Late Ordovician to earliest Silurian graptolite and brachiopod biozonation from the Yangtze region, South China, with a global correlation

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Abstract – Late Ordovician to earliest Silurian is an important geological period marked by large geological and biological events. However, the strata and fossils of this interval are not complete in many parts of the world. Based on studies of 43 sites in South China, in particular the continuous sections on the Yangtze platform, we recognize a complete succession including seven graptolite zones and two shelly faunas. In ascending order, the graptolite zones are the *Dicellograptus complanatus*, *Dicellograptus complexus*, *Paraorthograptus pacificus* (including Lower Subzone, *Tangyagraptus typicus* Subzone and *Diceratograptus mirus* Subzone), *Normalograptus extraordinarius–Normalograptus ojsuensis*, *Normalograptus persculptus*, *Akidograptus ascensus* and *Parakidograptus acuminatus* zones. The shelly faunas are the *Foliomena–Nankinolithus* and *Hirnantia* faunas, which may be correlated with *D. complanatus* Zone and *N. extraordinarius–N. ojsuensis* to part of *N. persculptus* zones respectively. The biozonation through this interval from the Yangtze region can be correlated with that of other parts of the world such as Dob’s Linn in Scotland, Spain and Portugal, Thruringia–Saxonia–Bavaria, Bohemia, Poland, Kazakhstan, Kolyma, Malaya Peninsula, Yukon, Canadian Arctic Islands, Nevada, Argentina, Niger and Victoria, Australia. The Hirnantian Substage, which has been proposed by us recently, includes the *N. extraordinarius–N. ojsuensis* Zone, *Hirnantia* fauna and *N. persculptus* Zone. The base of the Hirnantian Substage is marked by the First Appearance Data (FADs) of *N. extraordinarius* and *N. ojsuensis*, which have been determined to be synchronous on a global scale.

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1. Introduction

Latest Ordovician to earliest Silurian strata and fossils, mainly the strata of the Wufeng Formation, Kuanyinchiao Formation, and the lowest Lungmachi Formation, are widely distributed on the Yangtze platform (Fig. 1). Graptolites and brachiopods occur commonly in these rocks throughout the region. Thirty-seven sections from the Yangtze region (Locs 1–4, 6–38 in Fig. 1) have been measured and collected by the authors and other Chinese colleagues in the past 30 years (Mu et al. 1993). One section at Bajiaokou, Ziyang (Loc. 5) was recorded from the South Qinling mobile belt, along the north slope of the Yangtze platform. Five sections (Locs 39–43) are from the Xiangwan basin, the successor of the Zhujiang pre-Ashgill basin. Localities 39 to 41, along the former Jiangnan belt, occur along the slope of the Xiangwan basin. Cathaysian Land experienced uplift beginning in the Ashgill and merged with Dianqian Land (Central Guizhou Land). Moreover, Cathaysian Land became more prominent northwestwards during the late Ashgill. Thus, the Yangtze platform was surrounded by Cathaysian Land, Dianqian Land and the Chengdu uplift, forming a semi-enclosed bay that opened northwards during late Ashgill time (Chen, Xiao & Chen, 1987).

Lee & Chao (1924) and Grabau (1924) were the first to collect and identify the latest Ordovician to earliest Silurian fossils when they erected the Lungma Shale from the Yangtze Gorges. Sun (1931) identified the graptolites collected by Hsieh and Liu from Yuyangguan, Wufeng County, southern Hubei, as Ashgill in age and then named the strata the Wufeng Formation. Sun (1933) subsequently described the Wufeng graptolites. Despite this work, the Ashgill age of the Wufeng Formation was still not commonly accepted by palaeontologists in China. It was Mu (1954), when he re-studied the Wufeng graptolite fauna and correlated the Wufeng Formation with other related strata within South China, who firmly established the age of the formation, which was then used as
a mapping unit. Following upon the acceptance of an Ashgill age for the Wufeng Formation, a related problem, the age of the Hirnantia–Dalmanitina-bearing Kuanyinchiao Formation, arose during the 1960s. This problem was not solved until Rong (1979) placed the Kuanyinchiao Formation with a global correlation of the Hirnantia fauna.

Mu (1954) initially subdivided the Wufeng graptolites into two zones, the Pleurograptus lui Zone in the lower part and the Dicellograptus szechuanensis Zone in the upper. The graptolite biozonation was significantly improved when Mu and co-workers defined five graptolite zones from the Wufeng Formation across the Yangtze region at the 1965 Convention of the Palaeontological Society of China, Nanjing. The five zones were the Pleurograptus lui (W1), Dicellograptus szechuanensis (W2), Tangyagraptus typicus (W3), Dicerocladograptus mirus (W4) and Paraothragraptus uniformis (W5) zones, in ascending order. Unfortunately, this zonation was not published until 1974. Mu (1974) finally published the five Wufeng graptolite zones with an additional one, the Diplograptus bohemicus Zone (W6), at the top of the Wufeng Formation.

The Pleurograptus lui Zone was renamed the Amplexograptus disjunctus yangtzensis/Pleurograptus lui Zone by Mu (1980) and then the Amplexograptus disjunctus yangtzensis Zone by Mu et al. (1993). Chen & Zhang (1995) and Chen et al. (1995) abandoned the Amplexograptus disjunctus yangtzensis Zone since Riva (1987) demonstrated that the zonal fossil was a junior synonym of Amplexograptus latus (Elles & Wood). Chen & Zhang (1995) and Chen et al. (1995)
proposed that the *D. szechuanensis* Zone should be replaced by *Dicellograptus complexus* Zone since the former is obviously a junior synonym of the latter. They also abandoned the *P. uniformis* Zone. They specified two species, *N. bohemicus* (Marek) (based on the Chinese specimens) and *N. extraordinarius* (Sobolevskaya), as zonal index forms. They accepted the *Normalograptus persculptus* Zone, which was until then considered as the lowest Silurian biozone, as the highest Ordovician graptolite zone.

During 1996 to 1998, four reference sections, the Wangjiawan (Loc. 11 of Fig. 1) and Fenxiang (Loc. 12), Yichang County, western Hubei Province, Honghuayuan (Loc. 22), Tongzi County, northern Guizhou Province and Ludiping (Loc. 27), Songtao County, northeastern Guizhou Province, were re-measured and re-collected layer by layer through the Wufeng Formation to the base of the Lungmachi Formation by the present authors. We propose that the *Tanyagraptus typicus* Zone and *Diceratograptus mirus* Zone should be two subzones of the *Paraorthograptus pacificus* Zone. The First Appearance Datum (FAD) of *P. pacificus* (Ruedemann) is lower than that of *Tanyagraptus typicus* Mu but higher than that of *D. complexus* Davies. Thus, the lower part of the *P. pacificus* Zone is temporarily referred to as the Lower Subzone. *P. pacificus* (Ruedemann) is a more appropriate zonal fossil because of its wide palaeogeographic distribution and common occurrence within the interval. The occurrence of *Paraorthograptus uniformis* Mu & Li in the interval with *N. extraordinarius* and *N. ojsuensis* from the Wangjiawan and Fenxiang sections indicates that Mu’s *Paraorthograptus uniformis* Zone should be a part of the *Normalograptus extraordinarius–N. ojsuensis* Zone.

Koren (in Apollonov, Bandalaletov & Nikitin, 1980) has considered that *Normalograptus bohemicus* (Marek) (=*Glyptograptus bohemicus* Marek, 1954) is a subjective junior synonym of *Normalograptus persculptus* s.s. (=*Glyptograptus? persculptus* forma B, Koren, 1980). Storch & Loydell (1996) recently demonstrated that *Normalograptus bohemicus* (Marek) is conspecific with *Normalograptus persculptus* (Elles & Wood) based on their re-study of the type specimens of the former and additional specimens collected from both the Czech Republic and Wales. Thus, the conception of *N. persculptus* (Elles & Wood) has been slightly broadened. We recognize that the form which occurs in the Yangtze region and has been referred to as *N. persculptus* is indeed *N. persculptus* (Elles & Wood) *sensu stricto*. However, Fan (Fan Jun-xuan, unpub. Masters thesis, Nanjing Institute of Geology & Palaeontology, 1998) recently concluded that the species which Mu and his successors (1993) as well as Wang et al. (1987) called ‘*Glyptograptus bohemicus*’ or ‘*Diplograptus bohemicus*’ from below the Kuanyinchiao Formation is conspecific with *Normalograptus ojsuensis* (Koren & Mikhailova) based on his morphometric study of these two forms. Thus, the Chinese pre-*Hirnantia* specimens identified to ‘*Glyptograptus bohemicus*’ or ‘*Diplograptus bohemicus*’ by Chinese authors should be assigned to *Normalograptus ojsuensis* (Koren & Mikhailova) rather than *Normalograptus persculptus* (Elles & Wood). *N. extraordinarius* (Sobolevskaya) now is known to be a widely distributed species not only in Siberia, Kazakhstan, Europe and Australia, but also in the Yangtze region of China. Thus, we prefer to use the *N. extraordinarius–N. ojsuensis* Zone for the interval in China between the *Diceratograptus mirus* Subzone (below) and the *N. persculptus* Zone (above), which was formerly called the *N. bohemicus–N. extraordinarius* Zone in Chen et al. (1995).

Rong (1984a) suggested that the base of Kuanyinchiao Formation (*Hirnantia*-bearing beds) is diachronous across the Yangtze region and may correspond to the base of the *Diceratograptus mirus* Subzone in northeastern Guizhou. The top of the Kuanyinchiao Formation was regarded to be always below the base of the *N. persculptus* Zone. In the Yangtze Gorge area, however, he noted later (in Chen et al. 1995) that the top of *Hirnantia*-bearing beds may reach into the *N. persculptus* Zone. The brachiopod fauna of the strata below the *N. extraordinarius–N. ojsuensis* Zone is a very low diversity fauna characterized by *Manosia*. The *Manosia* assemblage is particularly abundant in the *Diceratograptus mirus* Subzone and extends to the *N. extraordinarius–N. ojsuensis* Zone (see Fig. 2). At the Honghuayuan section (Loc. 22 of Fig. 1), some elements of the *Hirnantia* fauna such as *Eostropheodonta* and *Hindella* may extend into the higher beds, possibly corresponding to *A. ascensus* Zone where the real *Hirnantia* is absent.

2. Biozonation

The Ashgill graptolites of the Yangtze region (Wufeng Formation) are highly diverse. The region was a semi-enclosed platform in this time interval, and lay at a low latitude within the warm water Pacific realm. Consideration of the high individual abundance of graptolites as well as the high species diversity in the Wufeng Formation, in the light of recent palaeoecological models (e.g. Finney & Berry, 1998), leads us to suggest that the Yangtze region may have experienced high and stable organic productivity. Chen & Zhang (1995) have reviewed the Wufeng graptolites described by Mu et al. (1993). They concluded that the Wufeng graptoloid fauna includes about 30 genera and 80 species rather than the 27 genera and 176 species recognized by Mu et al. (1993). However, the diversity of the Wufeng graptolite fauna is still very high and more than half of the late Ashgill fauna are endemic species. In the present study, the Ashgill to earliest Llandovery biozones from the Chientsaokou Formation to the base of the Lungmachi Formation are based mainly on four reference sections: the Wangjiawan, Fenxiang, Honghuayuan and
Ludiping sections. In the present systematic collections from these four sections, only four monospecific genera, Neurograptus, Nymphograptus, Orthoretiograptus and Sinoretiograptus described by Mu et al. (1993) have not yet been re-collected since they are all based on very rare specimens. The ranges of the graptolites and shelly fossil groups, mainly brachiopods, are demonstrated on four range charts (Figs 3–6). We also demonstrate some important forms of the related graptolite fauna in Figure 7 and the shelly fauna in Figure 8. Finally, we list the important species for which we differ significantly in our interpretations from those of Mu et al. (1993) in Table 1. The following abbreviations indicate different biozones: Dc, Dicellograptus complexus Zone; L–Tt, Lower Subzone to Tangyagraptus typicus Subzone of the Paraorthograptus pacificus Zone; Dm, Diceratograptus mirus Subzone of the P. pacificus Zone; Neo, Normalograptus extraordinarius–N. ojsuensis Zone; Np, N. persculptus Zone.

2.a. Foliomena–Nankinolithus Zone

The Foliomena–Nankinolithus Zone is widely recognized from the Chientsaokou Formation and corresponding units (lower Ashgill) on the Yangtze platform. The brachiopods from this horizon belong to the Foliomena fauna and trilobites to the Nankinolithus fauna. The Foliomena fauna was recorded from rocks of Caradoc to mid-Ashgill age in many localities from South China, North China, Avalonia, Baltica, Laurentia, Kazakhstan, Southern Europe, Sibumasu and others (Cocks & Rong, 1988; Rong & Zhan, 1995; Rong, Zhan & Harper, 1999). It has been commonly recovered from the lower Ashgill rocks in South China.

Rong et al. (1994) described a Kassinella–Christiania association in the early Ashgill Foliomena fauna of northern and northeastern Guizhou. A single specimen of Foliomena collected there is associated with Orbiculoidea, Paterula, Glyptorthis, Dedzetina, Leptestiina, Sericoidea, Kassinella, Eoplectodontia and Christiania in the Chientsaokou Formation at Donggongsi, Zunyi, northern Guizhou. In this region the Foliomena fauna is associated with a low diversity trilobite assemblage that includes Nankinolithus. This association has been recovered from the southernmost areas of the Upper Yangtze epicontinental sea, and occurred in relatively near-shore, shallower environments adjacent to Dianqian Land during the early Ashgill. However, the Foliomena fauna from Tangtou and Huangnekeang formations (early Ashgill) of southern Jiangsu, southern Anhui and western Zhejiang, east China, is more diverse, and includes the brachiopods Philhedra, Dedzetina, Kozlowskites, Leptestiina, Christiania, Foliomena, Cyclospira and others (Cocks & Rong, 1988). It is associated with a more diverse trilobite fauna (Lu & Zhou, 1981). In addition to Nankinolithus, there occur Lonchodomas, Ovalocephalus, Shumardia, Corrugagnostus, Nileus, Cyclopyge, Microparia, Dionide, Miaopopsis and 27
Figure 3. Lithological column and the vertical distribution of graptolite and shelly fossils from Wangjiawan, Yichang, western Hubei (Loc. 11).
<table>
<thead>
<tr>
<th>Revised species (present study)</th>
<th>Species described by Mu et al. (1993)</th>
<th>Graptolite zonation (present paper)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Dc</td>
</tr>
<tr>
<td><em>Dicellograptus graciliramosus</em> Yin &amp; Mu</td>
<td><em>D. graciliramosus</em> Yin &amp; Mu</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Leptograptus transformis Chen</td>
<td>+</td>
</tr>
<tr>
<td><em>D. ornatus</em> E.&amp; W.</td>
<td><em>D. ornatus</em> E.&amp; W.</td>
<td>+</td>
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<tr>
<td></td>
<td><em>D. excavatus</em> Mu</td>
<td>+</td>
</tr>
<tr>
<td><em>D. complexus</em> Davies</td>
<td><em>D. szechuanensis</em> Mu</td>
<td>+</td>
</tr>
<tr>
<td><em>D. anceps</em> (Nicholson)</td>
<td><em>D. anceps</em> (Nicholson)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td><em>D. brevis</em> Mu &amp; Chen</td>
<td>+</td>
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<tr>
<td><em>Glyptograptus gracilis</em> (Ge)</td>
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<td>+</td>
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<tr>
<td></td>
<td><em>G. mirus</em> Mu &amp; Lin (pars)</td>
<td>+</td>
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<tr>
<td></td>
<td><em>Diplograptus acutus</em> Lin</td>
<td>+</td>
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<tr>
<td></td>
<td><em>D. carebarus</em> Lin</td>
<td>+</td>
</tr>
<tr>
<td><em>Normalograptus ojuensis</em> (Koren &amp; Mikhailova)</td>
<td><em>Diplograptus bohemicus</em> (Marek)</td>
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<tr>
<td></td>
<td><em>D. vicatus</em> Lin</td>
<td>+</td>
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<tr>
<td></td>
<td><em>D. wanggangensis</em> Mu &amp; Li</td>
<td>+</td>
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<tr>
<td></td>
<td><em>Diplogr. vicatus</em> Lin (pars)</td>
<td>+</td>
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<tr>
<td></td>
<td><em>Glyptogr. sp.</em></td>
<td>+</td>
</tr>
<tr>
<td><em>N. angustus</em> (Perner)</td>
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<tr>
<td></td>
<td><em>C. miserabilis</em> E.&amp; W.</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td><em>C. pygmaeus</em> Ruedemann</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td><em>Climacogr. angustus</em> Ekström</td>
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<tr>
<td></td>
<td><em>C. celsius</em> Ekström</td>
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</tr>
<tr>
<td><em>N.? spicatus</em> (Ge)</td>
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<tr>
<td><em>N. extraordinarius</em> (Sobolevskaya)</td>
<td><em>Diplograptus orientalis</em> Mu et al.</td>
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</tr>
<tr>
<td><em>N.? sp.</em></td>
<td><em>C. raricaudatus</em> Ross &amp; Berry</td>
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</tr>
<tr>
<td></td>
<td><em>C. cornus</em> Ge</td>
<td>+</td>
</tr>
<tr>
<td><em>Amplexograptus latus</em> Elles &amp; Wood</td>
<td><em>A. regularis</em> Mu &amp; Lin</td>
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<tr>
<td></td>
<td><em>A. disjunctus</em> Yangtzensis</td>
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<td></td>
<td><em>A. vicatus</em> Lin (pars)</td>
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<td></td>
<td><em>A. inuus</em> (Cox)</td>
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<tr>
<td></td>
<td><em>A. suni</em> (Mu)</td>
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</tr>
<tr>
<td><em>A. sp. nov.</em></td>
<td><em>A. gansuensis</em> yichangicus</td>
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<td>+</td>
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<td></td>
<td><em>C. pygmaeus</em> Ruedemann</td>
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<td></td>
<td><em>C. tridentatus</em> Lapworth</td>
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<tr>
<td></td>
<td><em>C. acutus</em> Ge</td>
<td>+</td>
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<tr>
<td></td>
<td><em>C. abnormispinus</em> Ge</td>
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<td><em>C. yingpanensis</em> Ge</td>
<td>+</td>
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<tr>
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<td><em>Amplexogr. hubeiensis</em> Mu &amp; Lin</td>
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<td></td>
<td><em>Pseudoclimacogr. yilingensis</em></td>
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<td></td>
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<td><em>C. minor</em> Ge</td>
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<td><em>C. diplacanthus</em> Bulman, Ge (1993)</td>
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<td></td>
<td><em>C. venustus</em> simplex Ge</td>
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other genera represented by a total of 41 species. Although Foliomena, Christiania and Nankinolithus are also present in the Chientsaokou Formation, the trilobites and brachiopods in the Tangtou Formation are more diverse than those in the Chientsaokou Formation. Moreover, only a single specimen of Foliomena and no Cyclospira have been recovered from the latter, whereas these two genera are common in the Tangtou Formation. It should be pointed out that the brachiopods in the Tangtou Formation represent a typical Foliomena fauna inhabiting a relatively deeper water regime (Sheehan, 1973).

Two species of graptolites, Dicellograptus cf. johnstrupi (Hadding) and Rectograptus pauperatus (Elles &
Wood), have been recorded from the Chientsaokou Formation at Jiadanwan, near Donggongsi of Zunyi (Loc. 21 of Fig. 1) (see Zhang et al. 1964). The former was first reported and described by Hadding (1912) from the Zone of *Pleurograptus linearis* of Bornholm, Denmark. The latter was described by Elles & Wood (1907) from the *Dicranograptus clingani* Zone to *Pleurograptus linearis* Zone at Dob’s Linn, Scotland. Mu et al. (1993) have described *R. pauperatus* also from the *Dicellograptus complexus* Zone of the

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**Figure 4.** Lithological column and the vertical distribution of graptolite and shelly fossils from Fenxiang, Yichang, western Hubei (Loc. 12).
Wufeng Formation. However, we have not recognized this species in the Wufeng Formation of the present four reference sections.

At the Honghuayuan and Ludiping sections (Locs 22 and 27 of Figs 1, 5 and 6), we found *Dicellograptus complanatus* Lapworth at the base of the Wufeng Ordovician–Silurian biozonation of Yangtze region, China.
Figure 6. Lithological column and the vertical distribution of graptolite and shelly fossils from Ludiping, Songtao, northeastern Guizhou (Loc. 27).
Formation. This is the first time that *D. complanatus* has been reported from the Yangtze region. The graptolite fauna from these two sections may indicate the upper *D. complanatus* Zone. The fauna consists of 12 genera and 21 species, including several well-known species such as *Amplexograptus latus* (Elles & Wood), *Anticostia fastigata* (Davies) and *Appendispinograptus supernus* (Elles & Wood). Among the members of this assemblage, only the cosmopolitan *Appendispinograptus longispinus* (T.S. Hall), is limited in the *D. complanatus* Zone. All the species of *Dicellograptus*, *Normalograptus*, *Anticostia*, *Rectograptus*, *Orthograptus*, *Amplexograptus*, *Pseudoclimacograptus* and *Pararetograptus*, as well as other *Appendispinograptus* species, extend to the succeeding *Dicellograptus complexus* Zone (Figs 5, 6). At the Ludiping section, the FAD of *D. complexus* Davies is at bed AFA 382, 1.15 m above the LAD (last appearance datum) of *D. complanatus* Lapworth. This lowest Wufeng Formation fauna indicates that the base of the Wufeng Formation at this section lies slightly below the top of the *D. complanatus* Zone. It is, however, the lowest base of the Wufeng Formation within the Yangtze region. At most localities in the Yangtze region, the base of the Wufeng Formation is roughly coincident with the base of the *D. complexus* Zone.

The Chientsaokou Formation, characterized by the shelly *Foliomena–Nankinolithus* fauna with a few graptolites, is early Ashgill in age. The occurrence of the *D. complanatus* fauna at the base of the Wufeng Formation from Honghuayuan and Ludiping is in agreement with the biostratigraphic implications of this underlying fauna and likewise places the base of the Wufeng Formation in the lower Ashgill. The Chientsaokou Formation is characterized by mudstone and shale and is distributed around Dianqian Land. It appears to have been deposited in near-shore, low energy, mudstone facies or a mixed facies environment. The top of the unit also may be diachronous, from within the upper *D. complanatus* Zone (as at Honghuayuan and Ludiping) into the lowermost *D. complexus* Zone (Donggongsi, Zunyi, Loc. 21 of Fig. 1).

2.b. *Dicellograptus complexus* Zone

The *D. complexus* Zone, which is reported from all 43 Wufeng Formation localities, is the most widely distributed of the Ordovician biozones in South China. This biozone not only covers the whole Yangtze platform but also the whole Xiangwan basin as well as the slope belt in between. The base of the zone coincides with the FAD of the eponymous form based on the Honghuayuan and Ludiping sections (Figs 3, 5), where the boundary between the *D. complexus* Zone and the underlying *D. complanatus* Zone is within a continuous graptolite sequence. In the succeeding level to the base of the *D. complexus* Zone, more endemic forms occur, such as *Dicellograptus* sp. aff. *D. complanatus* Lapworth, *D. ornatus* Elles & Wood, *Paraplegmatograptus connectus* Mu, *Rectograptus songtaoensis* Li, *R. uniformis* Mu & Li, *Appendispinograptus fibratus* (Ge) and *Pararetograptus sinensis* Mu. The species *D. sp. aff.* *D. complanatus* Lapworth described by Chen (as *D. cf. complanatus* in Mu et al. 1993) is similar to *D. complanatus* Lapworth in general characters, but the stipes of the former are narrower and more uniform in width. It might be a geographical subspecies of *D. complanatus*. However, *D. sp. aff.* *D. complanatus* ranges into higher strata than *D. complanatus*. In the middle to upper part of the *D. complexus* Zone, *Dicellograptus anceps* (Nicholson), *D. minor* Toghill, *Leptograptus annectans amplexectus* Ruedemann, *Rectograptus abbreviatus* (Elles & Wood) and *Climacograptus? hastatus* (T.S. Hall) occur with two endemic forms, such as *Dicellograptus graciliramosus* Yin & Mu and *Yinograptus disjunctus* (Yin & Mu). Other widely distributed species in this interval include *Leptograptus macer* Elles & Wood, *Dicellograptus complanatus arkanساسensis* Ruedemann, *Amplexograptus latus* (Elles & Wood), *Normalograptus angustus* (Perner), *Rectograptus socialis* (Lapworth), *Appendispinograptus longispinus* hvalross (Ross & Berry), *A. supernus* (Elles & Wood), *A. hubeiensis* (Ge) and *Anticostia fastigata* (Davies). Many of these species continue into this zone from the underlying *D. complanatus* Zone.

The diversity of the *D. complexus* Zone is obviously greater than that of the lower *D. complanatus* Zone. There are 17 genera and a total of 41 species in the *D. complexus* fauna (not the genera *Neurograptus*, *Nymphograptus*, *Orthoretiograptus* and *Sinoretiograptus*, Mu et al. 1993). About half of the species (22 species) are endemic. Ten genera, including *Neurograptus*, *Nymphograptus*, *Orthoretiograptus*, *Sinoretiograptus*, *Yangzigraptus*, *Yinograptus*, *Paraplegmatograptus*, *Arachniograptus*, *Pleurograptus* and *Paraorthograptus*, originate in this zone. This pattern indicates that a burst of speciation in graptoloids, especially in reteograptids and archiretiolitids, began in this time interval. The Ashgill graptoloid radiation took place during the *D. complexus* Zone and *Paraorthograptus pacificus* Zone interval, which was followed by the climax episode of the late Ashgill mass extinction (Chen & Rong, 1991).

2.c. *Paraorthograptus pacificus* Zone

The base of the *P. pacificus* Zone coincides with the FADs of *Paraorthograptus pacificus* (Ruedemann), *P. brevispinus* Mu & Li, *Paraplegmatograptus uniformis* Mu, *Leptograptus planus* Chen and *Dicellograptus tumidus* Chen. The *P. pacificus* Zone may be subdivided into three parts: the Lower Subzone, the *Tangyagruptus typicus* Subzone and the *Diceratograptus mirus* Subzone. The middle and upper parts correspond to the *Tangyagruptus typicus* and...
Figure 7. For legend see facing page.
Diceratograptus mirus zones, respectively, of Mu et al. (1984, 1993).

2.c.1. Lower Subzone

In a similar fauna to that of the D. complexus Zone, 17 genera and 42 species have been recognized from this interval. Among them, 19 species are cosmopolitan or intercontinental. The diversity of the fauna is almost the same as that of the underlying D. complexus Zone, and the fauna consists mostly of the same species as in the D. complexus Zone with the addition of seven new species. In addition to the five species that appear at the base of the zone as mentioned above, two further species, Pararetiograptus parvus Mu and Pseudoreteograptus nanus Mu, originate within the subzone. This subzone and the underlying strata have not yet been restudied from the Wangjiawan section because of poor exposures.

2.c.2. Tangyagraptus typicus Subzone

The base of the subzone is marked by the FADs of Tangyagraptus typicus Mu, T. remotus Mu & Chen, T. flexilis Mu & Chen and T.? grandis Mu & Chen. A remarkable faunal change occurs at this level. It involves not only the occurrence of the Tangyagraptus species but also the appearance of many new species of Dicerograptus, Normalograptus, Paraorthograptus, Paraplegmatograptus, Yinograptus and Sunigraptus. The most important of these additional new species are Dicerograptus mirabilis Mu & Chen, Normalograptus normalis (Lapworth), N. tatiannae (Keller), Paraorthograptus longispinus Mu & Li and Yinograptus dubius Mu. The tangyagraptid species group, characterized by the presence of specialized secondary thecal cladia, is derived from Dicerograptus. The entire stratigraphic range of Tangyagraptus is limited to the T. typicus Subzone. Several new normalograptids, such as N. normalis (Lapworth), first appear within the subzone and become abundant higher up the succession in lower Silurian strata. There are four species of Normalograptus in this subzone, two of which originate near the top of the unit.

The diversity of the T. typicus Subzone reaches a late Ordovician peak with a total of 18 genera and 53 species. Among them, only 23 species are cosmopolitan or intercontinentally distributed. The Manosia inarticulate brachiopod assemblage occurs near the top of the subzone and flourishes in the succeeding Dicerograptus mirus Subzone.

2.c.3. Dicerograptus mirus Subzone

This Subzone occupies only a very thin stratigraphic interval. At the Ludiping section where the Wufeng Formation reaches its greatest thickness (17.53 m), the D. mirus Subzone is only 0.4 m in thickness. The base of D. mirus Subzone is marked by the FAD of Dicerograptus mirus, which is another specialized branch from Dicerograptus. Normalograptids, such as

Figure 8. For legend see facing page.
N. sp. aff. *N. angustus* (Perner) and *N. imperfectus* (Legrand), first appear in this subzone. There are a total of 17 genera and 38 species in this unit with 18 cosmopolitan or intercontinentally distributed species. However, in the shallow water areas such as Honghuayuan and Ludiping, the diversity of late *D. mirus* fauna decreased substantially compared with that of the early *D. mirus* fauna. Despite this overall diversity decline, it is noteworthy that the species diversity of *Normalograptus* increased from four species in *T. typicus* Subzone to five species in the present subzone. If this pattern of diversity change can be taken at face value (the subzone is markedly thinner than neighbouring units, so that some differences in diversity may reflect unequal sampling intervals or sampling opportunities or both), then normalograptids had begun to increase their representation in the latest Ordovician graptolite faunas of this region in the upper parts of the *P. pacificus* Zone, that is, prior to the onset of mass extinction.

### 2.d. *Normalograptus extraordinarius–N. ojsuensis* Zone

The base of *N. extraordinarius–N. ojsuensis* Zone is marked by the FADs of *N. extraordinarius* (Sobolevskaya) and *N. ojsuensis* (Koren & Mikhailova). The appearance of *Paraorthograptus uniformis* Mu & Li suggests that Mu’s *P. uniformis* Zone may correspond to a part of the present zone. *Neodiplograptus shanchon-gensis* (Li) first appears in the same level as *P. uniformis* Mu & Li.

The *N. extraordinarius–N. ojsuensis* Zone fauna contains 11 genera and 31 species in the deeper water facies from Yichang (Locs 10–13 of Fig. 1). Among them, 17 species are cosmopolitan or intercontinentally distributed. The *N. extraordinarius–N. ojsuensis* fauna is dominated by *Normalograptus* species. The nine *Normalograptus* species (seven of which are intercontinentally distributed) present in this interval comprise 29% of the fauna as well as the great preponderance of newly evolved species in the assemblage. In the relatively more shallow water facies such as at the Honghuayuan section near Tongzi, the *N. extraordinar-ius–N. ojsuensis* Zone includes only the two eponymous forms associated with *N. angustus* (Perner), *N. normalis* (Lapworth), as well as a new subspecies of *N. extraordinary* (Sobolevskaya). Thus, normalograptids make up the entire graptolite fauna in the shallower facies of this zone. The episode of mass extinction reached its peak in the deeper area of central Yangtze (Yichang region) within the interval of this zone.

#### 2.e. *Hirnantia* fauna

The well-known *Hirnantia* fauna is a short-lived (Hirnantian), widely distributed, relatively shallow and cool water brachiopod assemblage (Havlíček, 1976; Brenchley, 1984; Sheehan, 1988; Rong & Harper, 1988; Sheehan & Coorough, 1990, 1996; Owen, Harper & Rong, 1991; Brenchley et al. 1994; Brenchley, Carden & Marshall, 1995; Harper & Rong, 1995; Rong, Zhan & Harper, 1999, and others). It is known from the Hirnantian rocks of South China, Sibumus, Tibet, Kazakhstan, Baltic, Avalonia, Southern Europe, Northern Africa, South America, Laurentia and other palaeoplates. It is characterized by the association of typical, distinctive constituents such as *Hirnantia*, *Dalmanella*, *Kinnella*, *Paromalomena*, *Eostropheodonta*, *Plectothyrella* and *Hindella (=Cryptothyrella)*. In addition, *Cliftonia*, *Leptaena (=Leptaenopompa)* and *Fardenia (=Chilidiospis)* are sometimes common. We found the majority of these taxa associated with *Dalmanitina* in the Kuanyinchiao Formation at Ludiping, Songtao, northeastern Guizhou, which represents a near-shore, shallower water and lower diversity manifestation of the *Hirnantia* fauna that is typical in the Yangtze region. However, the *Hirnantia* fauna of the Kuanyinchiao Formation in the Yichang area, western Hubei and Changning, southern Sichuan, comprises...
more taxa and lived in deeper water environmental conditions. In addition to the genera mentioned above, *Philhedra, Acanthocrania, Pseudopholidops* (very abundant), *Toxorthis, Onniella, Draborthis, Dysprosorthis, Mirothris, Triplesia, Aegiromena, Sphenotre, Dorytre* and others are also present, along with *Dalmanitina, Platycoryphe* and *Leonaspis* (Rong, 1984b). The assemblages of Yichang and Changleq are similar to that of the Kosov bed of Bohemia (Marek & Havlíček, 1967).

*Hirnantia sagittifera* at Honghuayuan, Tongzi, northern Guizhou, has been recovered from the lower part of the Kuanyinchiao Formation (*Hirnantia* bed: AFA295–305) (Fig. 5) and is associated with *Dalmanella testudinaria, Kimella* sp., *Cliftonia* sp. nov., *Leptaena trifidum, Paromalomena polonica, Eostropheodonta parvicostellata, Plectothyrella* sp., *Hindella crassa incipiens* and a few others. In the upper part of the unit (shelly bed: AFA306–311c) no *H. sagittifera* specimens have been found, but *Dalmanella testudinaria, Leptaena trifidum, Paromalomena polonica, Eostropheodonta parvicostellata, Plectothyrella* sp. and *Hindella crassa incipiens* extend up to the upper part in which *Eospirifer* sp., *Nalivkinia* sp., *Hyattidina* sp., *Brevilamnulella* sp., *Pseudopholidops* sp., *Palaecoglossa* sp., *Trucizetina* sp. and a few others occur. It is interesting to note that some of the last-named genera also occur from the level of AFA305 (Fig. 5) with *H. sagittifera*. Thus, the brachiopod assemblage in the upper part of the Kuanyinchiao Formation at Honghuayuan is mixed, containing some typical elements of the *Hirnantia* fauna, along with some distinctive taxa, such as *Nalivkinia* and *Eospirifer*, which have not been found in the typical *Hirnantia* fauna. Stratigraphically, the *Hirnantia sagittifera*-bearing beds (AFA295–305) may be correlated with the upper part of the *Normalograptus extraordinarius–N. ojsuensis* Zone and part of the *N. persculptus* Zone, whereas the overlying shelly beds (AFA306–311c) may correspond to part of the *N. persculptus, Akidograptus ascensus* and part of the *Parakidograptus acuminatus* Zone. Therefore, Honghuayuan may be one of the well-exposed sections across the Ordovician–Silurian boundary in a continuous sequence of shelly facies with graptolite controls.

It should be pointed out that the *Hirnantia* fauna (the lower and upper boundaries of the *Hirnantia* beds) are diachronous within the Yangtze region. The timing of the first appearance of the *Hirnantia* fauna differs markedly among the studied sections. At relatively shallow water sites such as Ludiping, Songtao County, northeastern Guizhou, the *Hirnantia* fauna (AFA414–416) occurs immediately above the *Diceratograptus mirus* Subzone (AFA413) (see Fig. 6), indicating that the *Hirnantia* fauna appears at the base of the *N. extraordinarius–N. ojsuensis* Zone. As far as we know, this is one of the earliest occurrences of the *Hirnantia* fauna in South China (Rong et al. 1999).

Based on Mu et al. (1979), Rong (1984a) correlated the base of the Kuanyinchiao Bed at Ganxi, Yanhe County, northeastern Guizhou, with the *Diceratograptus mirus* Subzone (= upper Paraorthograptus pacificus Zone). However, having checked the graptolite lists (see Mu et al. 1979) and their ranges, this conclusion should be further confirmed. There are two horizons (ACC97a, lower and ACC97b, upper) at the top of the Wufeng Formation at Ganxi. ACC97a contains *Dicellograptus ornatus* Elles & Wood, *Yinograptus* sp., *Appendispinograptus venustus* (Hsu), *Rectograptus abbreviatus* (Elles & Wood) and others, and was correlated with *Tangyagraptus typicus* Subzone (= middle *Paraorthograptus pacificus* Zone) (Mu et al. 1979). It is followed in this paper. ACC97b yields *Yinograptus* sp., *Amplexograptus latus* (Elles & Wood) [= *A. sani* (Mu)], *Pararetiograptus* sp., *Paraorthograptus* sp. and others, and was correlated with *Tangyagraptus typicus* Zone by Mu and others (1979) (see Rong, 1984a). However, those taxa in the bed of ACC97b (such as *Yinograptus* and *Amplexograptus latus*) can extend into higher horizons. It is likely, therefore, that the assignment of the ACC97b to the *Diceratograptus mirus* Subzone (= upper *Paraorthograptus pacificus* Zone) cannot be excluded. If this is correct, the Kuanyinchiao Bed at Ganxi may be correlated with the horizon younger than the *Diceratograptus mirus* Subzone (that is, younger than *Paraorthograptus pacificus* Zone). Further investigation on this section is needed.

At Honghuayuan, Tongzi County, north of Dianqian Land, *Hirnantia* and its associates (AFA295–305) appear a little higher stratigraphically than the base of the *N. extraordinarius–N. ojsuensis* Zone (AFA290) (see Fig. 5).

At deeper water sites towards the central part of the Yangtze platform, such as those in the Yichang area (Wangjiawan and Fenxiang) (see Figs 3 and 4), the *Hirnantia* fauna (AFA 100–101, AFA144–145) there the *Hirnantia* fauna developed first and *H. sagittifera* specimens have been found, but *Dalmanella testudinaria, Leptaena trifidum, Paromalomena polonica, Eostropheodonta parvicostellata, Plectothyrella* sp. and *Hindella crassa incipiens* extend up to the upper part in which *Eospirifer* sp., *Nalivkinia* sp., *Hyattidina* sp., *Brevilamnulella* sp., *Pseudopholidops* sp., *Palaecoglossa* sp., *Trucizetina* sp. and a few others occur. It is interesting to note that some of the last-named genera also occur from the level of AFA305 (Fig. 5) with *H. sagittifera*. Thus, the brachiopod assemblage in the upper part of the Kuanyinchiao Formation at Honghuayuan is mixed, containing some typical elements of the *Hirnantia* fauna, along with some distinctive taxa, such as *Nalivkinia* and *Eospirifer*, which have not been found in the typical *Hirnantia* fauna. Stratigraphically, the *Hirnantia sagittifera*-bearing beds (AFA295–305) may be correlated with the upper part of the *Normalograptus extraordinarius–N. ojsuensis* Zone and part of the *N. persculptus* Zone, whereas the overlying shelly beds (AFA306–311c) may correspond to part of the *N. persculptus, Akidograptus ascensus* and part of the *Parakidograptus acuminatus* Zone. Therefore, Honghuayuan may be one of the well-exposed sections across the Ordovician–Silurian boundary in a continuous sequence of shelly facies with graptolite controls.

It should be pointed out that the *Hirnantia* fauna (the lower and upper boundaries of the *Hirnantia* beds) is diachronous within the Yangtze region. The timing of the first appearance of the *Hirnantia* fauna differs markedly among the studied sections. At relatively shallow water sites such as Ludiping, Songtao County, northeastern Guizhou, the *Hirnantia* fauna (AFA414–416) occurs immediately above the *Diceratograptus mirus* Subzone (AFA413) (see Fig. 6), indicating that the *Hirnantia* fauna appears at the base of the *N. extraordinarius–N. ojsuensis* Zone. As far as we know, this is one of the earliest occurrences of the *Hirnantia* fauna in South China (Rong et al. 1999).
2.f. Normalograptus persculptus Zone

The base of the *N. persculptus* Zone is marked by the appearance of *Normalograptus persculptus* (Elles & Wood), *N. avitus* (Davies), *N. wangjiawanensis* (Mu & Lin), *N. torithecatus* (Hsu), *Pseudorthograptus austrofilius* (Chen & Lin), *Glyptograptus laciniatus* Churkin & Carter, *G. lungmaensis* Sun, etc. The *N. persculptus* Zone fauna contains only biserial graptoloids, predominately normalograptids. This fauna includes only 9 genera and 29 species. Thus, the diversity at the generic level continued its dramatic decline. Among the 29 species, 17 are cosmopolitan or intercontinentally distributed. Five of these species, including *Normalograptus extraordinarius* Sobolevskaya, *Paraplagmatograptus bresvinsinus* (Mu & Li), *Climacograptus hastatus* (T. S. Hall), *Amplexograptus sp. aff. A. latus* (Elles & Wood) and *Parapclematograptus sp. (P. connectus group)*, are only supported by one or two specimens. These are all survivors from the *D. mirus* Zone extinction climax event but all expired in the *N. persculptus* episode. This last episode was identified by Chen & Rong (1991) as the epilogue episode. The samples from the *D. mirus* Subzone to *N. persculptus* Zone have been continuously and densely collected through the shallow water to deeper water facies belts in the Yangtze region. It seems unlikely that the disappearances of some taxa are the result of a Signor-Lipps effect.

Mu (1988) correlated the European *Akidograptus ascensus* Zone with the ‘*Glyptograptus persculptus*’ Zone of China. This correlation depends on data from before 1988. Based on the present detailed collections from the four reference sections mentioned above, the *Normalograptus persculptus* Zone and *Akidograptus ascensus* Zone are easily distinguished.

2.g. *Akidograptus ascensus* Zone

The base of the Zone coincides with the FADs of *Akidograptus ascensus* Davies. *Neodiplograptus bicaudatus* Chen & Lin and *Normalograptus lubricus* (Chen & Lin) are also newcomers and occur at a slightly higher level. There are a total of 6 genera and 23 species in this zone. Among them, 13 species occur elsewhere. Thus, more than half of the Lungmachi *A. ascensus* Zone fauna have an intercontinental distribution. The *A. ascensus* Zone is widely distributed through the Yangtze platform. It appears to reach its maximum thickness at Ludiping, where it is 8.22 m thick. At Yichang, in the central part of the Yangtze basin, for instance, it is only 0.18 m thick.

2.h. *Parakidograptus acuminatus* Zone

The base of the *P. acuminatus* Zone is marked by the appearance of *P. acuminatus* (Nicholson), as well as many globally or intercontinentally distributed species such as *Normalograptus praemediae* (Waern), *N. rectangularis* (M’Coy) and *Pseudorthograptus illustris* (Koren & Mikhailova) followed at slightly higher levels by *Hirsutograptus sintizini* (Chaletskaya), etc. The *P. acuminatus* Zone fauna contains a total of 11 genera and 39 species. Among them, 5 genera and 21 species are new. Twenty-two species are cosmopolitan or intercontinentally distributed. Thus, a substantial faunal turnover occurs at this level. Half of the genera present in the *P. acuminatus* Zone are newly evolved in this interval.

3. Correlation

A global correlation of the Ashgill to earliest Llandovery is based mainly on the graptolite sequences as well as the shelly *Hirnantia* fauna. Elements of the *Hirnantia* fauna occur in many sections that we have examined from the Yangtze platform (Locs 2-4, 7-15, 18-24, 26, 28, 29, 35, 37 and 40 of Fig. 1). A complete graptolite sequence without shelly *Hirnantia* fauna has been known from He Xian (Loc. 36 of Fig. 1; Zhang et al. 1966) and Jurong (Loc. 38 of Fig. 1; Chen et al. 1988) in the Lower Yangtze region. The palaeogeographic setting of the Yangtze region (particularly its nature as a semi-enclosed subtropical platform) fostered development of the most diverse and continuously preserved Ashgill graptolite fauna in the world. Despite high levels of endemism, the fauna includes a very good representation of the widely distributed elements that were present during the latest Ordovician. These widely distributed elements of the Wufeng Formation fauna permit global correlation of this unit.

3.a. Dob’s Linn, southern Scotland

The Dob’s Linn section was approved as the Global Stratotype Section and Point (GSSP) of the Ordovician–Silurian boundary (Holland, 1984; Williams, 1988). The Hartfell Shale and Birkhill Shale are the lithostratigraphic units that include the uppermost Ordovician and lowermost Silurian strata. However, continuous graptolitic shale within this interval is present only from the *Dieranograptus cliingani* Zone to lower *Pleurograptus linearis* Zone, and from the upper *Normalograptus persculptus* Zone to higher Llandovery graptolite zones. Between these two continuous graptolitic shales, there are 28 m of mostly pale grey, barren mudstone or shale (Williams, 1982b). Two graptolitic bands bear a *Dicellograptus complanatus* fauna in the *D. complanatus* Zone (Williams, 1982b). Five graptolitic bands comprise the *D. anceps* Zone including Bands A and B in the *D. complexus* Subzone, and Bands C to E in the *P. pacificus* Subzone.

Toghill (1970) described the graptolites from the *complanatus* Band, including *D. complanatus* Lapworth, *Rectograptus socialis* (Lapworth) and
Normalograptus miserabilis (Elles & Wood). These species are also present at the Ludiping section, Songtao, northeastern Guizhou. Toghill also recorded rare examples of Plegmatograptus nebula Elles & Wood from the complanatus Band. However, it has not yet been found from the D. complanatus Zone of the Yangtze region. P. nebula Elles & Wood occurs mainly within the D. clingani and P. linearis zones (Williams, 1982a). Plegmatograptus became extinct by the middle Ashgill (D. complexus Zone) where it was replaced by its descendent Paraplegramatograptus.

The Bands A and B contain a D. complexus–D. anceps fauna with a total of 9 genera and 12 species. All of them occur in the D. complexus Zone of the Yangtze region as well, except Normalograptus normalis Lapworth. N. normalis Lapworth appears a bit higher in the Yangtze region (in the Diceratograptus mirus Subzone), and is most abundant in the Paradiagramatograptus acuminatus Zone. Williams (1982b) proposed Dicellograptus anceps (Nicholson), which occurs in both bands A and B, as the zonal species for this interval. Based on the continuous sections from the Yangtze region, D. anceps occurs from the middle D. complexus Zone into the lower part of Tangyagraptus typicus Subzone. Thus, the presence of D. anceps and absence of P. pacificus (Ruedemann) from Bands A and B at Dob’s Linn indicate that these two bands may correlate to an interval above the mid-D. complexus Zone in the Yangtze region. The occurrence of D. anceps is later than that of D. complexus in the Yangtze region. This implies that the base of the ‘D. complexus Subzone’ at Dob’s Linn may not be higher than that of D. anceps as suggested by Williams (1982b, fig. 2; see Fig. 9 herein). Dicellograptus anceps may extend into the N. extraordinarius Zone based on its occurrence in the Dob’s Linn section.

Williams (1982b) reported the species Plegmatograptus? craticulus Williams and Orthoretiograptus denticulatus Mu (this species was first cited by Wang et al. (1977) from Mu et al.’s manuscript) from the D. anceps Zone at Dob’s Linn. Based on his illustrated specimens, P.? craticulus Williams may be a junior synonym of Paraplegramatograptus uniformis Mu, which was first cited by Wang et al. (1977) from Mu et al.’s manuscript. Orthoretiograptus denticulatus specimens illustrated by Williams (1982b, p. 43, pl. 4, figs 13–15, text-figs 12a–d) may not be Orthoretiograptus, but rather Pararetiograptus sinensis Mu 1974. These two species are well-known components of the D. complexus and P. pacificus zone faunas in the Yangtze region.

The Bands C and D from the Dob’s Linn section contain a P. pacificus fauna that Williams (1982b) referred to as the P. pacificus Subzone of his D. anceps Zone (Fig. 9). Twelve genera and 16 species have been recorded from these two bands. However, except for Paraorthograptus pacificus (Ruedemann), Plegmatograptus? nebula lautus Koren & Tzaj and Nymphograptus velatus Elles & Wood, most of them continue from the lower bands. P. nebula lautus Koren & Tzaj was described based on incomplete specimens without proximal ends. Thus, we are not sure whether it is a plegmatograptid. Nymphograptus velatus Elles & Wood (D. anceps Zone) is the only species which has not yet been recorded in the Yangtze region within this interval. Thus, the whole fauna is comparable with that of the P. pacificus Zone fauna from the Yangtze region.

The specimens described by Williams (1982b) as Dicellograptus ornatus Elles & Wood from Band E differ somewhat from one another and do not agree exactly with the form of D. ornatus sensu stricto. His specimens illustrated in plate 1, figure 6 and text-fig. 6f, 6g represent Dicellograptus mirabilis Mu & Chen, which occurs in the Tangyagraptus typicus Subzone and Diceratograptus mirus Subzone in the Yangtze region. Williams’ (1982b) specimen illustrated in plate 1, figure 8 is a specimen of Dicellograptus turgidus Mu, which occurs commonly in the Tangyagraptus typicus Subzone of P. pacificus Zone in Yangtze. Thus, it appears that these two species extend to a higher horizon, into the N. extraordinarius Zone at Dob’s Linn. The most important member of the Band E fauna is Normalograptus extraordinarius (Sobolevskaya), which indicates the existence of N. extraordinarius–N. ojsuensis Zone at this level. Williams (1983) stated that the D. anceps–N. extraordinarius zonal boundary lies within the pale, unfossiliferous mudstone that occurs a short distance above the D. anceps bands. If the FAD of N. extraordinarius (Sobolevskaya) coincides with the base of the named zone, then the base of the N. extraordinarius–N. ojsuensis Zone should lie below Band E at Dob’s Linn.

The FAD of N. cf. persculptus (Elles & Wood) (=N. parvulus (H. Lapworth; see Zalasiewicz & Tunnicliff, 1994)) is about 0.7 m above the base of the Birkhill shale at the Linn Branch section (Williams, 1983). Melchin (pers. comm., 1998) has re-examined the graptolite specimens of the Linn Branch section and confirms that no typical specimens of Normalograptus persculptus (Elles & Wood) occur there. Since there is an unfossiliferous interval between the extraordinarius Band and the Birkhill graptolite succession, the exact location of the base of the N. persculptus Zone at Linn Branch remains uncertain. However, the N. persculptus Zone from Linn Branch may partly correlate to the N. persculptus Zone in Yichang. The N. persculptus fauna from Linn Branch includes N. parvulus (H. Lapworth) (=G. cf. persculptus of Williams, 1983), N. avitus (Davies), N. normalis (Lapworth), N. miserabilis (Elles & Wood) (=N. angustus (Perner)), N. medius (Törnquist) and N. pseudovenustus (Legrand) (=Glyphiograptus? venustus cf. venustus Legrand: Williams, 1983). N. normalis occurs from the D. mirus Subzone and extends to the Rhuddanian strata near
Yichang. *N. angustus* (Perner) is a long-lived species, which occurs from the *D. complanatus* Zone to the Rhuddanian strata in the Yangtze region. *N. pseudovenustus* (Legrand) occurs in the *N. persculptus*-bearing beds from Djerance region of Algeria (Legrand, 1986). *N. medius* first appears in the *P. acuminatus* Zone of the Yangtze platform sections and is not present at lower levels.

As Melchin, Koren & Williams (1998) pointed out, the world-wide occurrences of *A. ascensus* and *P. acuminatus* have been dealt with in different ways. In many parts of the world, including Kazakhstan, Kolyma, Bohemia, Poland and Thuringia, as well as the present study area in the Yangtze region of China, a distinct interval with abundant *A. ascensus* occurs below the first appearance of *P. acuminatus*, and is often recognized as a separate *A. ascensus* Zone below the *P. acuminatus* Zone (Apollonov, Bandaletov & Nikitin, 1980; Koren et al. 1979; Storch & Loydell, 1996; Schauer, 1971; Teller, 1969; Chen & Lin, 1978).

Melchin, Koren & Williams (1998) also noted that the specimens of *P. acuminatus* s.l. that occur in the lower part of the combined *P. acuminatus–A. ascensus* Zone (that is, with the early *A. ascensus* specimens at the base of the Silurian System) at Dob’s Linn differ from typical specimens of *P. acuminatus* s.s. They referred these early representatives to the subspecies *P. acuminatus praematurus* (Davies). This suggests that the FADs of *A. ascensus* and *P. acuminatus acuminatus* may not coincide even at Dob’s Linn. Whatever the case at Dob’s Linn, it is clear that in many regions occurrences of *A. ascensus* and *P. acuminatus* reliably define two distinct intervals, and it is the lower of these two that most nearly corresponds to the Silurian GSSP at Dob’s Linn. A fuller understanding of these species ranges, and such a secure correlation...
of the base of the Silurian System, will emerge only by
the evaluation of these species and their ranges relative
to a carefully and consistently defined set of other
species ranges. It is our hope that the data presented
here from the Yangtze platform will contribute to this
effort.

3.b. Spain and Portugal

The glaciomarine sediments of Hirnantian age and the
earliest Llandovery graptolite shale are widely distrib-
uted in the West Asturian–Leonese Zone, Iberian
Cordillera, Central Iberian Zone and Ossa-Morena
Zone with low diversity shelly and graptolite faunas
(Gutiérrez-Marco, Robardet & Picarra, 1998). A typi-
cal Hirnantian fauna including Hirnantia sagittifera
and Plectothyrella crassicosta chaulei occurs from the
lower part of the ‘Criadero Quartzite’ in the southern
Central Iberian Zone, Spain. The lowest Llandovery
graptolites have been documented as ascensus–acumi-
natus Zone from the four tectonic belts as mentioned
above. Ashgillian conodonts of the Amorphognathus
ordovicicus Zone have also been documented from
Truchas syncline of the north Central Iberian Zone.
Although to conduct a precise correlation between the
Iberian Peninsula and the Yangtze region is premu-
ture, the Hirnantian to earliest Llandovery fossil
sequence is similar between these two regions.

3.c. Thuringia–Saxonia–N. Bavaria, Germany

Two different facies, the Thuringian facies (east) and
Bavarian facies (west) are recognized from this region
through Ordovician to Silurian (Jaeger, 1988).
Although the lithofacies of these two areas are
different, the graptolite sequences are similar. Normalograptus persculptus (Elles & Wood)
(=Diplograptus bohemicus (Marek), Jaeger, 1977) was
described by Jaeger (1977) from the uppermost Döbra
Sandstone (Bavarian facies belt). The Akidograptus
ascensus Zone was recognized as the lowest biozone
from the Thuringian facies belt (Ronneburg and
Oelsnitz) by Schauer (1971) and from the Bavarian
facies belt by Stein (in Jaeger, 1988). The overlying
strata are assigned to the P. acuminatus and C. vesicu-
losus zones, which are readily correlated with those
zones in the Yangtze region (Fig. 9).

3.d. Bohemia

Glyptograptus bohemicus Marek was the first grapto-
lite described from the upper Kosov Formation by
Marek (1954). Since then, both the Czech and Chinese
workers have used it as a zonal fossil for the latest
Ordovician biozone (Mu, 1974; Štorch, 1988). The
type specimens as well as additional materials from
the Czech Republic and Wales have been re-studied by
Štorch & Loydell (1996). They concluded that
‘Glyptograptus bohemicus (Marek)’ is a junior subjec-
tive synonym of Normalograptus persculptus (Elles &
Wood). This revision is accepted here. From the re-
description of N. persculptus (Elles & Wood) given by
Štorch & Loydell (1996), we note that the definition of
N. persculptus (Elles & Wood) has been slightly broad-
ened. As noted in Section 1, Fan (Fan Jun-xuan,
unpub. Masters thesis, Nanjing Institute of Geology &
Palaeontology, 1998) recently has made a morphomet-
ric study of these taxa and their relations to the species
recorded from the Yangtze region. He concluded that
the ‘Glyptograptus bohemicus’ materials described by
Chinese authors in the past agree very well with
Normalograptus ojsuensis (Koren & Mikhailova).
Thus, we refer the ‘Glyptograptus bohemicus’ materials
described by Mu and his colleagues to Normalograptus
ojsuensis (Koren & Mikhailova).

N. persculptus (Elles & Wood) occurs at the top of
the Kosov Formation with only a few other grapto-
lites, such as Normalograptus sp. aff. N. miserabilis
(Elles & Wood) and N. normalis (Štorch, 1988). The
occurrence of the persculptus graptolite fauna indi-
cates that the Hirnantia fauna in Bohemia may be per-
sculptus Zone in age. However, it is difficult to
correlate the N. persculptus Zone of Bohemia with
other regions in the world (Štorch & Loydell, 1996).
We are inclined to the view that N. persculptus Zone of
Bohemia may roughly correspond to the same zone in
the Yangtze region, that is, to a level somewhere within
the N. persculptus Zone, however, its exact location rel-
tive to the base of this zone cannot be determined
(Fig. 9).

The Akidograptus ascensus Zone has also been
employed by Štorch & Loydell (1996). The base of
the zone lies 70 cm below the base of the Silurian
black shales, and yields Akidograptus ascensus,
Normalograptus angustus, Neodiplograptus lanceolatus
Štorch & Serpagli, as well as the highest identifiable
‘Glyptograptus bohemicus’ (that is, N. persculptus s.l.).
The whole A. ascensus Zone fauna may include
more species, such as Neodiplograptus modestus,
Neodiplograptus sp. aff. N. parvulus (Lapworth), N.
parajanus (Štorch), Neodiplograptus (Trilobites)
Cystograptus ancestralis Štorch, Normalograptus sp.
Aff. N. praemedius (Waern) and N. trifilis (Manck).
The P. acuminatus Zone fauna has been recorded by
Štorch (1988). It is marked by the incoming of three species,
Parakidograptus acuminatus, Neodiplograptus diminu-
tus apographon (Štorch) and Normalograptus longifilis
(Manck). The first two species have also been recorded
from the P. acuminatus Zone of the Yangtze region.

3.e. Poland

A typical Hirnantia fauna, containing Hirnantia sagit-
tifera, Eostropheodonta, Dalmanella testudinaria and
trilobites Mucronaspis mucronata etc., occurs in the
uppermost Ashgill silty beds from the Holy Cross
Mountains, southeastern Poland (Temple, 1965; Teller, 1969). ‘Ashgillian’ to early Llandovery fossils and strata have been recorded from the Lebork borehole, northern Poland, Peribaltic depression and Podisiasie depression, eastern Poland, as well as the Carpathian and Holy Cross Mountains, southeastern Poland. However, from the fossils and strata through the Ordovician–Silurian boundary interval, the Lebork 1G-1 borehole sequence in northern Poland is probably the most important (Tomczyk & Tomczykowa, 1976). In ascending order, the sequence is Mucronaspis mucronata, Normalograptus persculptus, Akidograptus ascensus and Parakidograptus acuminatus zones, etc. Thus, it is correlative with those of the Yangtze region.

3.f. Southern Kazakhstan

Middle Ashgill to earliest Llandovery graptolite-bearing strata with Hirnantia–Dalmanitina beds are well developed in southern Kazakhstan (Apollonov, Bandaleto & Nikitin, 1980). The lower Subzone of the Appendispinograptus supernus Zone, the Appendispinograptus longispinus Subzone, includes A. supernus, A. longispinus hvalross and Rectograptus amplicaulis (Hall). These species are all common forms from the Dicellograptus complanatus Zone to the Lower Subzone of the Paraorthograptus pacificus Zone in the Yangtze region. Without a set of more characteristic species in the A. longispinus Subzone in southern Kazakhstan, precise correlation between southern Kazakhstan and the Yangtze region may not be possible at this level.

The upper Subzone of the A. supernus Zone in Kazakhstan, the Paraorthograptus pacificus Subzone, includes Paraorthograptus pacificus, Appendispinograptus supernus, A. longispinus hvalross, Dicellograptus ornatus, D. minor, Normalograptus tatariae, N. cf. normalis, Rectograptus amplicaulis, Orthograptus maximus Mu (=Glyptograptus posterius Koren & Tzaj) and Ampelograptus latus (Elles & Wood) (=A. stukalinae Mikhailova). Most of these species are also common in Paraorthograptus pacificus Zone fauna in Yangtze.

The FAD of N. ojsuensis is located near the LAD of Paraorthograptus pacificus (Ruedemann) and a little lower than the FAD of Normalograptus extraordinarius (Sobolevskaya) in southern Kazakhstan (Apollonov, Bandaleto & Nikitin, 1980). In the Yangtze region sections, the FADs of N. ojsuensis and N. extraordinarius coincide, and both appear immediately following the extinction of Diceratograptus mirus in Yichang area (deeper water area). Among the sections in this area (such as at Wangjiawan), Paraorthograptus pacificus and many of the associated species continue into the interval of the N. extraordinarius–N. ojsuensis Zone whereas among the southern, more near-shore sections (e.g. Honghuayuan), the P. pacificus assemblage disappears with D. mirus. This consistent pattern of occurrence relative to the highly distinctive and short-lived D. mirus, suggests that the simultaneous origin of N. ojsuensis and N. extraordinarius in our sections reflects the true timing of their evolutionary origins. Thus, the recorded FAD of N. extraordinarius (Sobolevskaya) from southern Kazakhstan may be a little later than that in the Yangtze region.

The Hirnantia–Dalmanitina-bearing beds in southern Kazakhstan include two graptolite species, N. ojsuensis (Koren & Mikhailova) and N. extraordinarius (Sobolevskaya) (=Glyptograptus persculptus forma A). Thus, the occurrence of the Hirnantia–Dalmanitina fauna in southern Kazakhstan may be comparable to the majority of localities in the Yangtze region. Koren (in Apollonov, Bandaleto & Nikitin, 1980) had already recognized that ‘Glyptograptus persculptus forma B’ (=N. persculptus s.s.) was synonymous with ‘Glyptograptus bohemicus Marek’. Mu & Lin (1984) and Chen (1984) also suggested that ‘Glyptograptus persculptus forma B’ from southern Kazakhstan is a junior synonym of Glyptograptus bohemicus Marek. However, recent investigations by Storch & Loydell (1996) demonstrate that ‘G. persculptus forma B’ is synonymous with N. persculptus (Elles & Wood). Thus, the ‘G. persculptus forma A’ and ‘G. persculptus forma B’ from Kazakhstan, which occur separately, may represent the N. extraordinarius–N. ojsuensis Zone and N. persculptus Zone, respectively, as recognized in the Yangtze region and elsewhere.

The N. persculptus Zone from southern Kazakhstan includes the eponymous form as well as N. angustus (Perner), N. normalis (Lapworth) and ‘Pseudoclimacograptus’ sp. Among them only the last, which is an early representative of Metaclimacograptus, has not yet been recognized in the Yangtze region. The Hirnantian shelly fauna from southern Kazakhstan is associated with the N. persculptus graptolite fauna (field number 287) at north Krylo section II (Apollonov, Bandaleto & Nikitin, 1980). Along the Zhideli river, there occurs a limestone bed (field number 264) yielding a typical Hirnantia fauna (Apollonov, Bandaleto & Nikitin, 1980) which is underlain by pacificus Zone (263) and overlain by mudstone (267) with some graptolites. The latter is in turn overlain by A. ascensus–P. cf. acuminatus-bearing beds (269, 270). It suggests that the brachiopod fauna may be corresponding to the extraordinarius Zone and part of the persculptus Zone.

Koren et al. (1979) did not recognize a separate A. ascensus–P. cf. acuminatus Zone in southern Kazakhstan. However, 2.5–3 km northwest of the Ojsu section, there is a graptolite fauna (F-290) above the Hirnantia beds (Apollonov, Bandaleto & Nikitin, 1980). This graptolite fauna includes A. ascensus Davies, Normalograptus angustus (Perner), N. sp. ex gr. N. normalis, Neodiplograptus modestus primus Mikhailova and Normalograptus cf. madernii (Koren & Mikhailova). This assemblage appears to be a typical
Akidograptus ascensu Zone fauna. The A. ascensu fauna also occurs at the Dulban section (F-280 of Apollonov, Bandalekt & Nikitin, 1980, p. 10). Bed F-280 yields Akidograptus sp., Normalograptus angustus, N. acceptus, N. sp. ex gr. N. normalis and N. modernii. Both of these two graptolite-bearing beds with Akidograptus ascensu or Akidograptus sp. lie strati-
graphically below occurrences of Parakidograptus acuminatus Zone fauna (Apollonov, Bandalekt & Nikitin, 1980). These observations suggest the presence in southern Kazakhstan of a separate A. ascensu Zone below the P. acuminatus Zone, which is comparable to the situation in the Yangtze region.

The Parakidograptus acuminatus Zone in southern Kazakhstan (in the sense used herein) includes P. acuminatus, Normalograptus acceptus, N. sp. aff. N. angustus, Akidograptus ascensu cultus Mikhailova, Metaclimacograptus fidus Koren & Mikhailova and M. pictus Koren & Mikhailova. The first three species are common in the P. acuminatus Zone of the Yangtze region. Metaclimacograptus is also present in the P. acuminatus Zone of the study area, but is represented by different species.

3.g. Kolyma, northeastern Siberia

The Appendispinograptus supernus Zone in this area includes Dicellograptus complanatus, numerous sub-

species of A. longispinus, Paraorthograptus pacificus and Rectograptus amplexicaulis, etc. (Koren et al. 1979). The A. longispinus Subzone of Kolyma con-
tains mainly D. complanatus and species of the R. amplexicaulis group. The P. pacificus Subzone includes P. pacificus, R. amplexicaulis, A. longispinus hvalRoss, A. supernus, Climacograptus? hastatus, Normalo-
graptus cf. angustus and D. complanatus, etc. Additional species occur in the upper part of the Subzone. These newcomers include P. pacificus affinis, Normalograptus tatiana and Nymphograptus velatus. However, Koren et al. (1983) reported that N. ojsuensis, N. angustus, N. normalis, P. pacificus and other new species occur near the top of the P. pacificus Subzone. Since the graptolite diversity from Kolyma is relatively low compared to that of the Yangtze region, it is difficult to make a precise correlation with these subzones. The A. supernus Zone of Kolyma is roughly corre-
late with the D. complanatus Zone to P. pacificus Zone interval in the Yangtze region (Fig. 9).

Mirny Creek, Kolyma River is the type locality of Normalograptus extraordinarius (Sobolevskaya). The N. extraordinarius–N. ojsuensis Zone at this locality contains mainly N. extraordinarius, N. ojsuensis, N. angustus, N. normalis and a few others (Oradovskaya & Sobolevskaya, 1979). The FADs of N. ojsuensis (108-2/1.3-5) and N. extraordinarius (107-1/1.2) are from successive collections separated by 2 m in the Mirny Creek section. Compared with the 89 m thickness of the N. extraordinarius and N. persculptus zones in this section, the 2 m separation may not be significant. However, from the Ina River section, Normalograptus ojsuensis occurs at the base of the N. extraordinarius Zone (Koren et al. 1983). This occurrence further supports the inference that the FAD of N. ojsuensis is coincident with that of N. extraordinar-

ious in Kolyma region.

The upper Tirekhtyakh horizon was further studied as two parts, the lower N. extraordinarius Zone and the upper N. persculptus Zone by Koren, Oradovskaya & Sobolevskaya (1988). The N. persculptus Zone includes N. persculptus, N. angustus, N. normalis, N. mirynensis (Obut & Sobolevskaya) (closely related to N. angustus) and N. torosus Koren & Sobolevskaya.

Koren, Oradovskaya & Sobolevskaya (1988) reported that the most complete and well-known section of the Tirekhtyakh horizon and the overlying Chalmak horizon is exposed along Mirny Creek. The systemic boundary between the Ordovician and Silurian systems is drawn at the base of unit 73, which is 1.5 m thick and coincides with the base of the Maut horizons. The index species Akidograptus ascensu occurs at the base of unit 74, 1.5 m above the bound-
ary, and Parakidograptus acuminatus occurs in the lower part of the unit 75, 11 m above the boundary. Their report (1988) clearly described two separated graptolite horizons that may correspond to the Akidograptus ascensu and Parakidograptus acuminatus zones in the Yangtze region.

It was reported that a Hirnantia fauna occurs from the Q Horizon of the Omulev Mountains, Kolyma (Oradovskaya in Koren et al. 1983). Rong & Harper (1988, p. 395) concluded that the Kolyma brachiopter fauna has no species common to the Hirnantia fauna and is better assigned to the Lower Edgewood fauna.

3.h. Malaya Peninsu

Uppermost Ordovician to lower Silurian graptolite and shelly sequences have been reported from the Langkawi Islands, northern Malaya (Jones, 1973). The Normalograptus persculptus Zone spans 1.1 m thick platy black siltstones with N. persculptus (Elles & Wood), Neodiplograptus modestus (Lapworth) and Glyptograptus temalaensis Jones. The top of the Zone is marked by a thick bed of gritty siltstone carrying shelly fossils amongst which Dalmanitina malayensis is prominent. There are 13.8 m thick cherty beds without fossils above the D. malayensis bed. The Cystograptus vesiculosus Zone and younger graptolite zones have been recognized above the cherty beds. Rong (1979) correlated the N. persculptus, D. malayensis as well as the unfossiliferous cherty beds to the N. persculptus Zone to P. acuminatus Zone interval. If the identifica-
tion of N. persculptus from the Langkawi Islands is correct (it has not yet been described), the shelly beds with the endemic Dalmanitina malayensis should be corre-
lated to the upper N. persculptus Zone or higher
level. Thus, the \textit{Dalmanitina malayensis} beds may be a little higher than that of the \textit{Hirnantiata}-bearing beds from Yangtze region.

In southern Thailand, close to the border with Malaysia, a \textit{Hirnantiata} fauna containing \textit{Hirnantiata sagittifera}, \textit{Aegiromena planissima}, \textit{Paromalomena} sp. etc., as well as trilobite \textit{Macronatus mucronata}, has been recognized (Cocks & Fortey, 1997). Graptolites have been identified by Rickards as \textit{N. persculptus} fauna, immediately underlying the shelly beds (Wongwanich \textit{et al.} 1990, p. 6). It indicates that the \textit{Hirnantiata} beds from southern Thailand are correlative with that of the Langkawi Islands. However, the components of the shelly fauna between Langkawi and southern Thailand are a little different; the Hirnantiata brachiopods as well as \textit{Dalmanitina mucronata} are absent at Langkawi. On the other hand, the \textit{Hirnantiata} fauna of southern Thailand does not fully agree with those of the Shan State of Burma and Yichang. Yangtze as suggested by Cocks & Fortey (1997). Many distinctive brachiopod taxa of the \textit{Hirnantiata} fauna elsewhere, such as \textit{Kimella}, \textit{Dalmanella}, \textit{Cliftonia}, \textit{Eostropheodonta}, \textit{Plectothyrella} and some others, are not present in these collections. Stratigraphically, we assume that the \textit{Hirnantiata} beds of southern Thailand are probably the equivalent of the upper part of \textit{N. persculptus} Zone.

\section*{3.i. Yukon, Canada}


The \textit{P. pacificus} Zone is recognized by the presence of abundant \textit{P. pacificus} and \textit{A. supernus}. The other species present include \textit{Anticostia} cf. \textit{fastigata}, \textit{Amplexograptus latus}, \textit{Rectograptus abbreviatus} and \textit{Appendispinograptus leptothecalis} \textit{Mu} \& Ge.

\textit{Diceratograptus} \textit{mirus} \textit{Mu} (=\textit{Diceratograptus} \textit{cf. mirus} \textit{Mu}, Chen \& Lenz, 1984), discovered from the top of the \textit{P. pacificus} Zone indicates the existence of the \textit{D. mirus} Subzone in the Yukon. \textit{Diceratograptus mirus} is associated there with \textit{D. ornatus}, \textit{P. pacificus}, \textit{A. supernus}, \textit{C. cf. longispinus}, \textit{C'} \sp. ex. gr. \textit{C'? hastatus}, \textit{Amplexograptus latus} and \textit{Arachniograptus laqueus} etc. All of these species except \textit{Arachniograptus laqueus} are also present in the \textit{D. mirus} Subzone of the Yangtze region. Different species of \textit{Arachniograptus} occur in these two regions.

The \textit{P. pacificus} and \textit{P. acuminatus} zones in the Yukon are juxtaposed across a cryptic unconformity at which the \textit{N. extraordinarius} and \textit{N. persculptus} zones are missing. This is most likely a consequence of regression and submarine erosion induced by the Hirnantiata glaciation (Melchin, 1987; Lenz \& McCracken, 1988). \textit{Parakidograptus acuminatus} occurs together with \textit{Akidograptus ascensus}, \textit{Normalograptus} \textit{cf. trifilis}, \textit{Cystograptus vesiculosus} and \textit{Neodiplograptus modestus diminutus} etc. Of the Yangtze platform zones, this fauna is most similar to that of the \textit{P. acuminatus} Zone.

\section*{3.j. Canadian Arctic islands}

Melchin (1987) erected the \textit{Anticostia fastigata} Zone (originally referred to as the ‘\textit{Orthograptus fastigatus}’ Zone) from the Canadian Arctic islands and suggested that this Zone is correlative with the \textit{Dicellograptus complexus} Zone. His \textit{Paraorthograptus pacificus} Zone contains \textit{Amplexograptus latus} (Elles \& Wood) and \textit{Appendispinograptus supersmus} (Elles \& Wood) from Huf ridge. In the Arctic islands, the \textit{P. pacificus} Zone is succeeded immediately by an interval containing ‘\textit{Neodiplograptus bohemicus} (Marek)’ and \textit{Normalograptus shancongensis} (Li) (Melchin, McCracken \& Oliff, 1991). Following previous interpretations of the Yangtze region graptolites, Melchin, McCracken \& Oliff (1991) referred this fauna to the \textit{N. bohemicus} Zone. Storch \& Loydell (1996) suggested that these pre-\textit{Hirnantiata} Canadian specimens of \textit{N. bohemicus}, like the type materials of \textit{N. bohemicus} (Marek), may be synonymous with \textit{Normalograptus persculptus} (Elles \& Wood). However, Fan’s (Fan Jun-xuan, unpub. Masters thesis, Nanjing Institute of Geology \& Palaeontology, 1998) demonstration that the Chinese ‘\textit{N. bohemicus}’ from the \textit{N. extraordinarius–N. ojsuensis} Zone is instead identical with \textit{Normalograptus ojsuensis} (Koren \& Mikhailova) raises the possibility of a similar relation for the Canadian Arctic materials. Based on its location between clearly corresponding \textit{P. pacificus} and \textit{N. persculptus} zones, we tentatively correlate the ‘\textit{N. bohemicus}’ Zone of Melchin, McCracken \& Oliff (1991) with the \textit{N. extraordinarius–N. ojsuensis} Zone in the Yangtze region. Melchin (pers. comm., Dec. 1998) also has recently come to the conclusion that his specimens referred as ‘\textit{N. bohemicus} (Marek)’ are \textit{N. ojsuensis} (Koren \& Mikhailova).

The \textit{Normalograptus persculptus} Zone from Arctic Canada includes \textit{Normalograptus} \textit{cf. persculptus} (Elles \& Wood), \textit{N. wangjiaowanensis} (Mu \& Lin) and \textit{Neodiplograptus shancongensis} (Li). The interval above the \textit{N. persculptus} Zone in the Canadian Arctic islands lacks \textit{A. ascensus} and \textit{P. acuminatus}. Melchin, McCracken \& Oliff (1991) placed the base of the post-\textit{N. persculptus} zone (their \textit{P. acuminatus} Zone) at the
FADs of *N. madernii* and *N. lubricus*. This *N. madernii*–*N. lubricus* fauna, which they recognized as a lower subzone of the *P. acuminatus* Zone, is succeeded by an upper subzone characterized by the appearance of *Hirsutograptus sinizcini*. Obviously it is impossible to confirm the relations of *A. ascensus* and *P. acuminatus* based on these data.

### 3.k. Eureka, Nevada, USA

Continuous graptolite, conodont and chitinozoan sequences through *Dicellograptus ornatus*, *Paraorthograptus pacificus*, *Normalograptus extraordinarius* and *N. persculptus* zones have been documented recently from Vinini Creek, and the Monitor Range, near Eureka, Nevada (Finney et al. 1999). From the graptolite fauna, the *Dicellograptus ornatus* Zone may correlate with the *Dicellograptus complexus* Zone of the Yangtze region. Most of the *P. pacificus* Zone from Nevada may be correlative to the same zone of the Yangtze region. The *Tangyagraptus typicus* and *Diceratograptus mirus* faunules have not yet been found in Nevada. The *Normalograptus extraordinarius* Zone of Nevada is marked by the FADs of *N. extraordinarius* (Sobolevskaya) and *N. pseudovenustus* (Legrand). The FAD of *Normalograptus ojsuensis* (Koren & Mikhailova) is little earlier than that of *N. extraordinarius* (Sobolevskaya) from the Vinini Creek section. The vertical distribution of these two species is similar to that of Mirny Creek, southeastern Siberia. Thus, this zone in Nevada is broadly correlative with the *N. extraordinarius*–*N. ojsuensis* Zone of the Yangtze region, but is slightly younger at its base. We would instead place the base of the zone at the first appearance of *N. ojsuensis*.

From the Monitor Range, Nevada, *Normalograptus persculptus* (Elles & Wood) and *Glyptograptus laciniatus* (Churkin & Carter) occur in the upper *N. persculptus* Zone. Conodonts of the *Amorphograptus ordovicicus* Zone as well as chitinozoans occur through *P. pacificus* and *N. extraordinarius* zones but exhibit a little change in their taxonomic composition. However, conodonts and chitinozoans considered typical of the Early Silurian appear in the *N. persculptus* Zone.

### 3.l. Talacasto, Argentina

Cuerda, Rickards & Cingolani (1988) reported graptolites of the *Normalograptus persculptus* Zone from the Talacasto region, listing among the fauna *N. persculptus*, *N. angustus*, *N. normalis* and *N. rectangulatus*. However, the last-named species are less known from the *N. persculptus* Zone elsewhere. The graptolite assemblage from the overlying beds, including *Talacastograptus leanzai* Cuerda, Rickards & Cingolani, *Metaclimacograptus robustus* (Cuerda, Rickards & Cingolani) and *Lagarograptus praeacinaces* Cuerda, Rickards & Cingolani, seem to be representatives of late Rheidanian graptolite faunas, although Cuerda, Rickards & Cingolani (1988) suggested they were a *P. acuminatus* Zone fauna. Among these new forms, *Metaclimacograptus robustus* has been recognized from the C. *vesiculosus* Zone at Honghuayuan section in the Yangtze region.

### 3.m. Djado plateau, Niger and Hodh, Mauritania

Legrand (1993) recognized *Normalograptus ojsuensis* (=*Glyptograptus* (Glyptograptus?)* ojsuensis* Koren & Mikhailova, Legrand, 1993) from the Djado plateau, Niger. Associated forms are *Normalograptus* sp., inarticulate brachiopods and trinucleid trilobites. Underwood, Deynoux & Ghienne (1998) reported that *Normalograptus persculptus* (=*Persculptograptus persculptus* s.l.: Underwood, Deynoux & Ghienne, 1998, fig. 5S) occurs with *Normalograptus extraordinarius* (=*N. extraordinarius* typical forms, Underwood, Deynoux & Ghienne, 1998, fig. 5H,G) from their lower *persculptus* Zone (at Hodh, Mauritania). It is important that *N. persculptus* (Elles & Wood) occurs together with *N. extraordinarius* (Sobolevskaya) in the *N. persculptus* Zone from Fenxiang (Fig. 4) and Huanghuachang, Yichang. The Djado plateau and Hodh are the only two localities of the latest Ordovician graptolites known from within Gondwana land near the Ordovician South Pole.

### 3.n. Darraweil Guim, central Victoria, Australia

Thick clastics (Bolinda Shale and Darraweil Guim Mudstone) and turbidites (Deep Creek Siltstone) occupy the *Dicellograptus ornatus*–*Amplexograptus latus* Zone to *Parakidograptus acuminatus* Zone interval from central Victoria (VandenBerg, Rickards & Holloway, 1984). The *D. ornatus*–*A. latus* Zone in the Bolinda Shale contains *Dicellograptus minor*, *D. ornatus*, *Appendispinograptus superbus*, *Climacograptus? hastatus*, *Normalograptus angustus*, *Paraorthograptus pacificus*, *Rectograptus amplexicalcis*, *Anticostia fastigata* and *Orthoretiograptus denticulatus*, etc. Among them ‘*O. denticulatus*’ may be *Pararetiograptus sinensis* Mu. The graptolite fauna indicates that this zone may be equivalent to the *D. complexus* Zone through *P. pacificus* Zone interval in the Yangtze region.

The *N. extraordinarius*–*N. ojsuensis* Zone includes one of the zonal fossils. *N. extraordinarius* as well as *N. angustus* associates with the trilobite Songxites darrweilensis (Campbell). *Normalograptus persculptus* occurs at the top of the Deep Creek Siltstone associated with *N. normalis* and *N. angustus*. VandenBerg, Rickards & Holloway (1984) described their *Parakidograptus acuminatus* sp. cf. *P. acuminatus acuminatus* (Nicholson) based on a single whole rhabdosome (NMV PL698). They reported there is no direct evidence of its stratigraphic relationship with the
beds containing *N. persculptus*. From the text-figure and description of this specimen, we are inclined to the view that *P. acuminatus* sp. cf. *P. acuminatus acuminatus* (VandenBerg, Rickards & Holloway, 1984, fig. 12) is *P. acuminatus praematurus* (Davies). Davies (1929) suggested originally that *P. acuminatus praematurus* occurs within the *N. persculptus* Zone. Rickards (1988) in his discussion of the position of the base of the Silurian, lowered the base of the *P. acuminatus* Zone to include these *P. acuminatus praematurus*-bearing strata. So far, *P. acuminatus praematurus* has not yet been found from China. We are not sure whether the occurrence of *P. acuminatus praematurus* in the Deep Creek siltstone indicates the existence of the Yangtze *A. ascensus* Zone in central Victoria, although this is likely if Melchin, Koren & Williams (1998) are correct in their interpretation of the ranges of these taxa. We interpret the occurrence of *P. acuminatus praematurus*, with its more ‘primitive’ features, to indicate the presence in the Victorian succession of a stratigraphically lower level within the Silurian than that marked by the FAD of *P. acuminatus*.

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