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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. Southwestern bank of Youshui River (Fengtan Reservoir) showing the Luoyixi section.
The Global Boundary Stratotype Section and Point (GSSP) of the Guzhangian Stage (Cambrian) in the Wuling Mountains, Northwestern Hunan, China

by Shanchi Peng\(^1\), Loren E. Babcock\(^3\), Jingxun Zuo\(^1,4\), Huanling Lin\(^1\), Xuejian Zhu\(^1,5\), Xianfeng Yang\(^1\), Richard A. Robison\(^6\), Yuping Qi\(^1\), Gabriella Bagnoli\(^7\), and Yong’ an Chen\(^8\)

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 (calcsilite) layer 121.3 m above the base of the Huaqiao Formation in the Louyixi section along the Youshui River (Fengtan 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 109º57.88' 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 Laiwunghathus laiwensis 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 \(\delta^{13}C\) 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
The purpose of this paper is to announce ratification of the GSSP for the base of the Guzhangian Stage, in the Wulinshan Formation, situated on the south bank of the Youshui River, which contains the same succession of strata, is referred to as the Wangcun South section (Peng et al., 2004c, 2005). The position of the section is in a roadcut delimited by a cliff at an elevation of approximately 216 m. A position corresponding closely to the first appearance of Lejopyge laevigata is recognizable in strata of Gondwana, Baltica, Laurentia, Kazakhstan, and Siberia (e.g., Opik, 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., 2004c; Peng, 2005; Peng et al., 2005) along the Youshui River (opposite the Luoyixi section), Yongshun County, China. The Youshui River forms the boundary between Guzhang County (to the south) and Yongshun County (to the north) in the Wuling Mountains (Wulingshan). A number of counties, including Guzhang County, border the river in northwestern Hunan Province, China. The Youshui River is easily accessible, and access for research is unrestricted. It is located on public land under permanent protection by the government of Hunan Province, China. The Youshui River forms the boundary between Guzhang County 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 28º43.20’N latitude and 109º57.88’E longitude (determined by handheld Garmin GPS), and at an elevation of approximately 216 m.

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, (Fengtan 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 28º43.20’ N latitude and 109º57.88’ 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
The geologic history of the region is contained in Peng and Babcock (2001).

The Wuling Mountains consist of an extensive series of folded and thrust slices resulting from post-Devonian compressional tectonics that extend through parts of northwestern Hunan, eastern Guizhou, and southeastern Sichuan provinces, China (Guizhou Bureau of Geology and Mineral Resources, 1987; Hunan Bureau of Geology and Mineral Resources, 1988). The Luoyixi section is situated on the southeast limb of an undulating syncline, the Liexi-Zhuitun Syncline. Cambrian strata of South China are assigned to three major depositional environments along a platform-to-basin transition (e.g., Pu and Ye, 1991; Pu and Ye, 1991; Peng and Robison, 2000; Peng and Babcock, 2001). Relatively shallow environments of the Yangtze (South China or Southwest China) Platform were flanked by deeper environments of the Jiangnan Slope Belt, and still deeper environments of the Jiangnan Basin. The GSSP occurs within the Huaqiao Formation, which consists of a thick succession of carbonate beds deposited in the outer part of the Jiangnan Slope Belt (e.g., Pu and Ye, 1991; Rees et al. 1992; Peng and Robison, 2000; Peng and Babcock, 2001).

**Location of Level and Specific Point**

The first lenticular calcisiltite limestone layer of the Huaqiao Formation that contains the cosmopolitanagnostoid trilobite *Lejopyge laevigata* occurs 121.3 m above the base of the Huaqiao Formation in the Luoyixi section. The species is rare in this bed, but becomes more abundant upsection.

**Stratigraphic Completeness**

Detailed correlation of Cambrian Series 3 strata through northwestern Hunan, coupled with detailed biostratigraphy (Peng and Robison, 2000; Peng et al., 2004a, 2004b), sedimentology (Fu et al., 1999; Zuo, 2006; Zuo et al., 2006), and carbon-isotope chemostratigraphy (Zuo, 2006; Zuo et al., 2008; Figures 6, 7), demonstrates the stratigraphic continuity of the basal interval of the Guzhangian Stage in the Luoyixi section. Biostratigraphic studies within Hunan Province and globally demonstrate that the succession of trilobite species (e.g., Westergård, 1946; Daily and Jago, 1975; Ópik, 1961, 1967, 1979; Robison et al., 1977; Ergaliev, 1980; Egorova et al., 1982; Rowell et al., 1982; Robison, 1964a, 1964b, 1984, 1994; Laurie, 1988, 1989; Geyer and Shergold, 2000; Axheimer et al., 2006; Peng et al., 2006) and conodont species (Peng et al., 2006) in the Luoyixi section is undisturbed. The section lacks synsedimentary and tectonic disturbance in the GSSP boundary interval, although minor bedding-plane slippage, which is expected in an inclined succession of strata, occurs along some beds. Bedding-plane-slip surfaces do not appear to have resulted in any loss or repetition of stratigraphic
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., Westergärd, 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
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 Boomerangan 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 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 Solenopeltus? brachymesota 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 Pseudophalacrorna dubium or Pseudophalacrorna? 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 bioclasts 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 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
Taylor, 1975, 1976; Babcock, 1994) led to the development of rather distinct trilobite biofacies in shelf and basin areas. Low-latitude shelf areas were inhabited mostly by endemic polymerid trilobites and some pan-tropical taxa. High-latitude shelf areas, and basin 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 solidotus* 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. 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 biostatigraphic correlation tools for identifying the base of the Guzhangian Stage (Peng et al., 2004b, 2006). A diverse assemblage...
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.

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**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).
Agnostoid Trilobite Biostratigraphy

Lejopyge laevigata has been recognized worldwide (e.g., Westergård, 1946; Pokrovskaya, 1958; Öpik, 1961, 1979; Demokidov, 1968; Palmer, 1968; Khaïrullina, 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 (Maly Karatau), Kyrgyzstan, Norway, northern Poland, Russia (southern and northeastern Siberian Platform), Sweden, Turkistan, Uzbekistan, and the United States (Nevada, Alaska). The species has been used as a zonal guide fossil in deposits of Baltic, 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; Geyer 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 paracondonts such as Yonshunella 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).

Chemostратigraphy

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 δ¹³C values. The horizon
corresponding to the first appearance of *L. laevigata* is near the peak of a rather long negative $\delta^{13}$C excursion of up to 0.58 ‰ (Figures 6, 7). Strata in the upper part of the Drumian Stage are characterized by slightly negative $\delta^{13}$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 $\delta^{13}$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 $\delta^{13}$C curve is the base of the SPICE excursion, one of the largest positive $\delta^{13}$C excursions known from the Paleozoic, which coincides with the base of the Paibian Stage.
(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 Tiajiangan 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, ×53; B, Laiwugnathus laiwuensis An, 1982: sample 10S, 121.0 m above the base of the Huaqiao Formation, posterior view, ×72; C, Furnishina kleithria Müller and Hinz, 1991: sample 39F, 120.8 m above the base of the Huaqiao Formation, posterior view, ×28; D, Shandongodus priscus An, 1982: sample 25F, 136.25 m above the base of the Huaqiao Formation, posterolateral view, ×207; E, Yongshunella polymorpha Dong and Bergström, 2001: sample 6S (117.15 m above the base of the Huaqiao Formation), lateral view, ×83; F, Yongshunella polymorpha Dong and Bergström, 2001: sample 6S (117.15 m above the base of the Huaqiao Formation), lateral view, ×82.

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