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CAMBRIAN AND ORDOVICIAN STRATIGRAPHY AT WA'ERGANG, HUNAN PROVINCE, CHINA: BASES OF THE WAERGANGIAN AND TAOYUANIAN STAGES OF THE CAMBRIAN SYSTEM

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INTRODUCTION

The section at Wa'ergang Village, in the northwestern corner of Taoyuan County (part of the Wulingshan Range; Figs. 1, 2), Hunan Province, exposes a long interval of richly fossiliferous Cambrian and Lower Ordovician strata (Fig. 3). The section contains the bases of the proposed Waergangian and Taoyuanian stages of the Cambrian. Wa'ergang Village is about 10 km north-west of Niuchehe Town, Taoyuan, and can be reached either by driving about 85 km east from Dayong (Zhangjiajie), or driving west about 90 km from Changde or Taoyuan, Hunan.

The Wa'ergang section was first measured by Peng in 1979, and was subsequently described, along with many of the trilobites, in Peng's (1981, 1984) M. Sc. and Ph.D. theses and papers stemming from that work (Peng, 1983, 1984, 1987, 1990a, 1990b). Afterward, Peng and Chen (1983), Shu (1990), and Lin (1991) described some of Cambrian nautiloids, bradoriids, and trilobites respectively, from the section. Yang *et al.* (1984) completed a biostratigraphic study for the interval containing *Linguagnostus reconditus*, *Glyptagnostus stolidotus*, and *G. reticulatus*. Fu *et al.* (1999) and Saltzman *et al.* (2000) reported on the sedimentology and carbon-isotope stratigraphy, respectively, for the section.

The Wa'ergang section contains strata assigned to the Aoxi, Huaqiao, and Shenjiawan formations of the Cambrian; and the Panjiazui and Madaoyu formations of the Ordovician (Tremadocian). The position of the village of Wa'ergang is in the middle part of the Huaqiao Formation.

The Cambrian and Tremadocian formations at Wa'ergang consist chiefly of alternating beds of shale and argillaceous to pure carbonates (both limestone and dolostone). Carbonates range in texture from lime mudstones to debris beds. Some beds of black shale occur within one unit,

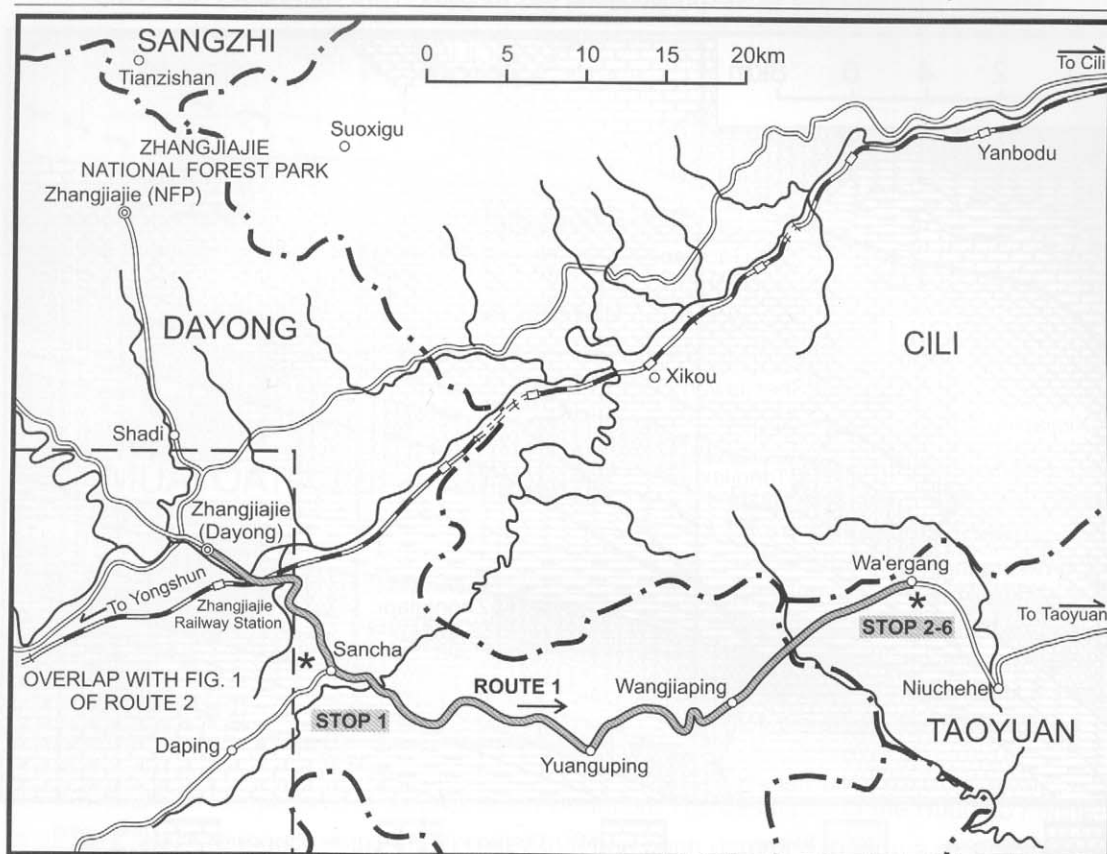


Fig. 1. Map showing the route (shadowed) to the Sancha and the Wa'ergang sections from Zhangjiajie, Hunan Province, China.

the Aoxi Formation (Taijiangian Stage). Debris beds, presumably the result of gravity displacement of sediment, are common in the Huaqiao Formation. Distal turbidites, including carbonate turbidites, and inferred hemipelagic sediments, which are the dominant deposits of the Huaqiao and Shenjianwan formations, are consistent with a basin-margin depositional setting (Fu *et al.*, 1999).

Stop 2

Aoxi Formation and lower Huaqiao Formation (*Ptychagnostus punctuosus* Zone through *Glyptagnostus stolidotus* Zone)

The purpose of this stop is to examine the lithologies of the main part of the Aoxi Formation and the lower part of the Huaqiao Formation. The interval of the Huaqiao Formation that will be examined extends from the base of the formation through the base of the *Glyptagnostus reticulatus* Zone (i.e., the base of the Waergangian Stage).

In the Cili-Taoyuan area, the Aoxi Formation is about 250 m thick. A section measured at Tangjiayi Village, which is near Shenjiawan and is about 5 km east of Wa'ergang, shows that the formation in this area can be divided into three informal members (Zhao and Yu, 1982, p. 51). In

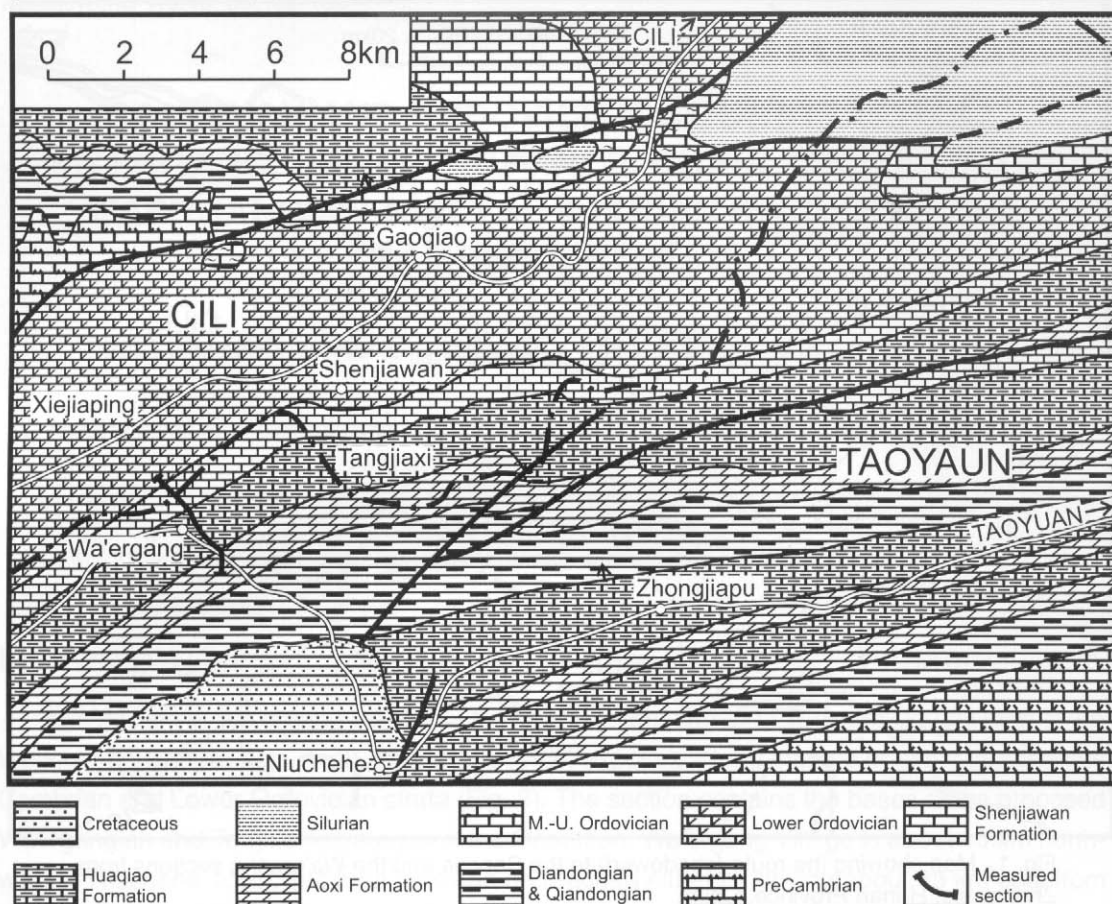


Fig. 2. Stratigraphic nomenclature for Stops 1 to 3. Heavy line shows chronostratigraphic boundaries to be examined.

ascending order the members are: 1, a dolomitic limestone; 2, a black shale; and 3, a thick-bedded dolostone. The lithology of the Aoxi Formation at Wa'ergang, which is situated on the same synclinal limb as Tangjiayi, is almost the same as that at Tangjiayi.

This stop will be in a small valley on the south side of the highway that extends from Wa'ergang to Taoyuan, and will demonstrate the lithology of much of the Aoxi Formation. Only the basal part of the formation is not exposed at this stop. The lower informal member of the Aoxi Formation is more than 85 m thick, and consists largely of thin-bedded dolomitic limestone with intercalated beds of dolostone. To date, fossils have not been recovered from this interval. The middle member, a black shale, is 26 m thick and contains dolostone intercalations. Locally, the shale contains rich concentrations of isolated sponge spicules (*Protospongia* sp.), and rare hyolithids. The upper member, a dolostone, is exposed on the east side of a small reservoir. It is dark in color, and characterized by being thinly laminated (Fig. 4). The laminations are chiefly horizontal, but cross-bedding can be also observed. The dolostone of the upper member has been interpreted as being of deep water origin (Zhang *et al.*, 2001).

STAGES	FORMATIONS
Tremadocian	Madaoyu
	Panjiazui
Taoyuanian	Shenjiawan
Waergangian	Huaqiao
Youshuian	
Wangcunian	
Taijiangian	Aoxi

Fig. 3. Stratigraphic nomenclature used for Stops 2 to 6. Heavy lines show lithostratigraphic and chronostratigraphic boundaries to be examined. The base of the Tremadocian Stage of the Ordovician System is provisionally placed at the base of the Panjiazui Formation pending further investigation.

The Huaqiao Formation overlies the Aoxi Formation. The basal part of the Huaqiao Formation occurs near the mouth of the small valley that has been dammed to form a reservoir. This location is at the intersection of the section line and the Wa'ergang-Taoyuan highway. The basal part of the Huaqiao Formation comprises lenticular limestone and argillaceous limestone. The

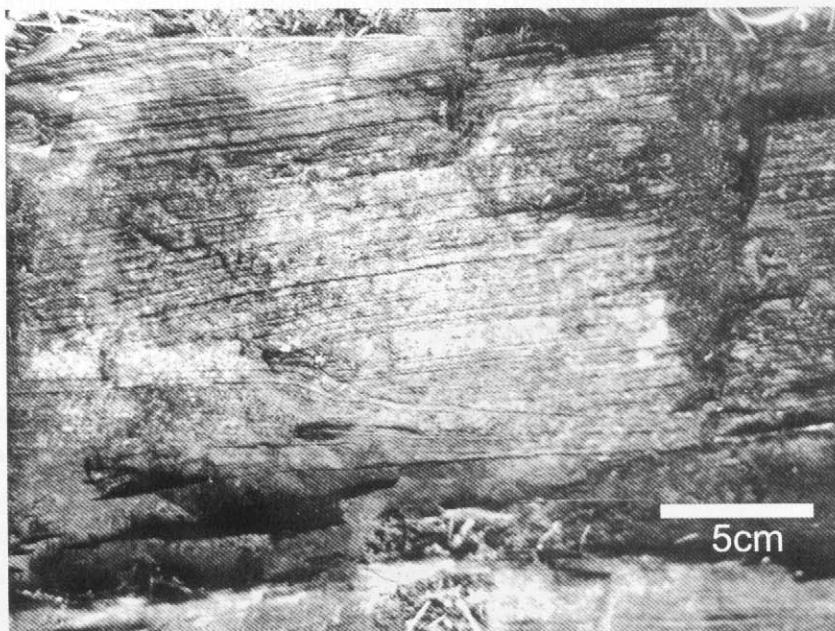


Fig. 4. Laminated dolostone in the upper dolostone member of the Aoxi Formation at 97 m in the Wa'ergang section. In this interval, the Aoxi Formation shows thin laminations and truncation structures.

limestone lenses are rich in fossils. *Pseudophalacroma ovale* and *Pseudophalacroma lundgreni* are present in this part of the section (Bed 8 of Lin, 1991; Fig. 5). These agnostoids suggest that this part of the Huaqiao Formation belongs to the *Ptychagnostus punctuosus* Zone. The Aoxi Formation at this locality was most likely deposited prior to the *Ptychagnostus punctuosus* Chron.

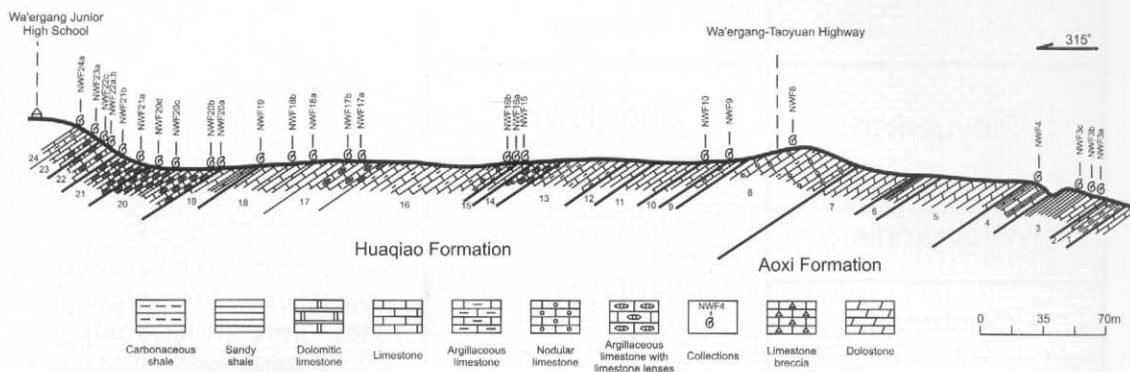


Fig. 5. Cross-section of initial part of the Wa'ergang section, showing the Aoxi Formation (Beds 1 to 7) and the lower part of the Huaqiao Formation (Beds 8-24). The Huaqiao Formation includes the interval strata of the *Ptychagnostus punctuosus* Zone through *Glyptagnostus stolidotus* Zone (modified from Lin, 1991).

Overlying beds of the lower part of the Huaqiao Formation are exposed for about 300 m (equivalent to 130 m of stratigraphic thickness) in a roadcut of the Wa'ergang-Taoyuan highway. Where the highway is north-south oriented, and prior to the point where it turns to the west, limestone beds in the roadcut yield diverse agnostoids including *Lejopyge sinensis*, *Goniagnostus fumicola*, *Tomagnostella sulcifera*, *Oidagnostus* sp., and *Kormagnostus* sp. (Peng, 1987). This interval is mainly composed of laminated argillaceous limestone, common limestone lenses and small nodules, and thin-bedded ribbon limestone. Two limestone debris beds, 20 cm and 10 cm thick, respectively, occur in the lower one-third of the interval (215 and 219 m above the base of section). Trilobites are less common in this interval (Lin, 1991) but include *Lejopyge laevigata*, *Hypagnostus correctus*, *Goniagnostus spiniger*, *Oidagnostus trispinifer*, *Proagnostus bulbus*, and *Fuchouia chiai*. This interval is equivalent to the *Goniagnostus nathorsti* through the lower part of the *Proagnostus bulbus* Zone of the Wangcun and Paibi sections (Peng and Robison, 2000).

Successive strata of the Huaqiao Formation are exposed on the south slope of a hill between the highway and the Wa'ergang Junior High School. The slope is relatively steep, and good exposure of rock are present on the west of the junior high school. Along the east side of the high school, the rocks were well exposed for a few years after the section was measured in 1979, but that area of the section is now somewhat overgrown with trees, grass, and vegetables. This interval contains fauna of the upper *Proagnostus bulbus* Zone through the *Glyptagnostus stolidotus* Zone (equivalent to the *Hadragnostus modestus-Distazeris* Zone, *Proagnostus bulbus sinensis* Zone, *Liostracina bella-Ammagnostus sinensis* Zone, and *Glyptagnostus stolidotus*

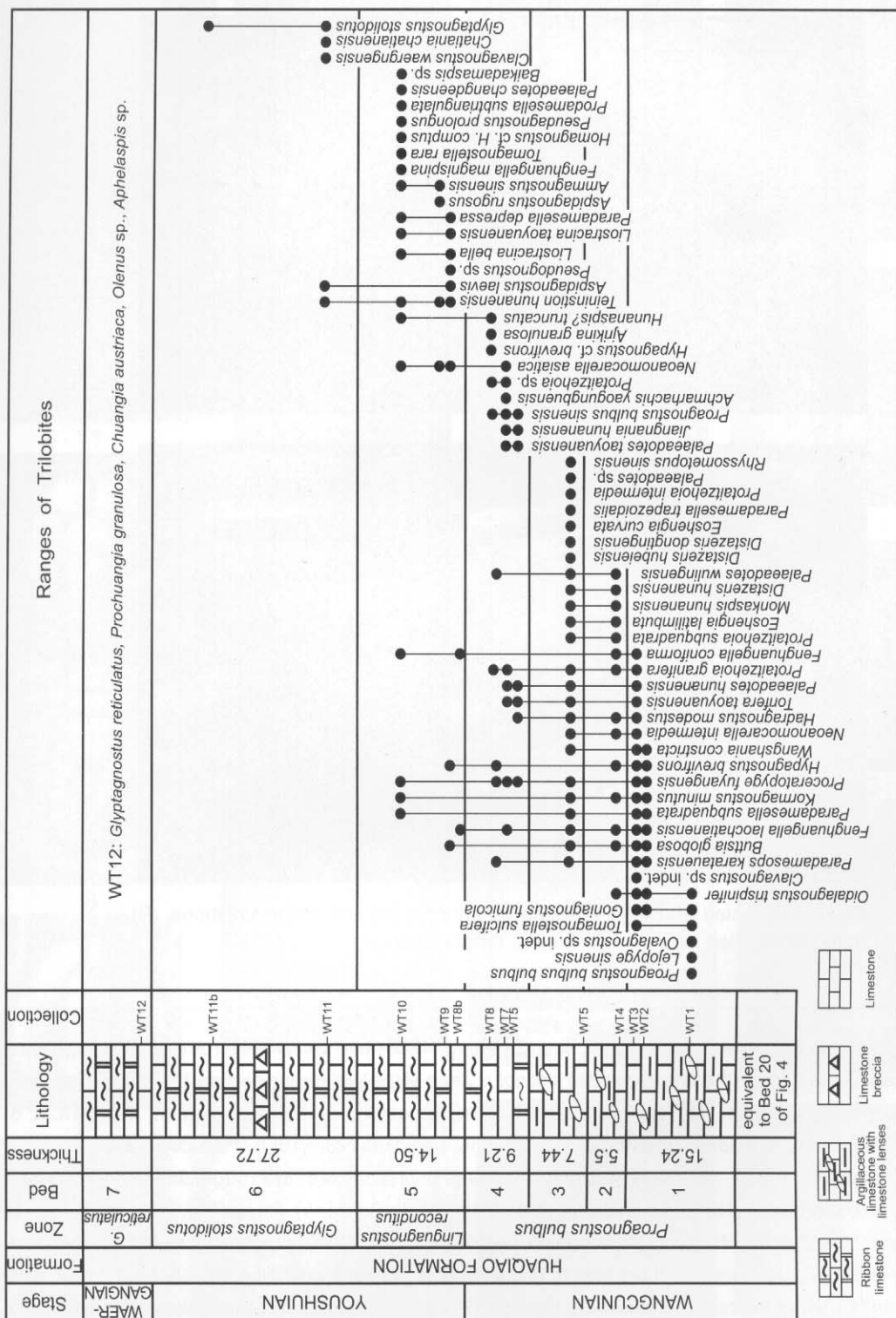


Fig. 6. Stratigraphic distribution of trilobite species described by Peng (1987) from the *Proagnostus bulbos* Zone through the *Glyptagnostus stolidotus* Zone of the Wa'ergang section (with nomenclatural updates, from Peng, 1987). This interval is equivalent to Beds 21 through 24 of Lin (1991).

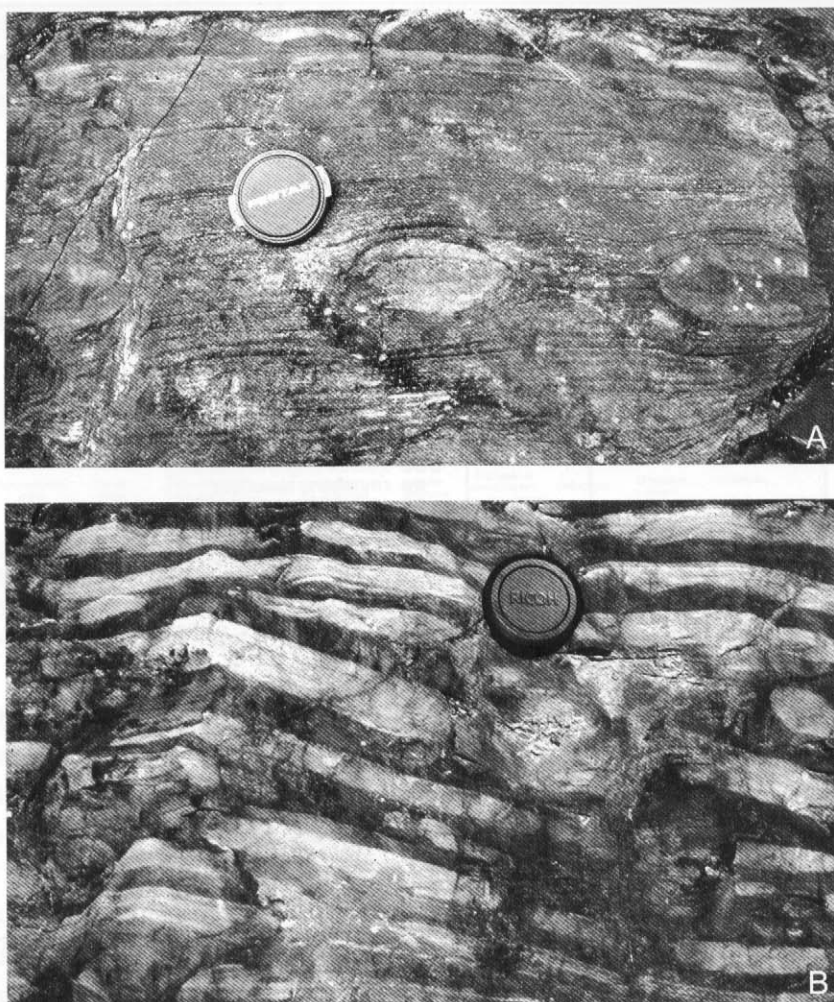
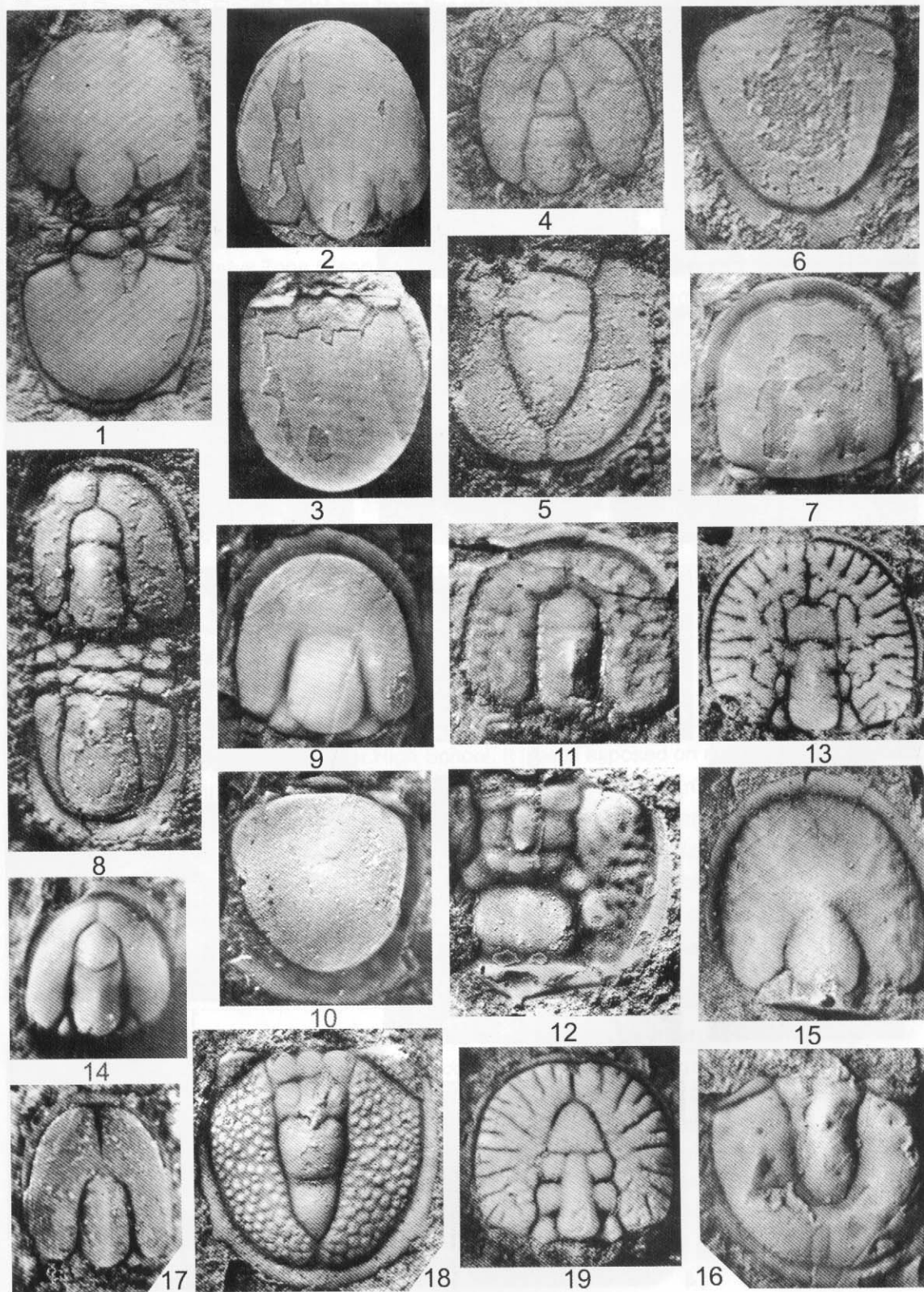
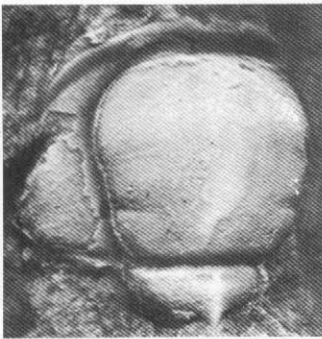


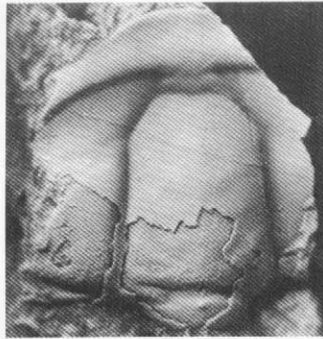
Fig. 7. Laminated limestone with limestone lenses (A) and ribbon limestone (B) from the Huaqiao Formation in the Wa'ergang section.

Fig. 8. Example agnostoid trilobites described by Peng (1987) and Lin (1991) from the *Ptychagnostus punctuosus* Zone through the *Glyptagnostus stolidotus* Zone of the Wa'ergang section. 1. *Lejopyge laevigata* (Linnarson), exoskeleton, x5; 2, 3. *Lejopyge sinensis* Lu et Lin, cephalon, pygidium, x10, x10; 5, 6. *Pseudophalacroma scanense* (Westergård), cephalon, pygidium, x8, x15; 6. *Pseudophalacroma ovale* (Yang), pygidium, x15; 7. *Ammagnostus sinensis* Peng, cephalon, x15; 8. *Proagnostus bulbosus sinensis* (Peng), exoskeleton, x15; 9, 10. *Kormagnostus minutus* (Schrank), cephalon, x15, x12; 11, 12. *Oidagnostus trispinifer* (Westergård), cephalon, pygidium, x9, x9; 13. *Glyptagnostus stolidotus*, cephalon, x8; 14. *Hadragnostus modestus* (Lochman in Lochman and Duncan), cephalon, x6; 15, 16. *Hypagnostus brevifrons* (Angelin), cephalon, pygidium, x10, x10; 17. *Nahanagnostus nganashanicus* (Rozova), x 20; 18, 19. *Goniagnostus fumicola* Öpik, pygidium, cephalon, x10, x9.

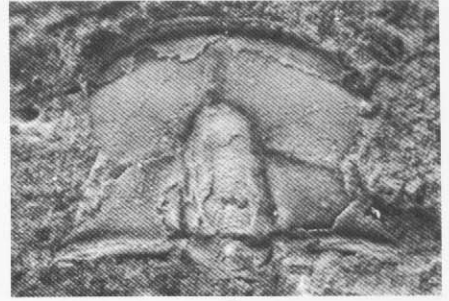




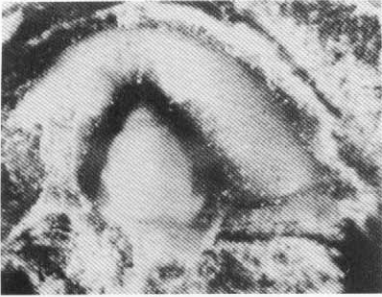
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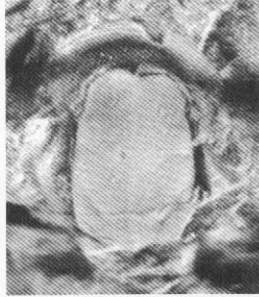
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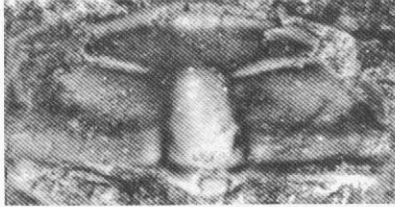
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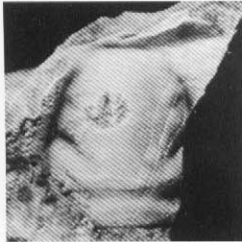
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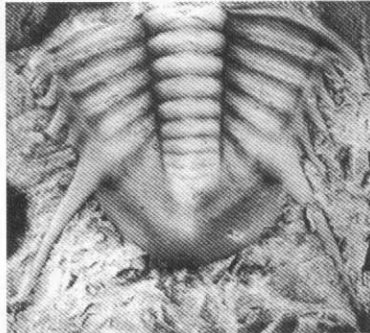
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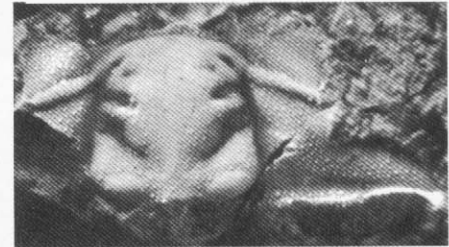
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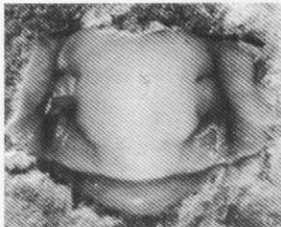
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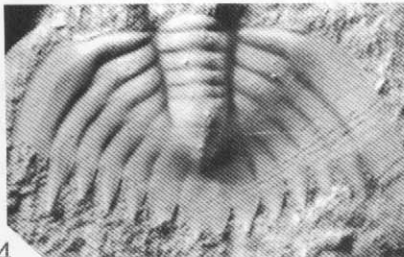
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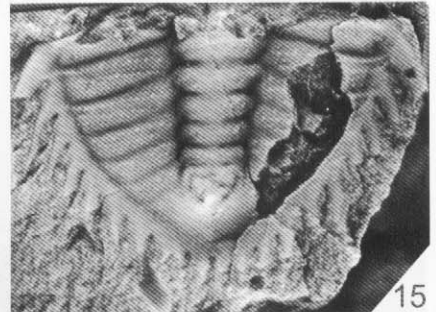
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Zone of Peng, 1987; Fig. 6). Trilobites from this interval were described by Peng (1987; Figs. 8, 9). The lithology of this interval is similar to that of the underlying strata, and largely includes nodular limestone in the basal part and ribbon limestone (Fig. 7) in the remaining part.

Stop 3

Base of the Waergangian Stage

The base of Waergangian Stage of the Cambrian is defined by the first appearance of the agnostoid trilobite *Glyptagnostus reticulatus*, which is the same point as the base of the *Glyptagnostus reticulatus* Zone (Peng *et al.*, 1988), in the Wa'ergang section, Hunan. The type locality for the base of the Waergangian Stage is 20 m east of the Wa'ergang Junior High School. The point is located in the gently sloping interval of the Huaqiao Formation that is currently overgrown by trees, grasses, and vegetables. However, the boundary position can be now observed in the quarry immediately behind the junior high school building.

The precise stratigraphic position of the base of the stage is 8.47 m above the base of Bed 7 (Peng, 1990b). Bed 7 is 22 m thick, and composed of medium- and thick-bedded dark gray limestone showing thin laminations, and intercalations of dark gray argillaceous limestone and fine-grained limestone. *Glyptagnostus reticulatus* first occurs in collection WT12a, where it is associated with *Chuangia wulingensis*, *Olenus austriacus*, *Peratagnostus obsoletus*, *Prochuangia granulosa*, *Shengia quadrata*, *S. spinosa*, and *Shengia trapezia* (Fig. 10).

Stop 4

Base of the Taoyuanian Stage

The base of the Taoyuanian Stage of the Cambrian is located upsection of Stop 3, about 200 m north of the Wa'ergang Junior High School. It is well exposed on east side of a trail that ascends the topography north of the school. The base of the Taoyuanian Stage is defined by the first appearance of the agnostoid trilobite *Agnostotes clavata* (Peng *et al.*, 1988). *Agnostotes clavata* occurs in association with the polymeroid trilobite *Irvingella angustilimbata* in the Shenjiawan, Cili, section, which is located 10 km west of Wa'ergang (Peng, 1992). However, in Wa'ergang, *Agnostotes clavata* has not been observed, so the base of the stage is identified by the first occurrence of *Irvingella angustilimbata* in the Huaqiao Formation. The precise position

Fig. 9. Example polymeroid trilobites described by Peng (1987) and Lin (1991) from the *Ptychagnostus punctuosus* Zone through the *Glyptagnostus stolidotus* Zone of the Wa'ergang section. 1. *Buttsia globosa* Lu et Lin, cranidium, x15; 2. *Neoanomocarella asiatica* Hsiang, cranidium, x5; 3. *Liostracina bella* Lin et Zhou, cranidium, x8; 4. *Fenghuangella magnispina* Lin, cranidium, x15; 5. *Rhyssometopus sinensis* Peng, cranidium, x8; 6. *Torifera taoyuanensis* (Peng), cranidium, x10; 7. *Chatiania chatianensis* Yang, cranidium, x22; 8. *Ajrikina hunanensis* (Peng), cranidium, x 15; 9. *Protaizehoia subquadrata* Peng, cranidium, x4; 10, 11. *Merigaspis karatauensis* (Ergalieva), cranidium, pygidium, x3, x2; 12. *Paradamesella trapezoidalis* Peng, cranidium, x 4; 13. *Palaeadotes hunanensis* Yang, cranidium, x3; 14. *Palaeadotes wulingensis* Peng, pygidium, x4; 15. *Paradamesella depressa* Peng, pygidium, x5.

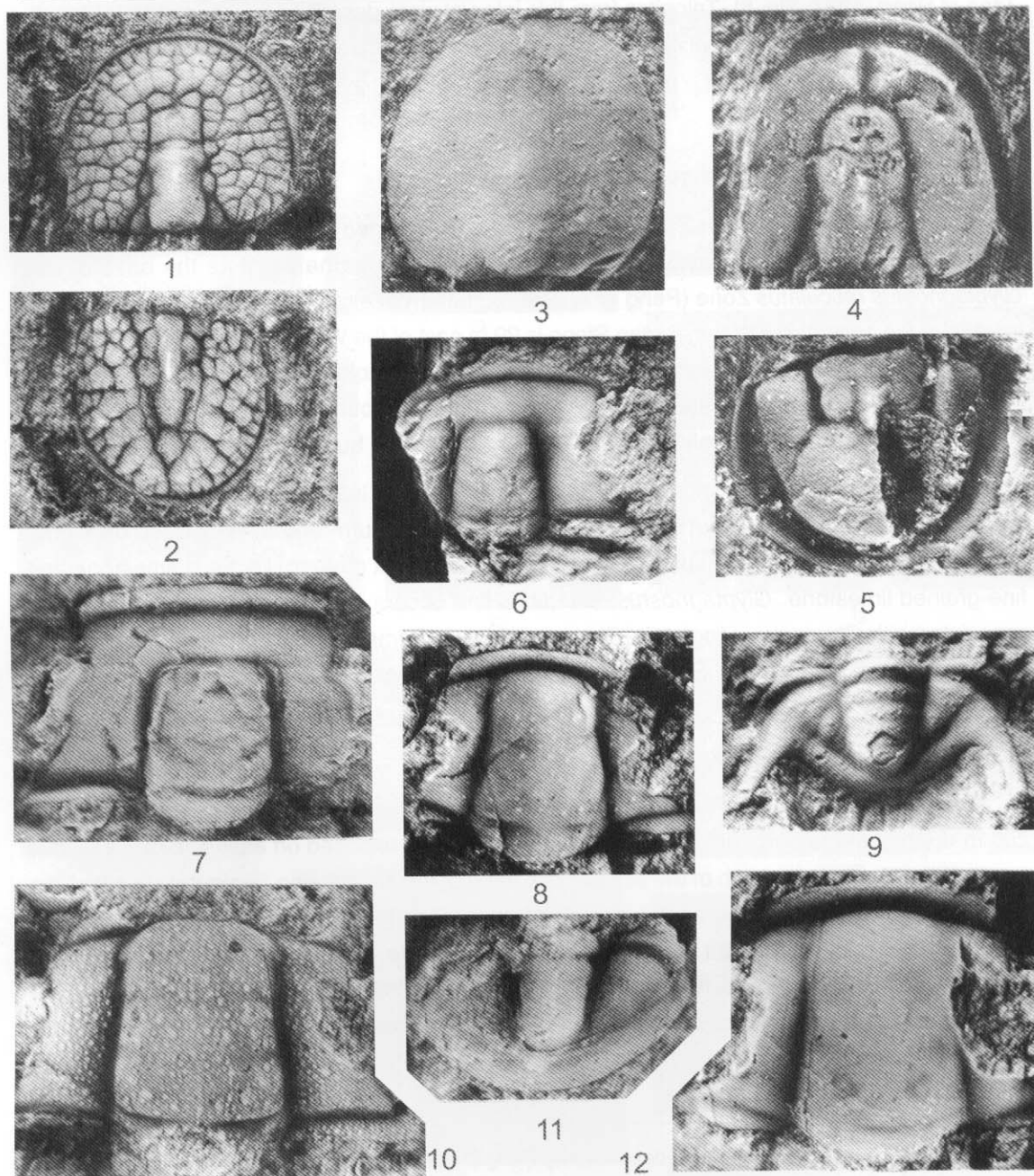


Fig. 10. Examples of trilobites described by Peng (1992) from the *Glyptagnostus reticulatus* Zone of the Wa'ergang section. 1, 2. *Glyptagnostus reticulatus* (Angelin), cephalon, pygidium, x6, x8; 3. *Peratagnostus sinicus* (Hsiang), cephalon, x10; 4, 5. *Pseudagnostus josepha* (Hall), cephalon, pygidium, x8, x8; 6. *Aphelaspis buttsi* (Kobayashi), cranidium, x4; 7. *Olenus austriacus* Yang, cranidium, x4; 8, 9. *Prochuangia licinispinata* Peng, cranidium, pygidium, x8, x4; *Prochuangia granulosa* Lu, cranidium, x8; 11, 12. *Chuangia wulingensis* Yang, pygidium, cranidium, x8, x8.

of the boundary is 0.34 m above the base of Bed 15 (Peng *et al.*, 1988; Fig. 11). Bed 15 is largely composed of grainstone intercalated with layers of argillaceous limestone. The grainstone contains small dolomitic nodules that are sporadically distributed and have rough appearances upon weathering. Bed 15 is richly fossiliferous. As shown in Figure 12, the base of the Taoyuanian Stage is marked by a significant change in the composition and diversity of the trilobite fauna.

The upper part of the Huaqiao Formation continues in discontinuous exposures along a trail for about 100 m beyond the position of the lower boundary of the Taoyuanian Stage.



Fig. 11. Exposure of the boundary interval that includes the base of the Taoyuanian Stage, Wa'ergang section. Handle of hammer indicates the position of the base of the stage.

Stop 5

Shenjiawan Formation

Strata assigned to the Shenjiawan Formation are reached by proceeding north along the trail extending away from the Wa'ergang Junior High School; about 100 m beyond the lower boundary position of the Taoyuanian Stage, turn left and walk to the west for about 0.5 km along a trail that parallels the strike line, to an unpaved highway. The roadcut along the highway exposes rocks of the Shenjiawan Formation.

The Shenjiawan Formation was named by Peng and Tan (1978). The type locality of the formation is near Shenjiawan Village, about 10 km east of Wa'ergang, Hunan. The lower Shenjiawan Formation is gradational with the upper Huaqiao Formation. The base of the Shenjiawan Formation is arbitrarily defined by a distinctive layer of light-colored, thick-bedded, fine-grained limestone. Lithologically, the Shenjiawan Formation consists largely of limestone beds, including argillaceous limestones and nodular to ribbon limestones. The Shenjiawan Formation differs from the underlying Huaqiao Formation by the more frequent presence of light-colored limestone beds (Fig. 13). Light-colored limestone beds are usually 10 to 60 cm thick,

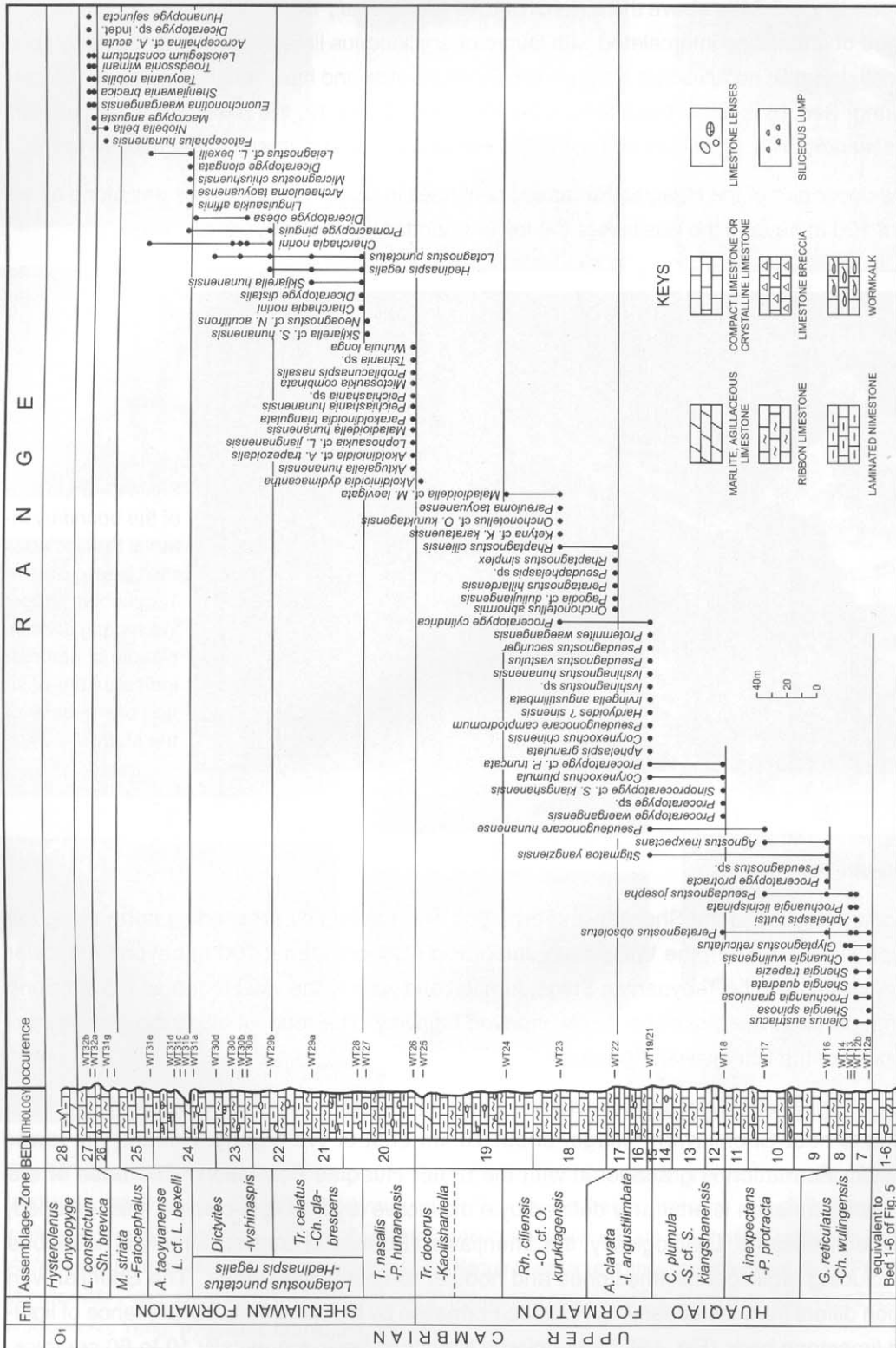


Fig.12. Stratigraphic distribution of trilobite species described by Peng (1992) from the Waerganian through Taoyuanian stages in the Wa'ergang section (modified, with nomenclatural updates, from Peng, 1992).

and rarely laminated. Small nautiloids are present in some of the light-colored limestone layers in the upper part of the Shanjiawan Formation (Peng and Chen, 1983; Peng, 1984). The upper part of the Shenjiawan Formation contains some carbonate debris beds, one of which is quite thick (2.54 m in thickness). This polymictic debris bed likely represents deposition formed in an upper slope environment (Fig. 14).



Fig.13. Lithology of the Shenjiawan Formation exposed in the interval of 794.5 to 797 m in the Wa'ergang section. Intercalated layers of thick-bedded, light-colored limestone (794.9 to 795.7 m) commonly occur in the dark-colored, thin bedded, argillaceous limestone.

Stop 6

Panjiазui and Madaoyu formations: lower part of the Ordovician System

The base of the Panjiазui Formation is marked by the base of Bed 28 (Peng, 1984, 1990a). Bed 28 comprises thin-bedded ribbon limestone interbedded with thinly laminated lime mudstone in the lower part, and weathers to a purplish yellow calcareous shale. The base of the formation is 10.5 m above the top of the thick limestone debris bed in the Wa'ergang section. The Panjiазui Formation is rich in lime mudstone layers that contain a diverse and abundant fauna including the trilobites *Micragnostus*, *Hospes*, *Proteuloma*, *Leiagnostus*, *Leiostegium*, *Troedssonia*, and the graptolites *Rhabdinopora* ex gr. *flabelliforma*, and *Callograptus* sp. The Panjiазui Formation, beginning with Bed 28, contains trilobites indicative of the *Onychopyge-Hysterolenus* Zone. The *Onychopyge-Hysterolenus* Zone is taken as the lowermost biozone of the Tremadocian Stage of the Ordovician System (Peng, 1984, 1990a). Recent research on the conodonts has resulted in the discovery of *lapetognathus fluctivagus* in the strata just above Bed 28 (Dong Xiping, personal communication, 2001). The first appearance of *lapetognathus*

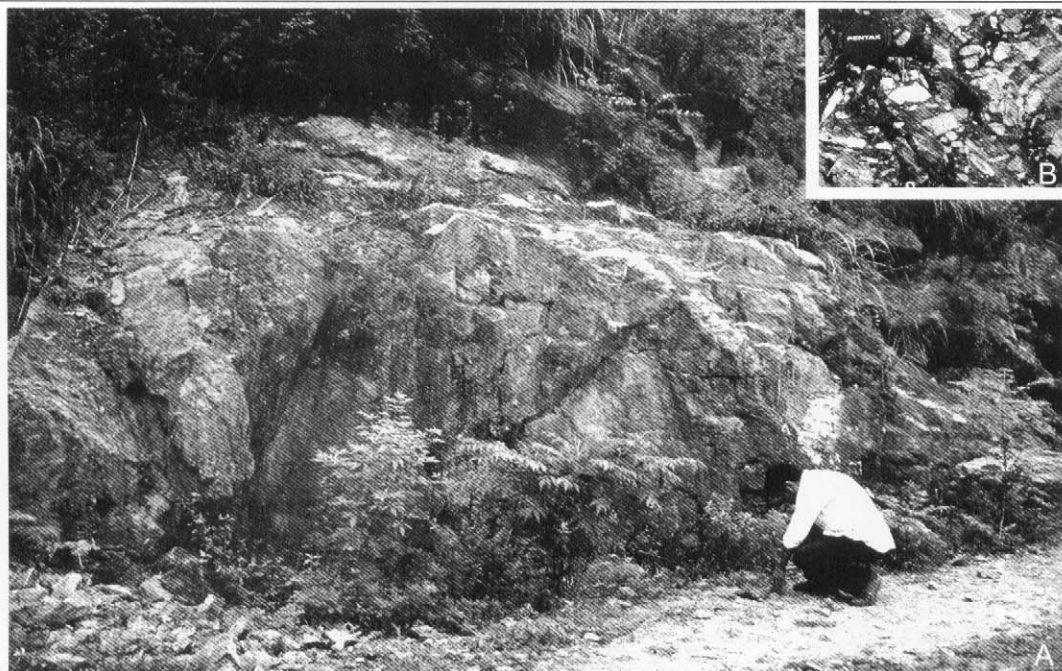


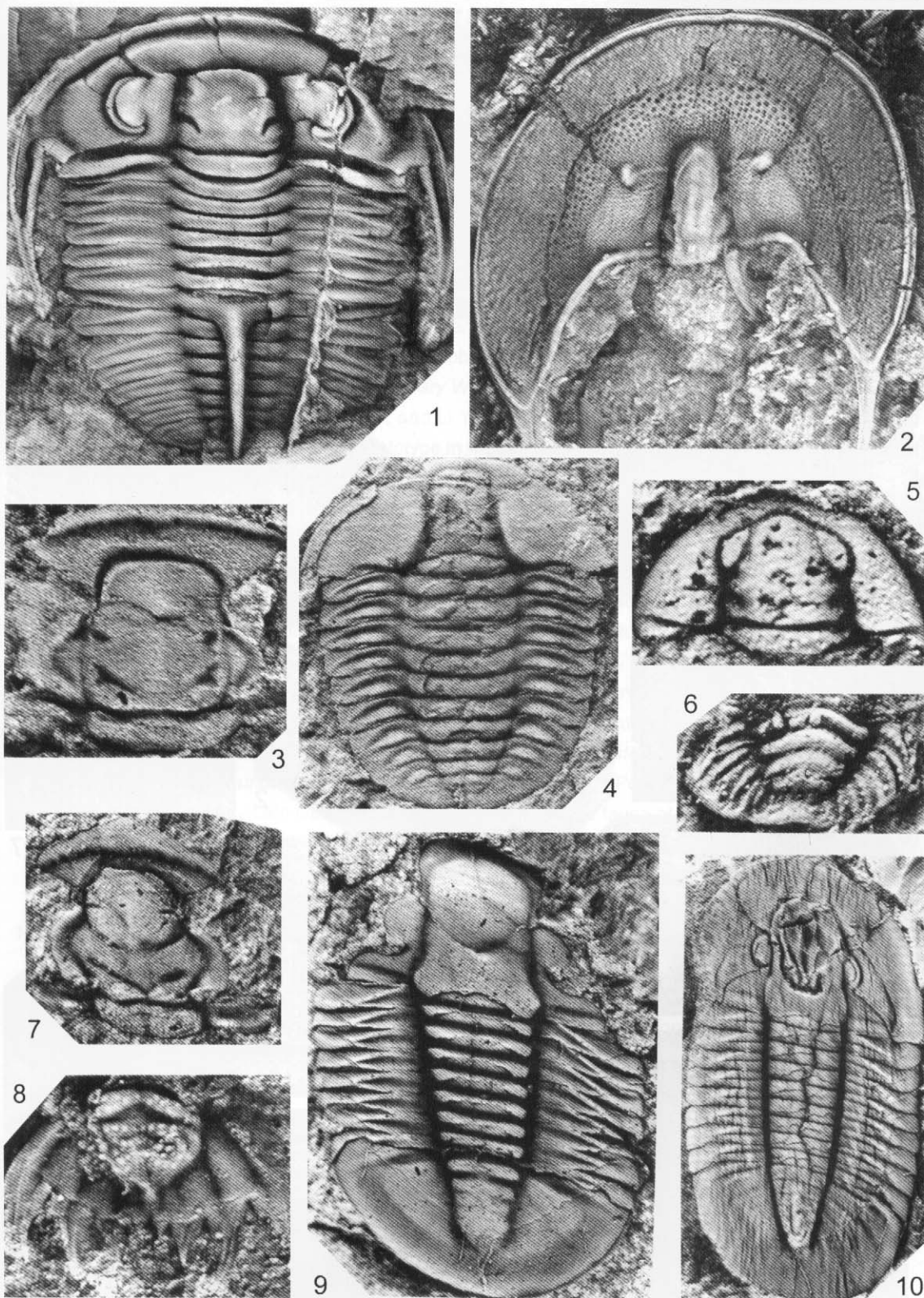
Fig. 14. A. Exposure of the Shenjiawan Formation showing massive limestone debris bed at 874 m in the Wa'ergang section; B. Close-up view of the bed.

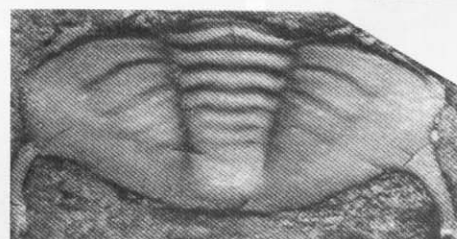
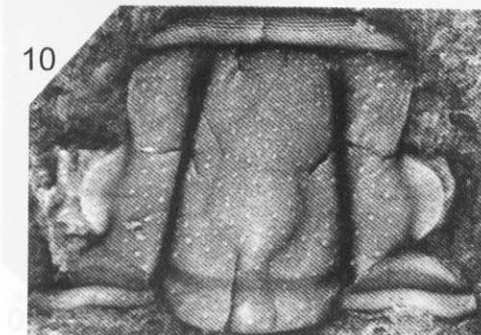
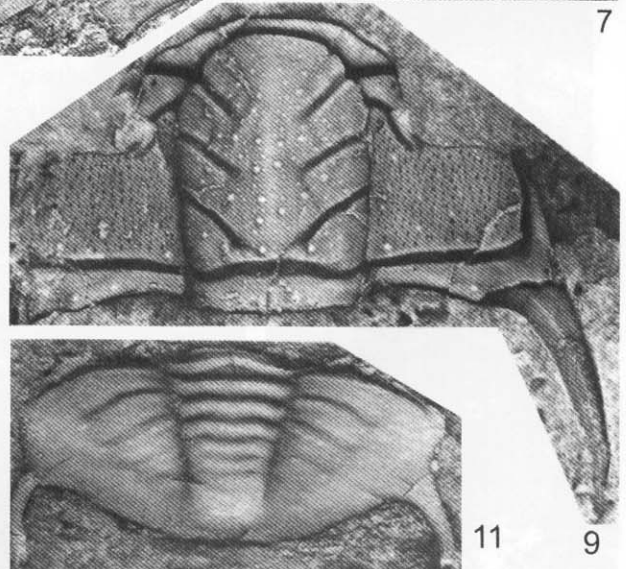
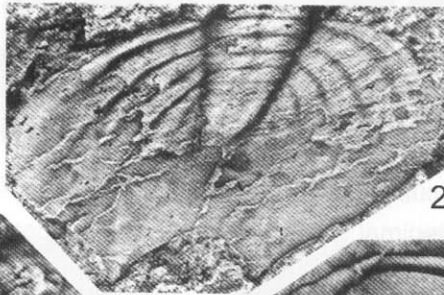
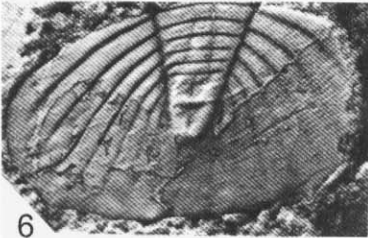
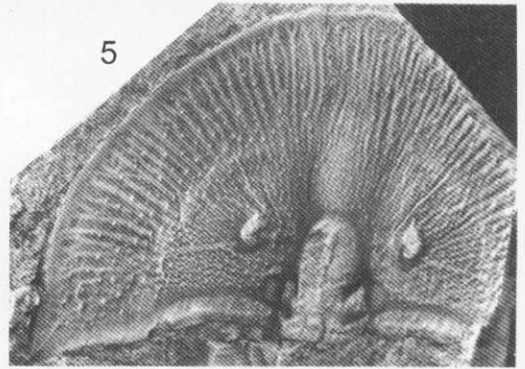
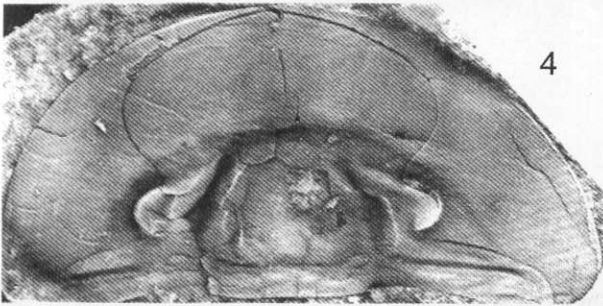
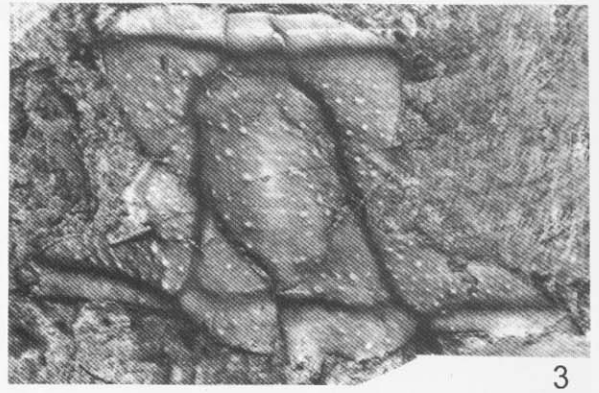
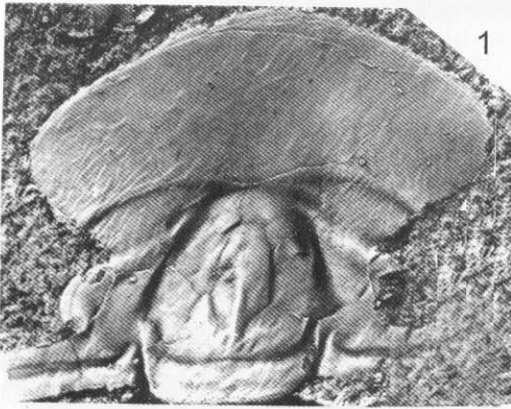
fluctivagus marks the GSSP for defining the lower boundary of the Ordovician System (Cooper, 1998; Cooper and Newlan, 1999). Further work is needed to determine precisely where the base of the Tremadocian Stage lies in the Wa'ergang section, but it is expected to be close to the base of Bed 28.

Overall, the Panjiazui Formation is predominantly a carbonate succession, consisting mostly of thin- to medium-bedded limestone, interbedded with thinly laminated lime mudstone layers that weather into yellow mudrocks. The formation has a thickness of 216 m in the Wa'ergang section. It is reasonably well exposed in the roadcut, but relatively few beds are fossiliferous.

Overlying the Panjiazui Formation is the Madaoyu Formation. The Madaoyu Formation is composed of dark-gray to grayish-black, massive lime mudstone that weathers to a yellow color. A diverse assemblage of Lower Ordovician (Tremadocian) trilobites has been described from the formation (Peng, 1990c).

Fig. 15. Examples of Ordovician (Tremadocian) trilobites from the Panjiazui or Madaoyu formations in the Wa'ergang section. 1. *Euloma orientale* Liu, exoskeleton, x8; 2. *Brachyhipposiderus secundus* Peng, cephalon, x6; 3. *Pseudokainella hunanensis* Peng, cranidium, x12; 4. *Hospis pinguis* Peng, exoskeleton, x15; 5, 6. *Shumardia acutifrons* Liu, cranidium, pygidium, x22, x22; 7, 8. *Apatokephalus latilimbatus* Peng, cranidium, pygidium, x10, x18; 9. *Metayuepingia angustilimbata* Liu, exoskeleton with liberigenae missing, x 2.8; 10. *Niobella ciliensis* Liu, exoskeleton, x 1.7.





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Fig. 16. Examples of Ordovician (Tremadocian) trilobites from the Panjiazui or Madaoyu formation in the Wa'ergang section. 1. *Ciliocephalus angulatus* Liu, cranidium, pygidium, x3.5, x5; 3. *Taoyuania xenisma* Liu, cranidium, x4.5; 4. *Asaphopsoides subtrapezius* Peng, cephalon, x4.5; 5. *Harpides taoyuanensis* Liu, cephalon, x3; 6. *Asaphopsis latilimbatus* Liu, pygidium, x3; 7, 8. *Protopliomerops taoyuanensis* (Liu), cranidium, pygidium, x16, x16; 9. *Sinoparapilekia panjiazuiensis* Peng, cranidium, x 4.5; 10-11. *Chosenia* (Madaoyuites) *longior* Peng, cranidium, pygidium, x 5, x 2.8.

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