# Global Standard Stratotype-section and Point (GSSP) of the Furongian Series and Paibian Stage (Cambrian)

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The Global Standard Stratotype-section and Point (GSSP) of the Furongian Series (uppermost series of the Cambrian System) and the Paibian Stage (lowermost stage of the Furongian Series), has been recently defined and ratified by the International Union of Geological Sciences (IUGS). The boundary stratotype is 369 metres above the base of the Huaqiao Formation in the Paibi section, northwestern Hunan Province, China. This point coincides with the first appearance of the cosmopolitan agnostoid trilobite *Glyptagnostus reticulatus*, and occurs near the base of a large positive carbon isotopic excursion (SPICE excursion). □ *Cambrian, China, GSSP, Furongian, Paibian, trilobite.*

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Recent International Union of Geological Sciences (IUGS) ratification of the Paibi, China, GSSP (Global Standard Stratotype-section and Point; Cowie 1986; Salvador 1994; Remane *et al.* 1996) for the base of the Paibian Stage and Furongian Series (Peng & Babcock 2003) marks an important step in the process of developing formal, globally applicable chronostratigraphic subdivisions of the Cambrian System. The base of the Cambrian System, and the Palaeozoic Eonothem, at the base of the *Trichophycus* (or *Treptichnus, Phycodes) pedum* Zone in Newfoundland has been ratified (Brasier *et al.* 1994; Landing 1994; Gehling *et al.* 2001), and the base of the overlying Ordovician System at the base of the *Iapetognathus fluctivagus* Zone (Cooper *et al.* 2001) likewise has been ratified. Previously, regional stage- and series-level schemes were available and in widespread use for all major Cambrian continents, but none of the regional schemes has been shown to have global applicability (Geyer & Shergold 2000; Fig. 1). Work currently in progress by the International Subcommission on Cambrian Stratigraphy (ISCS) is aimed at determining the best horizons for international correlation (Geyer & Shergold 2000; Shergold & Geyer 2001), and from this information, internal divisions of the Cambrian System are being developed.

In this paper, we provide a concise description of the stratotype section marking the base of the Paibian Stage and Furongian Series (Figs 2–7), and of the various tools that permit correlation of this boundary worldwide (Figs 5–8). The boundary can be correlated internationally using biostratgraphic, chemostratigraphic, and sequence-stratigraphic information. The Furongian Series differs in content from the upper Cambrian of the most recent versions of the preliminary Cambrian time scale (Geyer *et al.* 2000) and the global standard scale (Cowie & Bassett 1989; Remane *et al.* 2000). Following internationally accepted practice for defining global chronostratigraphic units (Hedberg 1976; Salvador 1994; Remane *et al.* 1996), the choice of a boundary stratotype at the base of the *Glyptagnostus reticulatus* Zone is the best available for defining the lower boundary of an upper Cambrian series (see review in Geyer & Shergold 2000). Although this position differs from most traditional, and regionally applicable, positions of the base of the upper Cambrian (Fig. 1), this position has the important advantage of being identifiable on a

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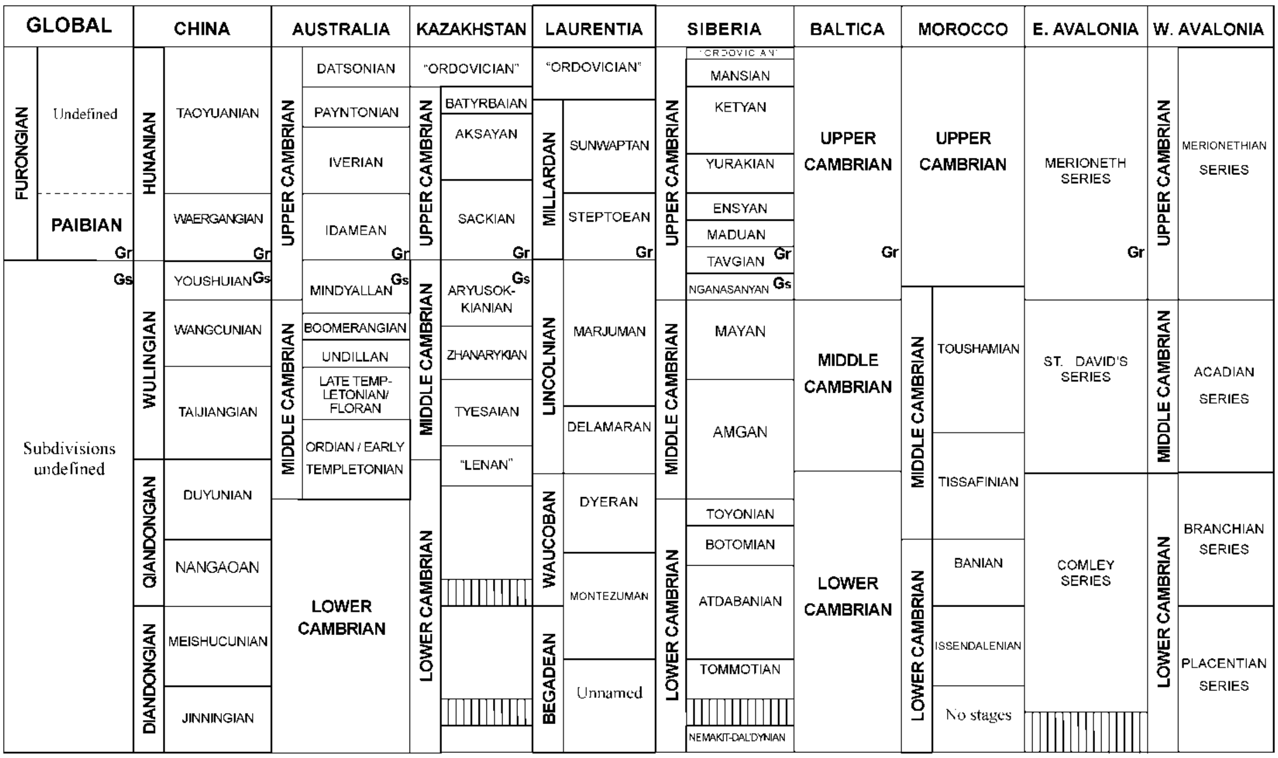


*Fig. 1.* Correlation chart of the Cambrian showing, at left, positions of the new global stage (Paibian) and series (Furongian), compared to usage in major areas of the world. Gr indicates the presence and horizon of the agnostoid trilobite *Glyptagnostus reticulatus* in a region; Gs indicates the presence and horizon of *G. stolidotus* in a region. Chart compiled from numerous sources, many of which are summarized in Geyer & Shergold (2000) and Peng (2000).

global scale, thus overcoming the problem of conflicting regional stratigraphic standards.

## Background

For much of the 19th and 20th Centuries, the Cambrian was subdivided into three parts, but recognition of a thick pre-trilobitic lower Cambrian (Landing 1994, 1998; Landing *et al.* 1998), equivalent to roughly half of Cambrian time (Landing *et al.* 1998) provides a strong incentive to adopt a four-fold division of the Cambrian (Landing 1998; Palmer 1998; Geyer & Shergold 2000), with two series in the lower half, and two series in the upper half, of the system. Geyer and Shergold (2000), in reviewing the current state of knowledge about internal Cambrian divisions, emphasized the need to subdivide the system according to practical, intercontinentally recognizable horizons instead of according to a tripartition carried over from traditional usage. With the addition of a large pre-trilobitic interval to the lower part of the Cambrian, subequal division of the system into three parts could lead to considerable confusion over newer and older Lower, Middle, and Upper Cambrian series, and would likely lack adequate horizons for recognition of stage and series boundaries globally. The Furongian Series, the uppermost series of the Cambrian, is the first of four series planned to replace the differentially applied terms Lower, Middle, and Upper Cambrian (Fig. 1).

At least 11 candidate horizons for global chronostratigraphic correlation are present in the upper half of the Cambrian System (Geyer & Shergold 2000), although not all are equally useful for stage and series boundaries. Assuming that a four-fold division of the Cambrian (Palmer 1998) is ultimately adopted, internal boundaries can be expected to roughly correspond to the first appearance datum (FAD) of trilobites, the FAD of an intercontinentally distributed fossil yet to be agreed upon, and the FAD of the agnostoid trilobite *Glyptagnostus reticulatus* (e.g. Palmer 1998; Geyer & Shergold 2000; Peng & Babcock 2001; Peng *et al.* 2001c). Of the suggested and recommended positions of series boundaries (Shergold & Geyer 2001), the FAD of *G. reticulatus* corresponds to palaeoceanographic and biotic events of considerable global importance (e.g., Geyer & Shergold 2000; Saltzman *et al.* 2000; Peng *et al.* 2001c). This position is one of the most clearly recognizable datum points in the Cambrian; a position closely corresponding to the first appearance of *G. reticulatus* is recognizable in strata of eastern and

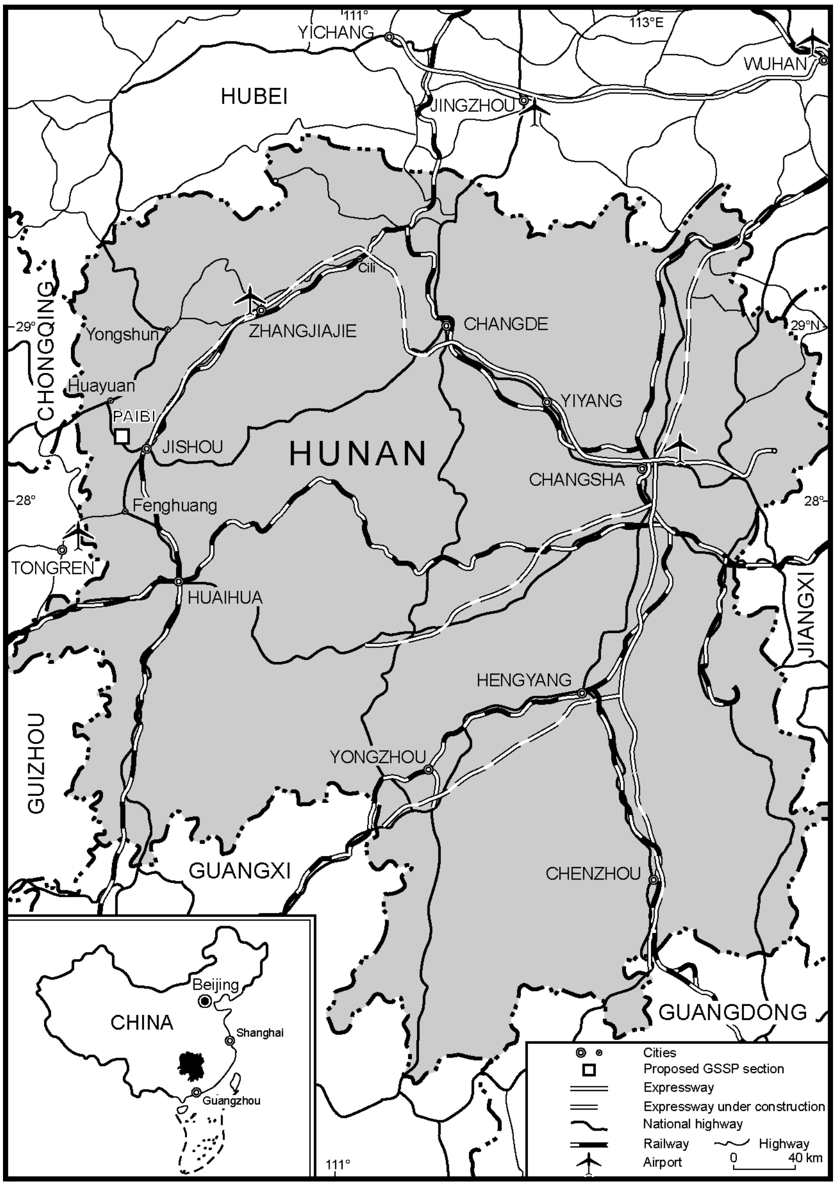


*Fig. 2.* Location map of Hunan Province, China, showing the position of the Paibi section.

western Gondwana, Baltica, Kazakhstan, Siberia, Laurentia, and Avalonia (e.g. Palmer 1962; Geyer & Shergold 2000; Peng & Robison 2000; Peng *et al.* 2001c; Fig. 1), and can be identified with precision using multiple lines of evidence (Figs 5–8).

The Paibian Stage (and Age) is a new name for the lower stage (and age) of the Furongian Series (and Epoch; also a new name). The name Furongian replaces in concept and content the traditional upper Cambrian (e.g. Cowie & Bassett 1989; Geyer & Shergold 2000; Remane *et al.* 1996, 2000), and the various concepts of the upper Cambrian used regionally around the world (see Geyer & Shergold 2000; Fig. 1).

The names Paibian and Furongian are derived from geographic localities in South China, where the base of the *G. reticulatus* Zone is well exposed, and well constrained in stratigraphic position. The name Paibian Stage (and Age) is derived from Paibi, a village near the GSSP site, in Hunan Province, China (Figs 2, 3). The Paibian Stage, proposed for global use, has the same lower boundary as the Waergangian Stage as used in South China (Peng *et al.* 1999b, 2000, 2001c; Geyer *et al.* 2000; Peng 2000, 2001; Peng & Babcock 2001; Fig. 1). The upper boundary of the stage is currently undefined (Fig. 1), and will be defined by the base of the succeeding stage, which has yet to be determined. The name Furongian is derived from Furong, which means *lotus*, referring to Hunan (Fig. 2), the Lotus State. Furong has been used as a nickname for Hunan since about A.D. 800, during the late part of the Tang Dynasty (A.D. 618–907). The Furongian Series is the global equivalent of the Hunanian Series as used in South China (Peng *et al.* 1999b, 2000, 2001c; Geyer *et al.* 2000; Peng 2000, 2001; Peng & Babcock 2001; Fig. 1). The upper boundary of the Furongian Series is the base of the Lower Ordovician Series and the Tremadocian Stage.

## Motivation

Numerous stadial and series schemes for the upper part of the Cambrian have been used regionally (e.g. Westergård 1946; Henningsmoen 1957; Öpik 1966, 1967; Rosova 1968; Robison 1976; Rushton 1978; Ergaliev 1980; Shergold 1982; Ludvigsen & Westrop 1985; Zhang & Jell 1987; Chang 1988; Ahlberg & Ahlgren 1996; Palmer 1998; Peng *et al.* 1999b, 2001c; Geyer & Shergold 2000; Peng & Robison 2000; Peng & Babcock 2001; Fig. 1), but the decision to place the base of a new globally applicable upper Cambrian stage and series boundary at the base of the *Glyptagnostus reticulatus* Zone (Shergold & Geyer 2001) follows the determination that this is one of the most widely recognizable and distinct horizons in the Cambrian System (e.g. Shergold 1982; Geyer & Shergold 2000; Peng *et al.* 2001c).

The agnostoid trilobite *G. reticulatus* (Fig. 8) has one of the broadest distributions of any Cambrian trilobite, and its first appearance has been acknowledged as the most favourable level for a GSSP defining the base of a global Cambrian series (Robison *et al.* 1977; Peng & Robison 2000; Geyer & Shergold 2000; Peng *et al.* 2001c; Shergold & Geyer 2001). 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 & 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 now recognized in the upper half of the Cambrian, indicates that the average duration of an agnostoid-defined biochron is about one million years (Peng & Robison 2000). *G. reticulatus* has been identified (Geyer & Shergold 2000; Peng *et al.* 2001c) from China, Australia, Antarctica, Kazakhstan, Russia, South Korea, Sweden, Denmark, Norway, the United Kingdom, the United States, Canada, and Argentina, and has been used as a zonal guide fossil in South China, Australia, Kazakhstan, Siberia, and Laurentia (Geyer & Shergold 2000; Peng & Robison 2000). Co-occurrences with other

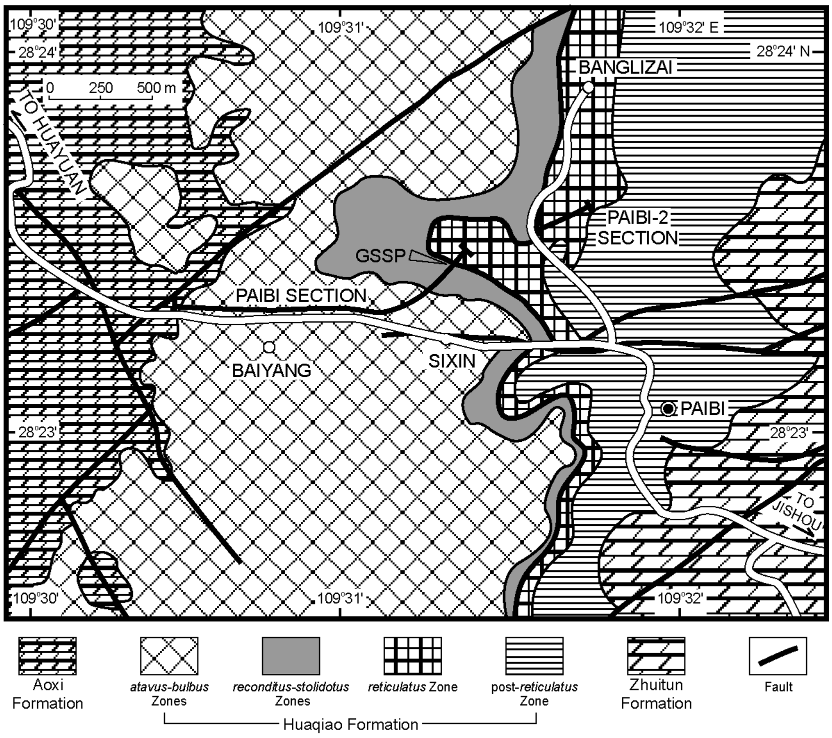


*Fig. 3.* Geological sketch map of part of northwestern Hunan, China, showing the location of the Paibi section and a supplementary section through the Huaqiao Formation (Paibi-2). The position of the basal Paibian and Furongian GSSP is indicated (modified from Peng *et al.* 2001e).

trilobites allow correlation into such regions as Baltica (*Homagnostus obesus* Zone; Ahlberg & Ahlgren 1996; Ahlberg 1998, 2003) and Argentina (lower *Aphelaspis* Zone/lower *G. reticulatus* Zone-equivalent; Shergold *et al.* 1995; Bordonaro, 2003).

Stratigraphically, *G. reticulatus* always succeeds *G. stolidotus* (Peng *et al.* 2001c; Fig. 8), and the ISCS deemed it desirable to select the position of a GSSP in a section showing a complete succession from the *G. stolidotus* Zone through the *G. reticulatus* Zone (Figs 5, 6). Consistent upsection changes in morphology, notably increased reticulation (Fig. 8), and consistent stratigraphic occurrence below *G. reticulatus* (except where inferred hiatuses exist in Baltica and Avalonia), together strongly suggest that *G. stolidotus* was ancestral to *G. reticulatus*. Selection of the FAD of *G. reticulatus* as the base of the uppermost Cambrian series ensures that the boundary will fall within the stratigraphic interval bearing *Glyptagnostus*, and at an arbitrary, but readily identifiable, point in an evolutionary series. Globally, the stratigraphic interval bearing *Glyptagnostus* species is relatively narrow but widely exposed. This allows the boundary to be tightly constrained as long as *Glyptagnostus*-bearing strata are present in a region.

Placement of a GSSP in a slope environment, and particularly a low-latitude Gondwanan slope environment such as the Jiangnan Slope Belt (e.g., Pu & Yi 1991; Peng & Robison 2000; Peng & Babcock 2001), was viewed as desirable because it provides faunal ties (and correlation tools) with low-latitude shelf areas, high-latitude 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 & Taylor 1975, 1976; Babcock 1994) led to the development of rather 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. The combination of cosmopolitan agnostoids, which have intercontinental correlation utility, Gondwanan shelf-dwelling polymerids, pan-tropical polymerids, and widespread polymerids in the Jiangnan Slope Belt (Egorova *et al.* 1963; Peng & Robison 2000; Peng *et al.* 2001a) allows for the precise correlation of the base of the *G. reticulatus* Zone (and other marker horizons) into such Gondwanan shelf areas as the North China Platform (Zhang & Jell 1987), and Australia (Öpik 1963, 1966, 1967; Shergold 1982; Jago & Brown 1992); and into such slope areas as Kazakhstan (Ergaliev 1980, 1990), France (Shergold *et al.* 2000), Iran (Peng *et al.* 1999a), Oman (Fortey 1994), and Victoria Land, Antarctica (Cooper *et al.* 1996). Correlation into high-latitude shelf areas of Baltica (Westergård 1946; Ahlberg & Ahlgren 1996; Ahlberg 2003), and shelf-edge regions of Laurentia (Palmer 1999) and Siberia (Ivshin & Pokrovskaya 1968; Rosova 1968, 1984) is also precise.

# The Paibian Stage and Furongian Series: description of the boundary

## *The section*

*Geographic location.* – The Paibi section (Figs 2–6) is situated in the Wuling Mountains (Wulingshan), Huayuan County, northwestern Hunan Province, China. Its geographic coordinates are latitude 28°23.37′ N, longitude 109°31.54′ E of Greenwich, England. The Paibi section consists of a nearly continuous series of roadcuts, small quarries, and hillside outcrops (Fig. 4A, B) located approximately 35 km west of the city of Jishou along the north side of the Jishou-Huayuan highway (Chinese National Highway 319), and approximately 28 km south of Huayuan (Fig. 2). Beginning just west of the village of Sixin (Sixicun), the section extends approximately 1.7 km to just west of the village of Paibi (Fig. 3). The Paibi section extends from the middle Cambrian through the Lower Ordovician. The stratotype section is represented on the Paibi topographic map (Hunan Branch of State Topographical Surveying Bureau, Map number H49 G 087025, 1:10,000 scale). Strata of the Huaqiao Formation extend from road level through the top of a hill that rises approximately 100 m above road level. The GSSP is at an elevation of approximately 774 metres.

*Geologic location.* – 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. The Paibi section is located along the northwest limb of 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 & Yi 1991; Peng & Robison 2000; Peng & 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

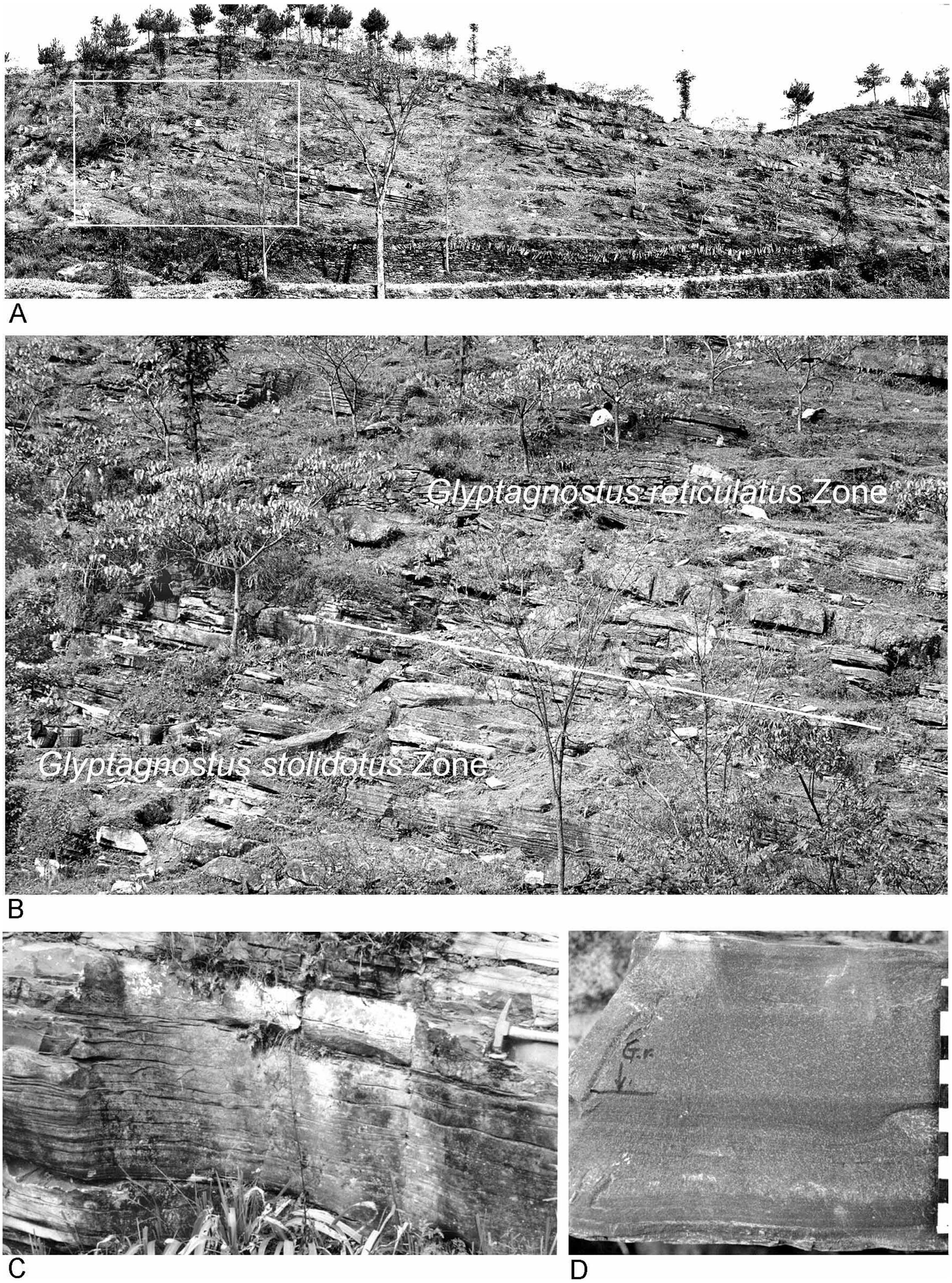


*Fig. 4.* Exposures of the GSSP for the base of the Paibian Stage and Furongian Series (base of the *Glyptagnostus reticulatus* Zone) in the Huaqiao Formation, Paibi section, Hunan, China. □A. General view of the exposure during October 2001, with position of view in B indicated by rectangle. □B. More detailed view of the GSSP. White line marks the FAD of *G. reticulatus*. □C. Close-up view of limestone exposure containing the GSSP (at base of hammer head). □D. Detailed view of calcilutite bed, split perpendicular to bedding, across the base of the *G. reticulatus* Zone, from the GSSP point in the Paibi section. The FAD of *G. reticulatus* is indicated by a line labeled G.r.

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 & Yi 1991; Rees *et al.* 1992; Peng & Robison 2000; Peng & Babcock 2001).

## *Definition and correlation of the boundary*

*Location of level and specific point.* – The base of the first calcilutite layer containing the cosmopolitan agnostoid trilobite *Glyptagnostus reticulatus* in the Huaqiao Formation in the Paibi section (369 m according to the measured section of Peng *et al.* 2001e) has been ratified as the GSSP of the Paibian Stage, and of the Furongian Series (Figs 4–6). The basal Paibian contact occurs in a mostly monofacial succession of dark grey to black, thin-bedded, calcilutite beds. The contact where *Glyptagnostus reticulatus* first appears is subtle, occurring at the base of a layer of dark grey calcilutite overlying a layer of black calcilutite (Fig. 4C, D). Except for containing the lowest occurrence of *G. reticulatus* in the Paibi section, this calcilutite bed is essentially indistinguishable from other beds of similar lithology. The basal Paibian in the Paibi section is observable in a rather prominent cliff face (Fig. 4A, B) in a hillside outcrop along a bedding plane length of more than 200 metres.

Agnostoid trilobite zonation of the Huaqiao Formation in the Paibi section reveals a complete, tectonically undisturbed, marine succession from the *Ptychagnostus* (or *Acidusus*) *atavus* Zone through the upper part of the *G. reticulatus* Zone (Peng & Robison 2000; Figs 5, 6). Formerly, the FAD of *G. reticulatus* was included in the lower part of the Bitiao Formation in northwestern Hunan, but following revision of stratigraphic nomenclature (Peng & Robison 2000), the Huaqiao, Chefu, and Bitiao formations of Hunan Province and adjacent areas of Guizhou Province (Peng & Babcock 2001) have been grouped into a single unit, the Huaqiao Formation. In the Paibi section, the Huaqiao Formation rests in conformable succession above the Aoxi Formation.

The Paibi section lacks evidence of synsedimentary and tectonic disturbances near the GSSP. The Huaqiao Formation at the Paibi section (Rees *et al.* 1992; Peng & Robison 2000; Peng *et al.* 2001c, 2001e) is a mostly monofacial succession of alternating thin-bedded, dark-grey to black argillaceous- and lime-rich calcisiltites and calcilutites. A few thin and laterally discontinuous matrix-supported calcirudites (representing debris flows of shelf-derived intraclasts) are intercalated between calcilutite beds below the boundary, but their bases appear to be non-erosional and flat (compare with the experimental work of Marr *et al.* 2001) over distances of tens of metres. Lenticular and channelized calcirudite beds, some of which display downslope textural transformations, are less common. Thin- to medium-bedded calcarenites containing Bouma divisions, and matrix-rich, clast-supported boulder- to pebble-calcirudites, are sporadically present below the FAD of *G. reticulatus* and are more common above that position. Many calcarenites and calcirudites contain identifiable shelf-derived allochems, as well as resedimented slope deposits. Soft-sediment deformation is rare in the succession, and truncation or slide surfaces are absent, suggesting distal deposition on relatively gentle slopes. Strata enclosing the proposed boundary position, between 361.5 and 376.5 m above the base of the Huaqiao Formation, include five laterally discontinuous calcirudite interbeds ranging from 8 to 66 cm in thickness. None of the calcirudite interbeds occurs at the proposed boundary or disrupts the stratigraphic appearance of taxa in any way. The biostratigraphic succession in the section is unaffected by the interbeds. Trilobite sclerites are common in the fine-grained limestones but are absent from the calcirudites.

*Stratigraphic completeness.* – Detailed bed-by-bed correlation of the middle–upper Cambrian through northwestern Hunan, coupled with detailed biostratigraphy, sedimentology and carbon-isotope chemostratigraphy (e.g. Dong 1990; Rees *et al.* 1992; Fu *et al.* 1999; Peng *et al.* 2000, 2001a,b,c,d,e; Peng & Robison 2000; Saltzman *et al.* 2000; Dong & Bergström 2001a,b; Peng & Babcock 2001), demonstrate the stratigraphic continuity of the basal Paibian in the Paibi section. The GSSP in the Paibi section is placed within a continuous evolutionary sequence of *Glyptagnostus* species (Figs 5, 6, 8). Successive stratigraphic levels show an evolutionary succession beginning with *G. stolidotus* (Fig. 8A, B), and continuing through weakly reticulated (primitive) *G. reticulatus* (commonly formalized as *G. reticulatus angelini*; e.g. Palmer 1962; Ergaliev 1980; Dong 1990; Fig. 8C–E), to strongly reticulated (derived) *G. reticulatus* (commonly formalised as *G. reticulatus reticulatus*; e.g. Henningsmoen 1958; Palmer 1962; Shergold 1982; Rushton 1983; Jago & Brown 1992; Peng 1992; Ahlberg & Ahlgren 1996; Clarkson *et al.* 1998; Fig. 8F–G). Peng & Robison (2000) synonymized the two morphotypes, along with other named morphological variants of the species. Globally, the weakly reticulated morphotype of *G. reticulatus* always precedes the strongly reticulated morphotype of the species in ascending stratigraphic order. The FAD of *G. reticulatus* in the Paibi section, as well as the base of the *G. reticulatus* Zone globally, is taken to be the first appearance of the weakly reticulated morphotype of *G. reticulatus* (Fig. 8C–E). The base of the bed containing

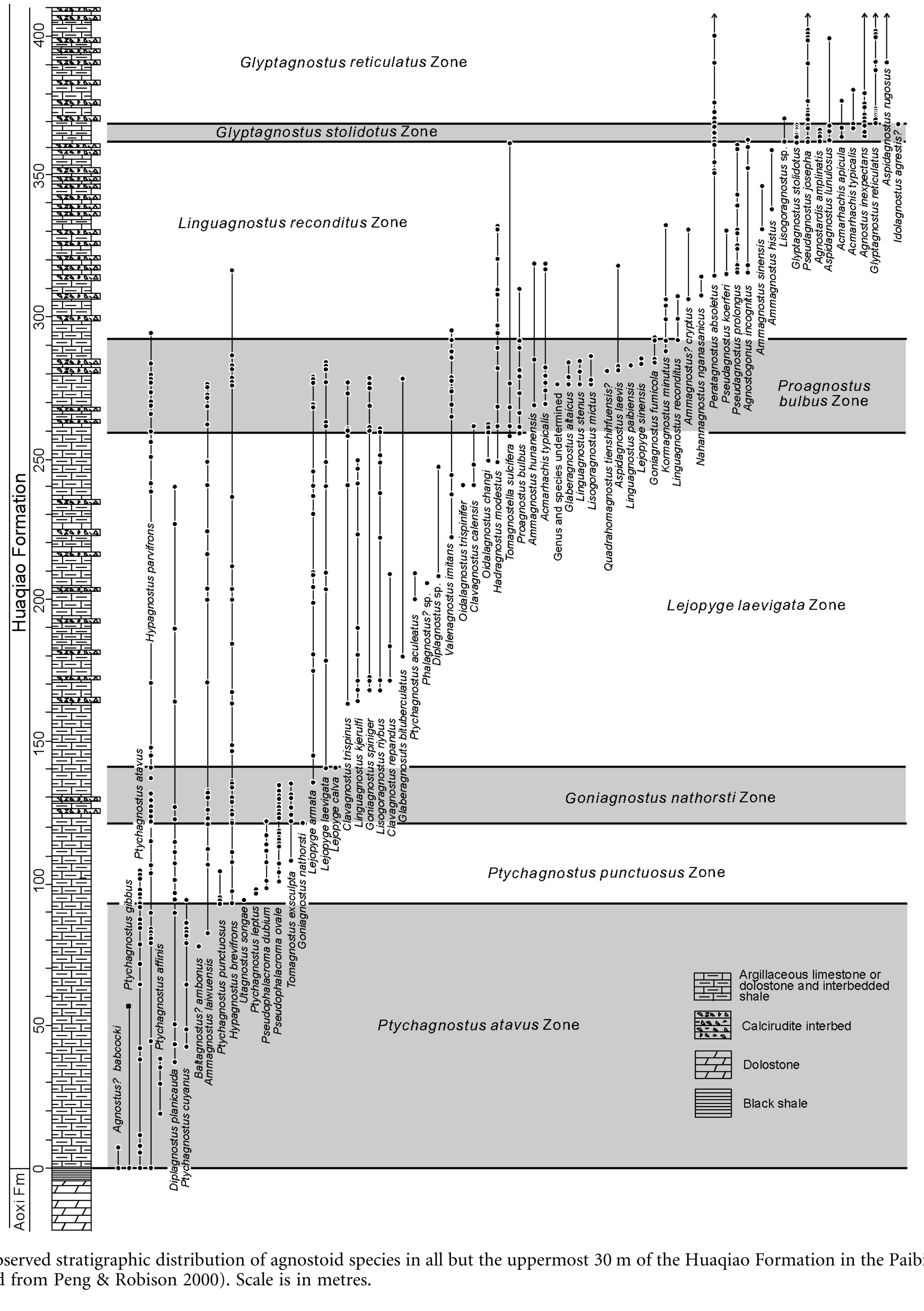


*Fig. 5.* Observed stratigraphic distribution of agnostoid species in all but the uppermost 30 m of the Huaqiao Formation in the Paibi section (modified from Peng & Robison 2000). Scale is in metres.

the FAD of *G. reticulatus* at the Paibi section is isochronous along its exposed length, although lithologically it is essentially indistinguishable from other layers in a succession of thinly bedded, dark-grey to black lime-rich and argillaceous calcilutites (Fig. 4).

Ranges of trilobites across the stratigraphic interval containing the GSSP are summarized in Figures 5 and 6. Besides species of *Glyptagnostus*, a number of other guide fossils, which have utility for correlation on a regional to intercontinental scale, help to constrain the

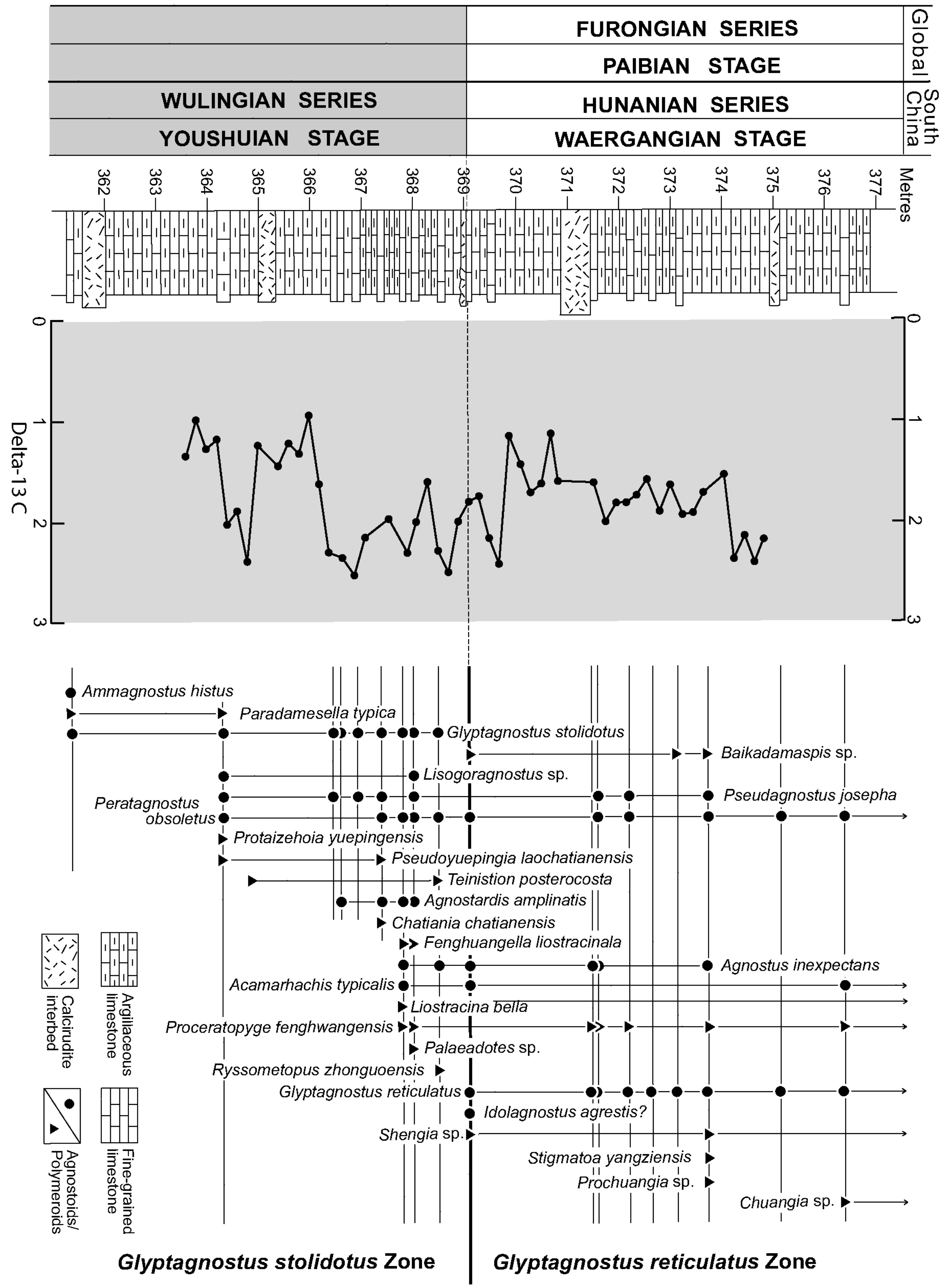


*Fig. 6.* Observed stratigraphic distribution of agnostoid and polymeroid trilobites in the *Glyptagnostus*-bearing interval of the Paibi section, Hunan, China, plus a curve of delta-13C isotopic values through the interval.

boundary position. They include the agnostoid trilobites *Acmarhachis typicalis, Peratagnostus obsoletus*, and *Pseudoagnostus josepha*, all of which first appear in the *G. stolidotus* Zone and range up into (or, in the case of *P. obsoletus*, through) the *G. reticulatus* Zone. Likewise, a polymerid trilobite, *Proceratopyge fengwangensis*, first appears near the top of the *G. stolidotus* Zone, and ranges through the *G. reticulatus* Zone. The widespread agnostoid trilobites *G. stolidotus, Ammagnostus histus*, and *Agnostardis amplinatus* occur in the *G. stolidotus* Zone but none ranges higher than that zone. Polymerid trilobites that occur within the stratigraphic interval containing *Glyptagnostus* in northwestern Hunan, China, but that range no higher than the FAD of *G. reticulatus*, include *Chatiania chatianensis, Fenghuangella liostracinala, Paradamesella typica, Protaizehoia yuepingensis, Pseudoyuepingia laochatianensis*, and *Teinistion posterocosta*. Zonation of conodonts from the Paibi section (Dong & Bergström 2001a) shows that the base of the *Westergaardodina proligula* Zone occurs just slightly below the base of the *G. reticulatus* Zone.

*Regional and global correlation.* – A position at or closely corresponding to the FAD of *Glyptagnostus reticulatus* in the Paibi section is one of the most easily recognizable horizons on a global scale in the Cambrian (e.g. Palmer 1962; Geyer & Shergold 2000; Peng & Robison 2000; Saltzman *et al.* 2000; Peng *et al.* 2001c; Figs 1, 7). Papers discussing the suitability of the FAD of this species for marking a global stage and series boundary have been summarized by Geyer & Shergold (2000). Key correlation tools (Figs 5–7) are biostratigraphy of agnostoid trilobites, polymerid trilobites, and conodonts; chemostratigraphy; and sequence stratigraphy.

The agnostoid trilobite *Glyptagnostus reticulatus* is recognized worldwide (e.g. Kobayashi 1949; Öpik 1966; Rosova 1968; Jago 1974; Robison *et al.* 1977; Shergold 1982 and references therein; Shergold *et al.* 1995; Geyer & Shergold 2000; Figs 1, 7, 8). It has been identified (Geyer & Shergold 2000; Peng *et al.* 2001c) from China (northwestern Hunan, eastern Guizhou, southern Anhui, northwestern Gansu, Xinjiang, western Zhejiang), Australia (western Queensland, Tasmania), Antarctica (Ellsworth Mountains), Kazakhstan (Lesser Karatau), Russia (northwestern Siberian Platform, northeastern Siberian Platform), South Korea, Sweden, Denmark, Norway, the United Kingdom, the United States (Alabama, Alaska, Nevada, Tennessee, Texas), Canada (British Columbia, Northwest Territories), and Argentina. The species is used as a zonal guide fossil in South China (Jiangnan Slope area), Australia, Kazakhstan, Siberia, and Laurentia (Geyer & Shergold 2000; Peng & Robison 2000). Co-occurrences with other trilobites allow correlation into Avalonia (*Homagnostus obesus* Zone; Rushton 1983), and Argentina (lower *Aphelaspis*

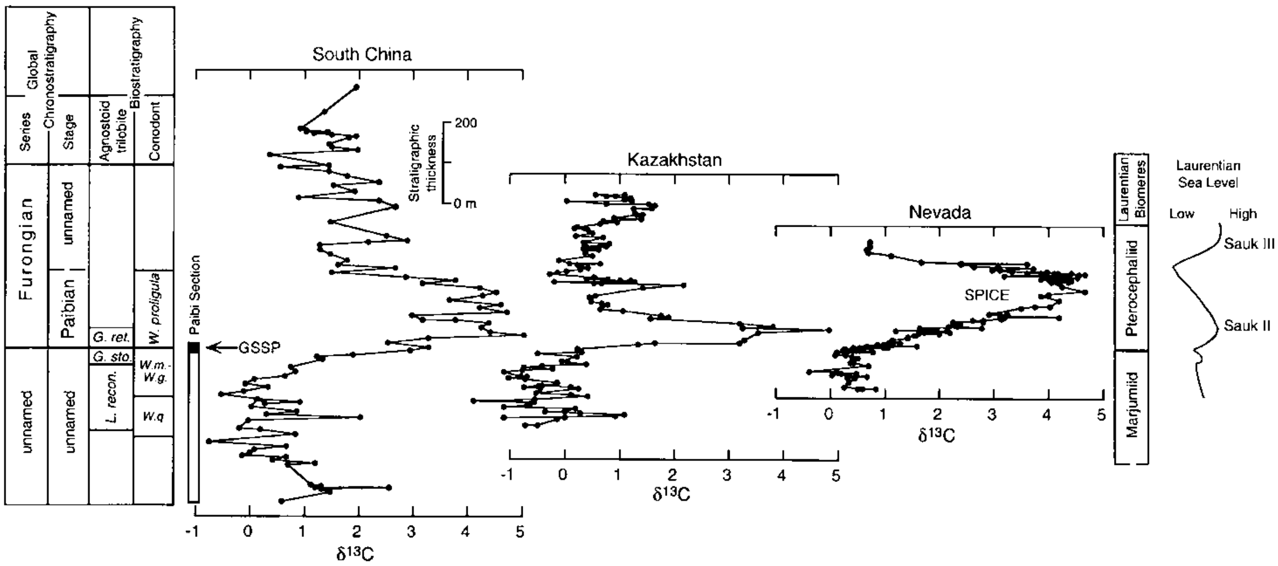


*Fig. 7.* Summary of primary and secondary stratigraphic indicators for the base of the Paibian Stage and Furongian Series. Abbreviations in the biostratigraphic columns are: *L. recon., Linguagnostus reconditus* Zone; *G. sto., Glyptagnostus stolidotus* Zone; *G. ret., Glyptagnostus reticulatus* Zone; W.q., *Westergaardodina quadrata* Zone; *W.m.-W.g., Westergaardodina matsushitai-W. grandidens* Zone; *W. proligula, Westergaardodina proligula* Zone. Agnostoid trilobite zonation from Peng & Robison (2000) and Peng *et al.* (2001c); conodont zonation from Dong & Bergström (2001a). Carbon isotopic data (Saltzman *et al.* 2000) includes a composite isotopic curve for three sections in Hunan Province, China (Paibi, Paibi-2, Wangcun); position of the Paibi section is indicated at the left under South China, and position of the GSSP within the Paibi section is shaded. SPICE stands for Steptoean positive carbon isotope excursion (Saltzman *et al.* 2000). Laurentian biomeres are from Palmer (1981), and relative sea level curve, derived mostly from Laurentia, is from Osleger & Read (1993).

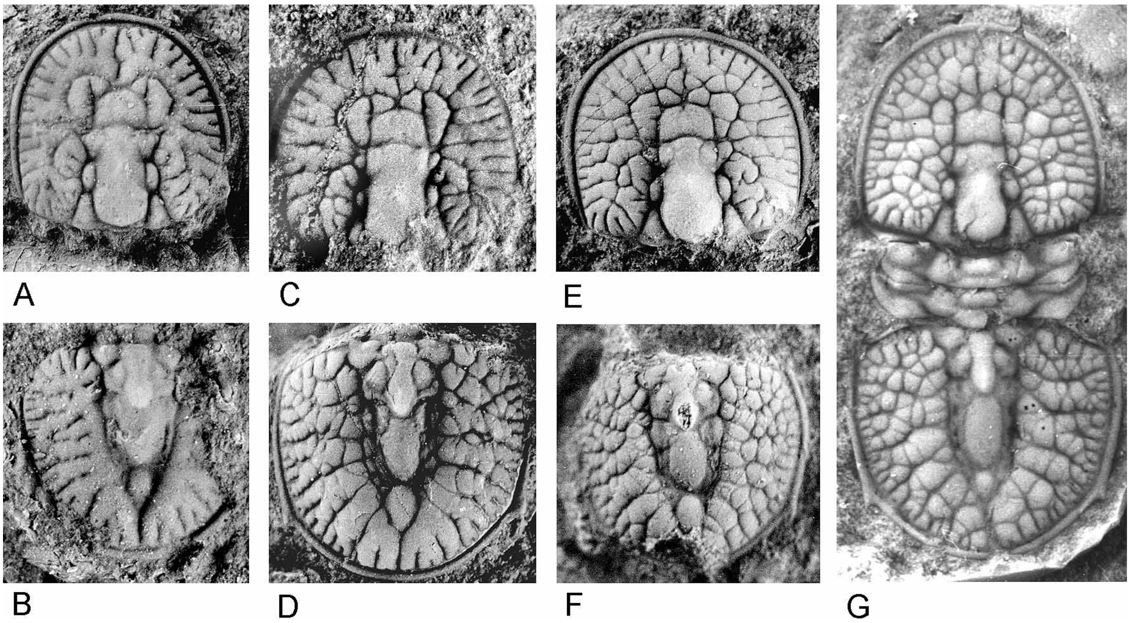


*Fig. 8.* Key species and morphotypes of *Glyptagnostus* used for recognition of the base of the Paibian Stage and Furongian Series. All specimens are from the Paibi section, Hunan, China; position of collections in metres (m) above the base of the Huaqiao Formation are indicated. □A-B. *Glyptagnostus stolidotus*, cephalon (A), ×9, from 364.5 m; pygidium (B), ×10, from 364.5 m. □C–E. *Glyptagnostus reticulatus*, weakly reticulate ('*G. reticulatus angelin*') morphotype; cephalon (C), ×7, from 369.06 m; pygidium (D), ×7, from 371.4 m; cephalon (E), ×8, from 371.4 m. □F-G. *Glyptagnostus reticulatus*, strongly reticulate ('*G. reticulatus reticulatus*') morphotype; pygidium (F), ×7, from 371.4 m; articulated exoskeleton (G), ×7, from 383.5 m.

Zone/lower *G. reticulatus* Zone-equivalent; Shergold *et al.* 1995).

The base of the *G. reticulatus* Zone coincides with turnovers in polymerid trilobite faunas recognized at the base of the Waergangian Stage and the Hunanian Series in South China (Peng *et al.* 1999b, 2001c; Peng & Babcock 2001; Fig. 6), the base of the Changshanian (Paishanian) in North China (Walcott 1913; Öpik 1967; Qian 1994), the base of the Idamean Stage in Australia and Tasmania (Öpik 1960, 1963, 1967; Jago 1974; Shergold 1982; Jago & Brown 1992), the base of the Sackian Stage and base of the Upper Cambrian Series in Kazakhstan (Ergaliev 1990), and the base of the Kugorian (Kutugunian) Stage in Siberia (*sensu* Rosova 1984). The base of the *G. reticulatus* Zone corresponds to the base of the Steptoean Stage and Millardan Series (Palmer 1965, 1998, 1999; Ludvigsen & Westrop 1985) in Laurentia. However, shelf successions lack the appropriate lithofacies for *G. reticulatus*. On the Laurentian shelf, the FAD of the trilobite *Coosella perplexa*, at the base of the *Aphelaspis* Zone, corresponds closely to the base of the *G. reticulatus* Zone. The *Aphelaspis* Zone can be recognized across much of the Laurentian shelf (see Palmer 1999) and in Argentina (Shergold *et al.* 1995). The *G. reticulatus* Zone corresponds to the lower part of the *Homagnostus obesus* Zone (*Olenus gibbosus* Zone) in Scandinavia (Westergård 1946, 1947; Henningsmoen 1957; Ahlberg & Ahlgren 1996; Ahlberg 1998, 2003), eastern Avalonia (central England; Rushton 1983), and western Avalonia (southeastern Newfoundland; Hutchinson 1962).

The base of a conodont biozone, the *Westergaardodina proligula* Zone (Dong & Bergström 2001a), occurs just slightly below the base of the *G. reticulatus* Zone. The intercontinental correlation potential of other biostratigraphic tools, such as brachiopods, near the base of the *G. reticulatus* Zone has not been extensively tested.

The base of the *G. reticulatus* Zone closely corresponds with the onset of a large positive shift in $\delta^{13}C$ values referred to as the Steptoean positive carbon isotope excursion (SPICE excursion; Brasier 1993; Runnegar & Saltzman 1998; Saltzman *et al.* 1998, 2000; Perfetta *et al.* 1999; Saltzman 2001; Fig. 7). The precise base of the SPICE excursion is subjective, as the excursion follows a monotonic positive shift in $\delta^{13}C$ values from values that are indistinguishable from background values. The SPICE excursion reaches peak values of about +4 ‰ $\delta^{13}C$ between the FAD of *G. reticulatus* and the FAD of *Irvingella* (Saltzman *et al.* 2000), at a position roughly corresponding to the interval of peak biotic diversity in the Pterocephaliid Biomere of Laurentia (Rowell & Brady 1976), and to an important sea level fall represented in Laurentia by the Sauk II–Sauk III hiatus (see Palmer 1981; Saltzman *et al.* 2000). The excursion has been documented from sections in South China (Paibi and Wa'ergang), Kazakhstan (Kyrshabakty River section, Lesser Karatau), Australia (Queensland), and the United States (Great Basin). Carbonate environments yielding the SPICE excursion range from slopes where dark, thin-bedded limestones predominate, through shallow platforms where a variety of carbonate lithofacies (boundstones, oolitic grainstones, and fenestral limestones) are present (Saltzman *et al.* 2000). A rise in seawater $^{87}Sr/^{86}Sr$ values, coinciding with the SPICE excursion has been documented from Laurentia (Montañez *et al.* 1996, 2000; Denison *et al.* 1998), and presumably has global expression.

Work in the Jiangnan Slope Belt of Hunan Province, China, shows that the base of the *G. reticulatus* Zone coincides with the initial stages of a transgressive event (Yang & Xu 1997a,b,c). Transgression coinciding with the lower part of the *G. reticulatus* Zone is followed by a highstand phase and then a shallowing that is expressed in South China, North China, and Laurentia (Palmer 1981; Yang & Xu 1997a); the eustatic sea level fall is represented in Laurentia as the Sauk II-Sauk III hiatus (Palmer 1981; Osleger & Read 1993; Fig. 7).

## Conclusion

Adoption of the Furongian Series and Paibian Stage represents an important step toward development of a global chronostratigraphic framework for the Cambrian System. Eventually, it is expected that the Cambrian will be subdivided into four series, each of which should have two or three stages. The ISCS is now working toward defining boundary-stratotypes for other series and stages.

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