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The Global Boundary Stratotype Section and Point (GSSP) of the Guzhangian Stage (Cambrian) in the Wuling Mountains, Northwestern Hunan, China

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*The Global boundary Stratotype Section and Point (GSSP) for the base of the Guzhangian Stage (Cambrian Series 3) is defined at the base of a limestone (calcisiltite) layer 121.3 m above the base of the Huaqiao Formation in the Louyixi section along the Youshui River (Fengtian Reservoir), about 4 km northwest of Luoyixi (4 km southeast of Wangcun), in northwestern Hunan, China. The GSSP is exposed in a road cut at a position of 28°43.20' N and 109°57.88' E. The GSSP level contains the lowest occurrence of the cosmopolitan agnostoid trilobite *Lejopyge laevigata* (base of the L. laevigata Zone). Secondary global markers near the base of the stage include the appearance of either *L. calva* or *L. armata* just below the base of the stage, the appearance of conodonts associated with the base of the *Laiwugnathus laiwuensis* Zone, and the transgressive phase of a small eustatic event. Faunal turnovers close to the base of the Guzhangian Stage are recognized as near the base of the Boomerangian Stage in Australia, the base of the Aldanaspis Zone (polymerid trilobites) in Siberia, and the base of the Paradoxides forchhammeri Zone in western Avalonia. The horizon corresponding to the first appearance of *L. laevigata* is near the peak of a rather long negative $\delta^{13}\text{C}$ excursion of up to 0.58 ‰.*

Introduction

The International Subcommission on Cambrian Stratigraphy (ISCS) has recommended a subdivision of the Cambrian System into four series (Babcock et al., 2005; Peng, 2006; Peng et al., 2006). Within

each series it is expected that two to three stages whose boundaries correspond to horizons that can be correlated with a high degree of confidence through all paleocontinents will be recognized. As emphasized by Geyer and Shergold (2000), communication of time-stratigraphic information will be maximized if the internal subdivisions of the system correspond to horizons recognizable on all paleocontinents. Traditional, regional stratigraphic schemes, based principally on unit stratotypes, do not meet this goal, and it is for this reason that the ISCS is now engaged in further developing our understanding of key horizons for correlation within the Cambrian, and newly defined series and stages that are readily traceable among Cambrian regions. The newly defined chronostratigraphic units are based on the principle of boundary stratotypes, in which the base of one unit (marked by a Global boundary Stratotype Section and Point, or GSSP) automatically delimits the top of the underlying unit. So defined, these intervals differ in substance from unit stratotypes, which have been variously defined in Cambrian regions (Geyer and Shergold, 2000; Peng et al., 2004a, 2006; Babcock et al., 2005). Apart from the Guzhangian Stage (discussed here), the boundary positions relevant to the Cambrian (Figure 1) that have been ratified are: 1, the conterminant base of the Paleozoic Erathem, Cambrian System, Terreneuvian Series, and Fortunian Stage (Brasier et al., 1994; Landing, 1994; Gehling et al., 2001; Landing et al., 2007); 2, the base of the Drumian Stage (Babcock et al., 2007); 3, the base of the Furongian Series and Paibian Stage (Peng et al., 2004a); and 4, the base of the Ordovician System (Cooper et al., 2001).

At least 11 candidate horizons for global chronostratigraphic correlation have been identified in the upper half of the Cambrian System, based on the first appearance datum (FAD) horizons of intercontinentally distributed agnostoid trilobites (Geyer and Shergold, 2000). To date, three of them have been chosen as the primary stratigraphic tools for correlation of the bases of stages, i.e. the FAD of *Ptychagnostus atavus* for the Drumian Stage, the FAD of *Lejopyge laevigata* for the Guzhangian Stage, and the FAD of *Glyptagnostus reticulatus* for the Paibian Stage. The FAD of the intercontinentally distributed agnostoid trilobite *Lejopyge laevigata* is one of the most

SYSTEMS	SERIES	STAGES	BOUNDARY HORIZONS (GSSPs) OR PROVISIONAL STRATIGRAPHIC TIE POINTS
Ordovician	Lower	Tremadocian	FAD of <i>Iapetognathus fluctivagus</i> (GSSP)
CAMBRIAN	Furongian Series	Cambrian Stage 10 (Undefined)	FAD of <i>Lotagnostus americanus</i>
		Cambrian Stage 9 (Undefined)	FAD of <i>Agnostotes orientalis</i>
		Paibian Stage	FAD of <i>Glyptagnostus reticulatus</i> (GSSP)
	Cambrian Series 3 (Undefined)	Guzhangian Stage	FAD of <i>Lejopyge laevigata</i> : GSSP position
		Drumian Stage	FAD of <i>Ptychagnostus atavus</i> (GSSP)
		Cambrian Stage 5 (Undefined)	?FAD of <i>Oryctocephalus indicus</i>
	Cambrian Series 2 (Undefined)	Cambrian Stage 4 (Undefined)	?FAD of <i>Olenellus</i> or <i>Redlichia</i>
		Cambrian Stage 3 (Undefined)	FAD of trilobites
	Terreneuvian Series	Cambrian Stage 2 (Undefined)	?FAD of SSF species
		Fortunian Stage	FAD of <i>Trichophycus pedum</i> (GSSP)
Ediacaran			

Figure 1. Chart showing working model for global chronostratigraphic subdivision of the Cambrian System, indicating lower boundary of the Guzhangian Stage (modified from Babcock et al., 2005).

recognizable levels in the Cambrian (Geyer and Shergold, 2000; Peng and Babcock, 2001; Peng et al., 2001, 2004a; Babcock et al., 2005). A position corresponding closely to the first appearance of *L. laevigata* is recognizable in strata of Gondwana, Baltica, Laurentia, Kazakhstan, and Siberia (e.g., Öpik, 1961, 1979; Ergaliev, 1980; Robison, 1984, 1994; Laurie, 1989; Geyer and Shergold, 2000; Peng and Robison, 2000; Peng and Babcock, 2001; Peng et al., 2001, 2006; Shergold and Geyer, 2003; Babcock et al., 2005, Axheimer et al., 2006), and can be identified with precision using multiple lines of evidence.

The purpose of this paper is to announce ratification of the Guzhangian Stage, the base of which coincides with the FAD of the cosmopolitan trilobite *Lejopyge laevigata*. The GSSP for the base of the new stage is 121.3 m above the base of the Huaqiao Formation in the Luoyixi section (formerly called the Wangcun South section; Peng et al., 2004c; Peng, 2005; Peng et al., 2005) along the Youshui River (Fengtian Reservoir), about 4 km northwest of Luoyixi (4 km southeast of Wangcun), in northwestern Hunan, China; Figs. 3, 5, 6, 10). Of the methods that should be given due consideration in the selection of a GSSP (Remane et al., 1996), biostratigraphic, chemostratigraphic, paleogeographic, facies-relationship, and sequence-stratigraphic information is available (e.g., Peng and Robison, 2000; Peng et al., 2001, 2004b), and that information is summarized below. The section is easily accessible, and access for research is unrestricted. It is located on public land under permanent protection by the government of Guzhang County, Hunan. Government protection of this area, a well-known tourist area with a National Geo-Park, ensures continued free access to the site for research purposes.

For comparative purposes, the FAD of *L. laevigata* in another excellent section, the Wangcun section, located on the north bank of the Youshui River (opposite the Luoyixi section), Yongshun County, Hunan Province, China (Peng et al., 2001), is also discussed. The

FAD of *L. laevigata* occurs 121.3 m above the base of the Huaqiao Formation in the Wangcun section (Peng et al., 2001, 2004b, 2004c). The boundary interval containing the FAD of *L. laevigata* in the Wangcun section also fulfills all of the geological and biostratigraphic requirements for a GSSP, and is located along a roadcut for which free access for research purposes is granted.

Stratigraphic Rank of the Boundary

The base of the Guzhangian Stage (Figs. 1, 2) will be embraced by a Cambrian series to be named at a future date. Currently the unnamed series is referred to as undefined Cambrian Series 3 (Babcock et al., 2005, 2007; Peng et al., 2006; Figs. 1, 2). The Guzhangian Stage is the third (uppermost) of three stages included in Cambrian Series 3. The base of the stage automatically defines the top of the Drumian Stage, and limits the Drumian to four globally recognized agnostoid trilobite zones, the *Ptychagnostus atavus* Zone, the *Ptychagnostus punctuosus* Zone, the *Goniagnostus nathorsti* Zone, and the *Lejopyge armata* Zone. The boundary is a standard stage/age GSSP.

Geography and Physical Geology of the GSSP

Geographic Location

The Luoyixi section (Peng et al., 2006) is exposed along a roadcut situated on the south bank of the Youshui River, (Fengtian Reservoir), in the Wuling Mountains (Wulingshan). A number of counties, including Guzhang County, border the river in northwestern Hunan Province, China. The Youshui River forms the boundary between Guzhang County (to the south) and Yongshun County (to the north) in this area (Figs. 3, 4). The roadcut along the opposite bank of the river, which contains the same succession of strata, is referred to as the Wangcun section. Previously, the Luoyixi section was referred to informally as the Wangcun South section (Peng et al., 2004c, 2005). The position of the section is in a roadcut delimited by a cliff represented on topographic map H49 G 0790032, 1:10,000 scale (Surveying and Mapping Bureau of Hunan Province, 1991, 1:10,000 scale; Figure 3D). The Luoyixi section exposes the uppermost part of the Aoxi Formation and more than 200 m of the overlying Huaqiao Formation. The boundary stratotype for the base of the Guzhangian Stage is in the lower portion of the Luoyixi section. The GSSP is exposed in a roadcut at a position of 28°43.20' N latitude and 109°57.88' E longitude (determined by handheld Garmin GPS), and at an elevation of approximately 216 m.

Geological Location

The Cambrian geology of northwestern Hunan, the site of the GSSP section, has been summarized in a number of publications, most notably Peng et al. (2001) and papers contained and cited therein. An overview of Cambrian paleogeography, biotic provinces, and

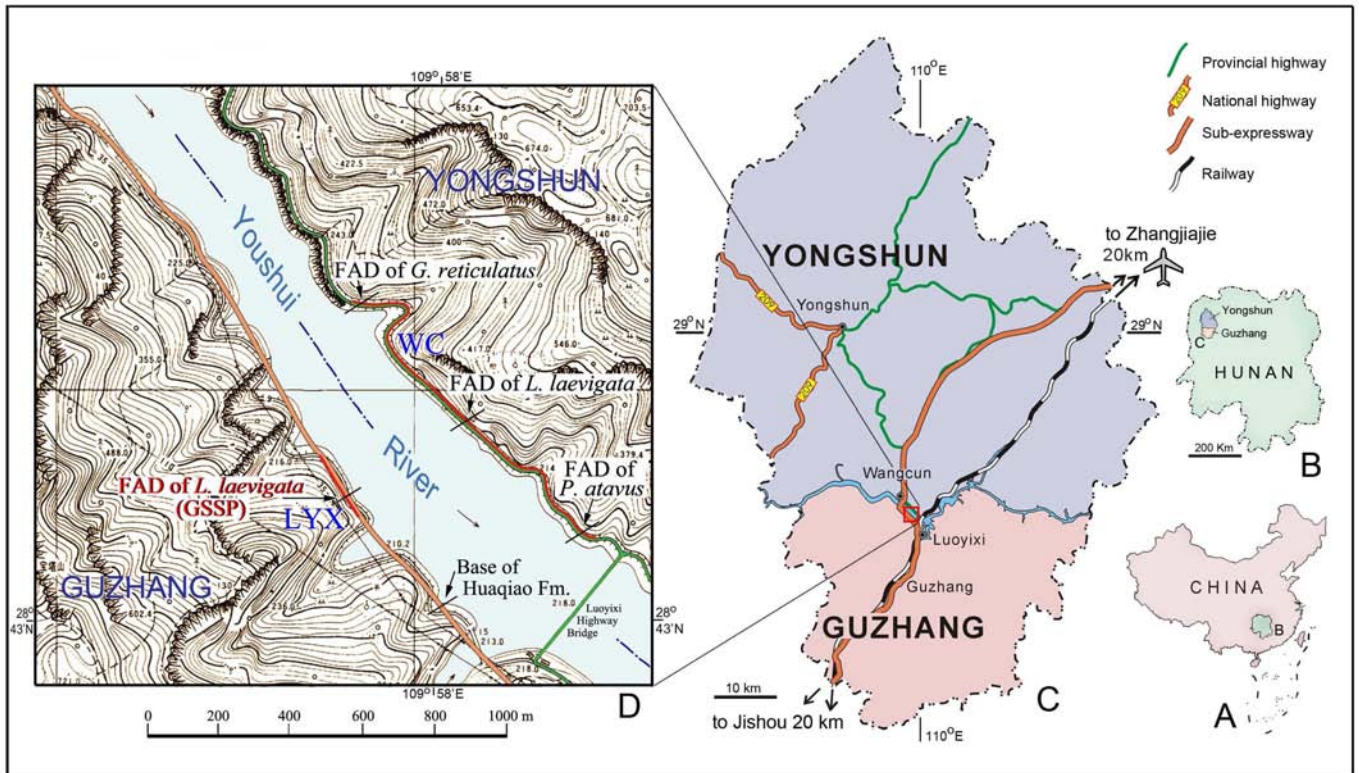


Figure 3. Topographic map of part of northwestern Hunan Province, China, along the Youshui River (Fengtian Reservoir), showing the position of the Luoyixi section (LYX, in northern Guzhang County) and the Wangcun section (WC, in southern Yongshun County). Part D of the figure is from topographic map H49 G 0790032 (Surveying and Mapping Bureau of Hunan Province, 1991, 1:10,000 scale). The position of the GSSP coincides with the FAD of *L. laevigata* in the Luoyixi section.

thickness, and the biostratigraphic succession in the section is unaffected. There appears to be no evidence of faulting resulting in either loss or repetition of section along the present exposure of the formation. Distal carbonate turbidite beds are present in the section, but weak turbidity currents do not appear to have disrupted the stratigraphic distribution of fossil taxa in the stratotype. Evidence of metamorphism and strong diagenetic alteration is absent.

Thickness and Stratigraphic Extent

In the Luoyixi section (Figure 5), the Huaqiao Formation consists of a succession of dark, thin-bedded, thinly laminated lime mudstones, argillaceous limestones, and fossiliferous limestone lenses; light-colored ribbon limestones are present in places. In the Wangcun-Luoyixi area, the Huaqiao Formation includes fine-grained carbonate turbidites and autochthonous carbonate sediments, mostly fine-grained, leading to the interpretation that it was deposited in the lower part of an outer slope-apron environment (Fu et al., 1999).

The basal contact of the Guzhangian Stage, marked by the FAD of *Lejopyge laevigata*, occurs in a mostly monofacial succession of dark gray to black limestones (lime mudstones, or calcimicrites and calcisiltites), and fine-grained argillaceous limestones interbedded with lenses of fossil-rich limestone (calcisiltite). The point where *L. laevigata* first appears occurs is the lower part of a 0.82 m-thick layer of dark gray, thinly laminated calcisiltite, overlying another layer of thinly laminated, dark-gray calcisiltite (Figure 5C, D). The basal contact of this bed in the Luoyixi section is observable up to the height of the roadcut. The total bedding plane length of the bed is approximately 28 m.

Provisions for Conservation, Protection, and Accessibility

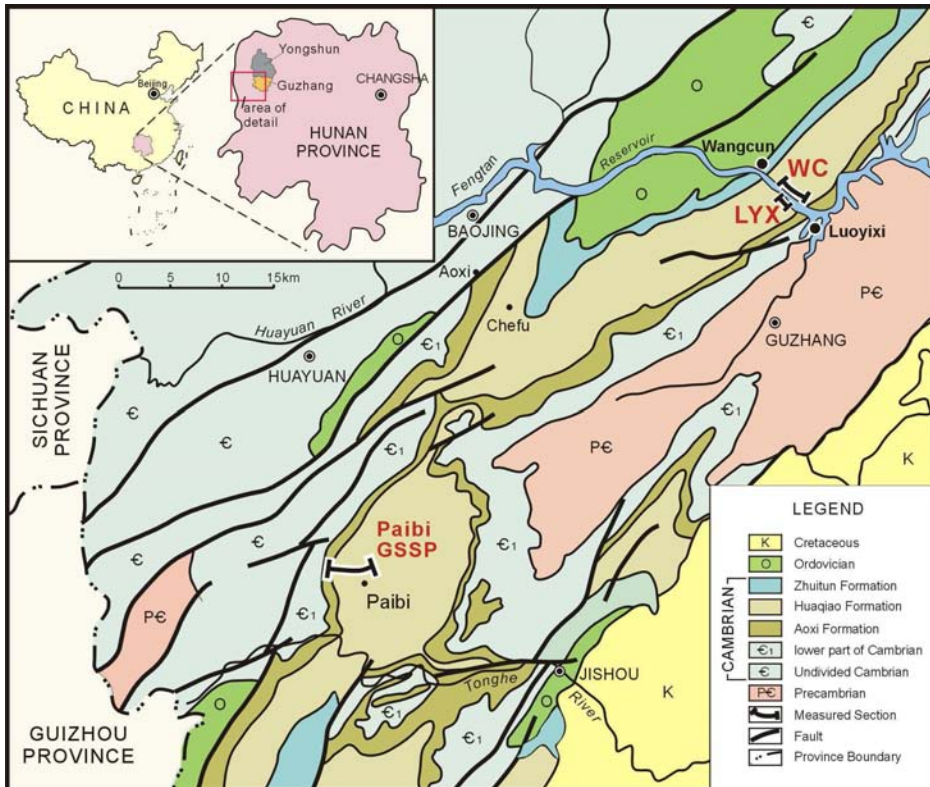
The exposure containing the GSSP is not subject to building, landscaping, or other destruction. It is located on public land along a road leading to some popular tourist destinations, such as the Fengtan Reservoir, the Hongshiling (Forest of Red Rocks) National Geo-Park, and the historic town of Wangcun. The roadcut is to be permanently managed by the government of Guzhang County.

Access to the outcrop is essentially unrestricted in all seasons. Travel to Hunan is open to persons of all nationalities, and travel for scientific purposes is welcomed. Ordinary vehicles can be driven along the length of the section, and can be parked adjacent to the GSSP point.

Motivation for Selection of the Boundary Level and of the Stratotype Section

Principal Correlation Event (marker) at GSSP Level

The agnostoid trilobite *Lejopyge laevigata* (Figure 9H-J) has one of the broadest distributions of any Cambrian trilobite (e.g., Westergård, 1946; Pokrovskaya, 1958; Öpik, 1961, 1979; Palmer, 1968; Khairullina, 1970, 1973; Robison et al., 1977; Yang, 1978, Ergaliev, 1980; Egorova et al., 1982; Robison, 1984, 1988, 1994; Laurie, 1989; Lu and Lin, 1989; Yang et al., 1991; Dong, 1991; Tortello and Bordonaro, 1997; Geyer and Shergold, 2000; Peng and Robison, 2000; Jago and Brown, 2001; Babcock et al., 2004, 2005; Axheimer et al., 2006; Peng et al., 2006), and its first appearance has



appearance of *L. laevigata*, rather than its local abundance, the base of the Scandinavian *L. laevigata* Zone can be extended downward so that the revised *L. laevigata* Zone in Scandinavia embraces the traditional *Solenopleura? brachymetopa* Zone (Axheimer et al., 2006).

Stratigraphically, the first appearance of *Lejopyge laevigata* (Figures 5B-D, 6, 7) always succeeds the first appearance of at least one other species of *Lejopyge*. In China, Kazakhstan, and Tasmania, where three *Lejopyge* species are present, the stratigraphic order of appearance is *L. calva* (at times assigned to *Pseudaphalacroma dubium* or *Pseudophalacroma? sp.*), followed by *L. armata*, and then followed by *L. laevigata* (Jago, 1975; Ergalieva, 1980; Peng and Robison, 2000). In Antarctica, *L. calva* is also followed by *L. armata* (Cooper et al., 1996). In Laurentia, however, the order of succession is *L. calva* followed by *L. laevigata*, followed by *L. armata*. The reason for the discrepancy in the first appearance of *L. armata* in Laurentia is unknown, but it may relate to limits on the exposure of favorable biofacies and stratigraphic occurrence. Morphological features of *L. calva* suggest it may be an ancestor of both of *L. armata* and *L. laevigata*. Species of *Lejopyge* always succeed the FAD of the agnostoid *Goniagnostus nathorsti*, which is the

Figure 4. Map of part of northwestern Hunan Province (location of Hunan inset), China, showing location of the stratotype section for the Guzhangian Stage (Luoyixi section, south side of the Fengtan Reservoir, Youshui River; indicated as LYX). Location of the Wangcun section (north side of the Fengtan Reservoir, Youshui River) is indicated as WC. For reference, location of the Paibi section, stratotype of the Furongian Series and Paibian Stage (indicated as Paibi GSSP), is also indicated. Map modified from Peng et al. (2004b).

been acknowledged as one of the most favorable levels for a GSSP defining the base of a global Cambrian stage (e.g., Robison et al., 1977; Rowell et al., 1982; Robison, 1999, 2001; Geyer and Shergold, 2000; Shergold and Geyer, 2001; Babcock et al., 2004; Peng et al., 2006). Agnostoid trilobites provide the best and most precise tools for intercontinental correlation in the upper half of the Cambrian System (e.g., Robison, 1984; Peng and Robison, 2000). Recent recalibration of radiometric ages for the Cambrian (Grotzinger et al., 1995; Davidek et al., 1998; Landing et al., 1998, 2000), scaled against the number of agnostoid zones recognized in the upper half of the Cambrian, indicates that the average duration of an agnostoid-defined biochron is about one million years (Peng and Robison, 2000). *Lejopyge laevigata* has been identified from Argentina, Australia, China, Denmark, England, Germany (in glacial erratics), Greenland, India, Kazakhstan, Norway, Poland, Turkestan, Uzbekistan, Russia, Sweden, and the United States, and has been used as a zonal guide fossil in deposits of Baltica, Gondwana, Kazakhstania, Siberia, Laurentia, and eastern Avalonia (e.g., Westergård, 1946; Cowie et al., 1972; Robison, 1976, 1984; Öpik, 1979; Shergold et al., 1985; Geyer and Shergold, 2000; Peng and Robison, 2000; Axheimer et al., 2006; Peng et al., 2006). The base of the Boomerangian Stage in Australia corresponds to the base of the *L. laevigata* Zone (Öpik, 1967; Shergold et al., 1985; Geyer and Shergold, 2000; Axheimer et al., 2006). In western Avalonia, the base of the *Paradoxides forchhammeri* Zone corresponds approximately to the base of the *L. laevigata* Zone (Geyer and Shergold, 2000). By using the first

eponymous guide fossil for the *G. nathorsti* Zone, and they always succeed the FAD of *Ptychagnostus punctuosus*, which is the eponymous guide fossil for the *P. punctuosus* Zone. It is desirable to select the position of a GSSP in a section showing a complete succession from the *P. punctuosus* Zone (or the *G. nathorsti* Zone and the *L. armata* Zone if recognized regionally) through the *L. laevigata* Zone. In a complete succession, the LADs of both *L. calva* and *L. armata* should fall within the *L. laevigata* Zone, and *L. calva* should be in the lowermost part of the zone. Selection of the FAD of *L. laevigata* as the primary correlation tool for the base of a Cambrian stage ensures that the boundary will fall within a stratigraphic interval bearing agnostoid trilobites, many of which are phylogenetically related. Globally, the stratigraphic interval bearing the overlap between *L. calva*, *L. armata*, and *L. laevigata* is relatively narrow but widely recognizable. Together, the narrow stratigraphic overlap of *Lejopyge* species (if more than one species is present), and the stratigraphic disappearance of both *P. punctuosus* and *G. nathorsti*, allows the boundary to be tightly constrained as long as ptychagnostid-bearing strata are present in a region.

Selection of a GSSP in an open-shelf to basinal deposit, and particularly in one from a low-latitude region such as the South China (Yangtze) Platform, is desirable because it provides faunal ties and correlation with low-latitude open-shelf areas, high-latitude open-shelf areas, and low- or high-latitude, slope-to-basinal areas. In the latter half of the Cambrian, stratification of the world ocean according to temperature or other factors that covary with depth (e.g., Cook and

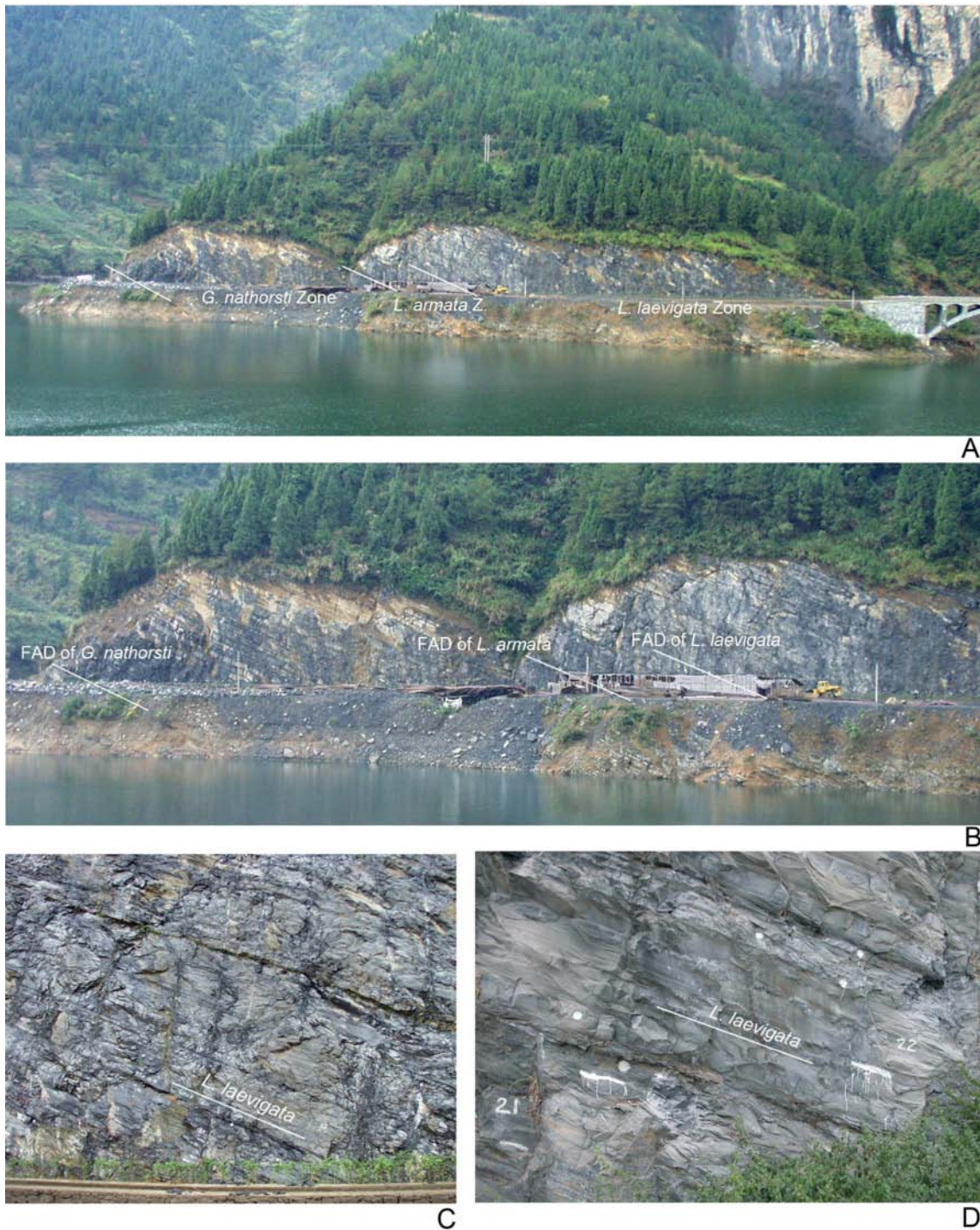


Figure 5. Exposure of the GSSP for the base of the Guzhangian Stage (coinciding with the FAD of *Lejopyge laevigata*) in the Huaqiao Formation, Luoyixi section, Guzhang County, Hunan Province, China. Strata underlying the Guzhangian GSSP belong to the Drumian Stage. **A**, Southwestern bank of Youshui River (Fengtan Reservoir) showing the Luoyixi section. **B**, Lower part of the Luoyixi section. **C**, **D**, Progressively closer views of the Luoyixi section showing the FAD of *L. laevigata* (marked by a white line), 121.3 m above the base of the Huaqiao Formation.

Taylor, 1975, 1976; Babcock, 1994) led to the development of rather distinct trilobite biofacies in shelf and basal areas. Low-latitude shelf areas were inhabited mostly by endemic polymerid trilobites and some pan-tropical taxa. High-latitude shelf areas, and basal areas of low and high latitudes, were inhabited mostly by widespread polymerid trilobites and cosmopolitan agnostoid trilobites. Slope areas are characterized by a combination of some shelf-dwelling taxa and

basin-dwelling taxa. A combination of cosmopolitan agnostoids, which have intercontinental correlation utility, shelf-dwelling polymerids, which mostly allow for intracontinental correlation, and pan-tropical polymerids, which allow for limited intercontinental correlation, provides for precise correlation of the base of the *L. laevigata* Zone through much of Gondwana. Likewise, the combination of these taxa provides for precise correlation of the base of the zone into areas of

Baltica, Siberia, Laurentia, Kazakhstan, and eastern Avalonia, and reasonably good correlation into western Avalonia (Hutchinson, 1962; Geyer and Shergold, 2000).

Stratotype Section

The FAD of *L. laevigata* in the Luoyixi section, Hunan Province, China (Figures 3, 5, 6), occurs in the Huaqiao Formation at a level 121.3 m above the base of the formation (Figures 5C, 5D, 6). At this section, and in the Wangcun section as well, the Huaqiao Formation rests on the Aoxi Formation. The Aoxi-Huaqiao contact is inferred to be a sequence boundary representing a major eustatic rise (transgressive event). Agnostoid trilobite zonation of the Huaqiao Formation in the measured section reveals a complete, tectonically undisturbed, marine succession through much of the Drumian Stage (lower part of the *P. atavus* Zone through the *P. punctuosus*, *G. nathorsti* and *L. armata* zones), through all of the Guzhangian Stage, and into the overlying Paibian Stage (Furongian Series). The Huaqiao Formation in the Luoyixi section is a mostly monofacial succession of dark, fine-grained limestones (Figure 5). Small truncation surfaces, and slide surfaces reflecting distal turbidite deposition are rare in the section and absent near the GSSP, suggesting deposition in an outer slope to carbonate apron environment (Rees et al., 1992).

The GSSP in the Luoyixi section lies within a long, apparently complete stratigraphic succession beginning in the uppermost part of the Drumian Stage and containing an assemblage of agnostoid trilobites, most of which are phylogenetically related ptychagnostid species. Successive stratigraphic levels show a succession beginning

with *Goniagnostus nathorsti* (79.4 m above the base of the Huaqiao Formation) and continuing through the FADs of *L. armata* (111.9 m above the base of the formation), *Lejopyge laevigata* (121.3 m, marking the base of the Guzhangian Stage), and *Proagnostus bulbus* (215.7 m). The section appears to be continuous through the entire *L. laevigata* Zone, the *Proagnostus bulbus* Zone, the *Linguagnostus reconditus* Zone, and the *Glyptagnostus stolidotus* Zone to the base of the Paibian Stage (marked by the base of the *Glyptagnostus reticulatus* Zone). In the bed containing the lowest *L. laevigata* in the section (121.3 m), the species is rather rare. *L. laevigata* remains uncommon through the first 40 m of its range in the Luoyixi section.

Observed ranges of trilobites across the stratigraphic interval containing the GSSP are summarized in Figure 6. Besides *L. laevigata*, a number of other guide fossils, important for intercontinental correlation, help to constrain the boundary position. They include the LADs of *L. calva* and *G. nathorsti*, both of which occur below the FAD of *L. laevigata*. *Ptychagnostus atavus* ranges from the base of the Drumian Stage through the lowermost part of the *L. laevigata* Zone (lowermost part of the Guzhangian Stage). The FADs of *Clavagnostus trispinus*, *Linguagnostus kjerulfi*, and *Ptychagnostus aculeatus* occur slightly below the base of the *L. laevigata* Zone, whereas the FAD of *Utagnostus neglectus* occurs in the lowermost part of the *L. laevigata* Zone.

Observed ranges of polymerid trilobites, some of which have utility for correlation on a regional scale, serve as secondary biostratigraphic correlation tools for identifying the base of the Guzhangian Stage (Peng et al., 2004b, 2006). A diverse assemblage

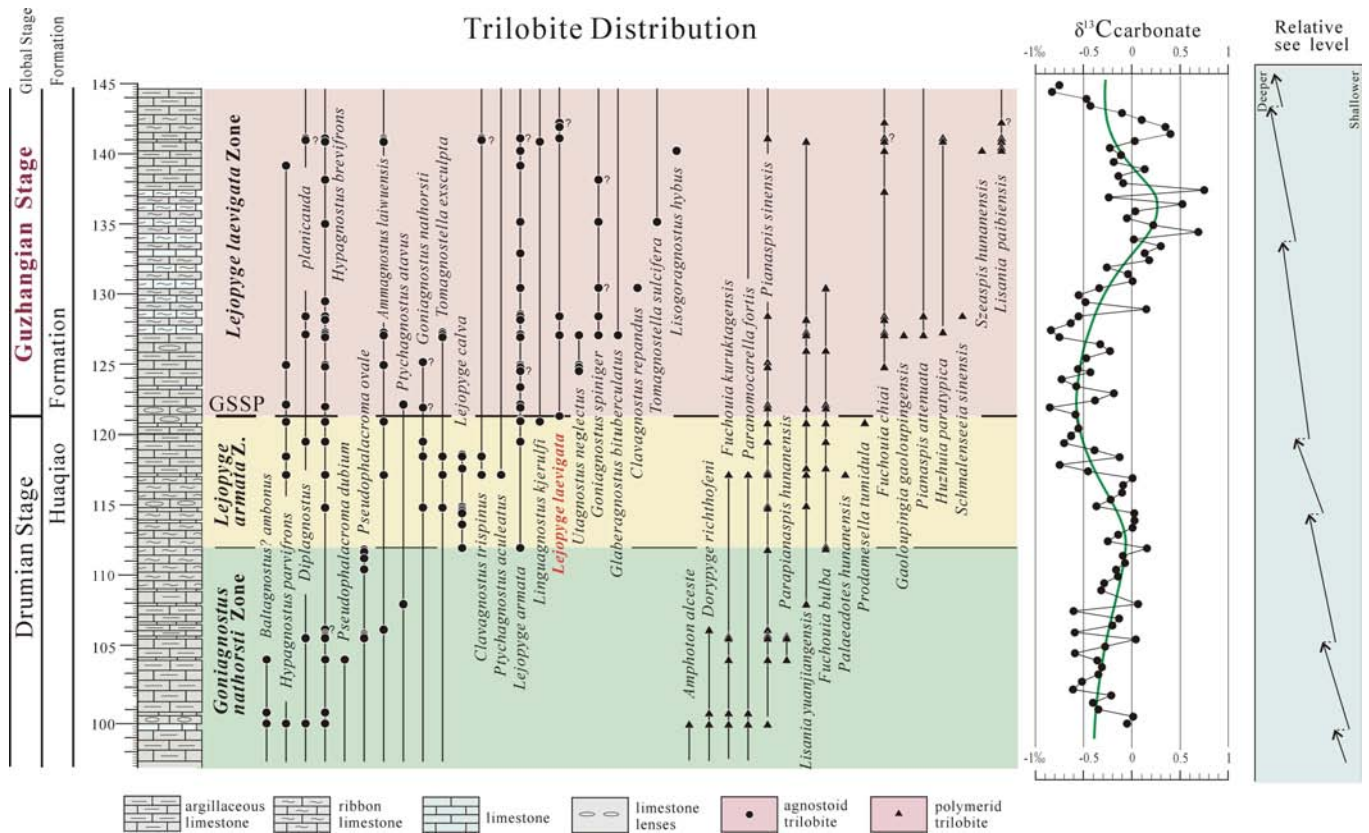


Figure 6. Observed stratigraphic distribution of trilobites in the Huaqiao Formation near the base of the *Lejopyge laevigata* Zone, Luoyixi section, Guzhang County, Hunan Province, China. The GSSP coincides with the base of the *L. laevigata* Zone in this section. An interpretive sea level history, reflecting small-scale regional or eustatic changes, is added for comparison. Also added for comparison is a curve of $\delta^{13}C$ isotopic values, derived from samples collected from the Luoyixi section.

of polymerid trilobites belonging to the *Pianaspis sinensis* Zone range through the *G. nathorsti* Zone and into the *L. laevigata* Zone. *P. sinensis*, *Fuchouia chiai*, *Lisania yuanjiangensis*, *Lisania paratungjenensis*, *Amphoton alceste* and *Prodamesella tumidula* disappear before the FAD of *L. laevigata*. The LADs of *Fuchouia bulba* and *Qiandongensis convexa* are in the lowermost part of the *L. laevigata* Zone.

Conodonts (Figure 11) help to constrain the base of the Guzhangian Stage in the Luoyixi section, the stratotype (Figures 7, 10), although the zonation is not as precise as that afforded by

trilobites. The first observed elements of *Shandongodus priscus* (the eponymous species of the *S. priscus* Zone) in the Luoyixi section occur in the lower part of the *L. laevigata* Zone.

Regional and Global Correlation

A position at or closely corresponding to the FAD of *L. laevigata* in the Luoyixi section is one of the most easily recognizable horizons on a global scale in the Cambrian (e.g., Geyer and Shergold, 2000; Figure 2). Suitability of the FAD of this species for marking a global stage and series boundary has been summarized principally by Geyer

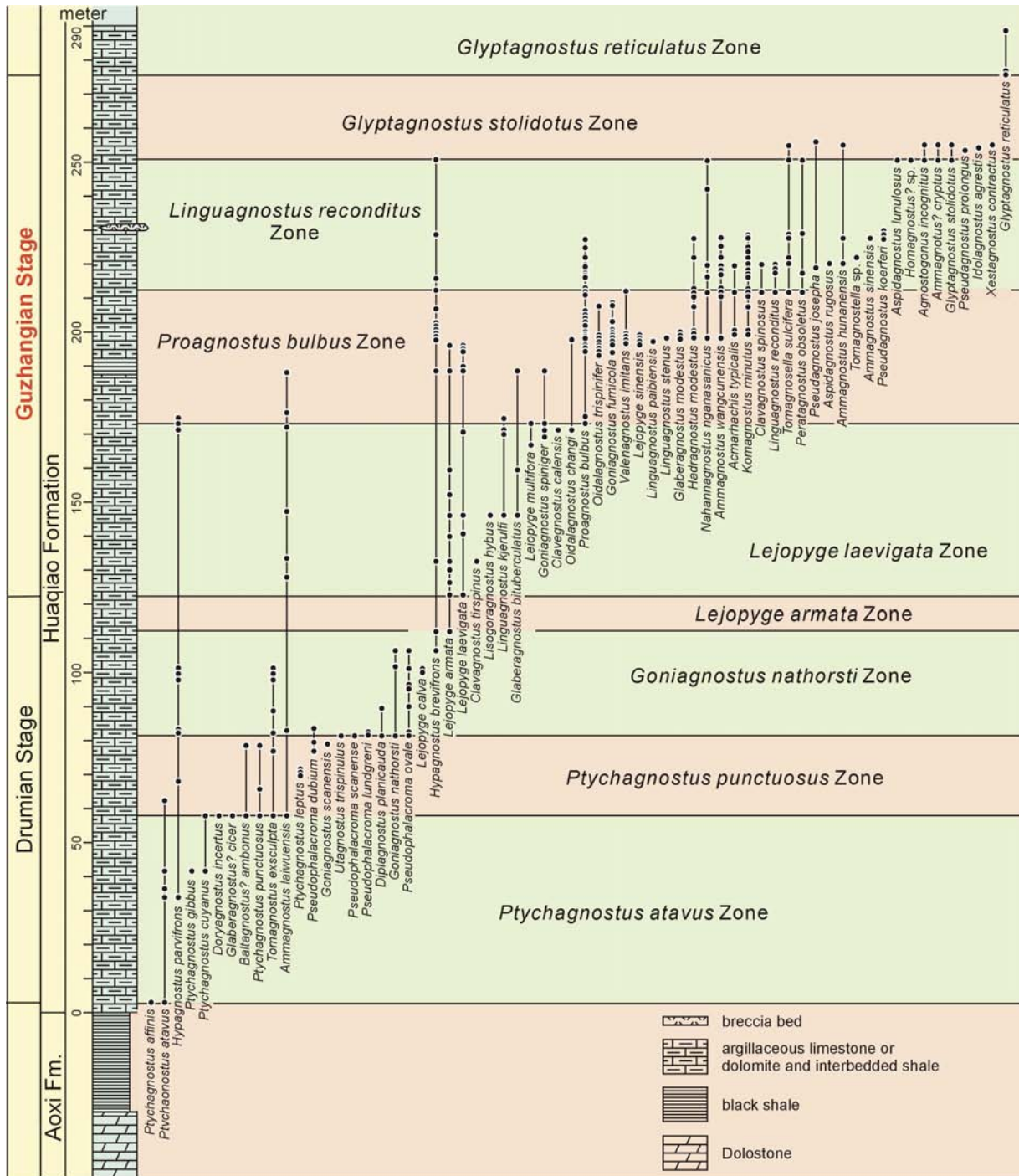


Figure 7. Observed stratigraphic distribution of agnostoid trilobites in the Huaqiao Formation, Wangcun section, on the northeastern bank of the Youshui River, Yongshun County, Hunan Province, China, added for comparison with the Luoyixi section, which is on the southwestern bank of the same river (modified from Peng and Robison, 2000).

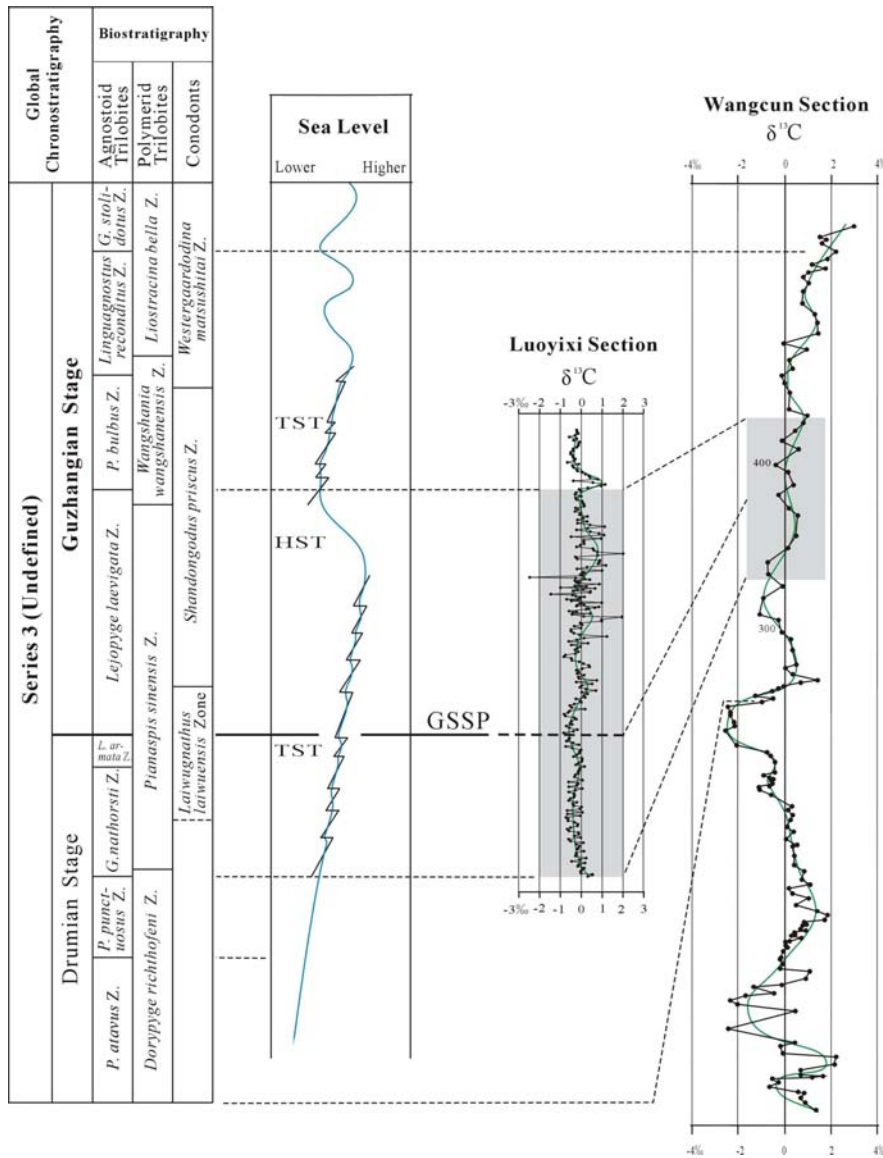


Figure 8. Summary of primary and secondary stratigraphic indicators for the base of the Guzhangian Stage of the Cambrian System. Major stratigraphic tools used to constrain the GSSP of the Guzhangian Stage are the zonation of agnostoid trilobites (Peng and Robison, 2000; Peng et al., 2006), the zonation of polymerid trilobites (Peng et al., 2004b; Peng et al., 2006), the zonation of conodonts (Peng et al., 2006), carbon isotope chemostratigraphy (records from the Luoyixi and Wangcun sections from Zuo, 2006; Zhu et al, 2004), and sequence stratigraphy (Zuo, 2006). All these techniques can be applied in the Luoyixi section, the stratotype. Two orders of inferred sea level history are illustrated: third order (in blue) and fourth order (in black).

and Shergold (2000), and Peng et al. (2004c, 2006). Key correlation tools are described in the following subsections.

Agnostoid Trilobite Biostratigraphy

Lejopyge laevigata has been recognized worldwide (e.g., Westergård, 1946; Pokrovskaya, 1958; Öpik, 1961, 1979; Demokidov, 1968; Palmer, 1968; Khairullina, 1970, 1973; Robison et al., 1977; Yang, 1978; Ergaliev, 1980; Egorova et al., 1982; Robison, 1984, 1988, 1994; Laurie, 1989; Lu and Lin, 1989; Yang et al., 1991; Dong, 1991; Tortello and Bordonaro, 1997; Geyer and Shergold, 2000; Peng and Robison, 2000; Jago and Brown, 2001; Babcock et al., 2004, 2005; Peng et al., 2004b, 2006; Axheimer et al., 2006; Figure 2),

having been identified from rocks of Argentina, Australia (western Queensland, Tasmania), China (Guizhou, Hunan, Sichuan, Xinjiang, Zhejiang), Denmark (Bornholm), England, Germany (erratics), North Greenland, India (Ladakh), Kazakhstan (Malyi Karatau), Kyrgyzstan, Norway, northern Poland, Russia (southern and northeastern Siberian Platform), Sweden, Turkestan, Uzbekistan, and the United States (Nevada, Alaska). The species has been used as a zonal guide fossil in deposits of Baltica, Gondwana, Kazakhstan, Siberia, Laurentia, and eastern Avalonia (e.g., Westergård, 1946; Cowie et al., 1972; Robison, 1976, 1984; Öpik, 1979; Ergaliev and Ergaliev, 2000; Geyer and Shergold, 2000; Peng and Robison, 2000; Ergaliev and Ergaliev, 2000, 2001; Axheimer et al., 2006). Co-occurrences with other trilobites allow for a close correlation into western Avalonia (near the base of the *Paradoxides forchhammeri* Zone; Geyer and Shergold, 2000).

Polymerid trilobite Biostratigraphy

The base of the *L. laevigata* Zone coincides with a change in polymerid trilobite faunas recognized near the base of the Boomerangian Stage in Australia (Öpik, 1967; Geyer and Shergold, 2000; Figure 2) and the base of the *Aldanaspis* Zone in Siberia (Egorova et al., 1982). It also approximately coincides with a faunal change associated with the base of the *Paradoxides forchhammeri* Zone in western Avalonia (Geyer and Shergold, 2000).

Conodont Biostratigraphy

Two conodont zones are recognized in the Luoyixi section, with terminology adapted from North China usage (An, 1982). A position near the base of the *L. laevigata* Zone corresponds with a change in conodont faunas (Figure 10). The interval from 117.2 m to 121.0 m, assigned to the *Laiwugnathus laiwuensis* Zone, is characterized by the first appearances of paraconodonts such as *Yongshunella polymorpha*, *Furnishina bigeminata*,

F. kleithria, and *F. cf. alata*. The eponymous guide fossil *Laiwugnathus laiwuensis* occurs immediately below the FAD of *L. laevigata*. The lower boundary of the *Shandongodus priscus* Zone is in the lower quarter of the *L. laevigata* Zone in the stratotype section. In the Wangcun section, conodont faunas show an increase in diversity above the lower boundary of the *S. priscus* Zone (Dong and Bergström, 2001).

Chemostratigraphy

The base of the *L. laevigata* Zone is not marked by a distinctive shift in carbon isotopic values (Figure 6), although its position can be recognized from a longer sequence of $\delta^{13}\text{C}$ values. The horizon

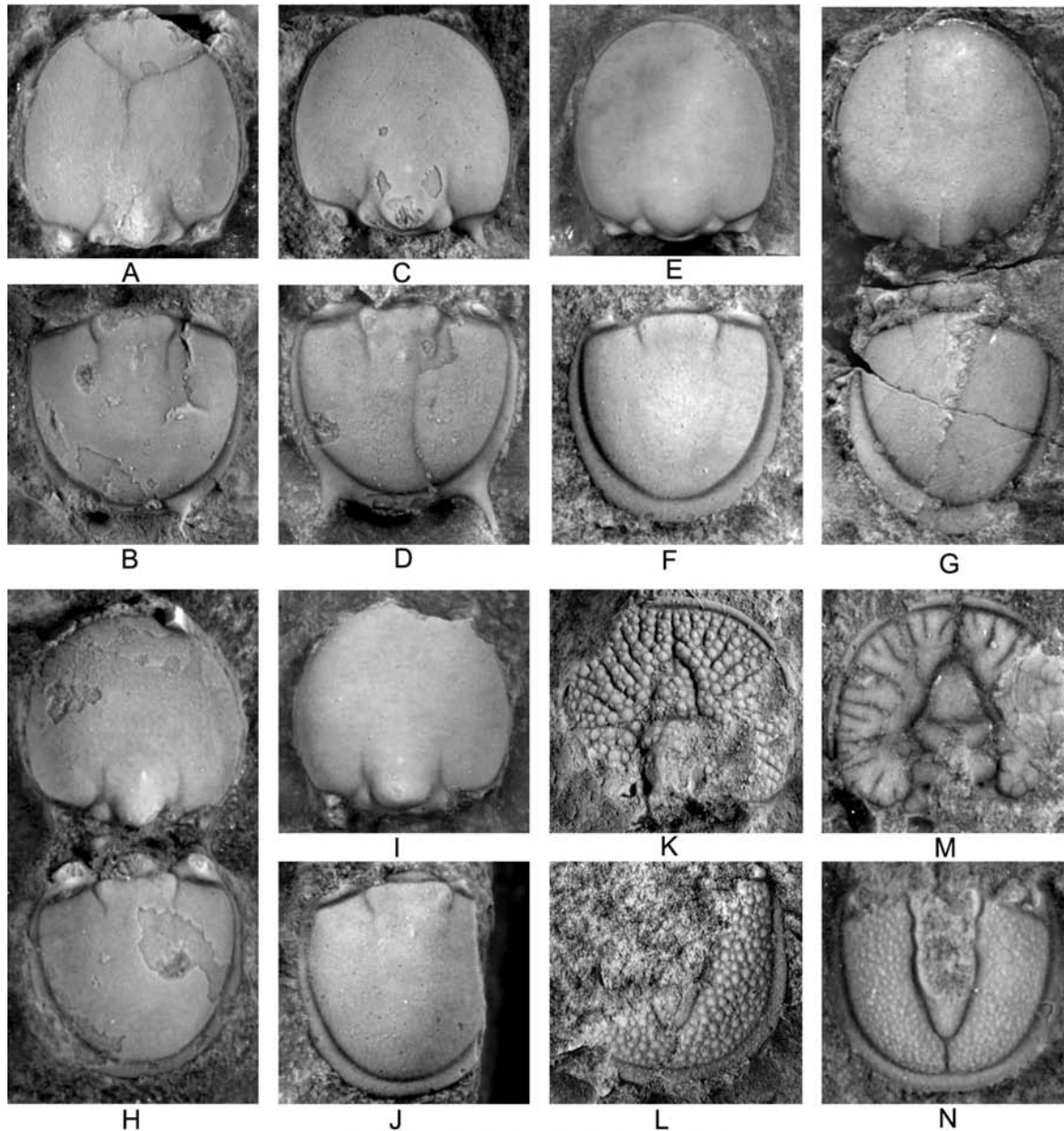


Figure 9. Key agnostoid trilobite species used for recognition of the base of the Guzhangian Stage. Numbers with the prefix LYX (for Luoyixi section) indicate collecting horizons in meters above the arbitrary 0 m position. All dorsal views. A-D, *Lejopyge armata* (Linnarsson, 1869), a series of primitive and derived forms. A, cephalon, LYX12.50, 111.9 m above the base of the Huaqiao Formation, x 6; B, pygidium, LYX21.45, 120.85 m above the base of the Huaqiao Formation, x 10; C, cephalon, LYX27.65, 127.05 m above the base of the Huaqiao Formation, x 8; D, pygidium, LYX27.65, 127.05 m above the base of the Huaqiao Formation, x 8; E-G, *Lejopyge calva* Robison, 1964. E, cephalon, LYX 15.4, 114.8 m above the base of the Huaqiao Formation, x 8; F, pygidium, LYX15.15, 114.55 m above the base of the Huaqiao Formation, x 10; G, exoskeleton, LYX19.05, 118.45 m above the base of the Huaqiao Formation, x 10; H-J, *Lejopyge laevigata* (Dalman, 1828), a series of primitive and derived forms. H, exoskeleton, LYX21.9, 121.3 m above the base of the Huaqiao Formation, x 9; I, cephalon, LYX64.40, 163.8 m above the base of the Huaqiao Formation, x 10; J, pygidium, LYX64.40, 163.8 m above the base of the Huaqiao Formation, x 10.5; K, *Ptychagnostus aculeatus* (Angelin, 1851). K, incomplete cephalon, LYX54.75, 154.15 m above the base of the Huaqiao Formation, x 7; L, fragmentary pygidium, LYX17.75, 117.15 m above the base of the Huaqiao Formation, x 7; M, N, *Goniagnostus nathorsti* (Brøgger, 1878). M, LYX15.40, 114.8 m above the base of the Huaqiao Formation, x 11; N, pygidium, LYX15.40, 114.8 m above the base of the Huaqiao Formation, x 15.

corresponding to the first appearance of *L. laevigata* is near the peak of a rather long negative $\delta^{13}\text{C}$ excursion of up to 0.58 ‰ (Figures 6, 7). Strata in the upper part of the Drumian Stage are characterized by slightly negative $\delta^{13}\text{C}$ values (reaching a maximum of 7.6 ‰). A small positive shift, which peaks at about 0.15 ‰, coincides with the base of the *L. armata* Zone, and this is followed by a longer negative shift,

the peak of which nearly coincides with the base of Guzhangian Stage. Oscillations in the $\delta^{13}\text{C}$ curve through the rest of the unnamed stage are minor, usually ranging between -1 and +1 ‰ (Figure 6). The next most distinct position in the $\delta^{13}\text{C}$ curve is the base of the SPICE excursion, one of the largest positive $\delta^{13}\text{C}$ excursions known from the Paleozoic, which coincides with the base of the Paibian Stage

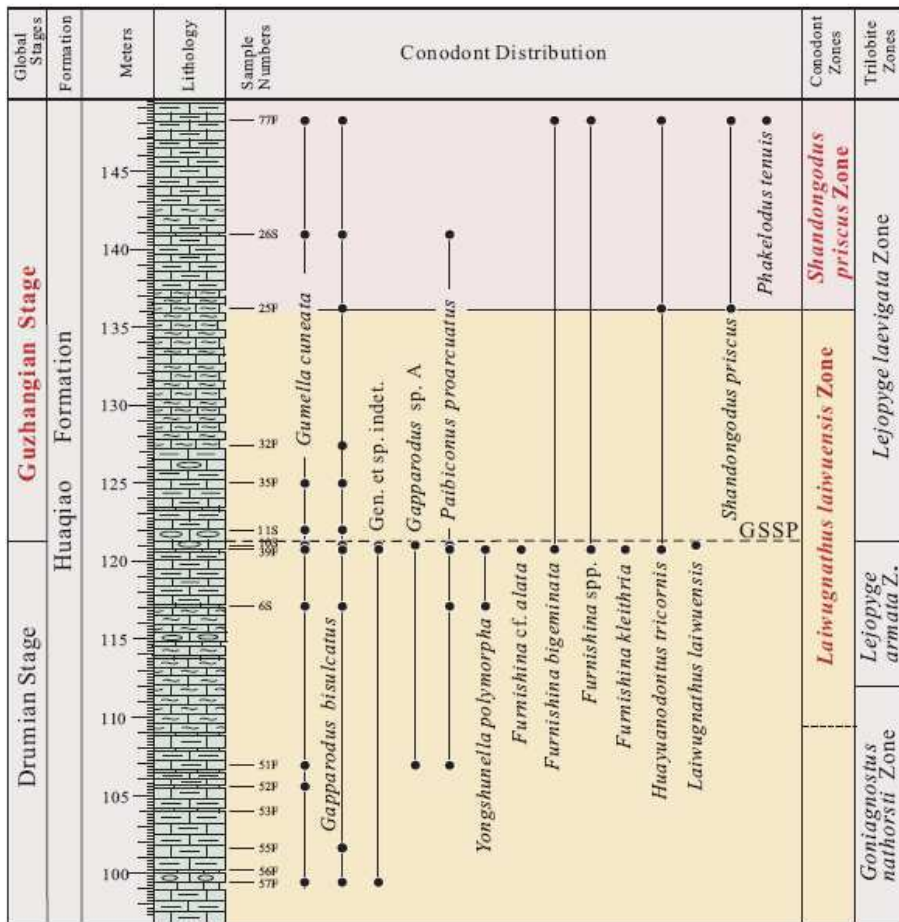


Figure 10. Observed stratigraphic distribution of conodonts in the Huaqiao Formation near the base of the *Lejopyge laevigata* Zone, Luoyixi section, Guzhang County, Hunan Province, China.

(Brasier and Sukhov, 1998; Montañez et al., 2000; Zhu et al., 2004).

Sequence Stratigraphy

Work in the Wuling Mountains of Hunan shows that the base of the *L. laevigata* Zone is associated with the early part of a transgressive event (Figures 6, 7). Overall, the Huaqiao Formation is inferred to have been deposited during eight third-order cycles (Zuo, 2006). Superimposed on these long-term cycles are a series of smaller scale transgressive-regressive cycles. Within the first third-order cycle, Zuo (2006) recognized 11 fourth-order cycles, and within the second fourth-order cycle he recognized 9 fifth-order cycles. In the Luoyixi section, the FAD of *L. laevigata* is associated with one of the small scale transgressive events, the lower part of the sixth fourth-order cycle (almost coinciding with the top of the first fifth-order cycle; Zuo et al., 2006, fig. 4). The species first appears less than 20 cm upsection of a surface inferred to represent a deepening event of small magnitude. Comparative work on sections elsewhere in Hunan Province, China (Paibi and Wangcun), and in the Great Basin, USA, shows that *L. laevigata* first appears in outer-shelf and slope lithofacies of Gondwana and Laurentia at an early stage of a transgressive event. The transgression with which the FAD of *L. laevigata* is associated is interpreted to be of eustatic scale.

Reference Section

Another excellent reference section exposing the Huaqiao

Formation in general, and the lower part of the *L. laevigata* Zone in particular, is located near Wangcun (across the Youshui River from the Luoyixi section), Hunan Province, China. There seems to be little difference between the Luoyixi section and the Wangcun section. The Luoyixi section was selected as the stratotype section because it has been more intensively collected in the boundary interval, making the position of the first appearance of *L. laevigata* more tightly constrained.

Estimate of Age

The base of the Guzhangian Stage is estimated to be 503.0 ± 1 Ma. This figure is derived from extrapolation between the estimated age of the base of the traditional Upper Cambrian (~500 Ma) (Shergold, 1995), which is closely correlative to the base of the *Linguagnostus reconditus* Zone of South China (Peng and Robison, 2000; Ahlberg, 2003; Ahlberg et al., 2004), and the estimated age of the base of the traditional Middle Cambrian (510.0 ± 1.0 Ma). The age of the base of the traditional Middle Cambrian is well constrained by U-Pb ages on zircons from an ash bed in the Hanford Brook Formation, southern New Brunswick (Landing et al., 1998; Bowring and Erwin, 1998). These estimates provide a duration of about 10 Ma for the traditional Middle Cambrian. In South China, seven to nine biozones are recognized in the

traditional Middle Cambrian (i.e., the Taijiangian and Wangcunian stages; Peng and Babcock, 2001, Yuan et al., 2002; Peng, 2003). In Australia, the same interval is covered by eight biozones (Geyer and Shergold, 2000). The average duration, then, for each zone is a little more than 1 million years. This suggests that the base of the Guzhangian Stage, coinciding with the base of the *Lejopyge laevigata* Zone, a level two or three biozones above the *P. punctuosus* Zone, is close to an age of 503.0 Ma (possibly slightly younger). This estimate accords well with a mean SHRIMP age on zircons of 503.2 ± 3.8 Ma (Perkins and Walshe, 1993) for an interval probably equivalent to the *Goniagnostus nathorsti* Zone through the basal part of the *L. laevigata* Zone in the Southwell Sub-group of the Mt. Read Volcanics, Tasmania (Jago and McNeil, 1997).

Encarnación et al. (1999) provided dates from volcanic tuffs in the Taylor Formation, Antarctica, that provide broad support for an age close to 503.0 Ma for the base of the Guzhangian Stage. U-Pb ages on zircons recovered from slightly above and below *Nilsonia*- and *Amphoton*-bearing carbonate beds yielded a weighted mean age of 505.1 ± 1.3 Ma. The sampled strata were interpreted as equivalent to the Floran-Undillan interval as used in Australia (Shergold et al. 1985; Shergold, 1995), but biostratigraphic control on the Taylor Formation is poor. Based on occurrences of trilobites in Australia, China, and Siberia, the sampled beds seem to be in a position near the base of the *Ptychagnostus punctuosus* Zone (equivalent to the Floran-Undillan boundary).

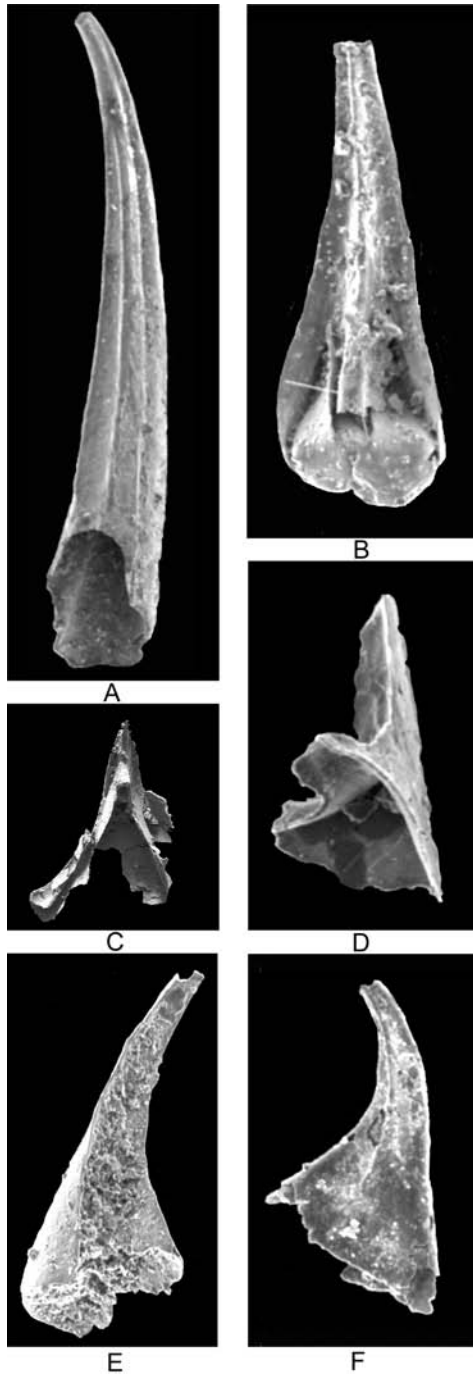


Figure 11. Conodonts used for recognition of the base of the Guzhangian Stage. **A**, *Gapparodus bisulcatus* (Müller, 1959): sample 51F, 106.9 m above the base of the Huaqiao Formation, posterolateral view, $\times 53$; **B**, *Laiwugnathus laiwuensis* An, 1982: sample 10S, 121.0 m above the base of the Huaqiao Formation, posterior view, $\times 72$; **C**, *Furnishina kleithria* Müller and Hinz, 1991: sample 39F, 120.8 m above the base of the Huaqiao Formation, posterior view, $\times 28$; **D**, *Shandongodus priscus* An, 1982: sample 25F, 136.25 m above the base of the Huaqiao Formation, posterolateral view, $\times 207$; **E**, *Yongshunella polymorpha* Dong and Bergström, 2001: sample 6S (117.15 m above the base of the Huaqiao Formation), lateral view, $\times 83$; **F**, *Yongshunella polymorpha* Dong and Bergström, 2001: sample 6S (117.15 m above the base of the Huaqiao Formation), lateral view, $\times 82$.

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