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STRATIGRAPHY, PALEONTOLOGY, AND DEPOSITIONAL SETTING OF THE CHENGJIANG LAGERSTÄTTE (LOWER CAMBRIAN),YUNNAN, CHINA

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Exceptionally preserved fossils from the Chengjiang Biota, eastern Yunnan, China, provide a remarkable window into the diversification of life forms during the Early Cambrian. Similar to the Burgess Shale (Middle Cambrian) of western Canada (e.g., Briggs *et al.*, 1994) and other similar deposits (Conway Morris, 1985; Babcock *et al.*, 2001), the Chengjiang deposit yields fossils of the hard skeletal parts of organisms, as well as fossils of nonmineralized skeletons and internal soft-parts of organisms. In the Chengjiang deposit, nonmineralized fossils greatly outnumber the fossils of shelly organisms. The Chengjiang fossils are important because they record some of the earliest-known representatives of major clades, they provide information about an Early Cambrian ecosystem, and they allow us to study important aspects of the processes of fossilization. Because many of the better-known Cambrian deposits of exceptional preservation are located on the Laurentian paleocontinent, the Chengjiang deposit provides an important perspective on the diversity of organisms present in the Gondwanan region (in this case, on the Southwest China Platform).

This paper provides a general introduction to the fossils of Chengjiang and their stratigraphic context. For more comprehensive information about the Chengjiang Biota, refer to Chen *et al.* (1996), Chen and Zhou (1997), Hou and Bergström (1997), Hou *et al.* (1999), and references cited in those papers.

HISTORY OF RESEARCH

The eastern part of Yunnan Province, China (Fig. 1), has one of the most richly fossiliferous successions of Lower Cambrian strata in the world. Geologic research in the region dates to the early part of the 20th Century. Mansuy (1912) recorded the first trilobites and bradoriid arthropods from the rocks that later were to be named the Heilinpu Formation. In 1913, the

Fig.1. Map of the Chengjiang area , Yunnan, showing some localities (stars) in the Yuanshan Member of the Heilinpu Formation yielding exceptional preserved fossils (modified from Babcock *et al.*, 2001). The discovery locality of the Chengjiang Lagerstätte is the locality labeled as Maotianshan.

Geological Survey of China was founded, and V. K. Ting was appointed its first director. During the early days of the Geological Survey, extensive studies were carried out on the Paleozoic stratigraphy of eastern Yunnan. Much of the geological literature published during the 1930s and 1940s (Ting and Wang, 1937; Lu, 1941; Wang, H. Z., 1941; Wang, Y. L., 1941; Ho, 1942; Sun, 1948) included information about the occurrence of phosphorite deposits, which are a major feature of the Lower Cambrian stratigraphic succession in eastern Yunnan (Luo *et al.*, 1982, 1992, 1984, 1994a; Luo and Jiang, 1996; Seigmund, 1997; Tang *et al.*, 1997; Fig. 2). Ho (1942) produced the first measured section of Maotianshan (which was later to become the discovery site of the Chengjiang Biota), and used the term "Maotianshan shale system" for those rocks.

In the 1930s and 1940s, the Lower Cambrian succession in eastern Yunnan was subdivided into formal formations. Ting and Wang (1937) proposed the name "Tsanglangpu (later spelled Canglangpu) Formation" for part of the Lower Cambrian section. Lu (1941) studied the Lower Cambrian stratigraphy and trilobites around the city of Kunming. He proposed the name "Chiungchussu (later spelled Qiongzhusi) Formation" for the strata immediately underlying the Tsanglangpu Formation, and proposed the name "Lungwangmiao (later spelled Longwangmiao) Formation" for the strata immediately overlying the Tsanglangpu Formation. Much later, Lu (1962) established three stage-level subdivisions of the Lower Cambrian succession in eastern Yunnan based on the previously named formations. The stages are the Chiungchussuan (based on the Chiungchussu Formation), the Tsanglangpuan (based on the Tsanglangpu Formation), and the Lungwangmiaoan (based on the Lungwangmiao Formation). Boundaries of these stages

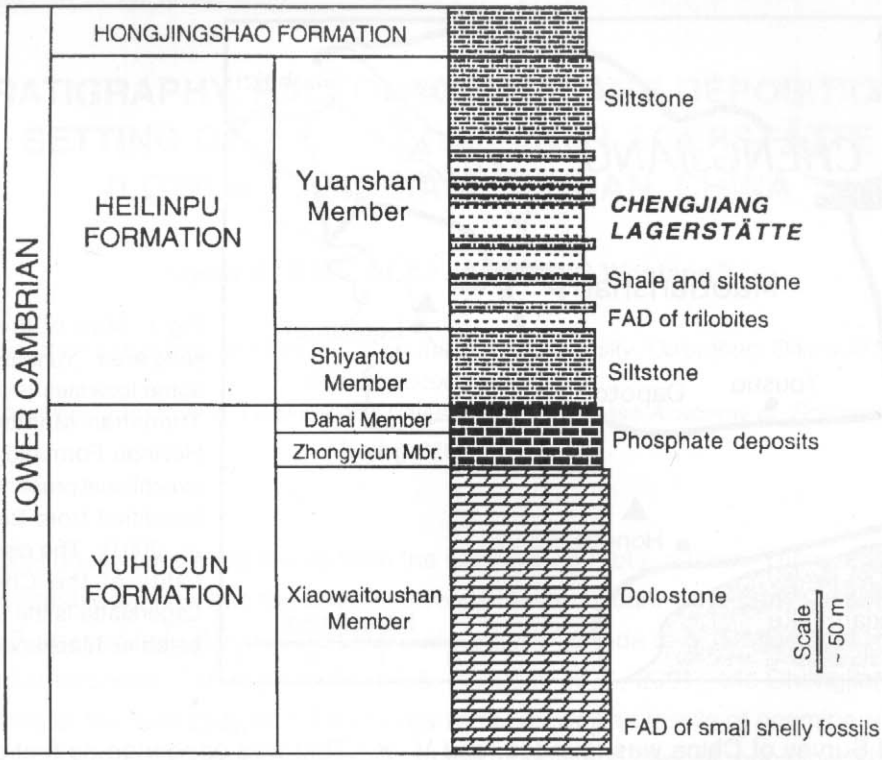


Fig. 2. Generalized columnar section of Lower Cambrian strata in eastern Yunnan, China (modified from Zhang and Babcock, 2001). Exceptionally preserved fossils are sporadically distributed in the upper part of the Yuanshan Member of the Heilinpu Formation. FAD indicates first appearance datum. Vertical scale is approximate.

(chronostratigraphic units) were the same as the boundaries of the Lower Cambrian formations (lithostratigraphic units). After further study, Qian (1977) added the Meishucunian Stage as the lowermost stage of the Lower Cambrian of China. The Meishucunian Stage was defined independently of any lithostratigraphic formation. Beginning in 1956, Chang (also spelled Zhang) *et al.* (1957, 1964, 1973) restudied Cambrian sections in many areas of Southwest China, including ones in eastern Yunnan Province, in the Yangtze Gorges area (Hubei Province), and in northern Guizhou Province. Biostratigraphic zonation of the Lower Cambrian that has resulted from that work (Chang *et al.*, 1957, 1964, 1973, 1979, 1980; Fig. 3) is the standard for Southwest China, and is widely used in international correlation. Further lithostratigraphic, biostratigraphic, or sequence-stratigraphic work, have been carried out by a number of investigators, including Zhou and Yuan (1980), Lu and Zhu (1981), Xiang *et al.* (1981), Luo *et al.* (1982, 1984, 1994a, 1996), Zhan (1989), Chen and Erdtmann (1991), Jin *et al.* (1993), Steiner *et al.* (1993), Luo and Jiang (1996), Zhang and Babcock (2001), and Zhang *et al.* (2001).

Fossils of nonmineralized organisms have been known from the Wulongqing Formation in the vicinity of Kunming since at least the late 1950s (P'an, 1957; Jiang, 1982). However, the importance of deposits in this region for preservation of nonmineralized fossils was not widely

SYSTEMS	FORMATIONS	MEMBERS	BIOSTRATIGRAPHIC ZONATION
Cambrian	Shanyicun		*Hoffetella-Redlichia* (*Pteroredlichia*) *murakamii* Assemblage-zone
	Wulongqing		*Megapalaeolenus* Assemblage-zone
			Palaeolenus Assemblage-zone
	Hongjingshao		*Drepanuroides* Assemblage-zone
			Yunnanaspis Assemblage-zone
			Yiliangella Assemblage-zone
			Dolerolenus (*Malungia*) Assemblage-zone
	Heilinpu	Yuanshan	*Chengjiangaspis* Assemblage-subzone
			Eoredlichia-Wutingaspis Assemblage-zone
			Tsunyidiscus Assemblage-subzone
			Parabadiella Assemblage-zone
		Shiyantou	*Sinosachites-Lapworthella* Assemblage-zone
	Yuhucun	Dahai	*Paragloborilus-Siphogonuchites* Assemblage-zone
		Zhongyicun	*Anabarites-Protohertzina* Assemblage-zone
		Xiaowaitoushan	
Neoproterozoic		Baiyanshao	
		Jiucheng	
	Donglongtan	Algal Dolomite	
	Lunasi		

Fig. 3. Upper Neoproterozoic-Lower Cambrian lithostratigraphic nomenclature and biostratigraphic zonation for eastern Yunnan.

recognized until Xianguang Huo discovered nonmineralized arthropods bearing appendages, and other fossils, in the Yuanshan Member of the Heilinpu Formation at Maotianshan in 1984. The Maotianshan locality is in the vicinity of the small village of Chengjiang (Fig. 2), Chengjiang County, near Kunming. Specimens of the relatively abundant arthropod *Naraoia* were reported shortly thereafter (Zhang and Hou, 1985). Since that time, dozens of scientific papers have been written, and more work is in progress. Species of Early Cambrian animals, plants, and bacteria have been reported from exceptionally preserved remains recovered from various exposures and formations across a broad area of eastern Yunnan (e.g., Chen *et al.*, 1996; Chen and Zhou, 1997; Hou and Bergström, 1997; Hou *et al.*, 1999; Zhang and Babcock, 2001; Fig. 1); those from the Yuanshan Member of the Heilinpu Formation now number more than 140.

GEOLOGIC SETTING

Stratigraphy Exceptionally preserved organisms are found in the Yuanshan Member of the Heilinpu Formation (Lower Cambrian; Fig. 2) at various localities in eastern Yunnan Province, China (e.g., Luo *et al.*, 1997; Hou *et al.*, 1999; Fig. 1). Most of these localities are in Chengjiang County, and collectively, they are referred to as the Chengjiang Lagerstätte or Chengjiang deposit. In earlier years, the Heilinpu Formation was often called the Qiongzhusi Formation.

The Heilinpu Formation includes two members. In ascending order, they are the Shiyantou Member and the Yuanshan Member. The Shiyantou Member, which ranges from about 50 to 80 meters in thickness, mostly consists of dark gray or black siltstones and shales. The overlying Yuanshan Member, which ranges from about 100 to 150 meters in thickness, consists of a thin black shale and siltstone unit at the base, followed by a succession of gray-green shale beds (weathering yellow) and sandstone interbeds. The basal black shale and siltstone con-

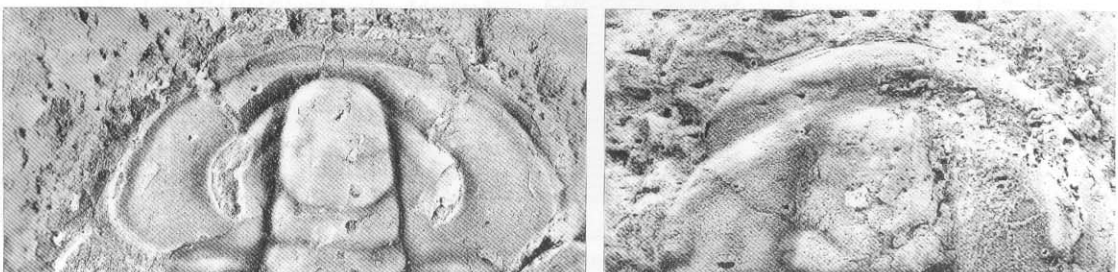


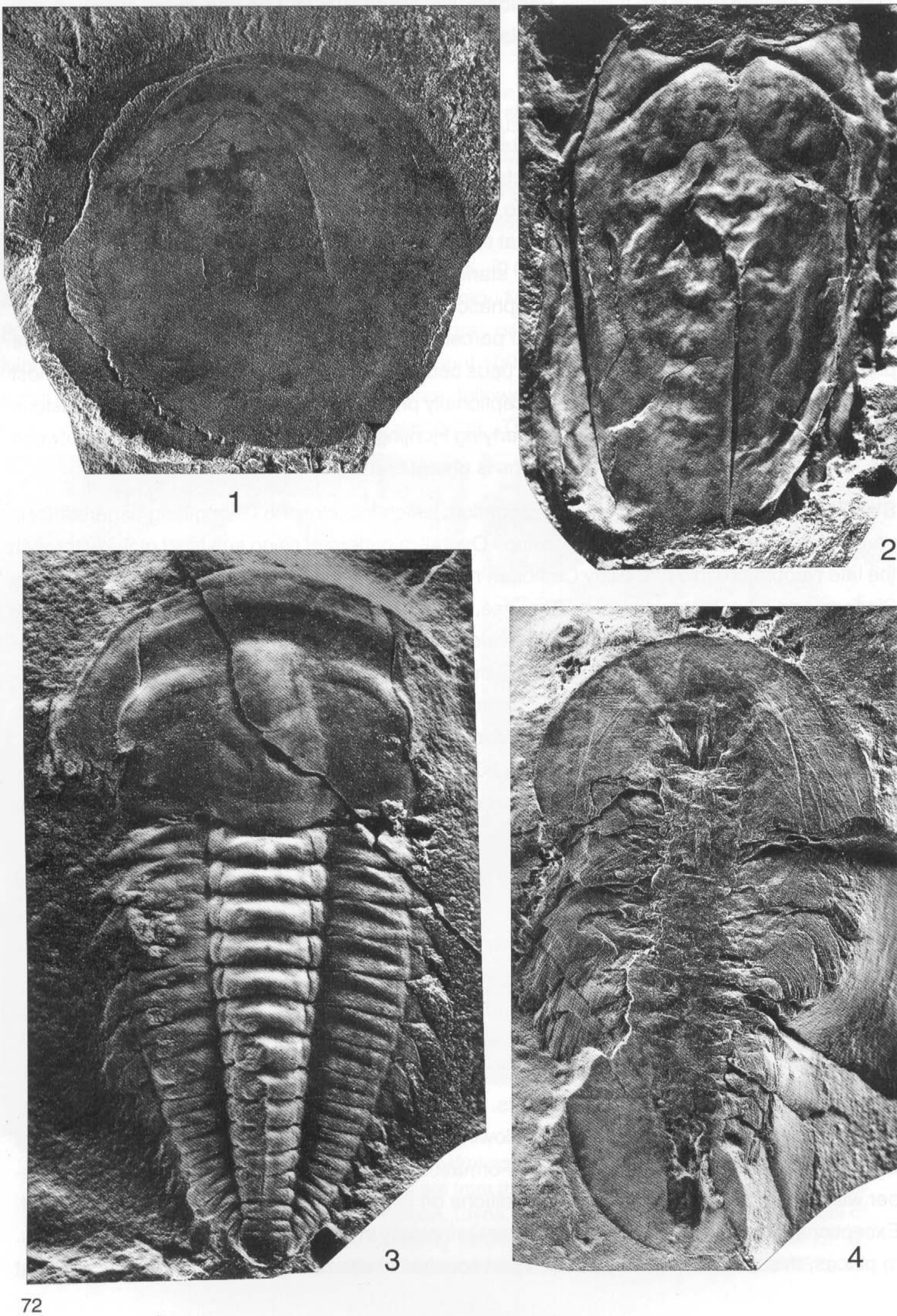
Fig. 4. Zonal guide fossils for the *Eoredlichia-Wutingaspis* Assemblage-zone, within which the Chengjiang Lagerstätte occurs. Specimens are from the upper part of the Yuanshan Member of the Heilinpu Formation at Maotianshan, Yunnan, China. Specimens are in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences. 1, *Eoredlichia intermedia*, x5. 2, *Malongocephalus* sp. nov. (previously referred to *Wutingaspis tingi*; Chen *et al.*, 1996, 1997), x4.

tains rare specimens of the trilobite *Parabadiella* (Zhang, 1987a; Luo and Jiang, 1996). A thin bentonite occurs near the base of the black shale interval, just above the first appearance of *Parabadiella* (Chen and Zhou, 1997).

Most exceptionally preserved fossils in the Yuanshan Member are in the upper part; these strata are assigned to the *Eoredlichia-Wutingaspis* Assemblage-zone (Figs. 3, 4). Exceptional preservation of animals, plants, and bacteria (Figs. 5-8) is concentrated along individual bedding planes in the mudrock-rich part of the upper Yuanshan Member. At most localities, beds of the Yuanshan Member that are exposed at the surface are deeply weathered, and the rocks are yellow in color. Body fossils commonly stand out from the matrix because of a reddish iron oxide staining or a white to bluish, phosphatic? appearance. Fossils seem to be largely preserved by clay minerals, although small percentages of limonite and phosphate seem to be present in some specimens. Sandstone beds become much more numerous in the uppermost part of the Yuanshan Member where exceptionally preserved fossils are quite rare. Sandstone beds are of the same lithology as the overlying Honjingshao Formation. The contact between the Heilinpu and Hongjingshao formations is gradational.

Stratigraphic context The Heilinpu Formation, which includes the Chengjiang Lagerstätte, is part of a thick Lower Cambrian succession. Overall, a pattern of rising sea level globally through the late Neoproterozoic and Early Cambrian resulted in marine flooding of the Southwest China Platform and other tectonic blocks. That rise, however, was punctuated by a series of relatively minor sea level drops that led to the development of a series of disconformities in Yunnan Province. Late Neoproterozoic and initial Cambrian sedimentation in eastern Yunnan was dominated by a series of shallow water carbonate deposits and phosphorites (e.g., Yang in Wang, 1985; Luo *et al.*, 1992, 1984, 1994a; Luo and Jiang, 1996; Seigmund, 1997; Tang *et al.*, 1997; Zhang and Babcock, 2001; Zhang *et al.*, 2001) deposited over a wide geographic expanse. Subsequent sedimentation of the Early Cambrian included mud-rich and sand-rich siliciclastic deposits.

The Heilinpu Formation is interpreted to have been deposited in a shallow shelf to coastal marine setting (e. g., Babcock *et al.*, 2001; Zhang and Babcock, 2001). The Shiyantou Member of the Heilinpu Formation was evidently deposited in relatively shallow water, as indicated by the presence of hummocky cross-bedding, a feature typical of deposits developed within storm wave base (Dott and Bourgeois, 1982). The Yuanshan Member of the Heilinpu Formation (Fig. 2) consists of a thin black mudrock (black shale and siltstone) at the base, followed by a thick succession of gray-green (weathering yellow) shale (or claystone) with numerous yellowish-brown siltstone to fine sandstone interbeds. The black shale records a relatively rapid onlap of marine water over the Yangtze Platform following deposition of the dark gray and black mudrocks of the Shiyantou Member of the Heilinpu Formation. Gray-green shale of the Yuanshan Member was deposited under quiet water conditions on this widespread, shallow continental shelf. Exceptional preservation of organisms occurs principally in this mudrock-dominated succession. In places, this mudrock is thinly bedded and consists of alternating lighter-darker couplets that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have a discernible periodicity, and interpreted as the result of tidally influenced sedimentation (Babcock *et al.*, 2001). Siltstone and sandstone interbeds are rare through most of the lower and middle parts of the Yuanshan Member but increase in frequency of occurrence toward the top of the unit. Bases of some of the sandstone interbeds show evidence of scour, indicating that they were rapidly deposited by some sedimentational process that was initially erosive and later depositional. On a broad, tidally inflenced shelf, rapid floods events (initiated by freshwater streams entering the ocean) are a likely possibility for the origin of some of the beds. Floods may have resuspended sediments that were once deposited within stream channels, and carried those sediments out to sea, where they were redeposited. It is also possible that storm events influenced sedimentation in the present-day area of Kunming.

The boundary of the Yuanshan Member (Heilinpu Formation) with the overlying Hongjingshao Formation, which consists predominantly of yellowish-brown to reddish-brown sandstone and siltstone with interbeds of gray-green mudrock, is arbitrary. Field relationships suggest that the upper part of the Yuanshan Member and the lower part of the Hongjingshao Formation were laterally adjacent lithofacies at the time of deposition. A relative coastal offlap would have led to the deposition of coarser Hongjingshao-type sediments overlying finer Yuanshan-type sediments (a coarsening-upward succession). The thick sandstone intervals within the Hongjingshao Formation are largely, if not entirely, the result of shallow, subtidal marine sedimentation. Most of the sandstone beds probably represent deposits of shifting sands such as submarine sand bars. Fossils in the Hongjingshao Formation consist mostly of resistant, calcified shelly parts of organisms. Particularly common in places are disarticulated trilobite sclerites and hyolith conchs.

Correlation of Lower Cambrian in Yunnan Globally, the base of the Cambrian is marked by the first appearance of the trace fossil *Trichophycus pedum* (Landing, 1994; Geyer, 1998). Unfortunately, a horizon equivalent to the global stratotype point cannot be unequivocally identified in eastern Yunnan.

Four major assemblages of body fossils mark the Lower Cambrian of Southwest China (Qian and Bengtson, 1989; Qian, 1990; Luo and Jiang, 1996). The first assemblage, which mostly contains small shelly fossils and paraconodonts, has been assigned to the *Anabarites-Protohertzina* Assemblage-zone. This assemblage occurs in the Xiaowaitoushan Member of the Yuhucun Formation in Yunnan. We consider the base of the Xiaowaitoushan Member to correlate approximately to the base of the Cambrian globally (see Geyer and Shergold, 2001). However, a disconformity seems to separate the Xiaowaitoushan Member from the underlying

Fig. 5. Representative fossils from the Chengjiang Lagerstätte, Maotianshan, Yunnan, China. All specimens are in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences. 1, Brachiopod, *Heliomedusa orienta*, showing mantle setae, x4. 2, Bivalved arthropod, *Combinivalvula chengjiangensis*, x7.5. 3, Trilobite, *Yunnanocephalus yunnanensis*, x5. 4, Naraoiid arthropod, *Naraoia longicaudata*, showing numerous ventral appendages, x2.

Baiyanshao Member of the Yuhucun Formation, and the thickness of strata missing at the disconformity is not known.

The second assemblage, which is assigned to the *Paragloborilus-Siphogonuchites* Assemblage-zone, occurs in the Dahai Member of the Yuhucun Formation. Abundance of fossils in this assemblage considerably exceeds the abundance of specimens in the Xiaowaitoushan Member. The base of the Dahai Member is inferred to be separated from underlying strata of the Zhongyicun Member of the Yuhucun Formation by a disconformity.

The third assemblage, which is assigned to the *Sinosachites-Lapworthella* Assemblage-zone, occurs in the Shiyantou Member of the Heilinpu Formation. It is separated from underlying strata of the Yuhucun Formation by a regional disconformity.

The fourth assemblage is indicated by the first appearance of trilobites, and occurs in the lower part of the Yuanshan Member of the Heilinpu Formation. In Yunnan Province, the oldest-known trilobite is *Parabadiella* (Zhang, 1987a), and strata of the lower Yuanshan Member are assigned to the *Parabadiella* Assemblage-zone.

Overlying strata of the *Parabadiella* Zone are strata that generally show a dramatically increased abundance and diversity of fossils. The Chengjiang Lagerstätte, which occurs in the upper part of the Yuanshan Member of the Heilinpu Formation, is part of this interval. Biostratigraphically, the deposit of exceptional preservation occurs in the *Eoredlichia-Wutingaspis* Assemblage-zone.

CHENGJIANG COMPOSITION AND TAPHONOMIC OVERPRINT

The Chengjiang Lagerstätte provides an interesting "window" into the diversity of life forms and the community structure of an ancient ecosystem. Each of the Burgess Shale-type biotas provides important information on the Cambrian radiation event, but the Chengjiang "window" is of particular importance because of the great diversity of life forms preserved, and because of its stratigraphic position in the Lower Cambrian. A variety of physical, chemical, and biological conditions have influenced fossil preservation at Chengjiang (Babcock *et al.*, 2001); it is necessary to understand these processes to fully appreciate the original community structure of the Chengjiang Biota, and to appreciate how unusual such deposits are compared to the fossil record as a whole.

The Chengjiang Biota contains one of the most diverse assemblages of fossil organisms

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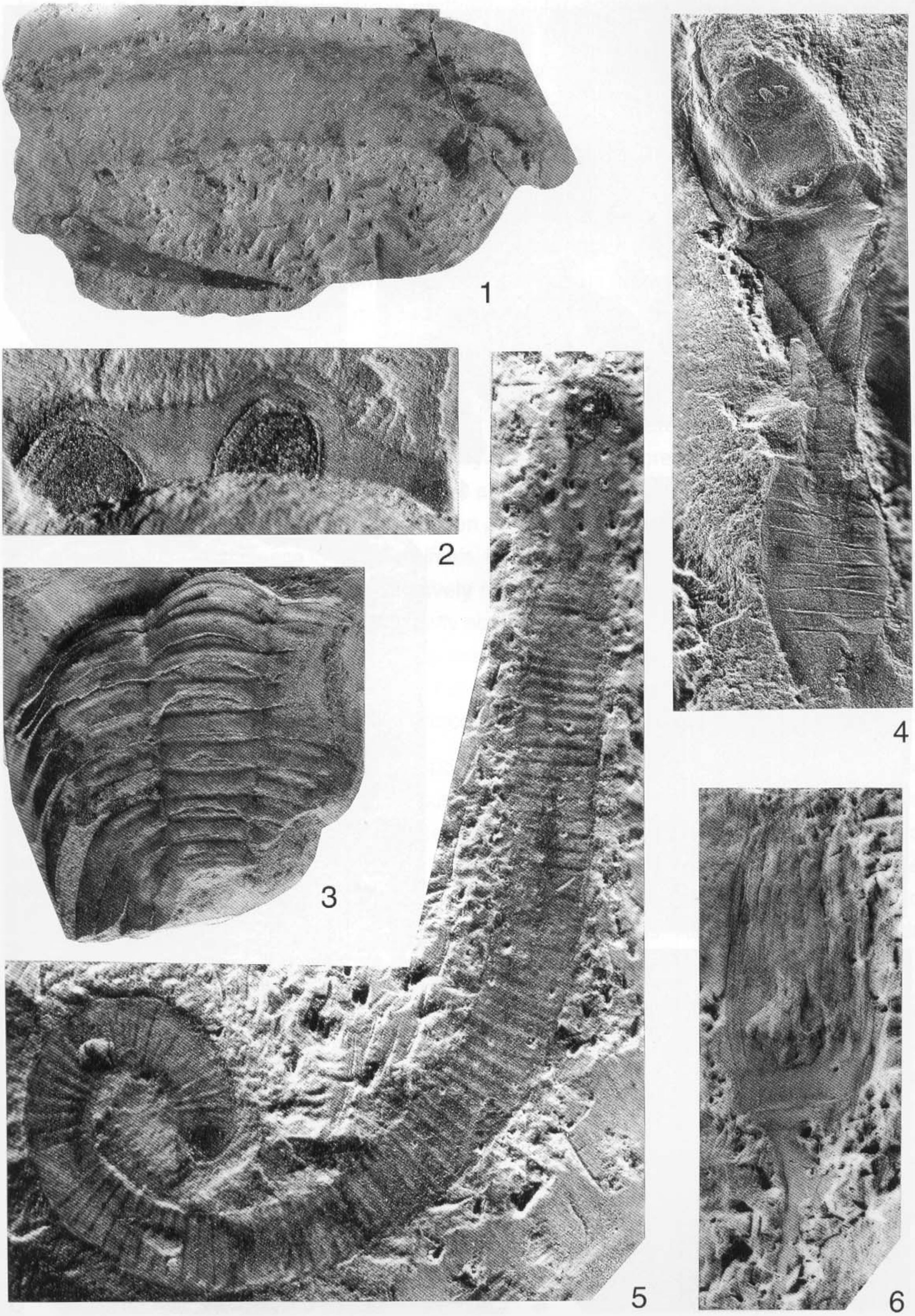
Fig. 6. Representative fossils from the Chengjiang Lagerstätte, Maotianshan, Yunnan, China. All specimens are in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences. 1, Claw of anomalocaridid, *Amplectobelua symbrachiata*, x1. 2, Incomplete body of *Microdictyon sinicum* showing two sclerites, x10. 3, Trilobite, *Malungia laevigata*, showing healed injury to plural tip on left side, x1.5. 4, *Banffia confusa*, x3. 5, Worm, *Maotianshania cylindrica*, x8. 6, *Dinomischus venustus*, x5.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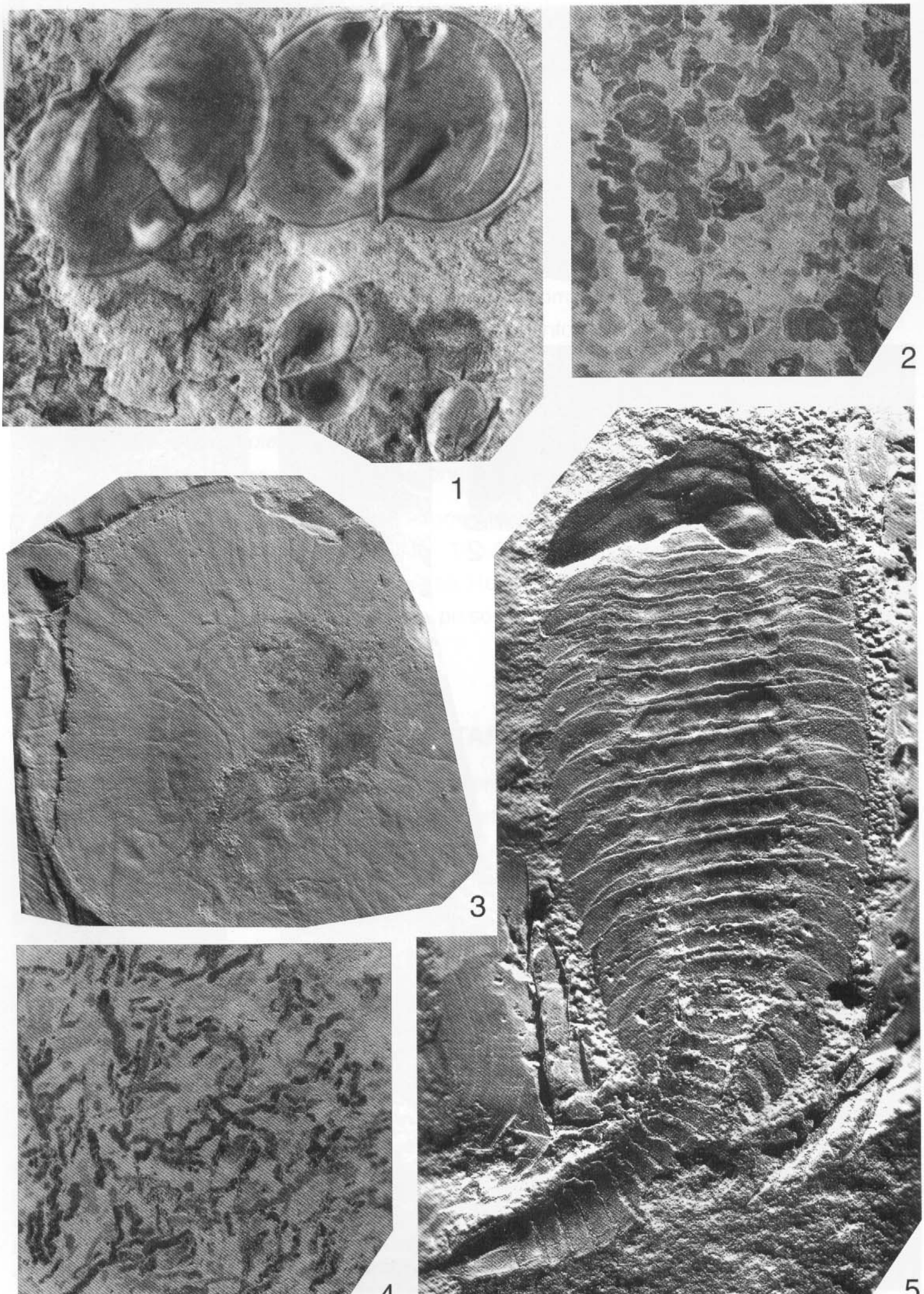
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known from any deposit of the Paleozoic Erathem. So far, approximately 140 species in about 90 genera have been documented from the biota. For comparison, approximately 170 species in 125 genera have been described so far from the Burgess Shale (Briggs *et al.*, 1994).

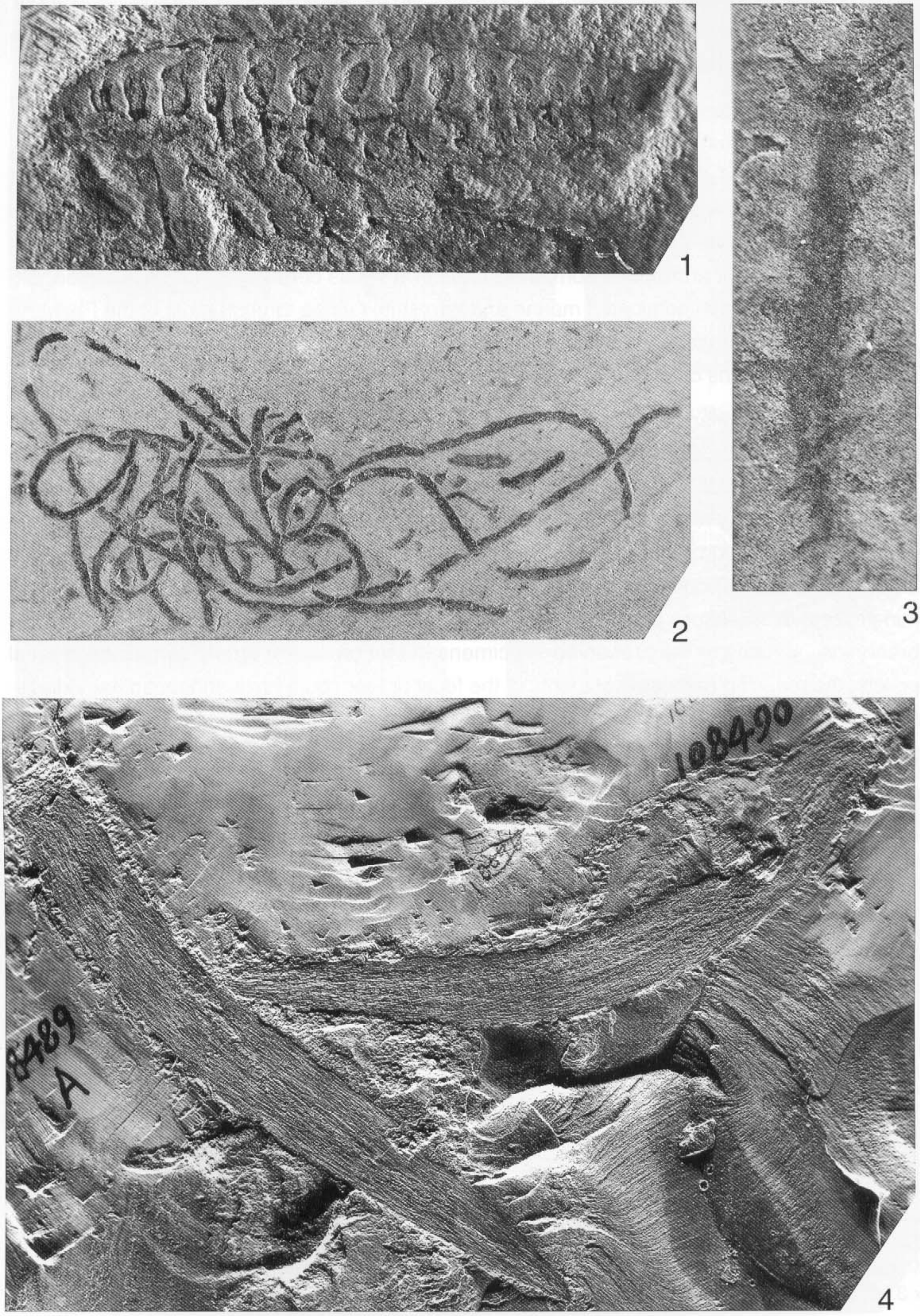
In a study of fossils found during the early years of collecting at Maotianshan, Leslie *et al.* (1996) determined that, among animal body fossils from the Chengjiang Biota, arthropods (Figs. 4, 5.2-5.4, 6.1, 6.3, 6.4?, 7.1, 7.5, 8.1) are the most abundant (in terms of number of preserved specimens) and the most diverse (in terms of species). Arthropods account for more than three-quarters of animal species, and approximately two-thirds of all fossils. Such an overwhelming number of arthropods compared to other animals certainly is not unexpected, because arthropods have dominated marine and terrestrial faunas through most of the Phanerozoic Eon. Information from the Chengjiang Biota indicates that arthropods have held a place of preeminence in terms of animal diversity since the early Paleozoic.

Among Chengjiang arthropods, bradoriids (Fig. 7.1) dominate in abundance. Although they have a relatively low species diversity, they nevertheless represent more than 70% of all arthropods. Bradoriids are often found in large aggregations. In some cases, these aggregations almost certainly represent coprolites (Chen *et al.*, 1996). If so, these creatures must have been an important food source for larger animals, which in most cases were probably arthropods and worms. Large populations and relatively resistant (although nonmineralized or lightly mineralized) exoskeletons probably only partly account for the preservation of large numbers of bradoriids. If many of the preserved specimens in fact represent empty carcasses in fecal pellets, the reducing microenvironments of the fecal pellets could have enhanced early diagenetic chemical activity, and ultimately, enhanced preservation potential.

Relatively large, non-bradoriid, arthropods constitute almost 30% of the arthropod fossils in the Chengjiang collections that were censused (Leslie *et al.*, 1996). Large bivalved arthropods (Fig. 5.2) comprise nearly 18% of the preserved arthropods. Naraoiids (Fig. 5.4) comprise a little more than 10% of the large arthropod fossils. Trilobites (Figs. 4, 5.3, 6.3) , which are the only group of arthropods represented in the Chengjiang Biota that have a strongly calcified exoskeleton, comprise fewer than 1.5% of the preserved arthropods. All other larger arthropods comprise fewer than 1% of the arthropod specimens in the studied collections.

Algae (Figs. 7.4, 8.2) and cyanobacteria (Fig. 7.2) comprise an important part of the Chengjiang Biota, about one-third of all fossils, although their abundance is underestimated because clumps were counted as single occurrences (Leslie *et al.*, 1996). Diversity of algae

Fig.7. Representative fossils from the Chengjiang Lagerstätte, Maotianshan, Yunnan, China. All specimens are in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences. 1, Bradoriid arthropods, *Kunmingella maotianshanensis* (two larger specimens at top of photograph) and *Yaoyingella inflata* (two smaller specimens at bottom of photograph), x5. 2, Cyanobacterium?, *Megaspirellus houi*, x3. 3, Eldoniid, *Eldonia eumorphus*, x1. 4, Green alga?, *Yuknessia* cf. *Y. simplex*, x 3. 5, Stem-group arthropod, *Fuxianhuia protensa*, x4.5.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and cyanobacteria seems to be relatively low, although this may be partly a result of an inability to easily distinguish some species from others.

The remaining types of organisms present in the Chengjiang Biota include brachiopods (Fig. 5.1), sponges (Fig. 8.4), worms (Fig. 6.5) of various kinds, lobopods (Figs. 6.2, 8.3), mollusks, hyoliths, and some enigmatic taxa such as eldoniids (Fig. 7.3) and dinomischids (Fig. 6.6). Together, these groups combine to account for fewer than 3% of the preserved remains of life forms; their diversity is also quite low. Some hyoliths occur in clusters, suggesting that they have passed in or through the guts of large predators, and are preserved either as gut contents or as coprolites (Chen *et al.*, 1996).

In most Cambrian localities worldwide, shelly animals such as trilobites, inarticulate brachiopods, hyolithids, and sponges not only dominate the preserved remains of animals, but are commonly the only types of macrofossils present. In the Chengjiang Biota these animals together account for fewer than 3% of the body fossils. This provides further indication that most Cambrian deposits greatly under-represent the true abundance and diversity of organisms that were once living in Cambrian marine ecosystems. Similar results were previously reported for the Burgess Shale (Conway Morris, 1986).

DEPOSITIONAL SETTING

The sedimentary history of the Chengjiang Lagerstätte has been interpreted in a variety of ways, and most interpretations incorporate key aspects of the most commonly held view for the origin of the Burgess Shale (turbidite deposition in an anoxic basin; e.g., Whittington, 1985; Conway Morris, 1986; Briggs *et al.*, 1994). One hypothesis involves sedimentary deposition as the result of a series of turbidity currents originating near a steeply dipping delta front and carrying sediment to distal offshore sites (e.g., Chen *et al.*, 1996; Chen and Zhou, 1997). Water depth in which the organisms were deposited has been estimated at 100 to 150 meters (Chen *et al.*, 1996). A variation on this hypothesis is that of Lindström (1995), who suggested that organisms were buried in relatively deep water by turbidity currents under the influence of fluviatile nearshore processes in an estuarine setting. Chen and Erdtmann (1991) suggested that the Chengjiang Biota was subjected to polycyclic anoxia followed by rapid burial under sheets of sediment from turbidites or tempestites in an outer shelf, normally quiet water, detrital belt.

Paleogeographic, sedimentological, and paleoecological evidence supports the interpretation that the Chengjiang deposit represents a variety of relatively shallow, tidally influenced conditions (Lindström, 1995; Babcock *et al.*, 2001; Zhang and Babcock, 2001) on a low, broad

Fig.8. Representative fossils from the Chengjiang Lagerstätte, Maotianshan, Yunnan, China. All specimens are in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences. 1, Arthropod, *Alalcomenaeus illecebrosus*, x10. 2, Alga?, *Sinocylindrica yunnanensis* x. 4. 3, Lobopod, *Luolishania longicrurus*, x8. 4, Sponges, *Paraleptomitella dictyodroma*, x1.3.

marine shelf influenced in places by estuarine or other fluvial sources. Exceptional preservation directly associated with black shale and turbidite deposition is unknown in the Chengjiang Lagerstätte. Environments represented range from shallow subtidal marine settings where tidal activity influenced sedimentational history, through estuaries, and periodically submerged tidal flats. Storm-resuspended muds are a likely source of burial in thin beds where large numbers of exceptionally preserved fossils are present. Available evidence indicates that deposition of the Chengjiang Lagerstätte was roughly analogous to deposition of some Carboniferous Lagerstätten in coastal (shallow shelf, estuarine, and tidal flat) environments where tidal rhythmites were preserved (e.g., Feldman *et al.*, 1992, 1993, 1994; Archer and Feldman, 1994; Babcock *et al.*, 2000). In such settings, exceptional preservation is probably at least partly related to temporary exclusion of predators, scavengers, and sediment bioturbators by salinity fluctuation (Babcock *et al.*, 2001). Rapid burial in oxygen-deficient mud would further promote preservation of nonmineralized skeletal parts, and occasionally internal soft-parts.

The Chengjiang Lagerstätte records deposition in a predominantly quiet water setting that frequently experienced the episodic input of coarse sediments from nearby terrigenous sources. Toward the top of the Yuanshan Member of the Heilinpu Formation, sandstone layers increase in number. These more coarsely grained sedimentary rocks apparently record rapid deposition from nearby streams that emptied into coastal marine environments. Occasionally, body fossils are found near the bases of the coarse beds in Yunnan, indicating that they were picked up by currents and buried in neighboring areas.

Muddy deposits at Chengjiang localities are dominated in places by thin, so-called "pinstripe" bedding, which develops only where there are so few burrowing organisms alive in an area that they do not often disturb the original fine laminations of sediment. Pinstripe-style bedding can develop in a number of places where sediment bioturbators are excluded, thus leaving the original thin lamination of the sediment undisturbed (Droser and Bottjer, 1988), so this line of evidence must be combined with others to develop a coherent picture of a depositional site. It is important to note, however, that sporadically distributed beds have experienced minor burrowing by wormlike animals (Luo *et al.*, 1994b). This indicates that conditions inimical to bioturbators were not always present in these areas; there were occasional intervals of time during which conditions were suitable for minor colonization of the bottom muds. Environments where muds were deposited and that excluded most burrowers, thus allowing for retention of pinstripe-style bedding, include places that had anoxic pore water in the sediment (e.g., the Cambrian Alum Shale of Sweden and Denmark; Berg-Madsen, 1985a, 1985b; Bergström, 1990 and the Devonian-Carboniferous black shales of North America and Europe; e. g., Heckel, 1977; Provo *et al.*, 1978; Babcock, 1998); and tidal flats, where salinity fluctuation and desiccation occurred (e.g., various Silurian or Carboniferous marginal-marine deposits deposits in eastern and midcontinent North America; Kluessendorf, 1994; Babcock *et al.*, 2001). At Chengjiang localities, exceptionally preserved fossils are often concentrated in thinly laminated shale beds. Although many such fossils were probably buried by tidal ebb and flow, some such layers were affected by weakly erosive forces, as indicated by minor truncation of underlying shale layers, and by evidence of multidirectional flow. Such layers probably represent mud-rich tempestites.

Lithofacies architecture of the Yuanshan Member of the Heilinpu Formation and sedimentary features of adjacent deposits support deposition of the Yuanshan Member in a range of tidally influenced coastal areas. In addition to the evidence already discussed concerning the physiography of the region and the episodic input of coarse terrigenous sediments, the stratigraphic units that underlie and overlie layers containing exceptionally preserved fossils provide documentation of a shallow water, relatively nearshore origin for the deposit. The Shiyantou Member of the Heilinpu Formation, which underlies the Yuanshan Member, contains hummocky cross-stratification, a sedimentary feature indicative of relatively shallow water. The Hongjingshao Formation, which overlies the Heilinpu Member, and which was evidently deposited in lateral continuity with the Heilinpu Member, consists mostly of sandstone beds showing planar cross-bedding, herringbone (bidirectional) cross-bedding, intraclasts, and other features indicating deposition as shallow submarine sand bars through perhaps beach sands. Scoured bases, and weak fining-upward sequences on some beds, indicate that rapid deposition occurred episodically in places, perhaps as the result of sediments carried to the oceans by streams during times of flood. The Hongjingshao Formation is inferred to be the nearshore lithofacies equivalent of the Yuanshan Member, and it was deposited under conditions of higher current energy than was the Yuanshan Member. The influence of terrigenously derived, stream-carried sedimentation was greater in the Hongjingshao Formation than in the Heilinpu Member. Lenticular sandstone layers in the Yuanshan Member are of Hongjingshao-type lithology, which supports the view that the two units were deposited laterally adjacent to each other. Those sandstone beds that are recorded in the Yuanshan Member probably resulted, to a large extent, from major floods or other high energy, episodic evidents that carried sediment from adjacent environments into mud-rich areas of Yuanshan-type lithology.

Fossils from the Chengjiang Biota include most of the marine groups represented in the Burgess Shale, but stenohaline echinoderms are virtually absent (save two possible homoiosteleans illustrated by Chen and Zhou, 1997). Furthermore, cnidarians are represented by rare sea anemones, mollusks are exceedingly rare, and brachiopods are not diverse but include lingulids. The near-lack of echinoderms suggests that water of normal marine salinity was not typical at the depositional site. Sea anemones seem to prefer marine water, but can survive in intertidal areas. The inferred inconsistent presence of marine water has probably led to a scarcity of mollusks at Chengjiang. Finally, the presence of lingulid brachiopods, which are relatively abundant in some beds, is consistent with interpretation of the depositional environment as a tidal flat. Although lingulids tend to be euryhaline (Thayer and Steele-Petrovic, 1974), they are often found in large numbers in inferred tidal flat environments. Their preservation with the pedicles extended (Jin *et al.*, 1993), rather than pointed downward into the mud suggests either that they have been transported, or when they came up to the surface during low tides, succumbed to conditions at the sediment surface (compare Thayer and Steele-Petrovic, 1974).

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