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The Most Complete Sequence of Telychian Graptolite Zones in the World

FU Lipu, ZHANG Zifu

Xi'an Institute of Geology and Mineral Resources, Xi'an 710054, Shaanxi
and GENG Liangyu

*Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences,
Nanjing 210008, Jiangsu*

Abstract This paper divides the Telychian into 7 graptolite zones, 12 subzones and 4 chitinoans in the Ziyang region, China. The zones and subzones of England are almost totally suitable for the case of Ziyang in China, though they are 10000 km apart. All the above-mentioned biozones are found only in a unitary continuous section in Ziyang. It has been proved that the Ziyang section is the one with the most complete sequence of Telychian graptolite biozones in the world.

Key words: high-resolution graptolite zone, chitinozoan, Telychian

1 Introduction

As lower Palaeozoic shell-facies faunas and strata are well developed in some regions of the world, palaeontologists have established a series of benthic biozones with great efforts in the development of biostratigraphy. To meet the needs of more widespread and precise international correlation, they have diverted their attention and strengthened the study of pelagic facies biozones, and begun to replace the Cambrian benthic facies trilobite zones by pelagic facies agnostid zones and determined the "golden spikes" of Ordovician stage boundaries by using graptolite zones (Chen and Bergstrom, 1995). A shell-facies section in Llandorery of Britain was selected as the stratotype of the Llandovery Series, but now the study of Llandovery graptolite zones in Britain has been enhanced. It has been found the graptolite zones are much valuable than shell facies zones. When Loydell (1993) made a world-wide correlation of the Telychian stage using graptolites, he said: "the Ziyang section is the most important discovered in China and appears to contain the most complete sequence of Telychian graptolite biozones in the world". Along with launching work for high-resolution stratigraphy all

over the world, Loydell (1992–1993) and Zalasiewicz (1994) divided the previous 6 Telychian graptolite zones into 13 zones and subzones in mid-Wales. Through re-examination of the Ziyang section (Figs. 1, 2 and 3), we have proved that the 13 zones and subzones of England are almost totally suitable for the case of Ziyang in China (Table 1). Seven zones, 12 subzones and their cover zones are introduced as follows.

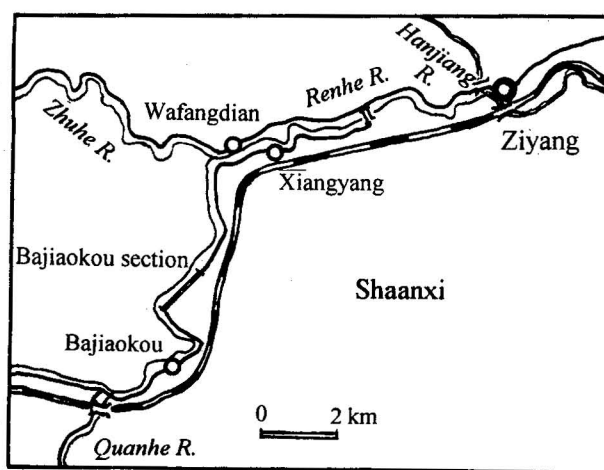


Fig. 1. Location map of the Bajiaokou section along the Renhe River in Ziyang, Shaanxi.

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2 Graptolite Zones

1. *Spirograptus guerichi* Zone

1a. *Paradiversograptus runcinatus* Subzone

This is the lowest subzone within the Telychian. Except abundant *P. runcinatus* and *S. guerichi*, there exist assemblages of *R. linnaei*, *T. planus*, *Petalolithus* sp., *Glyptograptus* sp. and others. 20 m in thickness.

1b. *Monograptus gemmatus* Subzone The first occurrence of *M. gemmatus* is at 69.5 m from the bottom of clastic limestone of this section. Features of the genera and species are not much different from the aforesaid subzone. 20 m in thickness.

1c. *Pristiograptus renoudi* Subzone Basic features of graptolites are close to the aforesaid subzones, but the number and diversity of *Pristiograptus* and *Petalolithus* increase and there appears *P. renoudi* whose proximal portion of rhabdosome is curved dorsal and *P. shurcherti* whose proximal portion of rhabdosome is straight, ca. 20 m in thickness.

2. *Spirograptus turriculatus* Zone

This zone is divided into 4 subzones in Europe and only 3 subzones are distinguished in Ziyang. The lowermost *M. utilis* Subzone in Europe is absent in Ziyang because this part of sandstone is a single unit of strata about 1–1.3 m thick, which was possibly caused by the unfavourable depositional environment for preservation of graptolites.

2a. *Streptograptus johnsonae* Subzone This subzone is characterized by slender fishhook graptolites. The rate of sedimentation was very rapid as deduced from the thick-bedded sandstone and poor bedding of shale. > 60 m in thickness.

2b. *Toquigraptus proteus* Subzone This subzone is defined by the first appearance of this species. ca. 5 m in thickness.

2c. *Torquigraptus carnicus* Subzone This subzone is characterized by the first appearance of this species. *S. turriculatus* and *S. guerichi* both remain up to the present. Only 2–3 m in thickness.

3. *Monograptus crispus* Zone

The assemblage of *M. discus* Tornq. (= *M. veles* Richter) and *M. crispus* is commonly discovered in Europe but is absent in China. ca. 20 m in thickness.

3a. *Monoclimacis galaensis* Subzone *M. cf. galaensis*, *M. crispus* and *S. exiguus* appear first at the bottom of this subzone and *S. turriculatus* does not disappear.

3b. *M. crispus* Subzone *M. crispus*, *S. exiguus* and *S. turriculatus* coexist, while other zonal graptolites have not been seen.

4. *Streptograptus exiguus* Zone

Thousands of fishhook *S. exiguus* occur crowdedly together, being suspected to be fragments of *S. sartorius*. Zalasiewicz (1994, p.377) considered that the *S. sartorius* Zone is the interval between the disappearance of *M. crispus* and the first appearance of the monoclimacid monograptids which characterize the *gresatoniensis* Biozone. The same is true in England and Bornholm of Denmark and such characters are also present in Ziyang of China. Therefore, the *S. exiguus* Acme Zone in Ziyang full corresponds with the *S. sartorius* Zone in Europe.

5. *Monoclimacis griestoniensis* Zone

This zone begins from first appearance of *M. griestoniensis*. *Oktavites contortus* (width of rhabdosome, 1.5–2 mm), *Stomatograptus asiaticus* (5 mm in width) and *T. spiraloïdes* are present in various layers 25 m thick, and the earliest *Cyrtograptus* occurs in the upper part of this zone.

6. *Oktavites spiralis* Zone

It is divided into 4 subzones. ca. 340 m thickness.

6a. *Toquigraptus tullbergi* Subzone Four very important graptolites *O. spiralis*, *T. tullbergi*, *S. grandis* and *M. crenulata* first occur simultaneously at 237.5 m of the Ziyang section and *M. griestoniensis* does not disappear. On the basis of the presence of the *O. spiralis* Zone, previously the *M. crenulata* Zone was treated as an independent zone in England and the precise correlation with other regions has been uncertain for a long time. Boucek (1953) continued to use this name in Bohemia. Storch (1994) thought that *M. crenulata* is uncommon and difficult to determine if not well-preserved and underwent a very long course in Bohemia. So, the name is changed to the *T. tullbergi* Zone which is common and easy to distinguish, even if it is fragments. It is also reported from the same level in Germany (Schauer, 1971) and Denmark (Bjerreskov, 1975). We agree with this point. The first occurrence of *O. spiralis* is in the upper part of the *T.*

tullbergi Zone in Bohemia. The occurrence of *O. spiralis* is much earlier in Ziyang.

6b. *O. spiralis* Subzone This is a partial range zone, which refer to the interval between the disappearance of *T. tullbergi* and the first appearance of *M. geinitzi* and *C. lapworthi*.

6c. *Monoclimacis geinitzi* Subzone As the stratigraphic range of the *O. spiralis* Zone is too long, some people attempt to make a further division. Boucek (1953) divided the *O. spiralis* Zone into 3 subzone and the *S. grandis* Zone containing *C. lapworthi* is above the *M. geinitzi* Subzone. Based on the relative position, such a stratigraphic position of the subzone with the same name in China and Bohemia is roughly equivalent. The same level in Litonia (Baskevicius, 1982) is also named the *M. geinitzi* Subzone.

6d. *Cyrtograptus lapworthi* Subzone This subzone is characterized by the occurrence of *Cyrtograptus* spp., *O. spiralis* and *S. drandis*; and this name is both adopted in Sweden (Waern, 1948) and Denmark (Bjerreskov, 1975). The name is also used for the *S. grandis* Zone in Bohemia.

7. *Cyrtograptus sakmaricus* Zone

The first establishment of this zone is in Nevada by Berry and Murphy (1975). It is broadly distributed over Canada (Lenz, 1982, 1988; Melchin, 1989), North Greenland (Bjerreskov, 1992), East Qinling of China (Fu and Song, 1986), West Qinling (Fu and Song, 1986), Guangdong and Guangxi. In South Ural

of Russia (Koren, 1968), South Tianshan and Uzbekistan. *Cyrtograptus sakmaricus* is discovered quite earlier. This species occurs alone and is not assembled with other zonal graptolites anywhere except in two places in Canada where *C. sakmaricus* can be assembled with *O. spiralis* (Lenz, 1982) but is still regarded as an independent zone.

8. *Cyrtograptus insectus* Zone

This zone was built first by Boucek (1931) in Bohemia and is confirmed to be a basal zone of the Wenlockian (Boucek, 1933). In China and Bohemia, some slender *Streptograptus*, *Monograptus* and subspecies of *M. griestoniensis* are associated with *C. insectus*.

9. *Cyrtograptus centrifugus* Zone

We discovered samples containing flattened and in-relief material at 625 m of the section. The proximal portion of the main stipe in the flattened material is preserved completely and has a helical spiral with up to 2.5 circles. Its 3–4 cladia form a cross-shaped balance state and are similar to Boucek's design (1933, Pl.3, Fig. 2). As the proximal portion of *C. centrifugus* rotates in three-dimensional space, it can form a pyramid as shown in Fig. 7H of Storch (1994) when suffered lateral pressure. The proximal portion of the main stipe in relief under the straight pressure breaks very easily in varying degrees as argillaceous sandstone is opened along bedding. Only 1.3 circles of the proximal portion of the main stipe is preserved, as seen in Fig. 2, Pl. 23 of Fu and Song (1986), and 2

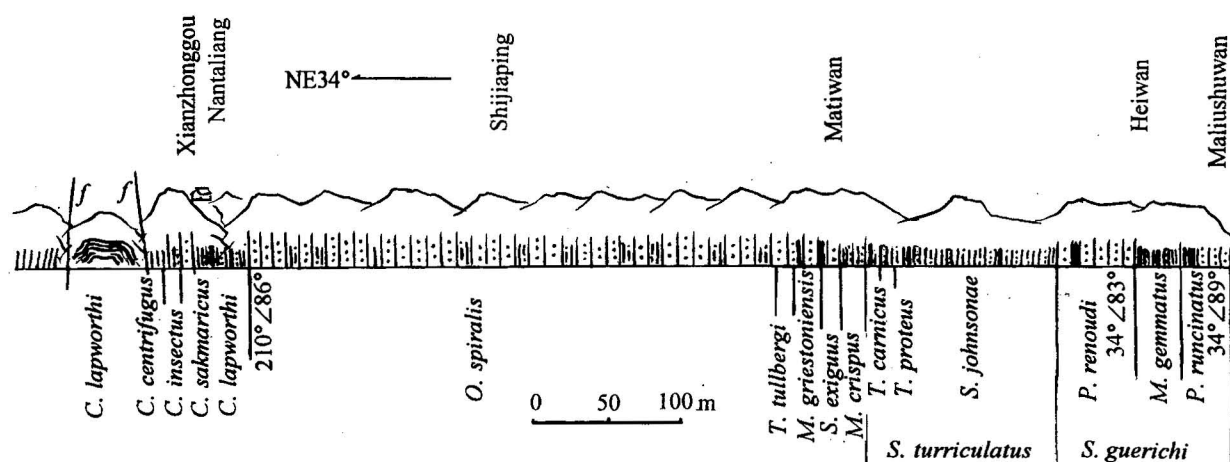


Fig. 2. Bajiaogou section along a highway on the right bank of the Renhe River.

circles in material have been found in this study.

3 Chitinozoans and Their Correlation with Graptolite Zones

At present, many countries are accumulating data. Though their views for correlation are diverse, some data are valuable. Chitinozoans of Ziyang occur just in the graptolite zones; therefore they have higher value for correlation.

Angochitina longicollis first occurs in the *O. spiralis* Zone in Bohemia (Dufka et al., 1995) and in the upper part of the *S. turriculatus* Zone in Estonia (Loydell et

al., 1998). Verniers et al. (1995) put the *A. longicollis* Zone in the upper half part of the Telychian, while the lower half part of the Telychian is the *E. dolioliformis* Zone. We obtained *A. longicollis* from the *O. spiralis* Subzone and *M. geinitzi* Subzone of the *O. spiralis* Zone in the Ziyang section and gained *E. daozenensis* from the *S. johnsonae* Subzone of the lower *S. turriculatus* Zone. Geng Liangyu (1994) consider the *E. daozenensis* Zone to be equal to the Chinese early Telychian *P. drevicollis* Zone which corresponds with the *E. dolioliformis* Zone of Europe. Therefore the *E. daozenensis* Zone in Ziyang corresponds with the *E. dolioliformis* Zone in Europe. We agree with the view

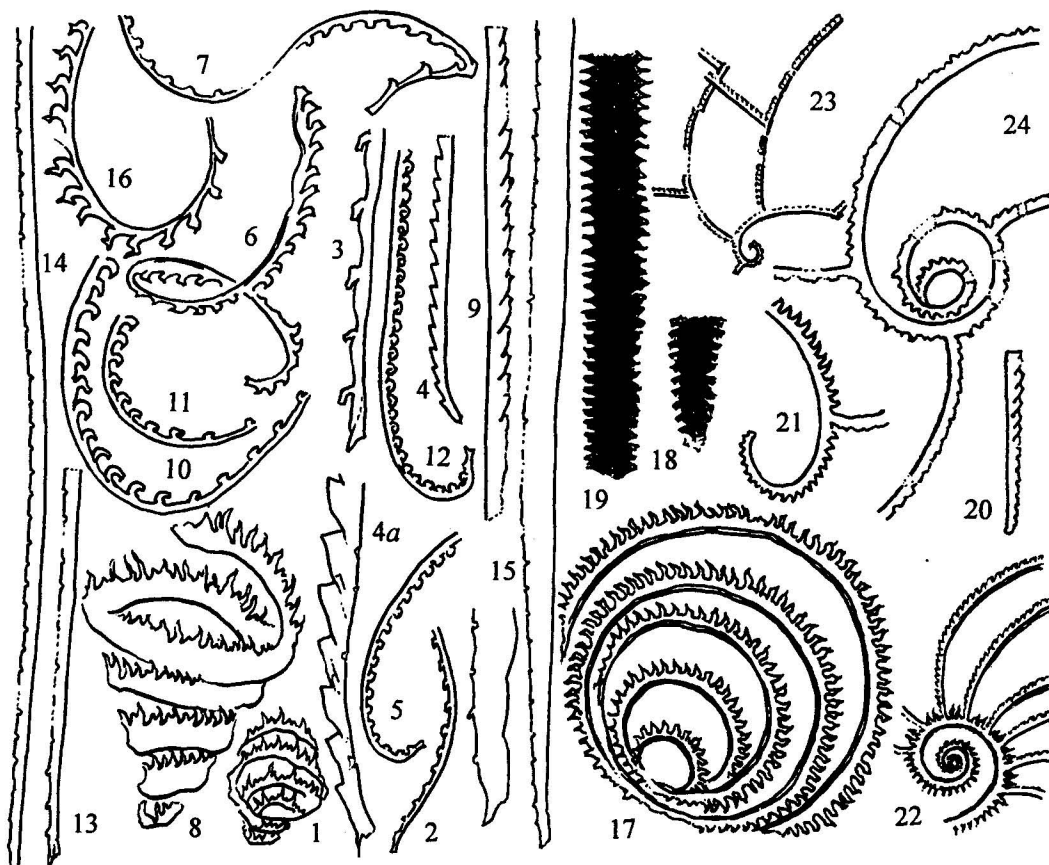


Fig. 3. Telychian and Wenlockian zonal index graptolites of the Bajiaokou section in Ziyang. The samples housed in the Xi'an Institute of Geology and Mineral Resources.

1. *Spirograptus guerich* Loydell, Storch and Melchin, n.66.7×3.2; 2. *Paradiversograptus runcinatus* (Lapworth), n.57×3.2; 3. *Monograptus gemmatus* (Barrande), n.69.5×10; 4. *Pristiograptus renoudi* (Philippot), n.100×3.2, 4a×8; 5. *Streptograptus johnsonae* Loydell, n.121×3.2; 6. *Torquigraptus proteus* (Barrande), n.166.5×3.2; 7. *T. carnicus* (Gordani), n.169.6×3.2; 8. *Spirograptus turriculatus* (Barrande), n.193×3.2; 9. *Monoclimacis* cf. *galaensis* Lapworth, n.173×3.2; 10-11. *Monograptus crispus* Lapworth, n.173, 10×5, n. 192, 11×3.2; 12. *Streptograptus exiguus* (Nicholson), n.193×3.2; 13-14. *Monoclimacis griestoniensis* (Nicol), n.231×3.2; 15. *M. crenulata* (Elles et Wood), n.237.5×3.2; 16. *Torquigraptus tulbergi* (Boucek), n.237.5×3.2; 17. *Oktavites spiralis* (Geinitz), n.237.5×1.6; 18-19. *Stomatograptus grandis* (Suess), n.237.5×1.6; 20. *Monoclimacis geinitzi* Boucek, n.450×1.5; 21. *Cyrtograptus lapworthi* Tullberg, n.550×1; 22. *C. sakmaricus* Koren, n.590×0.5; 23. *C. insectus* Boucek, n.610×0.38; 24. *C. centrifugus* Boucek, n.624×1.6.

M. gemmatus Subzone in the middle part of the *S. guerichi* Zone, on the basis of which Geng Liangyu built the *C. protracta* Zone.

There are different views about the top boundary of *A. longicolis*. As *M. margaritana* first occurs in the *C. insectus* Zone in Bohemia, the *C. insectus* Zone becomes the top boundary of the *A. longicolis* Zone. Geng Liangyu established the *C. pauca* Zone according to *C. pauca* acquired from the *C. lapworthi* Zone in Ziyang.

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About the first author

Fu Lipu Born in 1941; graduated from the Department of Geology, Northwestern University in 1963; now research professor with the Xi'an Institute of Geology and Mineral Resources. His main research interests include graptolites, brachiopods, Silurian and Ordovician and their ecological environments and palaeogeography. Fax: (029)7802701; E-mail: xigmr@pub.xa-onlirn.sn.cn