PROPOSED GLOBAL STANDARD STRATOTYPE-SECTION AND POINT FOR THE GUZHANGIAN STAGE (CAMBRIAN)

Prepared for the International Subcommission on Cambrian Stratigraphy by:

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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 developing proposals for 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 Standard 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). So far, the boundary positions relevant to the Cambrian (Fig. 1) that have been ratified are: 1, the base of the Cambrian System and the Paleozoic Erathem (Brasier et al., 1994; Landing, 1994; Gehling et al., 2001); 2, the base of the Drumian Stage (Babcock et al., 2006); 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 the intercontinentally distributed agnostoid trilobites (Geyer and Shergold, 2000). To date, two 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 and the FAD of *Glyptagnostus reticulatus* for the Paibian Stage respectively. Among the remaining horizons having potential as stage boundaries (Shergold and Geyer, 2001), the FAD of the intercontinentally distributed agnostoid trilobite *Lejopyge laevigata* is one of the most 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 proposal is to seek formal recognition for the base of a global stage boundary (provisionally called Cambrian Stage 7) coinciding with the FAD of the cosmopolitan trilobite *Lejopyge laevigata*. Available information (e.g., Peng and Robison, 2000; Peng et al., 2001), including new information presented here, indicates that the Louyixi section (formerly called the Wangcun South section; Peng et al., 2004c; Peng, 2005; Peng et al., 2005) along the Youshui River (Fengtan Reservoir), about 4 km northwest of Luoyixi (4 km southeast of Wangcun), in northwestern Hunan, is an excellent candidate for the GSSP of

the stage boundary. The proposed GSSP for the base of the new stage is 121.3 m above the base of the Huaqiao Formation; Figs. 3, 6, 7, 11). This point fulfills all of the geological and biostratigraphic requirements for a GSSP (see Remane et al., 1996). 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); 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, will ensure 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.

Proposal: Luoyixi section, along the Youshui River, Wuling Mountains (Guzhang County, Hunan Province, China) as the GSSP for the base of the Guzhangian Stage

1. Stratigraphic rank of the boundary

The base of the proposed 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, 2006; Peng et al., 2006; Figs. 1, 2). The stage is proposed to be the third (uppermost) of three stages included in the Cambrian series 3. The base of the stage, once ratified, will automatically define the top of the Drumian Stage, and will limit 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 will be a standard stage/age GSSP.

2. Proposed GSSP – geography and physical geology

2.1. 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 Yongshan 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; Fig. 3D). The Luoyixi section exposes the uppermost part of the Aoxi Formation and more than 200 m of the overlying Huaqiao Formation. The proposed boundary stratotype for the base of the Guzhangian Stage is in the lower portion of the Luoyixi section. The proposed GSSP is exposed in a roadcut at a position of 28°43.20′ N latitude and 109º57.88′ W longitude (determined by handheld Garmin GPS), and at an elevation of approximately 216 m.

2.2. Geological location

The Cambrian geology of northwestern Hunan, the site of the proposed GSSP section, has been summarized in a number of papers, most notably those contained in Palaeoworld 13 (Peng and Babcock, 2001; Peng et al., 2001). An overview of Cambrian paleogeography, biotic provinces, and geologic history of the region is contained in Peng and Babcock (2001).

The Wuling Mountains consist of an extensive series of folded and thrusted 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; 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 proposed 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).

2.3. Location of level and specific point

The first lenticular calcisiltite layer of the Huaqiao Formation that contains the cosmopolitan agnostoid trilobite *Lejopyge laevigata* occurs 121.3 m above the base of the Huaqiao Formation in the Luoyixi section.

2.4. Stratigraphic completeness

Detailed bed-by-bed correlation of undefined Cambrian Series 3 (Babcock et al. 2005; Fig. 1) strata through northwestern Hunan, coupled with detailed biostratigraphy (Peng and Robison, 2000; Peng et al., 2004a, 2004b), sedimentology (Zuo, 2006; Zuo et al., 2006), and carbon-isotope chemostratigraphy (Zuo, 2006; Figs.7, 9), clearly demonstrates the stratigraphic continuity of the basal interval of the proposed 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; Öpik, 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 at the proposed 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 proposed stratotype. Evidence of metamorphism and strong diagenetic alteration is absent.

2.5. Thickness and stratigraphic extent

In the Luoyixi section (Figs. 5, 6), 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 proposed Guzhangian Stage, marked by the FAD of *L. 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 *Lejopyge laevigata* first appears occurs in 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 (Fig. 6C, 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.

2.6. Provisions for conservation, protection, and accessibility

The exposure containing the proposed 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 proposed GSSP point.

3. Motivation for selection of the boundary level and of the potential stratotype section

3.1. Principal correlation event (marker) at proposed GSSP level

The agnostoid trilobite *Lejopyge laevigata* (Fig. 10H-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 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 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* (Figs. 6B-D, 7, 8) 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 FAD of *L. armata* in Laurentia is unknown, but it may relate to limits on the exposure of favorable biofacies. Stratigraphic occurrence and morphological features of *L. calva* suggest it may be an ancestor of both of *L. armata* and *L. laevigata*. Species of *Lejopyg*e 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 distinct trilobite biofacies in shelf and basinal areas. Low-latitude shelf areas were inhabited mostly by endemic polymerid trilobites and some pan-tropical taxa. High-latitude shelf areas, and basinal 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).

3.2. Potential stratotype section

The FAD of *L. laevigata* in the Luoyixi section, Hunan Province, China (Figs. 3, 6, 7), occurs in the Huaqiao Formation at a level 121.3 m above the base of the formation (Figs. 6C, 6D, 7). 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 proposed 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 (Fig. 6). Small truncation surfaces, and slide surfaces reflecting distal turbidite deposition are rare in the section and absent near the proposed GSSP, suggesting deposition in an outer slope to carbonate apron environment (Rees et al., 1992).

The proposed 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 proposed GSSP are summarized in Figure 7. 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 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 parartungjenensis*, *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 (Fig. 12) help to constrain the base of the Guzhangian Stage in the Luoyixi section, the proposed stratotype (Figs. 9, 11), 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.

3.3. Demonstration of 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; Fig. 2). Suitability of the FAD of this species for marking a global stage and series boundary has been summarized principally by Geyer and Shergold (2000), and Peng et al. (2004c, 2006). Key correlation tools are described in the following subsections.

3.3.1. 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; Fig. 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, and 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).

3.3.2. 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; Fig. 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).

3.3.3. 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 (Fig. 11). 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 *Yongshunella polymorpha*, *Furnishina bigeminata*, *F. kleithria*, and *F.* cf. *alata*. The eponymous guide fossil *Laiwugnathus laiwuensis*, here reported for the first time from South China, 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 proposed 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).

3.3.4. Chemostratigraphy

The base of the *L. laevigata* Zone is not marked by a distinctive shift in carbon isotopic values (Fig. 7), although its position can be recognized from a longer sequence of $\delta^{13}C$ 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 ‰ (Figs. 7, 9). 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 ‰ (Fig. 7). 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).

3.3.5. 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 (Figs. 7, 9). 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 10 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.

4. Other regional candidate section

Another potential GSSP candidate 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, and the Wangcun section is deemed adequate to serve as a stratotype for the base of a stage whose GSSP coincides with the FAD of *L. laevigata*. However, the Luoyixi section has been more intensively collected in the boundary interval, making the position of the first appearance of *L. laevigata* more tightly constrained.

5. Other extraregional section: Kyrshabakty section, Malyi Karatau Range, Kazakhstan

Outside of South China, perhaps the next best section exposing an inferred complete succession of strata through the base of the *L. laevigata* Zone occurs along the Kyrshabakty River, southeast of Zhanatas, Malyi Karatau Range, Kazakhstan (Ergaliev, 1980; Ergaliev and Ergaliev, 2000, 2001). The base of the section is located at 43°32′02′′N, 69°51′28′′ and an elevation of 571 m. It is located in a protected area, the Aksai State Natural Reserve, and will be conserved but accessible for study. The Malyi Karatau Range represents an northwestern extension of the Tien Shan Mountains.

In the Kyrshabakty section, Cambrian strata ranging from the Drumian Stage through the proposed Guzhangian Stage are assigned to the Zhumabai Formation, a succession dominated by dark gray to black, thin to medium bedded limestones (lime mudstones). The FAD of *L. laevigata* is 10 m above the base of Unit 3 in the Zhumabai Formation. This position is 3 m above the FAD of *L. armata*. Ergaliev (1980) reported the FAD of *L. laevigata* at a position 39.7 m higher in section than the level indicated here, but recent resampling confirmed a much lower first occurrence.

Detailed bed-by-bed correlation, coupled with detailed biostratigraphy suggest that the Zhumabai Formation records a complete, essentially continuous stratigraphic succession. The

order of trilobite occurrences is consistent with an unbroken stratigraphic succession. However, sequence stratigraphic interpretation of the section is not available, and comparative, neighboring sections are not recorded.

6. Best estimate of age for the base of the proposed Guzhangian Stage

As discussed below, the base of the Guzhangian Stage is estimated to be 503.0 ± 1 Ma. Shergold (1995) estimated an age of ~500 Ma for the base of the traditional Upper Cambrian, 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). The base of the traditional Middle Cambrian is estimated to be 510.0 ± 1.0 Ma, an age that 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 proposed 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 Subgroup of the Mt. Read Volcanics, Tasmania (Jago and McNeil, 1997).

Encarnación et al. (1999) provided dates from volcanic tuffs in the 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 Undillan/Floran Stage 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 boundary between the Floran and Undillan stages).

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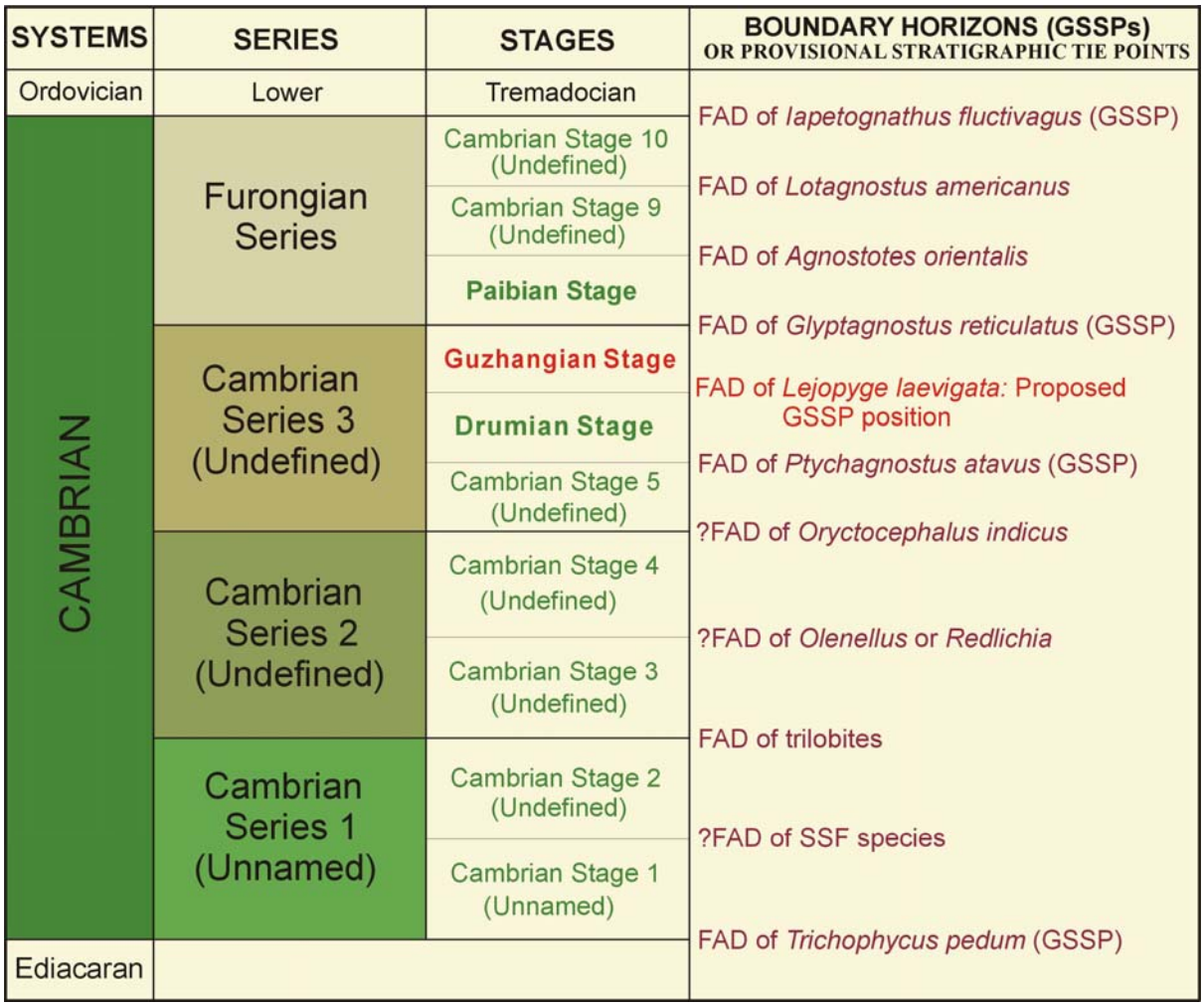

Fig. 1. Chart showing working model for global chronostratigraphic subdivision of the Cambrian System, indicating lower boundary of the proposed Guzhangian Stage (modified from Babcock et al., 2005).

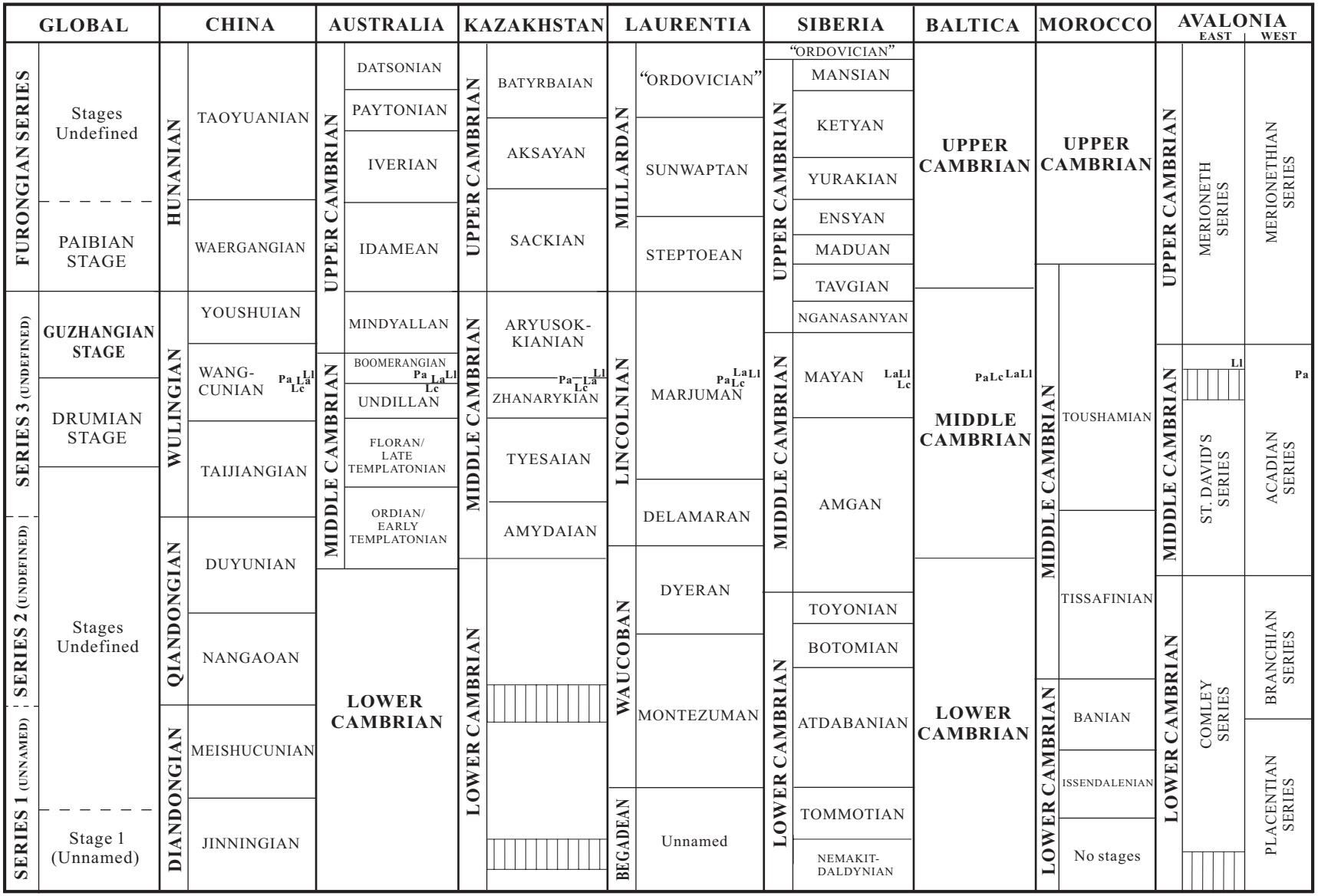

Fig. 2. Correlation chart of the Cambrian showing the proposed global chronostratigraphic stages compared to regional usage in major areas of the world (modified from Peng et al., 2004a). Ll indicates the presence and horizon of *Lejopyge laevigata* in a region; La indicates the presence and horizon of *Lejopyge armata* in a region; Lc indicates the presence and horizon of *Lejopyge calva* in a region; Pa indicates the presence and horizon of *Ptychagnostus aculeatus* in a region. Chart compiled from numerous sources, summarized principally in Geyer and Shergold (2000) and Babcock et al. (2004).

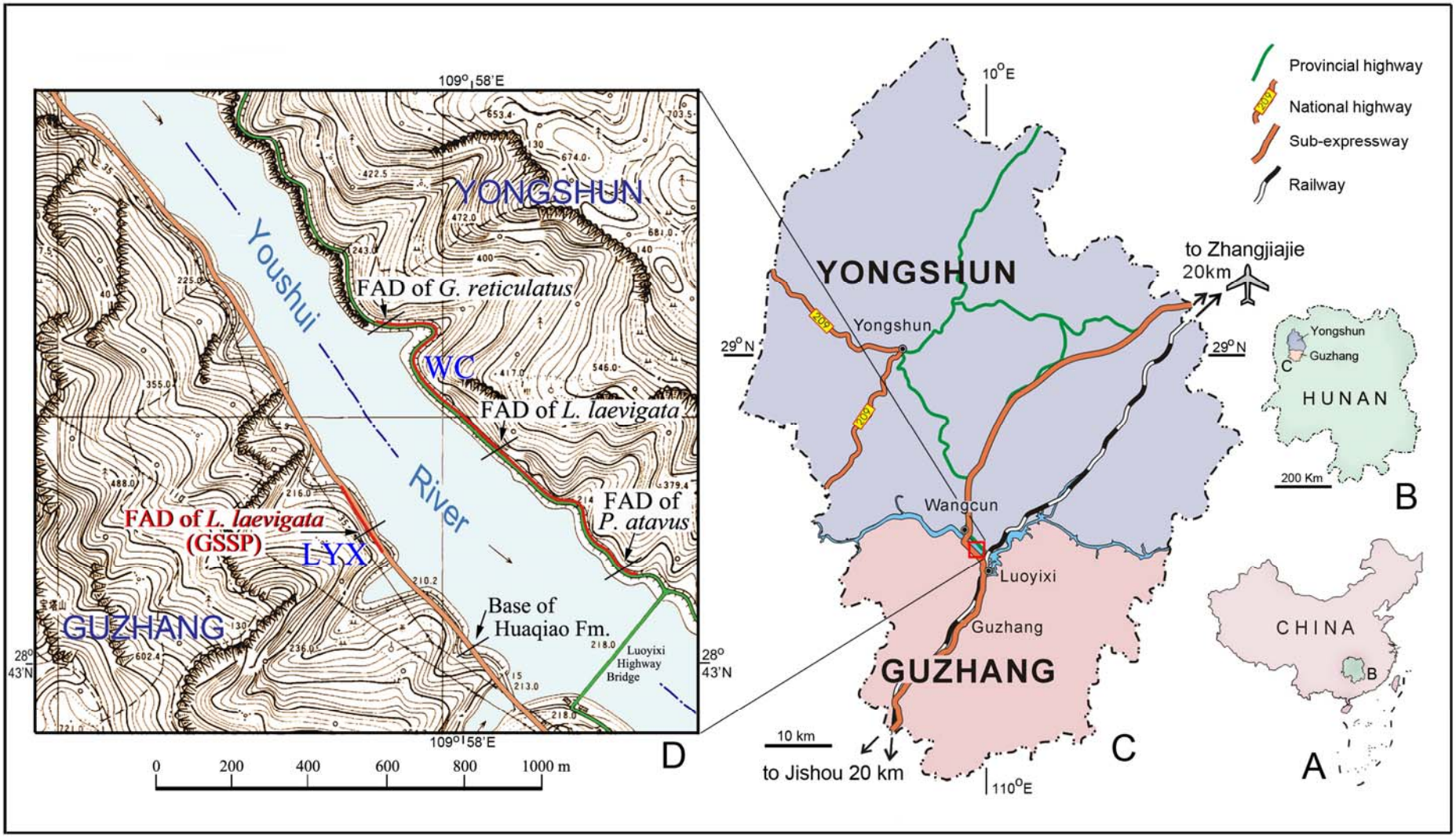

Fig. 3. Topographic map of part of northwestern Hunan Province, China, along the Youshui River (Fengtan Reservoir), showing the position of the Luoyixi section (LYX, in northern Guzhang County) and the Wangcun section (WC, in southern Yongshun County). Part D of the figure is from topographic map H49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

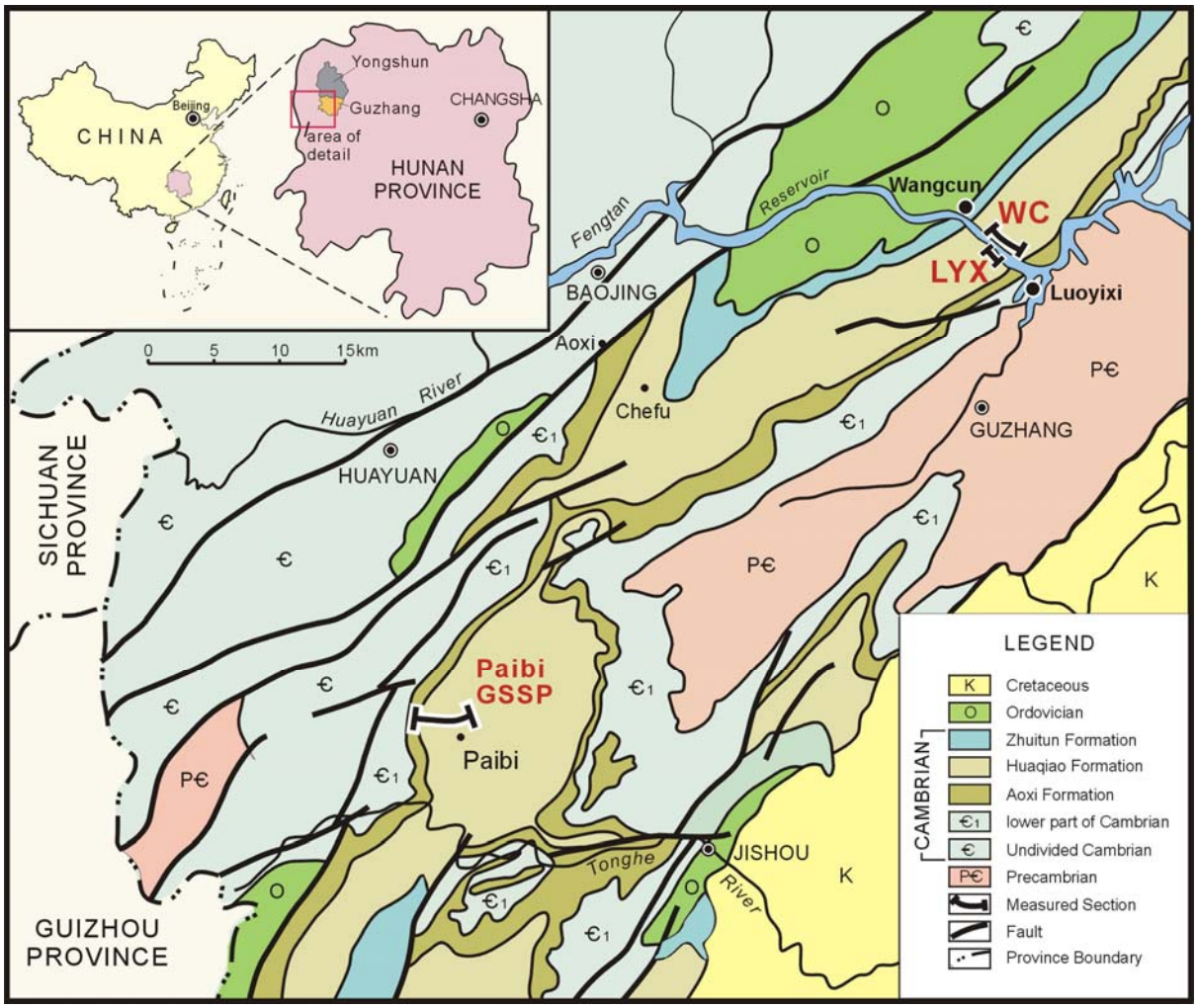

Fig. 4. Map of part of northwestern Hunan Province (location of Hunan inset), China, showing location of proposed stratotype section for the Guzhangian Stage (Luoyixi section, south side of the Fengtan Reservoir, Youshui River; indicated as LYX). Location of the Wangcun section (north side of the Fengtan 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).

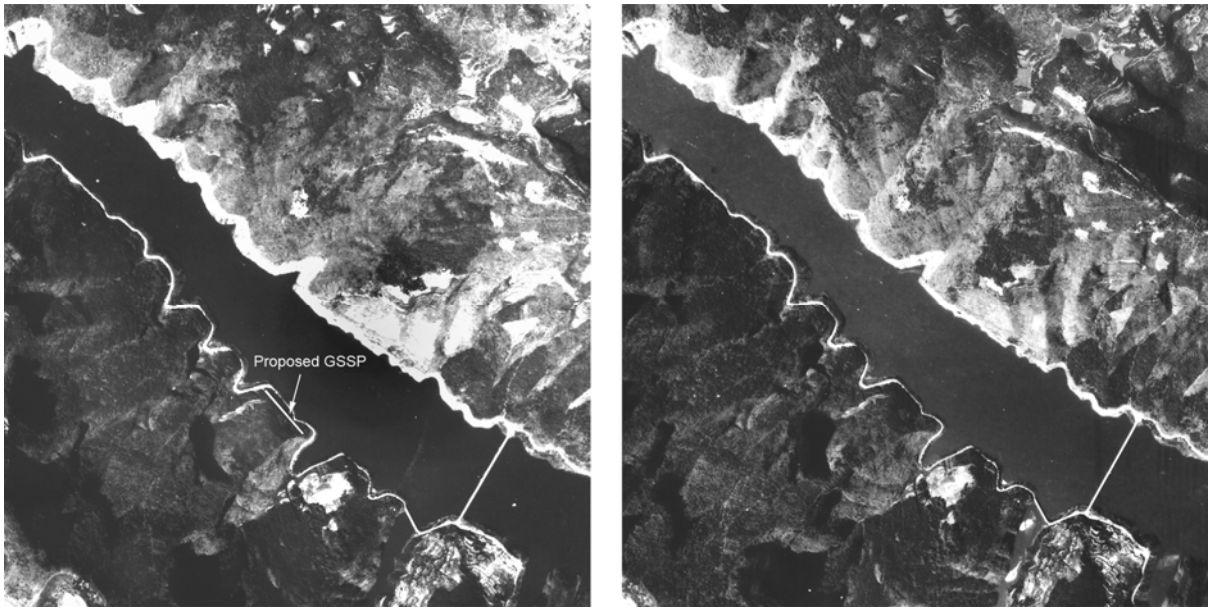

Fig. 5. Stereo-pair of air photographs along the Youshui River (Fengtan Reservoir) showing proposed GSSP of the Guzhangian Stage in the Luoyixi section along the southwestern bank of the river.

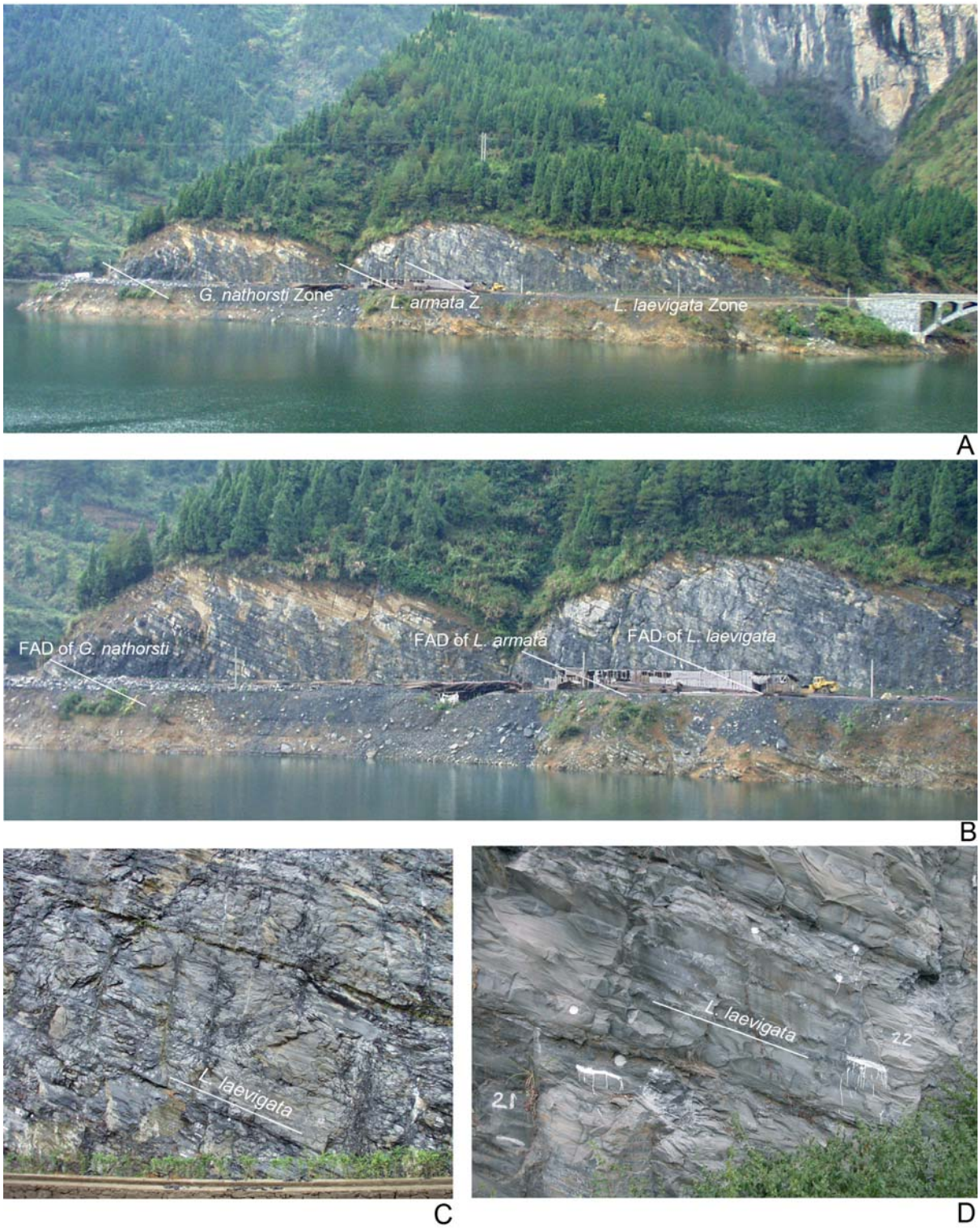

Fig. 6. Exposure of the proposed GSSP for the base of the Guzhangian Stage (coinciding with the FAD of *Lejopyge laevigata*) in the Huaqiao Formation, Luoyixi section, Guzhang County, Hunan Province, China. Strata underlying the proposed GSSP belong to the Drumian Stage. A, Southwestern bank of Youshui 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.

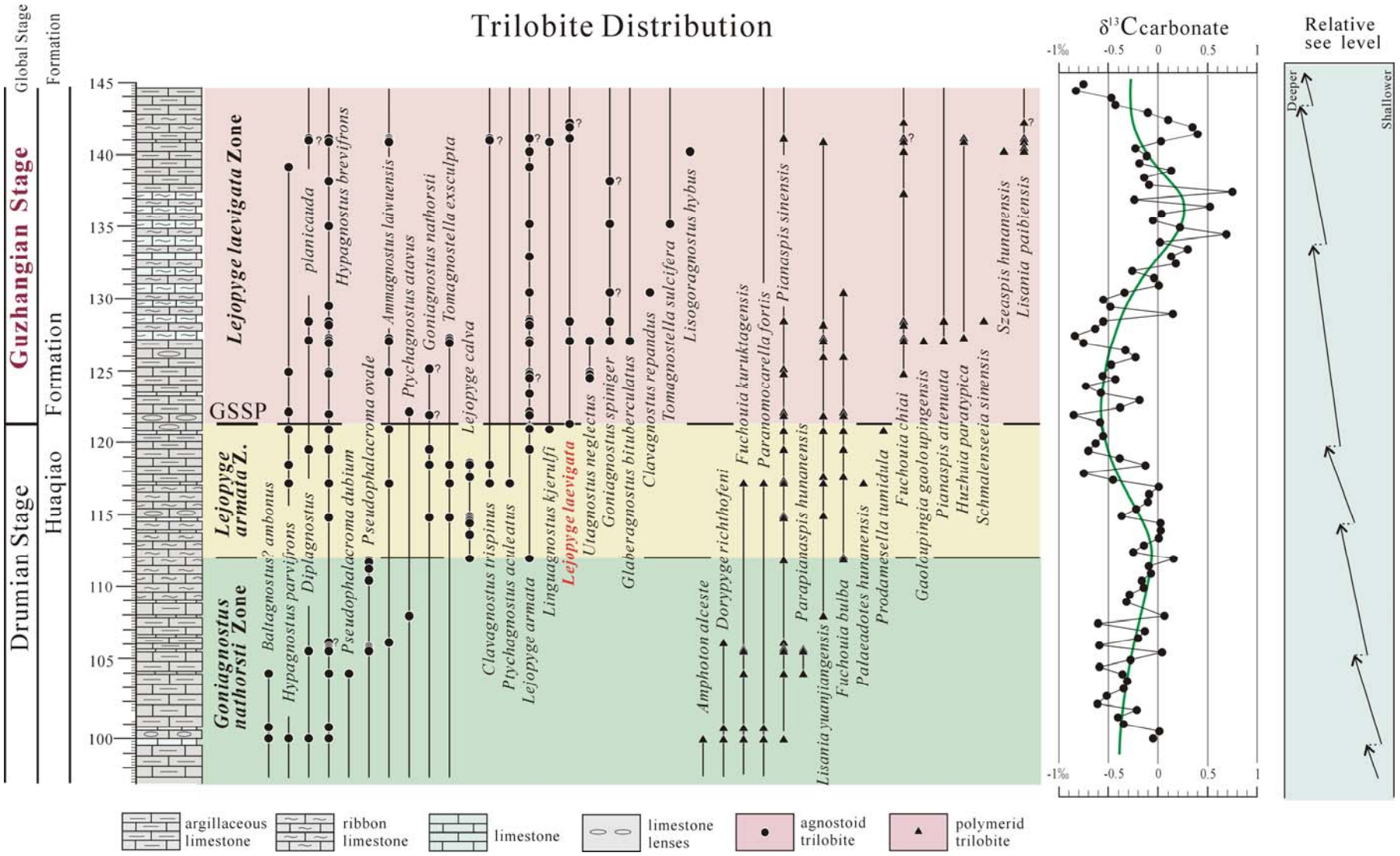

Fig. 7. Observed stratigraphic distribution of trilobites in the Huaqiao Formation near the base of the *Lejopyge laevigata* Zone, Luoyixi section, Guzhang County, Hunan Province, China. The proposed GSSP coincides with the base of the *L. laevigata* Zone in this section. An interpretive sea level history, 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.

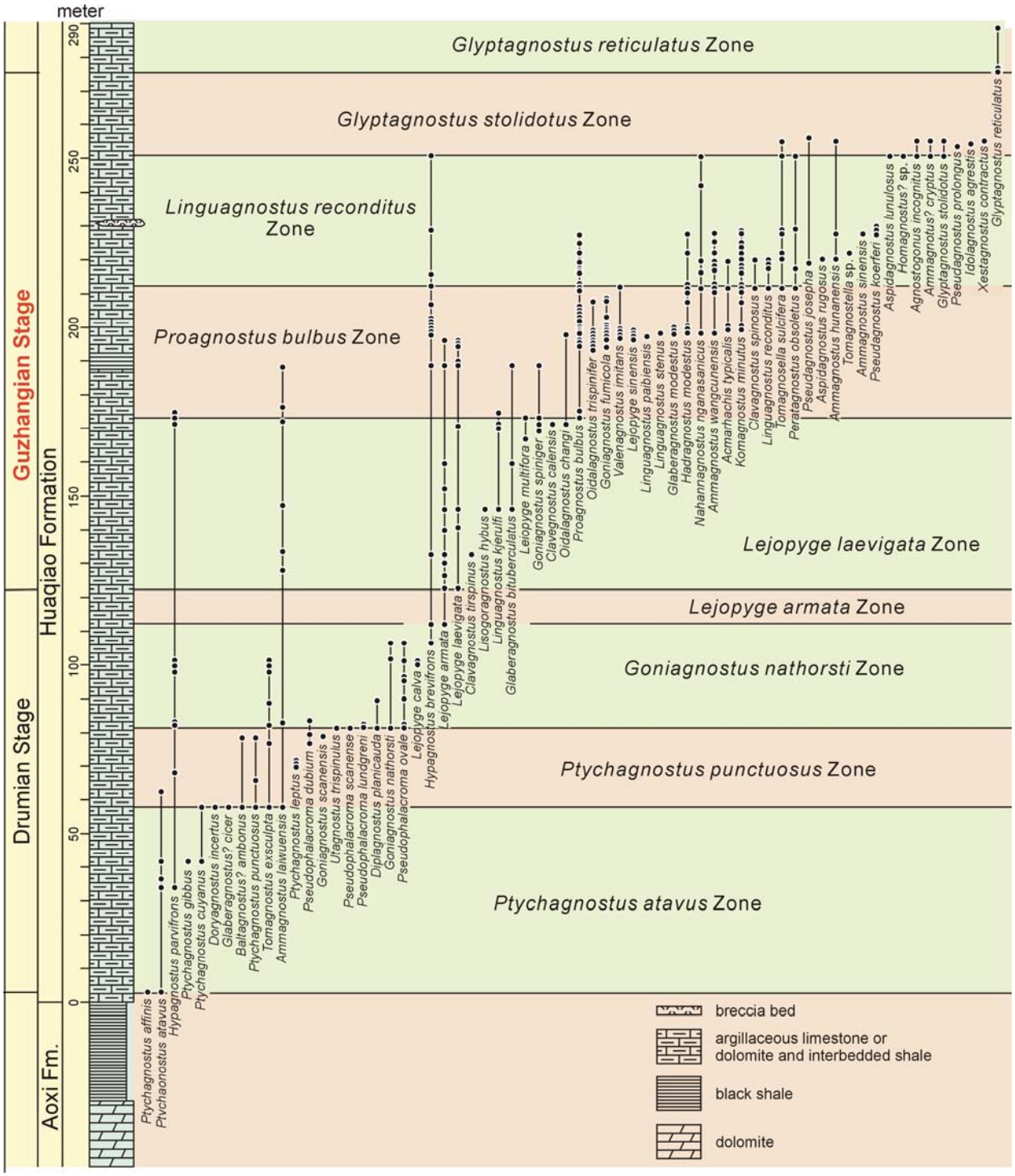

Fig. 8. Observed stratigraphic distribution of agnostoid trilobites in the Huaqiao Formation, Wangcun section on the northeastern bank of the Youshui River, Yongshun County, Hunan Province, China, added for comparison with the Luoyixi section, which is on the southwestern bank of the same river (modified from Peng and Robison, 2000).

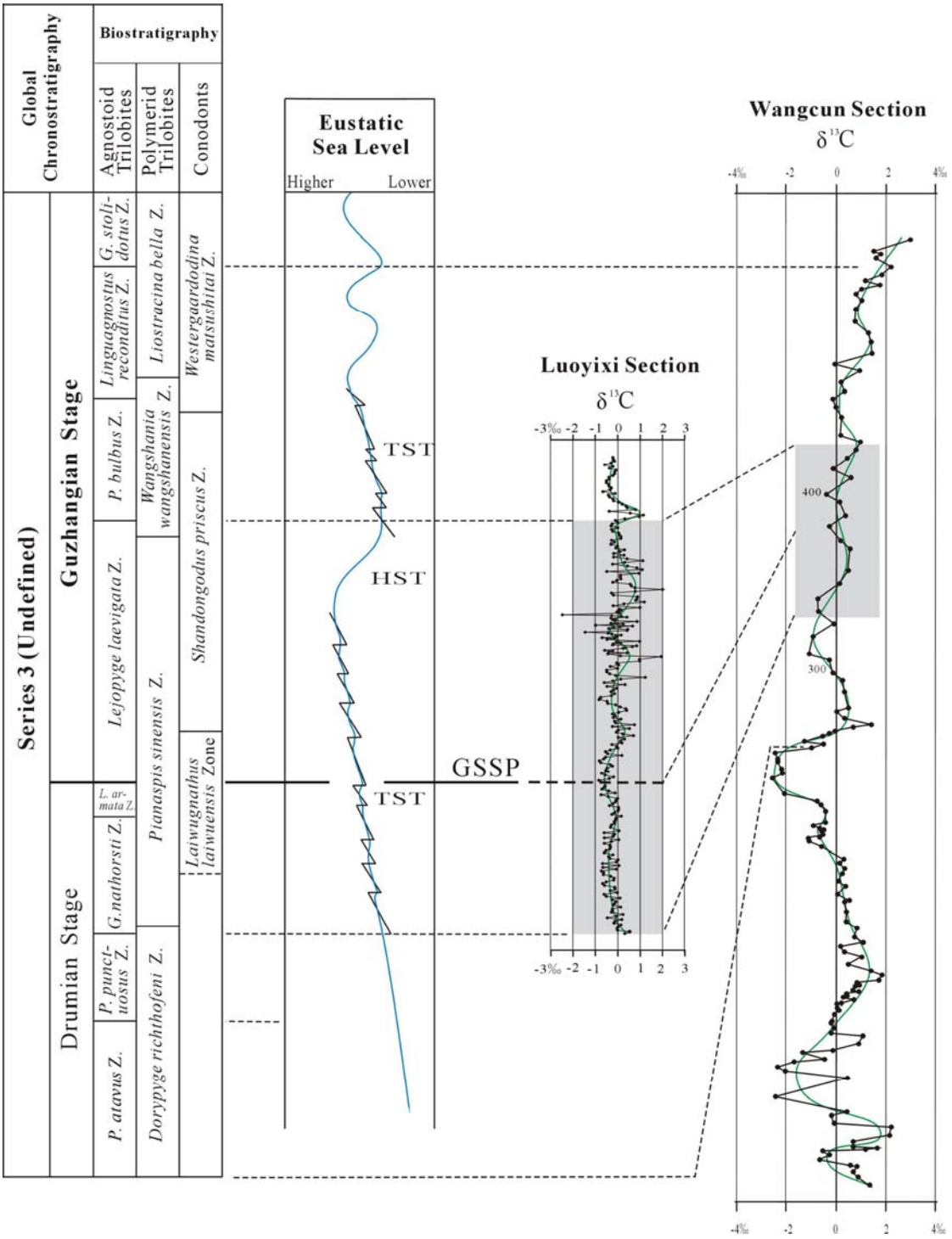

Fig. 9. Summary of primary and secondary stratigraphic indicators for the base of the proposed Guzhangian Stage of the Cambrian System. Major stratigraphic tools used to constrain the GSSP of the proposed stage are the zonation of agnostoid trilobites (Peng and Robison, 2000; Peng et al., in press), the zonation of polymerid trilobites (Peng et al., 2004b; Peng et al., in press), the zonation of conodonts (Peng et al., in press), 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 proposed stratotype.

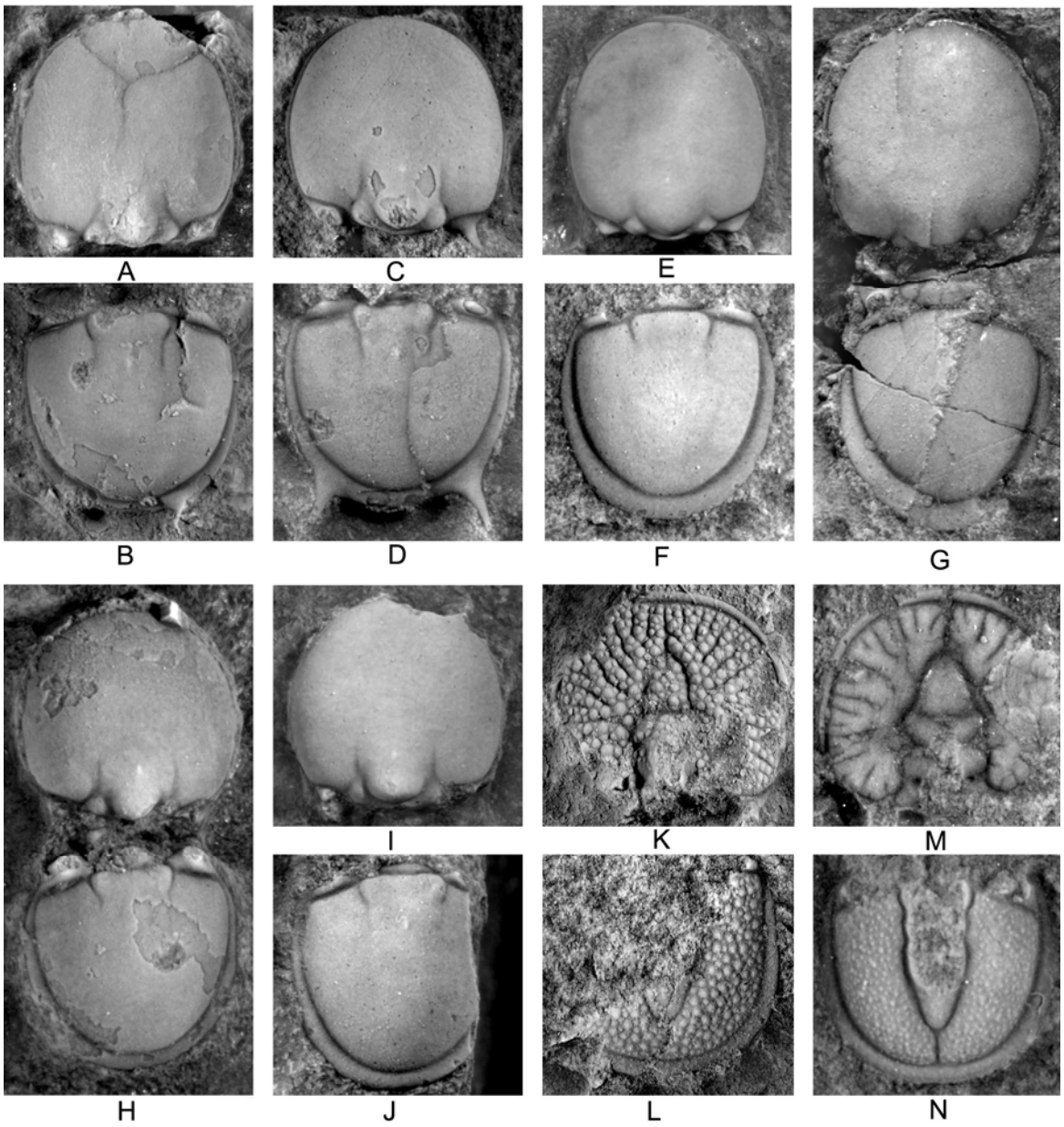

Fig. 10. Key agnostoid trilobite species used for recognition of the base of the proposed Guzhangian Stage. Numbers with the prefix LYX (for Luoyixi section) indicate collecting horizons in meters above the arbitrary 0 m position. All dorsal views. A-D, *Lejopyge armata* (Linnarsson, 1869), a series of primitive and derived forms. A, cephalon, LYX12.50, 111.9 m above the base of Huaqiao Formation, x 6; B, pygidium, LYX21.45, 120.85 m above the base of Huaqiao Formation, x 10; C, cephalon, LYX27.65, 127.05 m above the base of Huaqiao Formation, x 8; D, pygidium, LYX27.65, 27.05 m above the base of Huaqiao Formation, x 8; E-G, *Lejopyge calva* Robison, 1964. E, cephalon, LYX 15.4, 114.8 m above the base of Huaqiao Formation, x 8; F, pygidium, LYX15.15, 114.55 m above the base of Huaqiao Formation, x 10; G, exoskeleton, LYX19.05, 118.45 m above the base of 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 Huaqiao Formation, x 9; I, cephalon, LYX64.40, 163.8 m above the base of Huaqiao Formation, x 10; J, pygidium,. LYX64.40, 163.8 m above the base of Huaqiao Formation, x 10.5; K, L, *Ptychagnostus aculeatus* (Angelin, 1851). K, incomplete cephalon, LYX54.75, 154.15 m above the base of Huaqiao Formation, x 7; L, fragmentary pygidium, LYX17.75, 117.15 m above the base of Huaqiao Formation, x 7; M, N. *Goniagnostus nathorsti* (Brøgger, 1878). M, LYX15.40 (114.8 m above the base of Huaqiao Formation), x 11; N, pygidium, LYX15.40, 114.8 m above the base of Huaqiao Formation, x 15.

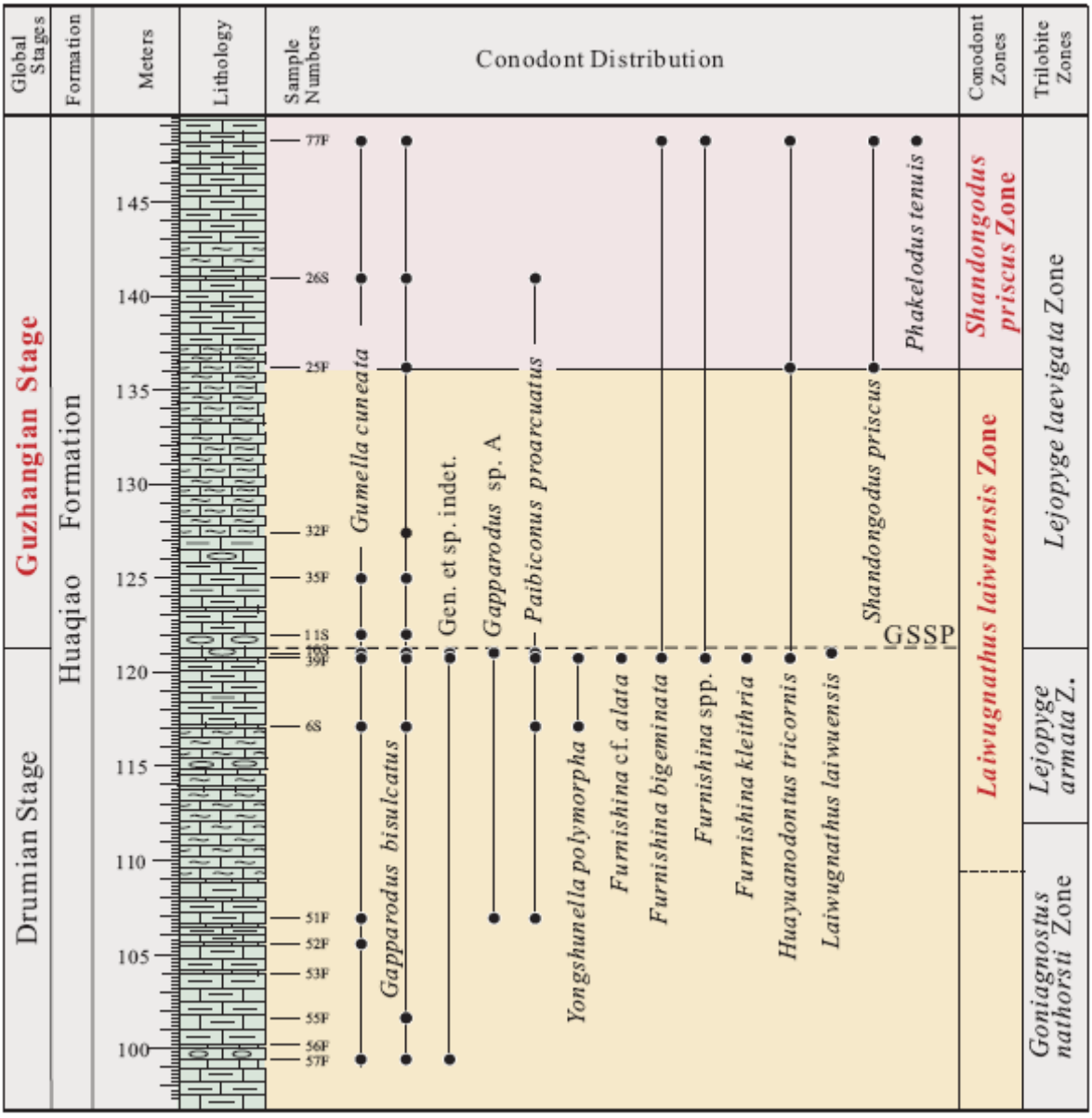

Fig. 11. Observed stratigraphic distribution of conodonts in the Huaqiao Formation near the base of the *Lejopyge laevigata* Zone, Luoyixi section, Guzhang County, Hunan Province, China.

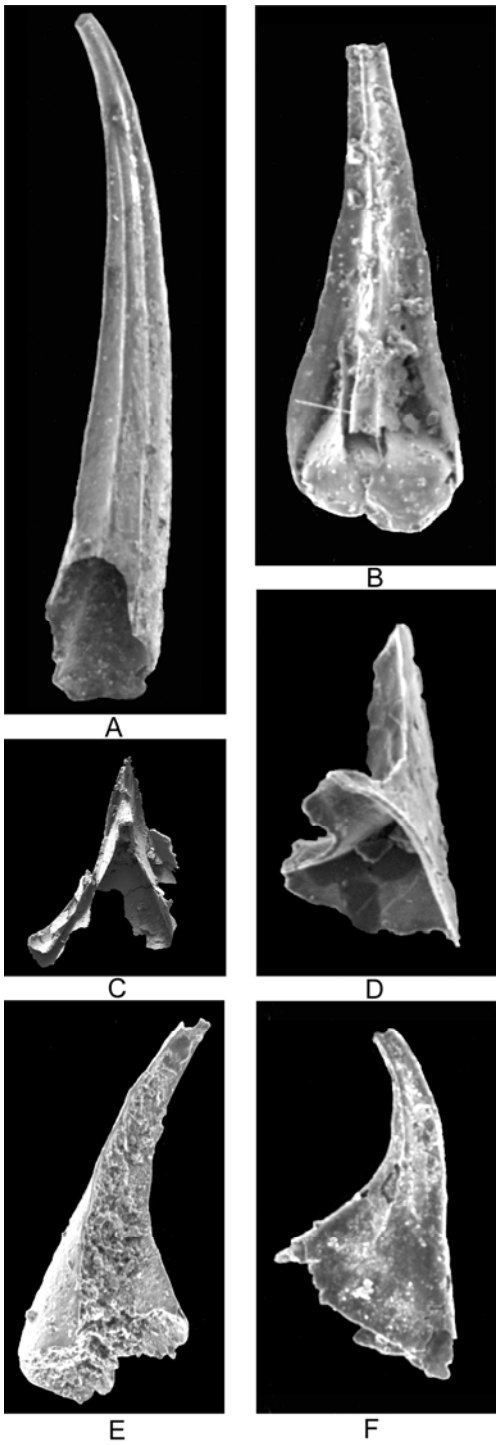

Fig. 12. Conodonts used for recognition of the base of the Guzhangian Stage. A, *Gapparodus bisulcatus* (Müller, 1959): sample 51F, 106.9 m above the base of Huaqiao Formation, posterolateral view, ×53; B, *Laiwugnathus laiwuensis* An, 1982: ample 10S, 121.0 m above the base of Huaqiao Formation, posterior view, ×72; C, *Furnishina kleithria* Müller & Hinz, 1991: Sample 39F, 120.8 m above the base of Huaqiao Formation, posterior view, ×28; D, *Shandongodus priscus* An, 1982: Sample 25F, 136.25 m above the base of Huaqiao Formation, posterolateral view, ×207; E, *Yongshunella polymorpha* Dong & Bergström, 2001: Sample 6S (117.15 m above the base of Huaqiao Formation), lateral view, ×83; F, *Yongshunella polymorpha* Dong & Bergström, 2001: Sample 6S (117.15 m above the base of Huaqiao Formation), lateral view, ×82.