin; the anterior is narrowly rounded, the posterior truncated, the dorsal margin obtusely angular, the posterodorsal margin long and straight, and the ventral margin broadly rounded; the umbo lies approximately at the anterior third of shell length and projects well above the hinge line; the shell surface is smooth except for faint commarginal growth lines.

Middle – Late Jurassic assemblages

Jurassic bivalves are fairly abundant, but they are all of Middle – Late Jurassic age.

6. Bathonian – Kimmeridgian *Entolium corneolum* – *Radulopecten pamirensis* – *Protocardia stricklandi* assemblage

This assemblage (Table 6) comes from bioclastic limestone of the Yanshiping Group of east Wulanwulaco and southwest Wangshengshan (loc. 7,6) and is associated with the gastropod *Ampullina*, echinoderm debris (including *Isocrinus* columnals), and trace fossils (*Arenicolites*, *Thalassinoides*, *Planolites* etc.).

Ecologically, this fauna includes abundant variously sized mobile infaunal siphonate suspension-feeders, such as the large *Pholadomya qinghaiensis* (>35 mm long), the very small *Corbulomima obscura* and *C. wulanwulaensis* (up to 9.5 mm long) and medium-sized (18–28 mm) *Protocardia stricklandi*, *Anisocardia rostrata* and *A. cf. tenera*. There is also the epibyssate, closely attached and exposed but solitary suspension feeder *Modiolus imbricatus*. *Radulopecten* was epibyssally attached throughout life (except in its larval stage) to objects on the sea floor, and species vary in size, the small *R. tipperi* being 11 mm long and the giant *R. pamirensis* up to 162 mm long. *Camptonectes auritus* had a similar mode of life. There are quite a few byssate fissure dwellers, such as *Pseudolimea duplicata*, numerous cemented suspension feeders, e.g. *Lopha wulanwulaensis*, and abundant byssate forms, such as *Gervillella cf. qinghaiensis* and *Pteroperna decorata*, and rare forms that were possibly free-living and capable of swimming during the adult stage, e.g. *Entolium corneolum*. There are almost no detritus feeders in the fauna. The presence of rare specimens of the non-marine bivalve *Undulatula* in this assemblage also merits attention.

Taphonomically, various bivalves are often piled up together, forming shell lenses and shell beds in which many or even most of the shells are fragmented, although separated single valves and bivalved individuals are fairly common. This preservation seems to suggest that these bivalves were buried in the inner sublittoral zone or on a beach near the lower to moderate-energy habitats in which they lived. The few non-marine bivalves are regarded as allochthonous and were probably carried onto the beach or into the inner sublittoral zone from a nearby fresh or brackish environment.

This bivalve fauna includes nine species endemic to the Qinghai – Xizang Plateau (Gu et

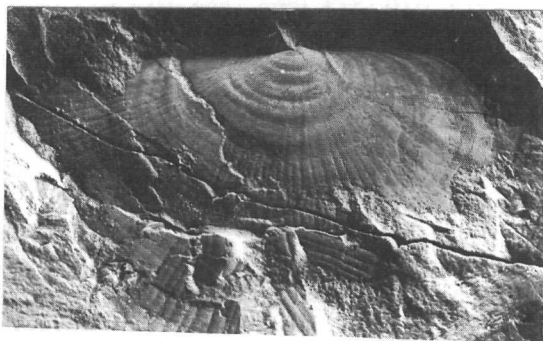
Fig. 5 Norian index bivalves from the upper part of the lower unit of the Bayanhar Group of north Leixiwudanco (loc. 10, Fig. 1) (A–D) and brackish index bivalves of the Late Triassic Goulushankeco Formation of north Gouluco (loc. 3, 4) (E–J). **A** – **B**. *Halobia yandongensis* Chen **A**, right valve (rubber cast) (RN118377); **B**, internal mould of left valve (RN118378). **C**. *Halobia* aff. *dilatata* Kittl, internal mould of right valve (RN118403). **D**. *Halobia* aff. *yunnanensis* Reed, internal mould of left valve (RN118394). **E** – **G**. *Unionites? rhomboidalis* Chen & Zhang, internal mould of left valve (RN118455, RN118447, RN118448). **H** – **J**. *Trigonodus carniolicus* Bittner; **H** – **I**, internal mould of right valves (RN118462, RN118461); **J**, internal mould of left valve (RN118463). Scale bars = 4 mm. ►



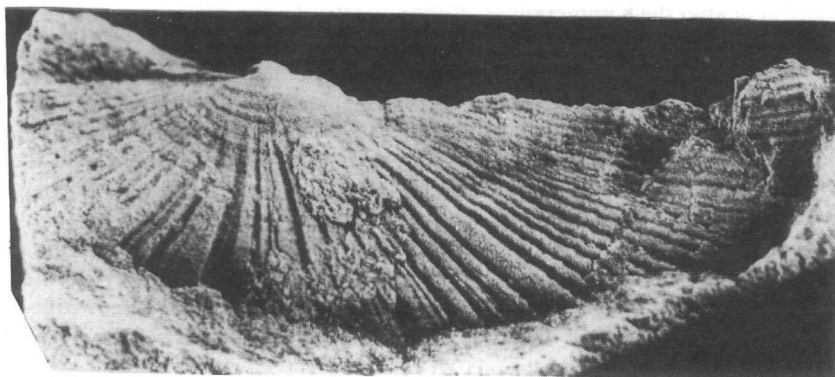
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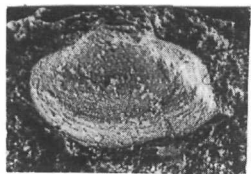
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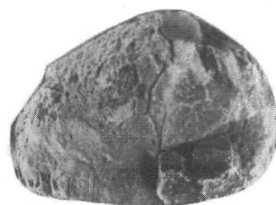
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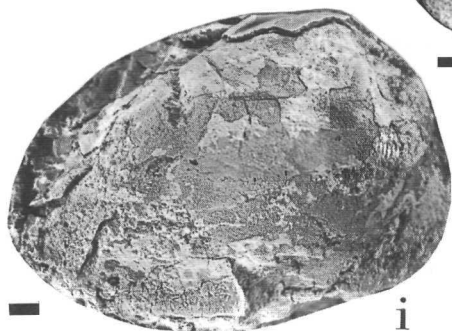
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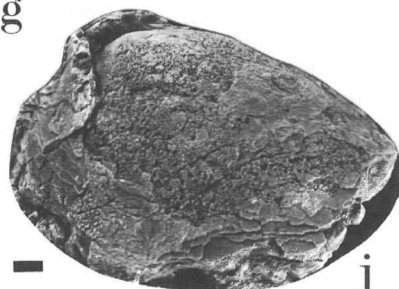
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al. 1976; Wen 1979, 1982, 1985; Wen et al. 1976; Sha 1995; Yin & Fürsich 1991) and south China (Gu et al. 1976; Ma et al. 1976) and 18 cosmopolitan species, but the latter were mainly distributed in a belt from west, central and southwest Europe through Turkey, Iran, Palestine, Bahrein Island, Afghanistan, Qinghai-Xizang Plateau, southwest China, India, Myanmar, and east Africa, including Tanzania and Kenya (Arkel 1929–1937; Clausen & Wignall 1988; Cossmann 1905; Cox 1936, 1940, 1965, 1969; Cox & Arkel 1948; Duff 1978; Fürsich & Werner 1987, 1988; Gu et al. 1976; Johnson 1984; Lycett 1863; Ma et al. 1976; Morris & Lycett 1853; Reed 1936; Ronchetti 1970; Ronchetti & Sestini 1961; Sha 1995; Staesche 1926; Wen 1979, 1982, 1985, 1994, in press; Wen et al. 1976; Yang et al. 1983; Yin 1990). Some forms, such as *Lopha gregarea* and *Camptonectes* cf. *auritus*, also possibly entered the Pacific region, reaching Japan (e.g. Hayami 1975; Tamura 1960), and a few, e.g. *Entolium corneolum* and *Protocardia striatula*, reached East Greenland in the Boreal Realm (e.g. Fürsich 1982).

It is difficult to give a precise age for this bivalve assemblage because analysis is not yet complete, and even for those species which have been studied in detail there are age discrepancies from area to area and among authors. However, no member is known before the Bathonian or after the Kimmeridgian. Consequently, the age of the assemblage is given as Bathonian – Kimmeridgian.

There are many easily recognized species in this assemblage. *Modiolus imbricatus* (Fig. 6 A) is of medium to large size (up to 47 mm long) and has a typical modioliform outline, broadening posteroventrally and narrowing anteriorly, with the anterior obtusely pointed, the posterodorsal margin broadly rounded, the dorsal margin almost straight, and the ventral margin slightly concave; the umbo is located a little behind the small anterior lobe, and the surface is smooth except for commarginal growth lines.

Gervillella cf. *qinghaiensis* (Fig. 6 B) is nearly 50 mm long, ensiform, prosocline, distinctly elongated posteriorly, with both anterior and posterior margins obtusely pointed, dorsal margin straight, ventral margin almost straight, the body of the shell narrow, the posterior wing a little more than half shell length, the anterior wing very small, and the surface bearing only commarginal growth lines.

Entolium corneolum (Fig. 6 D) is medium to large (up to 44 mm long), subcircular, equilateral, equivalve and smooth; the auricles are large and a byssal notch is lacking.

Camptonectes auritus (Fig. 6 C) is of medium size (up to 35 mm long), subcircular, with large auricles and a large byssal notch, and the shell surface is ornamented with faintly divaricating radial striae.

Radulopecten tipperi (Fig. 6 F) is oval, its height approximately equal to or slightly greater than its length, and is ornamented with strong radial ribs. Its auricles are large and smooth except for strong commarginal growth lines. *Radulopecten pamirensis* (Fig. 6 E) is characterized by its giant size.

Protocardia stricklandi (Fig. 6 H–I) is no more than 20 mm long, suboval in outline, with a subcentral umbo, strong regularly spaced commarginal growth lines, and c. 15–17 radial ribs on the siphonal area.

Corbulomima obscura (Fig. 6 L) is very small (7 mm long), inflated, rounded trapezoidal to rounded triangular in outline, and posteriorly sometimes more or less rostrate; its test is thick and strong, the surface smooth except for commarginal growth lines, and adductor buttresses are well developed.

Pholadomya qinghaiensis (Fig. 6 G) is up to 37 mm long, transversely trapezoid, and centrally inflated, although flattened posteriorly; commarginal growth costae are strong and regularly spaced; the umbonal

Table 5 Bivalves of the *Trigonodus carniolicus* – *Unionites? rhomboidalis* assemblage.

Trigonodus carniolicus Bittner

T. sp. aff. *bittneri* Waagen

Trigonodus sp.

Myophoriopsis guizhouensis Chen

Pseudocorbula sp. aff. *nuculiformis* (Zenker)

Unionites griesbachi (Bittner)

U.? rhomboidalis Chen & Zhang

surface is ornamented with several weak radial ribs which are gemmate where they cross concentric costae.

Lopha wulanwulaensis (Fig. 6 M) is small (8–12 mm long) and characterized by its palmate outline.

7. Late Jurassic *Pseudolimea* – *Opis* assemblage

After the *Entolium* – *Radulopecten* – *Protocardia* assemblage, Late Jurassic bivalves became monotonous in their composition and very poorly preserved. In the Jiri Group east of Wulanwulaco (loc. 7), bivalves are preserved as thin concentrated shellbeds up to 50 cm thick. Only 3 groups have been recognized, i.e. the byssate fissure dwelling *Pseudolimea* ex gr. *duplicata* J. de C. Sowerby, the shallow burrowing siphonate suspension feeders *Opis* sp. and possibly *Anisocardia* sp.

Pseudolimea ex gr. *duplicata* (Fig. 6J) is small (c. 9 mm long), dorsoventrally oval, slightly prosocline, and with ornament of at least 20 regularly spaced radial ribs. *Opis* sp. (Fig. 6K) is of medium size (>27 mm long) and obliquely quadrilateral in outline except for the long beak.

Poor preservation perhaps implies that these fossils were buried in the intertidal zone or on a high-energy beach.

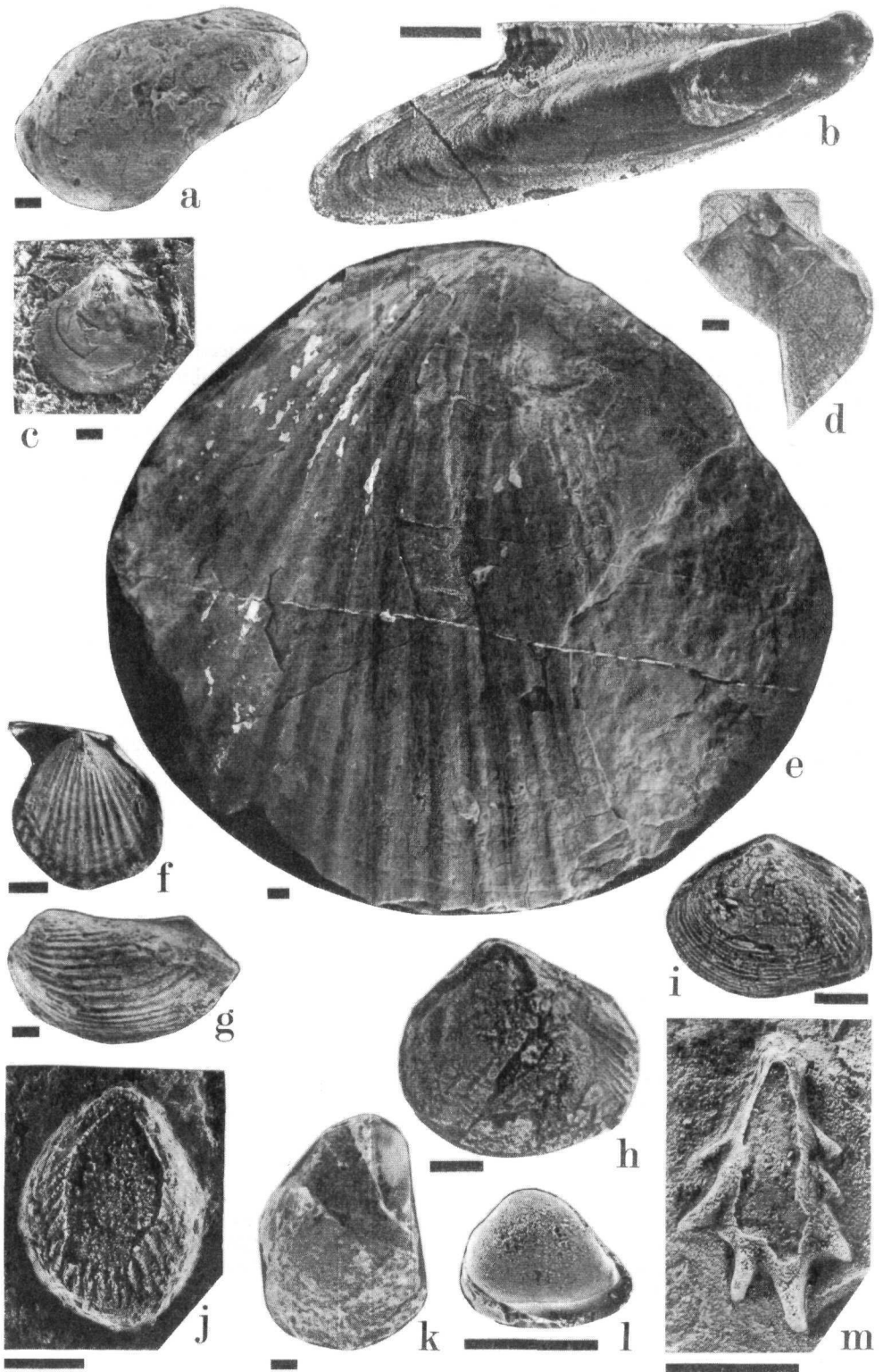
It is very difficult to constrain the age of this assemblage on the basis of the fossils themselves because of the low diversity and poor preservation. However, in the east Wulanwulaco section, this assemblage occurs above the Bathonian – Kimmeridgian *Entolium* – *Radulopecten* – *Protocardia* assemblage, so there are stratigraphic grounds for a Kimmeridgian or post-Kimmeridgian age. Secondly, there are no marine Cretaceous bivalves so far known from anywhere in the south Tanggula Mountains. Consequently, this bivalve assemblage is probably Late Jurassic (Kimmeridgian – Tithonian).

Early Cretaceous bivalve assemblage

With the Cretaceous, marine bivalves disappear from the record and never return. They are replaced by non-marine bivalves in the Hohxil area, as a result of marine regression and/or uplift of the region.

Table 6 Bivalves of the *Entolium corneolum* – *Radulopecten pamirensis* – *Protocardia stricklandi* assemblage.

<i>Modiolus</i> (<i>M.</i>) <i>imbricatus</i> (J. Sowerby)	<i>Lopha</i> sp.
<i>Modiolus</i> (<i>M.</i>) sp.	<i>Undulatula?</i> <i>tanggulaensis</i> Gu
<i>Pteroperna decorata</i> Reed	<i>U.?</i> <i>nyainrongensis</i> Wen
<i>Gervillella</i> cf. <i>qinghaiensis</i> Wen	<i>Machomya</i> sp.
<i>Isognomon</i> (<i>Mytiloperna</i>) <i>bathonicus</i>	<i>Opis</i> sp.
(Morris & Lycett)	<i>Protocardia</i> (<i>P.</i>) <i>stricklandi</i> (Morris & Lycett)
<i>I.</i> (<i>M.</i>) sp	<i>P.</i> (<i>P.</i>) <i>qinghaiensis</i> Wen
<i>Entolium</i> (<i>E.</i>) <i>corneolum</i> (Young & Bird)	<i>P.</i> (<i>P.</i>) <i>striatula</i> (J. de C. Sow.)
<i>Camptonectes</i> (<i>C.</i>) <i>auritus</i> (Schlotheim)	<i>Anisocardia</i> (<i>A.</i>) <i>rostrata</i> (J. Sow.)
<i>Chlamys</i> sp.	<i>A.</i> (<i>A.</i>) cf. <i>tenera</i> (J. Sow.)
<i>Radulopecten tipperi</i> Cox	<i>A.</i> (<i>Antiquicyprina</i>) cf. <i>loweana</i>
<i>R. pamirensis</i> Wen	(Morris & Lycett)
<i>Radulopecten</i> sp.	<i>Corbula</i> sp.
<i>Placunopsis</i> sp.	<i>Corbulomima obscura</i> (J. de C. Sow.)
<i>Pseudolimea duplicata</i> (J. de C. Sow.)	<i>C. wulanwulaensis</i> Sha
<i>Liostrrea birmanica</i> (Reed)	<i>Pholadomya qinghaiensis</i> Wen
<i>Lopha</i> cf. <i>costata</i> (J. de C. Sow.)	<i>Myopholas multicostata</i> (Agassiz)
<i>L.</i> cf. <i>gregarea</i> (J. Sow.)	<i>Myopholas</i> sp.
<i>L.</i> sp. ex gr. <i>vulsa</i> Chen	<i>Pleuromya?</i> sp.
<i>L. wulanwulaensis</i> Sha	<i>Platymyoidea?</i> sp.
<i>L.</i> sp. ex gr. <i>wulanwulaensis</i> Sha	



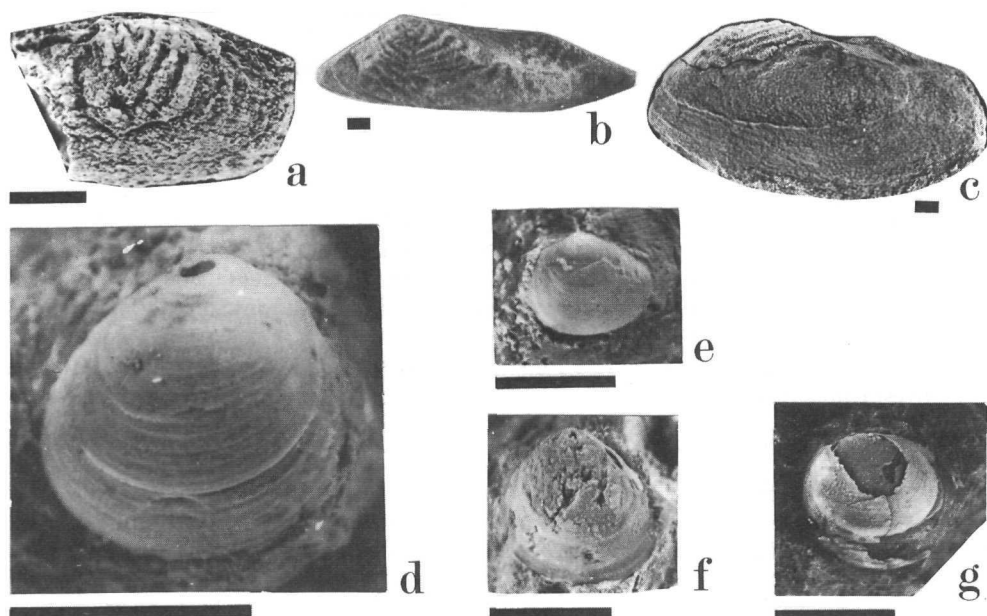


Fig. 7 Index bivalves of the Early Cretaceous Fukuoshan Group of southwest Gangqiu (loc. 5, Fig. 1) (A – C) and the Miocene of south Gouluco (loc. 2) (D – G). A – C. *Eokoreanaia qinghaiensis* Sha; A, internal mould of right valve (RN118468); B – C, internal mould and shell remnant of left valve (RN118470); B, dorsal view, C, lateral view. D – G. *Sphaerium nitidum* Clessin; D, right valve (RN118526); E, left valve (RN118524); F, internal mould of left valve (RN118525); G, left valve (RN118523). Scale bars = 2 mm.

8. Early Cretaceous *Eokoreanaia qinghaiensis* assemblage

This fauna is restricted to *Eokoreanaia qinghaiensis* Sha and some associated small gastropods (*Discohelix*, *Luciellina*) from the lower part of the Fenghuoshan Group, southwest Gangqiu (loc. 5).

Eokoreanaia qinghaiensis (Fig. 7 A – C) is up to 31 mm long and characterized by its ornament of V-shaped ribs with an angle of 32°–140° on the central part of the disc. The posterior is sculptured with inverted V-shaped ribs, and the anterior smooth; the submedian ribs do not reach the ventral margin. This bivalve is a typical trigonioidid, inhabiting freshwater (probably lakes) and limited in its distribution to Asia (Sha 1990, 1992b, 1993; Sha & Fürsich 1993a). *Eokoreanaia* is a relatively primitive trigonioidid. It also occurs in northeast China in the Jehol and Fuxin Groups, with *Ferganoconcha*. The latter genus is also found in the Chengzihe Formation of eastern Heilongjiang, northeast China, which includes

Fig. 6 Index bivalves of the Bathonian – Kimmeridgian Yanshiping Group (A – I, L – M) and Late Jurassic Jiri Group (J – K) of east Wulanwulaco (loc. 7, Fig. 1). A. *Modiolus* (s.s.) *imbricatus* (J. Sowerby), right lateral view of a steinkern (RN118315). B. *Gervillella* cf. *qinghaiensis* Wen, external mould of left valve (RN118341). C. *Camptonectes* (s.s.) *auritus* (Schlotheim), internal mould of left valve (RN118420). D. *Entolium* (s.s.) *corneolum* (Young & Bird), external mould of left valve (RN118409). E. *Radulopecten pamirensis* Wen, right valve of a bivalved individual (RN118430). F. *Radulopecten tipperi* Cox, left valve (rubber cast) (RN118427). G. *Pholadomya qinghaiensis* Wen, left lateral view of a steinkern (RN118549). H – I. *Protocardia* (s.s.) *stricklandi* (Morris & Lycett), internal mould of left valve (RN118500, RN118501). J. *Pseudolimea* ex gr. *duplicata* (J. de C. Sowerby), internal mould of left valve (RN118444). K. *Opis* sp., right valve (RN118488). L. *Corbulomima obscura* (J. de C. Sowerby), internal mould of right valve (RN118529). M. *Lopha wulanwulaensis* Sha, left valve (RN118557). Scale bars = 4 mm.

a marine intercalation with Barremian-Aptian *Aucellina* (Sha & Füsich 1993b). Thus *Eokoreanaia* and the Jehol and Fuxin Groups are Early Cretaceous in age, probably not extending down into the Latest Jurassic (Sha & Füsich 1993a).

Neogene bivalve assemblage

9. Miocene *Sphaerium nitidum* assemblage

This assemblage consists of a single species, *Sphaerium nitidum* Clessin (Fig. 7 D – G), associated with numerous gastropods (*Valvata (Concinna)*, *Galba*, *Gyraulus*), and comes from marls within lacustrine limestone of south Gouluco (loc. 2, Fig. 1). Shells are well-preserved but individuals are very small, no longer than 3 mm in length, and very rare. This is possibly due to restricted facies occurrence and limiting conditions such as high salinity, under which sphaeriids could not thrive.

Sphaerium nitidum is also known from the Miocene of the Zhunger Basin, Xinjiang, northwest China (Gu et al. 1976).

BIOGEOGRAPHY

Distribution patterns

No Bivalvia are known in pre- Late Permian strata of Hohxil. During the Permian benthic bivalves including *Netschajewia* migrated, most probably from south and east China, into the Hohxil sea. The *Netschajewia* fauna is known only from the northern margin of the Tethys in east, south and southwest China, and Russia, with an extension into England through the Germanic Zechstein Sea.

During the late Early Triassic, bivalves rapidly evolved and dispersed. The *Bakevellia* – *Leptochondria* – *Entolium* assemblage was not only distributed along the northern margin of the Tethys, from Vietnam to the European Alps, and abundantly so in southern, southern central and southwestern China, including Hohxil, but also extended northwestwards through the Germanic sea into central and western Europe, and northeastwards to Japan, Wusuli and Siberia. This fauna, or at least close relatives, was possibly distributed along the Salt Range – Iran – Afghanistan – Turkey region (Wittenburg 1909; Chen 1983) along the western and southwestern margin of the Tethys.

In the Late Triassic, mobile infaunal bivalves, including *Palaeoneilo*, *Myophoriopsis*, *Pseudocorbula*, *Unionites* and *Trigonodus*, were distributed along the northern margin of the Tethys from Vietnam through China to Germany. However, some species of the generally opportunistic genus *Halobia*, such as *H. austriaca*, *H. dilatata* and *H. yunnanensis*, have a global distribution.

In the Middle and Late Jurassic, Hohxil bivalves, particularly benthic forms, reached their widest distribution and are found along all margins of the Tethyan Realm. Occasionally, some species with great dispersive ability (e.g. *Entolium*, *Camptonectes*, *Lopha*) entered neighbouring areas on the northwest margin of the Pacific Realm and east Greenland in the Boreal Realm.

At the end of the Jurassic the sea retreated from the Hohxil area. Non-marine bivalves are known in Cretaceous and Miocene strata. A Hohxil Early Cretaceous trigonioidid fauna is found elsewhere only in east and central Asia and Indochina. A Miocene species of *Sphaerium* has been found in Xinjiang and Russia in addition to Hohxil.

No Bivalvia are known in Hohxil at the present day.

Interpretation

Geographic ranges of the Hohxil bivalve assemblages appear to have been controlled mainly by geography and ecologic limitations. Before the Late Permian there was a rift valley or ocean basin, Paleotethys, of which the Hohxil region was a part (Huang & Chen 1987; Zhang 1991; Bian & Zheng 1991; Sha et al. 1992), possibly too deep for bivalves to survive there. However, with the closure of the Hohxil rift, the disappearance of the ocean, and the

formation of a littoral-deltaic environment in the Late Permian, bivalves from south and east China rapidly occupied the Hohxil sea.

With reduction of the Tethys and fragmentation on its southern margin, and particularly with the Iran, Afghanistan, Lhasa, Indochina and Malay blocks drifting northwards (Smith & Briden 1977; Smith et al. 1981; Ziegler et al. 1982; Nakazawa 1985; Dercourt et al. 1993), the marginal area considerably expanded. As the distance between the southern and northern margins diminished, additional island “stepping stones” appeared, creating more available habitat for benthic faunas to become established. Shifts of north-south oriented marine currents probably enabled greater mixing of water masses. These geographic modifications would have created more opportunities for animals to migrate between the Tethys margins, improving gene flow. All these factors were very advantageous to the dispersal of Mesozoic benthic bivalves. Consequently, in the late Early Triassic, bivalves not only thrived on the northern margin of the Tethys, but elements of the same fauna are found also on the southern margin, the European Alps, northwest Pacific, the blocks in the Tethyan sea, and occasionally on the northeast margin of the Pacific and in the southeastern Austral Realm. During the Middle and Late Jurassic, the Hohxil bivalve fauna spread further northwest into central and west Europe, southwest into east Africa, and even into the Boreal Realm along the northern margin of the European continent.

However, with the southwards enlargement of the Eurasian continental land area at the end of the Jurassic or in the earliest Cretaceous, the sea regressed (retreated) from Hohxil. It is now of the central Asian mainland, well removed from ocean. Since the Early Cretaceous it has been occupied by numerous lakes, some of great size. Non-marine bivalves first appear in the Early Cretaceous, represented by an Asian trigonoidid fauna that migrated from neighbouring areas of Yunnan and Sichuan. In the Miocene, *Sphaerium* reached Hohxil, possibly from Xinjiang.

At the present day, although there are many lakes in Hohxil, none of them is suitable for bivalves as their waters are too saline.

The Hohxil non-marine bivalve faunas were limited to Asia, but all the marine bivalves, except the widespread *Bakevellia* (e.g. *B. exporrecta*), *Leptochondria* (e.g. *L. virgalensis*), *Halobia* (e.g. *H. austriaca*, *H. dialata*), *Entolium* (e.g. *E. microtis*, *E. corneolum*), *Camptonectes* (e.g. *C. auritus*), and *Lopha* (e.g. *L. gregarea*), were distributed along the Tethyan margins, particularly the northern margin from Vietnam through southern China and the Alps to central and west Europe. *Bakevellia*, *Leptochondria*, *Halobia*, *Entolium*, *Camptonectes* and *Lopha* are interpreted to have had a planktotrophic larval stage, which could probably survive as long as 6 months or more (Jablonski & Lutz 1980; Sha 1991b; Sha & Fürsich 1994). During their adult stage, some may have had a free-swimming or floating life (e.g. *Entolium*, *Halobia*), pseudoplanktonic life style (e.g. *Bakevellia*, *Leptochondria*, *Halobia*, *Camptonectes*, *Lopha*) through byssal attachment or cementation to floating (e.g. seaweed, wood), or swimming (e.g. nektonic animals) objects, or suspended within the current, but the major portion of their distribution is likely to have been achieved during their planktonic larval phase. Some (e.g. *Halobia*) were opportunists, or marginal environment colonizers, facies breakers or “r-strategists”. They could bear very high physical stresses including near-anoxia, colonize marginal environments or break into and rapidly multiply in a new facies (Levinton 1970; Hallam 1977, 1981; Cerrato 1980; MacDonald 1982; Sha 1991b; Sha & Fürsich 1994).

The Hohxil bivalve fauna is not only distributed in Tethys, but is also very abundant in west and central Europe. This is because the Germanic sea (Ziegler 1980, 1982) was connected to the western end of the Tethys. Some members of the Hohxil fauna also occur on the northwest Pacific margin as this area formed a connection between the Tethys and the Pacific proper.

However, there is only one element of the Hohxil fauna, *Halobia*, that spread into the Austral Realm. The absence of faunas common to the Hohxil area of the Tethys and the

Austral Realm during Late Permian – Late Jurassic probably reflects major facies differences as well as geographic separation.

CONCLUSION

Bivalves from Hohxil include nine assemblages (Table 1), 7 marine and 2 non-marine. Their distribution was controlled mainly by the interplay of environmental requirements and available environments, and the taxonomic make-up of these assemblages varied also as a result of the impact of changing land/sea relations, ocean currents, and migration opportunities. Marine Late Permian – Late Jurassic assemblages were distributed mainly in Tethys and western and central Europe; some members also lived on the northwest Pacific margin; opportunists and forms with high dispersive potential reached as far as the southeast Austral Realm, the Boreal margin (Greenland) and the east Pacific margin. This study confirms that during the whole of its marine phase the Hohxil region occupied an area along the northern margin of the Tethys.

Early Cretaceous and Miocene non-marine faunas were confined to Asia.

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