Distribution of the *Hirnantia* fauna and its meaning

By RONG JIA-YU

The geographic and stratigraphic distribution of the late Ashgill *Hirnantia* brachiopod fauna is here recorded and discussed based mainly on Chinese data. The *Hirnantia* fauna from the Kuanyinchiao Beds and their equivalents in southern China is approximately contemporaneous with the late Ordovician graptolite zones of *Diceratograptus mirus, Paraorthograptus uniformis* and *Diplograptus bohemicus.* The *Hirnantia* faunal assemblage became extinct before the *Glyptograptus persculptus* Zone, although the fauna is undoubtedly diachronous. Ecologic communities of the *Hirnantia* fauna are discussed. The present data reveal that the distribution of the *Hirnantia* fauna might not be restricted to one hemisphere and its development was not necessarily controlled by a cold water environment. It probably extended into the temperate and even subtropical zones during the latest Ordovician. The ecologic distribution of the main elements of the *Hirnantia* fauna were much broader than previously thought.

Rong Jia-yu, Nanjing Institute of Geology and Palaeontology, Academia Sinica, Chi-Ming-Ssu, Nanjing, The People's Republic of China.

The *Hirnantia* fauna is a geographically widespread and distinctive brachiopod fauna that occurs near the boundary between the Ordovician and Silurian systems. It seems to have appeared abundantly at the beginning of the Hirnantian (i.e. Late Ashgill), spread rapidly, and become extinct as a whole fauna beneath the *Glyptograptus persculptus* Zone. Temple (1965) introduced the term *Hirnantia* fauna for the brachiopod assemblage in the *Dalmanitina* Beds of the Holy Cross Mountains of S. Poland, the Ashgill Shales of N. England, and the Hirnant Beds of N. Wales. The common taxa in this fauna are *Hirnantia sagittifera* (M'Coy), *Dalmanella testudinaria* (Dalman), *Kinnella kielanae* (Temple), *Paromalomena polonica* (Temple), *Eostropheodonta hirnantensis* (M'Coy) and *Plectothyrella crassicosta* (Dalman) (= *P. platystrophoides* Temple). The unusually distinctive *Hirnantia* fauna is commonly associated with the trilobites *Dalmanitina (Mucronaspis), Brongniartella* and *Leonaspis* (Kielan 1960). Since 1965 the *Hirnantia* fauna has been recognized from the following areas: Bohemia (Marek & Havlíček 1967; Havlicek 1977), Västergötland, Sweden (Bergström 1968), Kildare, Ireland (Wright 1968), Keisley, England (Temple 1968), Maine, U.S.A. (Neuman 1968), Anti-Atlas, Morocco (Havlicek 1971; Destombes 1976), Carnic Alps, Austria (Schönlaub 1971; Jaeger *et al.* 1975), W. Libya (Havlicek & Massa 1973), Quebec, Canada (Lesperance 1974; Lesperance & Sheehan 1976, 1981), Southwest Wales (Cocks & Price 1975), Kazakhstan (Nikitin 1976), Southern China (Rong 1979), Kolyma (Oradovskaya & Sobolevskaya 1979), Anticosti Island, Canada (Cocks & Copper 1981), the Garth area, Wales (Williams & Wright 1981), and the Girvan District, Scotland (Lamont 1935; Harper 1981) (Fig. 1). The Burmese brachiopod assemblage described by Reed (1915), from the Northern Shan States, should also be considered as a representative of the *Hirnantia* fauna in southeastern Asia. Amsden (1971, 1974) compared the brachipod fauna from the Noix Limestone (lower part of the Edgewood Group), with the *Hirnantia* fauna and noted that these two faunas had some genera in common and were probably of the same age. However, in general these two faunas have a different composition. There are many genera in the older Edgewood fauna, such as *Stegerhynchus, Brevilamnulella, Dolerorthis, Eospirigerina, Leptoskelidion, Thebesia, Orthostrophella, "Homoeospira", Dictyonella* and others, which are un-

In Bruton, D. L. (ed.), 1984. *Aspects of the Ordovician System.* 101–112. Palaeontological Contributions from the University of Oslo, No. 295, Universitetsforlaget.

known in the typical *Hirnantia* fauna, and conversely there are a number of genera in the *Hirnantia* fauna, for example, *Draborthis, Kinnella, Paromalomena, Leptaenopoma, Eostropheodonta, Plectothyrella, Hindella* and others, which are not present in the Edgewood fauna (Amsden 1974: 28). The older Edgewood fauna, therefore, seems significantly different from the *Hirnantia* fauna at both the generic and specific level.

Hirnantia fauna in China

Recent discovery of the widespread occurrence of the *Hirnantia* fauna in China (Rong 1979) has considerably expanded the geographical distribution of this fauna. During the last two decades, large collections of the *Hirnantia* fauna, usually associated with the trilobites *Dalmanitina, Platycoryphe* and *Leonaspis,* have been made from a great number of places in China (Fig. 2). In northern China no representatives of the fauna are as yet known.

The *Hirnantia* fauna is well developed in the upper Yangtze Basin, including north-eastern Yunnan, Sichuan, southern Shaanxi, northern Guizhou, and western Hubei. Lu (1959) named the strata bearing the fauna in these regions the Kuanyinchiao beds, which are intercalated between the Wufeng and Lungmachi Formations. They include shelly and graptolitic facies, and consist mainly of marls, mudstones, and argillaceous limestones, usually 0.2–1 m thick. Zhang & Sheng (1958) reported the following taxa from these beds in Tongzi, northern Guizhou: *Hebertella* aff. *occidentalis* (Hall), *Rafinesquina* cf. *alternata* (Emmonds), *Platystrophia lynx* (Eichwald) and *Orthis* sp. The specimens collected by Zhang & Sheng from these beds at the same localities have been reidentified by the author as follows: *Hirnantia sagittifera* (M'Coy), *Aphanomena* cf. *ultrix* Marek & Havlíček, *Plectothyrella crassicosta* (Dalman) and *Dalmanella testudinaria* (Dalman), as well as

Fig. 1. Global distribution of the Hirnantia *fauna.*

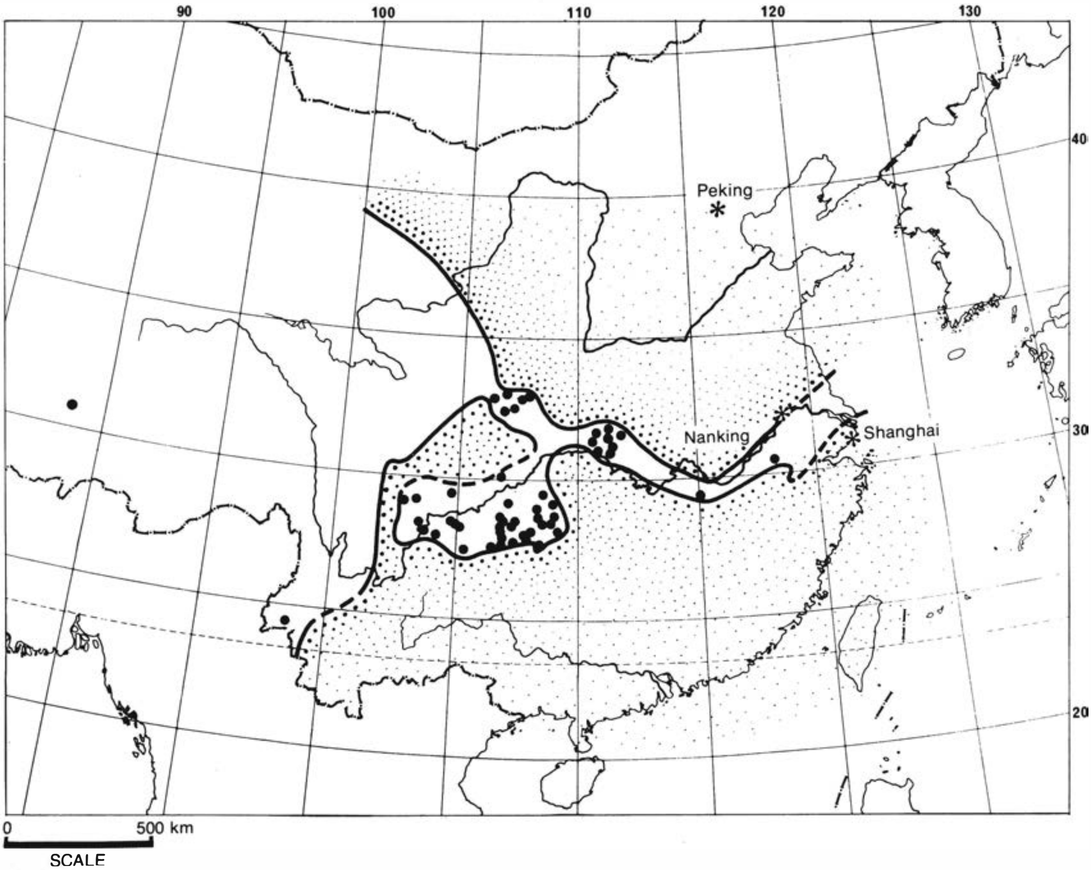

Fig. 2. Occurrences of the Hirnantia *fauna in China.*

Kinnella kielanae (Temple) and *Hindella crassa incipiens* (Williams). This is a typical (or strict) *Hirnantia* fauna which has been known from a great number of localities not only in northern Guizhou and southern Sichuan, but also in north-eastern Yunnan, northern Sichuan, southern Shaanxi and western Hubei (Rong 1979). A strongly diversified *Hirnantia* fauna has been found in Shuanghe, Changning in south-western Sichuan and Huanghuachang, Yichang in western Hubei by Mu and others during their field work in 1972 (Mu *et al.* 1978; Chang 1982). The Kuanyinchiao Beds yield the following taxa: *"Paracraniops"* sp. nov., *Philhedra* sp., *Philhedrella* sp., *Acanthocrania* sp. nov., *Comatopoma* sp., *Toxorthis* sp. nov., *Dalmanella testudinaria* (Dalman), *Horderleyella inexpectata* (Temple), *Trucizetina* sp., *Hirnantia sagittifera* (M'Coy), *Kinnella kielanae* (Temple), *Draborthis caelebs* Marek & Havlicek, *Cliftonia* cf. *oxoplecioides* Wright, *Aegiromena ultima* Marek & Havlicek, *Paromalomena polonica* (Temple), *Leptaenopoma trifidum* Marek & Havlicek, *Aphanomena ultrix* Marek & Havlicek, *Coolinia* sp., *Dorytreta* sp. nov., *Plectothyrella crassicosta* (Dalman), and *Hindella crassa incipiens* (Williams). The composition of this fauna is quite similar to those of Bohemia (Marek & Havlicek 1967), northern England (Temple 1968) and Västergötland (Bergström 1968). In the Upper Yangtze Basin, a highly diverse *Hirnantia* fauna has also been recorded from Qiaoting, Nanjiang in northern Sichuan, Wanjiawan and Tangya, Yichang in western Hubei and Sanlangpu, Xixiang in southern Shaanxi (Rong 1979).

In the Lower Yangtze Basin, in the provinces of Jiangxi and Anhui, the strata containing the *Hirnantia* fauna lie between the Kaochiapien and Wufeng formations. The fauna comprises only three brachipod taxa, viz. abundant *Paromalomena polonica* (Temple), fairly common *Aegiromena ultima* Marek & Havlicek, and very rare *Coolinia* ? sp. They are associated with *Dalmanitina* and *Platycoryphe.*

A *Hirnantia* fauna has most recently been found in western Yunnan and northern Xizang (northern Tibet). A good sample from the uppermost unit of the Ordovician rocks near the Mangjiu reservoir in Luxi, western Yunnan has been collected by Sun Dong-li and his colleagues during their field work in 1981. The unit yields a shelly fauna with *Hirnantia sagittifera* (M'Coy), *Cliftonia* sp., *Paromalomena polonica* (Temple), *Aphanomena* cf. *ultrix* Marek & Havlicek, *Coolinia* cf. *dalmani* Bergström, *Plectothyrella crassicosta* (Dalman) and *Hindella crassa incipiens* (Williams) associated with *Dalmanitina.* The first occurrence of the typical *Hirnantia* fauna in northern Xizang (northern Tibet) has been reported by Ni *et al.* (1981) from the upper part of the Xainza Formation in Xainza. It contains *Hirnantia, Kinnella, Cliftonia, Paromalomena, Aphanomena,* and *Hindella,* but the identifications are at present only at the generic level.

Stratigraphic distribution of the *Hirnantia* fauna

The time of both the appearance and extinction of the *Hirnantia* fauna in China is apparently not the same at all localities, although it is always within the Late Ashgill (= Hirnantian). Mu (1974) distinguished six graptolite zones in the Wufeng Formation, in ascending order, the zones of *Pleurograptus lui* (W_1), *Dicellograptus szechuanensis* (W_2), *Tangyagraptus typicus* (W_3), *Diceratograptus mirus* (W_4), *Paraorthograptus uniformis* (W_5), and *Diplograptus bohemicus* (W_6). The relationship of these zones to the base and top of the beds with the *Hirnantia* fauna is as follows (Fig. 3):

1) In Ganxi, Yanhe in north-eastern Guizhou, the Kuanyinchiao Beds with the *Hirnantia* fauna lie between the *D. bohemicus* (W_6) and *T. typicus* (W_3) zones (Mu *In* Lu & Mu 1980).
2) In Honghuayuan, Tongzi in northern Guizhou, the beds yielding the *Hirnantia* fauna occur beneath the *D. bohemicus* (W_6) Zone and above the *D. mirus* (W_4) Zone (Zhang *et al.* 1964).

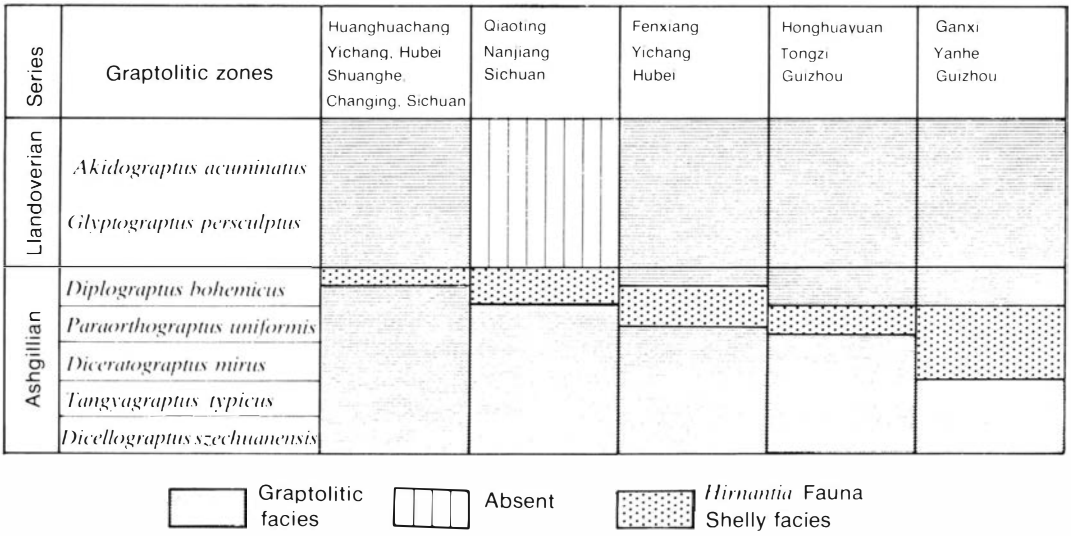

Fig. 3. Different levels of the Hirnantia *fauna in south-western China.*

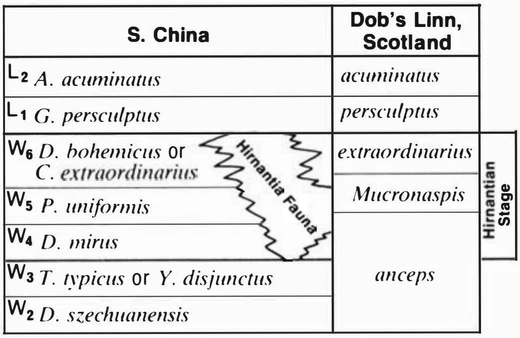

Fig. 4. Correlation of the Hirnantia *fauna with the graptolitic zones across the Ordovician and Silurian boundary in southern China and Scotland.*

3) In Fenxiang, Yichang in western Hubei, the Kuanyinchiao Beds lie between the *D. bohemicus* (W_6) and *P. uniformis* (W_5) zones (Mu en-zhi, pers. comm.).
4) In both Huanghuachang, Yichang in western Hubei and Shuanghe, Changning in southwestern Sichuan, the beds containing the *Hirnantia-Dalmanitina* fauna occur between the *G. persculptus* (L_1) and *D. bohemicus* (W_6) zones (Mu *et al.* 1978).

Thus, the *Hirnantia* fauna in China is basically contemporaneous with the *D. mirus* (W_4), *P. uniformis* (W_5), and *D. bohemicus* (W_6) zones, although the *Hirnantia* fauna-bearing beds may also be within or above the *D. bohemicus* (W_6) Zone. It always occurs beneath the *Glyptograptus persculptus* (L_1) Zone which, in turn, is followed by the *"Akidograptus" acuminatus* (L_2) Zone.

It is also worth mentioning that in Shahe, Baosha (Western Yunnan) *Diplograptus bohemicus* (Marek) occurs in association with *Climacograptus extraordinarius* (Sobolevskaya) and *Diplograptus* cf. *orientalis* Mu *et al.*, in a grey black silty shale (Ni *et al.* 1982). This indicates that the *D. bohemicus* Zone may be correlated with the *C. extraordinarius* Zone. The latter zone has been reported from Scotland (Rickards 1979), Kazakhstan and Kolyma Basin (Koren' *et al.* 1979). Thus, the Ordovician and Silurian boundary could be placed at the level where the *Hirnantia* fauna disappears in the shelly facies and at the level between *G. persculptus* and *D. bohemicus* (or *C. extraordinarius*) zones in the graptolitic facies (Fig. 4).

Within the last decade or so, a mixture of Ordovician shelly fossils with so-called earliest Silurian graptolites have been reported from a few localities in various parts of the world (Rukavishnikova *et al.* 1968; Mikhajlova 1970; Nikitin 1972, 1976; Lespérance 1974; Jaeger *et al.* 1975; Koren' *et al.* 1979; Apollonov *et al.* 1980). Some workers have suggested that the Ordovician-Silurian boundary should be placed at the base of the *"Akidograptus" acuminatus* (L_2) Zone. However, *Glyptograptus ? persculptus* forma A or B (Koren' *et al. In* Apollonov *et al.* 1980), known in the association with the *Hirnantia-Dalmantina* fauna of the Chu-Ili Monuntains, Kazakhstan, is probably not *G. persculptus* (Salter) (Mu & Ni, in press). The *G. ? persculptus* Zone of Koren' *et al.* has been considered in China to correspond to the *D. bohemicus* (W_6) or *Cl. extraordinarius* Zone, rather than to the *G. persculptus* (L_1) Zone (Lin, pers. comm. 1981; Mu & Ni 1982). In the Portage River area, near Percē, Quebec, Lesperance (1974) reported the association of *Dalmanitina, Cryptolithus* and *Brongniartella* with the early Llandovery graptolite *Climacograptus rectangularis medius.* However, Rickards (*In* Cocks & Price 1975), on the other hand, considered the graptolite in question to be a Ordovician form and Ingham (1977) believes this shelly fauna to be older than the late Ashgill. It should also be noted that no *Hirnantia* fauna is present with these graptolites. In Feistritzgraben of the Karawank Alps, southern Austria, Jaeger *et al.* (1975) reported the occurrence of *G.* cf. *persculptus* in a black slate which has been correlated with the *Hirnantia* fauna-bearing beds in the Cellon section, Carnic Alps. However, the shelly fauna associated with *G.* cf. *persculptus* contains neither a *Dalmanitina* nor *Hirnantia* fauna. The identification of *G.* cf. *persculptus* is in doubt. The above occurrences of these taxa are insufficient to correlate the *G. persculptus* Zone with the *Hirnantia-Dalmanitina* fauna.

Ecologic communities within the *Hirnantia* fauna of northern Guizhou and southern Sichuan

When Cocks (1972; 627) discussed the ecology of the *Clarkeia* shelly fauna of S. America, he postulated that the low-diversity *Hirnan-*

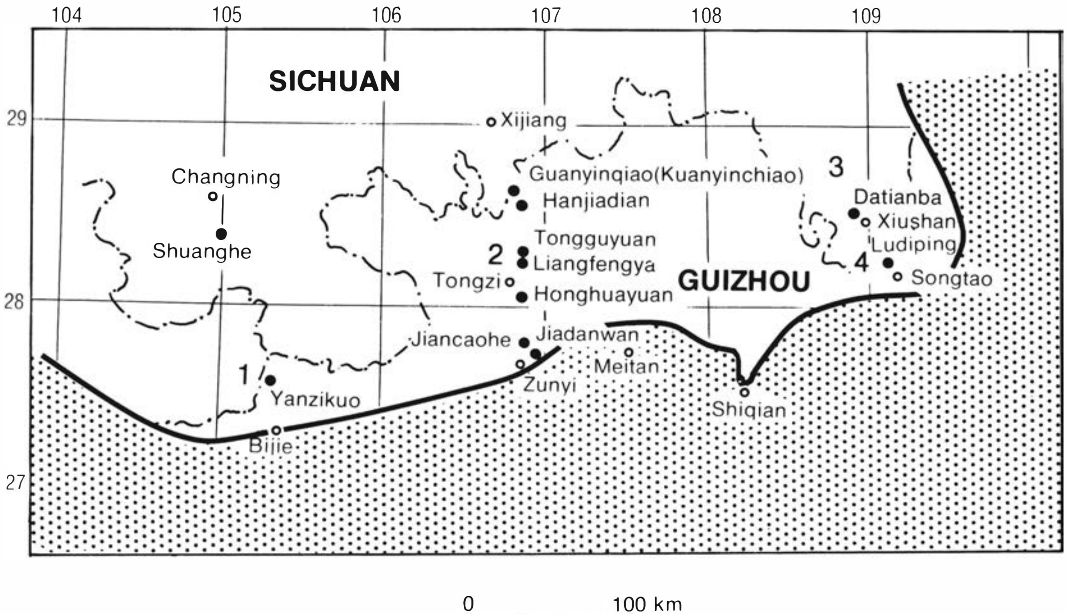

Fig. 5. Occurrences of the Hirnantia *fauna in southern Sichuan and northern Guizhou.*

tia fauna represents a community filling an ecologic niche comparable to the *Eocoelia* and *Crytothyrella* communities (i.e. Benthic Assemblage 2 of Boucot 1975) of the early Silurian. Lespérance & Sheehan (1976: 720) considered that the term *Hirnantia* Community should be used instead of the "*Hirnantia* fauna". The *Hirnantia* Community has been assigned to Benthic Assemblage 4 (possibly 5) by Sheehan (1979). The available data in southern China indicate, however, that the *Hirnantia* fauna may comprise more than one ecological community.

During the latest Ordovician, the southern margin of the Upper Yangtze Basin was located approximately in the Bijie-Zynyi-Songtao region of northern Guizhou. There are seven localities yielding the *Hirnantia* fauna from Zunyi to Xijiang (Fig. 5). The sandy shale Kuanyinchiao Beds at Jiadanwan, Donggongsi, Zunyi immediately north of the Mid-Guizhou Late Ordovician Land area, have yielded a rich brachiopod assemblage along with the trilobite *Dalmanitina.* The assemblage is characterized by the abundant occurrence of "*Whitfieldella*" n.sp., comprising 97% of the whole fauna, associated with a few specimens of *Hindella crassa incipiens* (Williams) and *Coolinia* sp. This is not a typical *Hirnantia* fauna, although *H. crassa incipiens* is one of the most common taxa in the *Hirnantia* fauna elsewhere. The assemblage may have lived in a very shallow water environment near the shore and probably is a representative of Benthic Assemblage 2. Northwards, the conditions are quite different. From Jiancaohe, Zunyi in northern Guizhou to Guanyinqiao, Xijiang in southern Sichuan, no "*Whitfieldella*" has been found from the mudstone or argillaceous limestone of the Kuanyinchiao Beds and *Hirnantia sagittifera, Dalmanella testudinaria, Kinnella kielanae, Paromalomena polonica, Aphanomena ultrix, Cliftonia psittacina, Plectothyrella crassicosta* as well as *H. crassa incipiens* are all common elements of the typical *Hirnantia* fauna (Fig. 6). It seems possible that these *Hirnantia*-bearing faunas may occupy a position equivalent to high Benthic Assemblage 3, although the relative frequencies of the genera vary. It is suggested that the sea floor bottom of the Upper Yangtze Basin in N. Guizhou appears to have been relatively even, and the depth of the basin there did not change appreciably.

It is also interesting to compare the composition of the brachiopod fauna along the line (see Fig. 5) from locality 1 (Yanzikou, Bijie

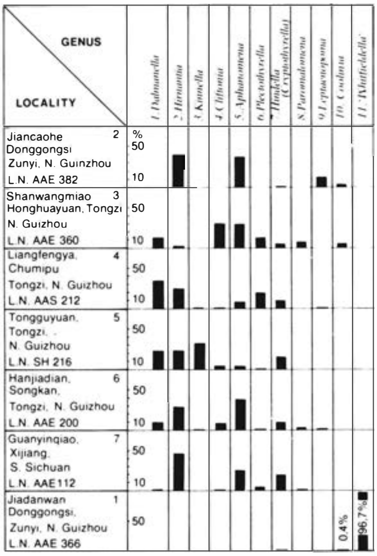

Fig. 6. Percentage of elements of the Hirnantia *fauna in different localities from Jiadanwan to Guanyinqiao in northern Guizhou and southern Sichuan.*

in north-western Guizhou), through 2 (Liangfengya, Tongzi in northern Guizhou) to 3 (Datianba, Xiushan in south-eastern Sichuan) and 4 (Ludiping, Songtao in north-eastern Guizhou). The line runs approximately parallel to the northern coast of the Mid-Guizhou Late Ordovician Land. The brachiopod assemblages from the Kuanyinchiao Beds at these four localities represent a typical *Hirnantia* fauna and contain about 5–8 taxa (Fig. 7). It is *Dalmanella testudinaria* (Dalman) which is the most abundant taxon comprising about 66.7% (1), 34.3% (2), 38.95% (3), 48.7% (4) in the respective assemblages. The overall similarities in both diversity and composition between these assemblages might indicate that they have belonged to a single palaeoecologic community. All of them probably inhabited a normal shallow water environment and may occupy a high Benthic Assemblage 3 position. With respect to the dominance of *Dalmanella,* the *Hirnantia*

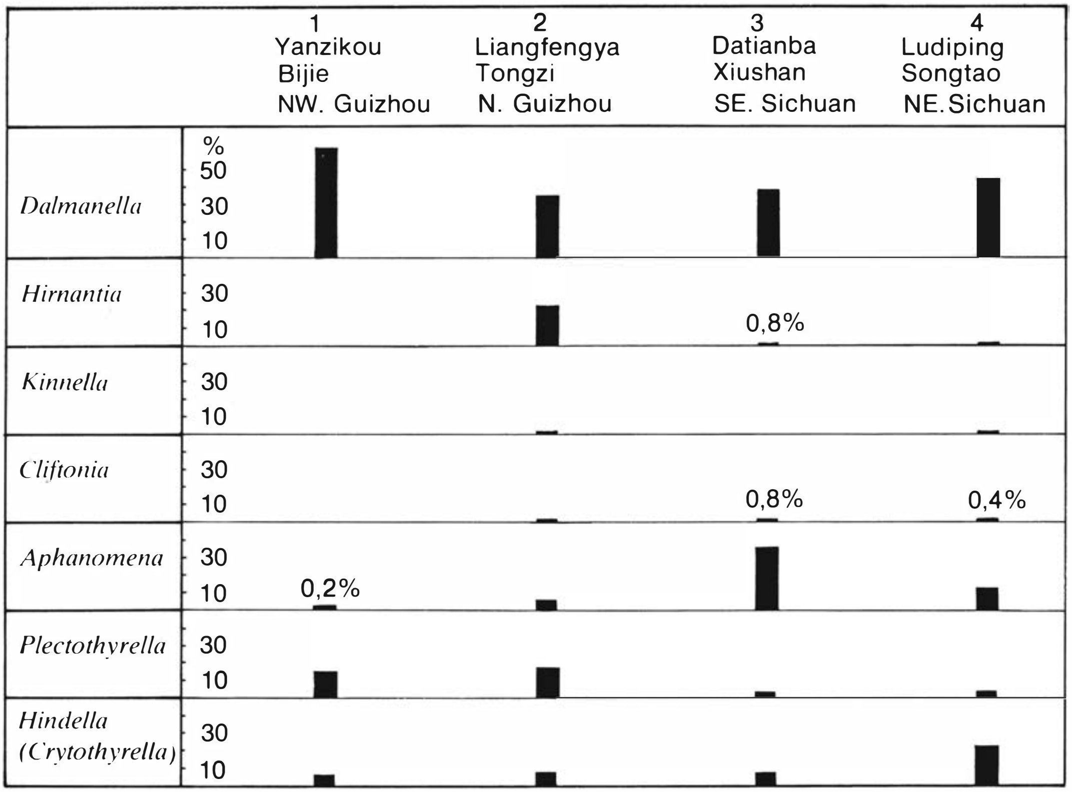

Fig. 7. Percentage of the components of the Hirnantia *fauna in Yanzikou, Liangfengya, Datianba and Ludiping.*

fauna mentioned above is comparable to the Caradoc *Dalmanella* Community of the southern Berwyns in North Wales (Pickerill & Brenchley 1979). The latter has been also assigned to Benthic Assemblage 3.

In a northerly direction towards Shuanghe, at the locality Changning in south-western Sichuan, situated in the central part of the basin (Fig. 5), there occurs a strongly diversified *Hirnantia* fauna which consists of 21 taxa associated with *Dalmanitina, Platycoryphe* and *Leonaspis.* Here the *Hirnantia* fauna includes not only the common representatives of the typical *Hirnantia* fauna (such as *Dalmanella, Hirnantia, Kinnella, Cliftonia, Paromalomena, Aphanomena, Plectothyrella* and *Hindella*), but also such genera as *Toxorthis, Comatopoma, Trucizetina, Horderleyella, Draborthis, Triplesia, Dorytreta, Sphenotreta, Philhedra, Philhedrella, Paracraniops,* and *Acanthocrania* which are very rare or absent in the typical *Hirnantia* fauna. Within this fauna there are four very abundant genera: *Hirnantia, Kinnella, Aphanomena* and *Paromalomena.* However, *Dalmanella, Plectothyrella* and *Hindella* are rare, usually making up only 1–4% of the whole fauna, or absent.

It appears that this highly diversified *Hirnantia* fauna may have lived in a deeper water environment than that of the strict *Hirnantia* fauna and may occupy a position about that of low Benthic Assemblage 3.

Evidently, the strict or typical low diversity *Hirnantia* fauna lived in more restricted conditions (compared to the highly diversified *Hirnantia* fauna) but also reached a wider distribution. It is possible that the Late Ordovician glaciation lowered sea levels (Sheehan 1973) and decreased broad shallow water environments during that time.

Climatic significance of the *Hirnantia* fauna

The occurrence of continental glaciation centered in North Africa during the Late Ordovician has been documented by Beuf *et al.* (1971), Bennacef *et al.* (1971), Fairbridge (1971), Berry & Boucot (1973) and others. Evidence of periglacial deposits has been obtained not only from Morocco, Mauritania, Mali, Chad, Ethiopia, Niger and Sierra-Leone, but also from South Africa, the Amazon Basin of Brazil, Argentina, Peru, Bolivia and southern Spain. Possible later Ordovician glacio-marine deposits also occur in the Armorican Massif (Normandy) of France (Dore & Legall 1972). Based on the discovery of a *Hirnantia* fauna in the Upper 2nd Bani Formation, a detrital deposit of glacial origin, in the central Anti-Atlas of Morocco (Havlicek 1971; Destombes 1971), it has been concluded that the maximum glaciation was reached at the end of the late Ashgill (Destombes 1976). Havlíček (1976) pointed out that the distinctive features of the *Hirnantia* fauna in the Kosov Beds were presumably a reflection of the very cool climate, whose influence can be traced all over the Mediterranean Province. Sheehan (1975) and Sheehan & Lespérance (1978, 1979) postulated that the development of glaciers was accompanied by the expansion of a cold water fauna which originated in the high latitudinal Mediterranean Province. Thus they considered that the *Hirnantia* fauna was composed largely of Mediterranean Province genera and was part of a relatively cold water province. As Cocks & Price (1975) suggested, however, the extent to which the *Hirnantia* fauna is a direct reflection of cold water condition is as yet uncertain.

Recently, the distribution of the *Hirnantia* fauna has been shown to be much wider than previously assumed. In addition to Morocco and Libya, where both the *Hirnantia* fauna and Late Ordovician glacial deposits occur, this brachiopod fauna is known not only in Europe and North America, but also in vast regions of Asia including most of southern China (from Xizang (Tibet) on the west to Anhui on the east), Burma, Kazakhstan and Kolyma. In these regions no late Ordovician deposits of glacial origin have been encountered so far. It is evident that most of these regions were far from the occurrences of the late Ashgill continental glaciation. On palaeomagnetic evidence the Ordovician south pole was in northwest Africa (McElhinny & Luck 1970; Whittington & Hughes 1972). Regions with the *Hirnantia* fauna in Asia, northern Europe and North America were situated much closer to the palaeoequator than to the pole during that time. Southern China, Kazakhstan and Kolyma may have been within the temperate zone, or even subtropical zone, according to palaeomagnetic data or other evidence (Morel & Irving 1978; Scotese *et al.* 1979; Seslavinsky 1979). It is also clear that the distribution of the *Hirnantia* fauna might not be restricted to one hemisphere. The fauna was apparently distributed far beyond the area of influence of the late Ordovician glaciation, into temperate and even subtropic climatic belts.

A much more diverse *Hirnantia* fauna than the typical one has been observed in Bohemia, Västergötland, Yunnan, Sichuan and Hubei. Here it is generally composed of 13 to 20 brachiopod taxa with a diversity greater than one would expect if it were a cold water fauna of the type described from the Malvinokaffric Realm in the Silurian and Devonian (Boucot *et al.* 1969; Boucot 1975). As yet no highly diversified *Hirnantia* fauna has been found in the cold water regions of North Africa and neighbouring areas.

A typical *Hirnantia* fauna comprising *Dalmanella testudinaria, Aphanomena* sp., *Coolinia* sp., *Plectothyrella crassicosta, Dorytreta* n. sp., and *Hindella crassa incipiens,* associated with *Dalmanitina,* has been found to occur in a 1.5 m thick argillaceous limestone in Yanzikou, Bijie in north-western Guizhou, south-western China (Rong 1979). It is associated with many solitary corals, such as *Brachyelasma, Streptelasma, Grewingkia, Borealasma, Crassilasma, Siphonoplasma, Pycnactics, Paramplexoides, Singkiangolasma, Lambeophyllum,* and *Kenophyllum* (Ho 1980). Rugose corals, in part the same genera, also occur in the Borenshult fauna in Östergötland, Sweden, where there are also some elements of the *Hirnantia* fauna. A similar rugose coral fauna with some associated tabulates, such as *Palaeofavosites, Schedohalysites* and *Propora,* is known from an argillaceous limestone of the Kuanyinchiao beds in Leijiatun, Shiqian in north-eastern Guizhou (Yang Sheng-wu, pers. comm. 1982). The abundance of corals of southern China seems to cast doubt on the view that this *Hirnantia* fauna lived exclusively in a cold water regime.

Of special interest is the occurrence of the *Hirnantia* fauna in bioclastic, argillaceous limestones and bituminous limestone in many localities in south-western China (Rong 1979). The intimate association of the *Hirnantia* fauna with the upper part of the Chair of Kildare reef limestone at Kildare, Ireland and with oolitic limestones in the Hirnant beds at Aber Hirnant, North Wales is also known (Wright 1968). The presence of oolite indicates that the limestone was deposited in shallow water at an estimated water temperature of at least 25 to 27°C (Jaanusson 1973). Moreover, Bahaman-type sediments (Beales 1958; Bathurst 1971; Jaanusson 1973), such as peloids and ooids, occur in the *Dalmantina* Beds in Västergötland (Stridsberg 1980) together with the highly diversified *Hirnantia* fauna (Bergström 1968). Modern bahamitic sediments have been described by Newell *et al.* (1960) and Purdy (1963). Therefore, the author considers it more likely that the *Hirnantia* fauna did not necessarily live only in cold water. It probably extended into the temperate and even subtropical zones during the latest Ordovician, although these zones would have been influenced indirectly by the glacial events, accompanied by a significant eustatic lowering of sea-level (Sheehan 1973) and a cooling of the oceans (Jaanusson 1979).

The above discussion seems to suggest that the ecologic tolerances of the main elements of the *Hirnantia* fauna, such as *Hirnantia, Kinnella, Paromalomena, Eostropheodonta* and *Plectothyrella,* were much broader than previously implied. Other members of the fauna, such as *Dalmanella, Aphanomena, Cliftonia, Leptaena* and *Leptaenopoma* may have expanded to the regions near the equator associated with *Dolerorthis, Brevilamnulella, Stegerhynchus, Eospirigerina* and *Dictyonella,* which are almost absent in the typical *Hirnantia* fauna. Interestingly, an approximately contemporaneous *Holorhynchus* brachiopod fauna is located immediately to the north of the known limits of the *Hirnantia* fauna in Eurasia. It is possible that the *Holorhynchus* fauna lived in a warmer water environment than the *Hirnantia* fauna, although in central Sweden, the two are mixed (Jaanusson, per. comm. 1978).

Acknowledgements

I am grateful to Prof. Mu En-zhi, who generously provided the graptolite data for correlation of the *Hirnantia* fauna in China and to Prof. V. Jaanusson who gave encouragement, corrected the manuscript and provided valuable comments. Prof. A. J. Boucot and Prof. P. Copper also critically read the manu-

script and suggested improvements. Mr H.-A. Nakrem kindly redrew the text figures. Thanks are due to Drs. Yang Sheng-wu and Gu Cheng-dong for their kind help during the preparation of the manuscript.

References

Amsden, T. W. 1971: Late Ordovician–early Silurian brachiopods from the central United States. *Mem. Bur. Rech. geol. minier. 73, Colloque Ordovicien-Silurien,* Brest, Sept. 1971, 19–25.

Amsden, T. W. 1974: Late Ordovician and early Silurian articulate brachiopods from Oklahoma, southwestern Illinois and eastern Missouri. *Oklah. Geol. Surv. 119,* 1–154.

Apollonov, M. K., Bandaletov, S. M. & Nikitin, I. F. (eds.) 1980: *The Ordovician–Silurian boundary in Kazakhstan.* 300 pp, 61 pls. Nauka Kazakh. SSR Publ. House, Alma-Ata.

Bassett, D. A., Whittington, H. B. & Williams, A. 1966: The stratigraphy of the Bala district, Merionethshire. *J. Geol. Soc. Lond. 122,* 219–271.

Bathurst, R. G. C. 1971: *Carbonate sediments and their diagenesis.* 620 pp. Elsevier, Amsterdam.

Beales, F. W. 1958: Ancient sediments of Bahaman type. *Amer. Assoc. Petrol. Geol. Bull. 42,* 1845–1880.

Bennacef, A., Beuf, S., Biju-Duval, B., DeCharpal, O., Gariel, O. & Rognon, P. 1971: Examples of cratonic sedimentation: Lower Paleozoic of Algerian Sahara. *Amer. Assoc. Petrol. Geol. Bull. 55,* 2225–2245.

Bergström, J. 1968: Upper Ordovician brachiopods from Västergötland, Sweden. *Geol. et Palaeontol. 2,* 1–35.

Berry, W. B. N. & Boucot, A. J. 1973: Glaco-eustatic control of Late Ordovician–Early Silurian platform sedimentation and faunal changes. *Geol. Soc. Amer. Bull. 84,* 275–284.

Beuf, S., Biju-Duval, B., DeCharpal, O., Rognon, P., Gariel, O. & Bennacef, A. 1971: Les gres du Paleozoique inferieur au Sahara-sedimentation et discontinuites, evolution structural d'un craton. *Inst. Franc. Petrol. -Sci. et Tech. du Petrol. 18,* 1–464.

Boucot, A. J. 1975: *Evolution and extinction rates controls.* Elsevier, Amsterdam.

Boucot, A. J., Johnson, J. G. & Talent, J. A. 1969: Early Devonian brachiopod zoogeography. *Geol. Soc. Amer. Spec. Pap. 119,* 1–106.

Ghang Mei-li 1982: *Hirnantia* fauna of the Uppermost Ordovician in Yichang, Hubei. *Acta Paleont. Sinica 20* (6), 557–566.

Chang Wen-tan 1964: *Ordovician System of China.* Science press, Beijing.

Cocks, L. R. M. 1972: The origin of the Silurian *Clarkeia* shelly fauna of South America, and its extension to West Africa. *Palaeontology 15,* 623–630.

Cocks, L. R. M., Brunton, C. H. C., Rowell, A. J. & Rust, I. C. 1970: The first Lower Palaeozoic fauna proved from South Africa. *J. Geol. Soc. Lond. 125,* 583–603.

Cocks, L. R. M. & Copper, P. 1981: The Ordovician-Silurian boundary at the eastern end of Anticosti Island. *Can. Jour. Earth Sci. 18,* 1029–1034.

Cocks, L. R. M. & Price, D. 1975: The biostratigraphy of the Upper Ordovician and Lower Silurian of South-west Dyfed, with comments on the *Hirnantia* fauna. *Palaeontology 18,* 703–724.

Destombes, J. 1976: The Ordovician of the Moroccan Anti-Atlas. *In* Bassett, M. G. (ed.): *The Ordovician System:* proceedings of a Palaeontological Association Symposium, Birmingham, Sept. 1974, 411–416. University of Wales Press and National Museum of Wales, Cardiff.

Dore, F. & Legall, J. 1972: Sedimentologic de la 'Tillite de Feuguerolles' (Ordovicien superieur de Normandie). *Bull. Soc. geol. Fr. 14,* 201–211.

Fairbridge, R. W. 1971: Upper Ordovician glaciation in northwest Africa? Reply. *Bull. Geol. Soc. Amer. 82,* 269–274.

Ge Zhi-zhou, Rong Jia-yu, Yang Xue-chang, Liu Geng-wu, Ni Yu-nan, Dong De-yuan & Wu Hong-ji, 1979: The Silurian system in Southwest China. *In The Carbonate Biostratigraphy of Southwest China,* 155–220. Science Press, Beijing.

Harper, D. A. T. 1981: The stratigraphy and faunas of the Upper Ordovician High Mains Formation of the Girvan district. *Scott. J. Geol. 17,* 247–255.

Havliček, V. 1971: Brachiopodes de l'Ordovicien du Maroc. *Not. et Mem. Serv. Geol. 230,* 1–135.

Havliček, V. 1976: Evolution of Ordovician brachiopod communities in the Mediterranean Province. *In* Bassett, M. G. (ed.): *The Ordovician System:* Proceedings of a Palaeontological Association Symposium, Birmingham, Sept. 1974, 349–358. University of Wales Press and National Museum of Wales, Cardiff.

Havliček, V. 1977: Brachiopods of the order Orthida in Czechoslovakia. *Rozpr. Ustr. ust. geol. 44,* 1–327.

Havliček, V. & Massa, D. 1973: Brachiopodes de l'Ordovicien superieur de Libye occidentale. Implecations stratigraphiques regionales. *Geobios 6,* 267–290.

Ho Xin-yi. 1980: Tetracoral fauna of the Late Ordovician Guanyinqiao Formation, Bijie, Guizhou Province. *Prof. Pap. Stratigr. Palaeont. 6,* 1–45.

Ingham, J. K. 1977: The Upper Ordovician Trilobites from the Cautley and Dent districts of Westmoreland and Yorkshire. *Palaeontogr.* Soc. Monogr. (3), *89–121.*

Ingham, J. K. & Wright, A. D. 1970: A revised classification of the Ashgill Series. *Lethaia 3,* 233–242.

Jaanusson, V. 1973: Aspects of carbonate sedimentation in the Ordovician of Baltoscandia. *Lethaia 6,* 11–34.

Jaanusson, V. 1979: Ordovician. *In* Orbinson, A. & Teichert, C. (eds.): *Treatise on Ivertebrate Paleontology, Part A, Introduction + Biogeography and Biostratigraphy,* A136–A166. University of Cansas Press.

Jaeger, V. H., Havlicek, V. & Schönlaub, H. P. 1975: Biostratigraphie die Ordovizium/Silur Grenze in den Sudalpen. Ein Beitrag zur Diskussion um die *Hirnantia* Fauna. *Ver. Geol. Bundes.* 4, 271–289.

Kielan, Z. 1960: Upper Ordovician trilobites from Poland and some related forms from Bohemia and Scandinavia. *Palaeont. Polonica 11,* 1–198.

Koren', T. N. & Sobolevskaya, R. F. 1977: A new standard succession of graptolite assemblages at the Ordovcian/Silurian boundary (North-eastern USSR). *Dokl. Akad. Nauk SSSR, 236,* 950–953.

Koren', T. N., Sobolevskaya, R. F., Mikhajlova, N. F. & Tzai, D. T. 1979: New evidence on graptolite succession across the Ordovician-Silurian boundary in the Asian part of the USSR. *Acta Palaeont. Polonica 24,* 123–136.

Lamont, A. 1935: The Drumock Group, Girvan; a stratigraphical revision with descriptions of new fossils from the lower part of the group. *Trans. Geol. Soc. Glasgow 19,* 288–334.

Lespérance, P. J. 1974: The Hirnantian Fauna of the Perce area (Quebec) and the Ordovician-Silurian boundary. *Amer. J. Sci. 274,* 10–30.

Lespérance, P. J. & Sheehan, P. M. 1976: Brachiopoda from the Hirnantian stage (Ordovician–Silurian) at Perce, Quebec. *Palaeontology 19,* 719–731.

Lespérance, P. J. & Sheehan, P. M. 1981: Hirnantian fauna in and around Perce, Quebec. *In* Lesperance, P. J. (ed.): *Subcommission on Silurian stratigraphy. Ordovician–Silurian Boundary Working Group. Field Meeting, Anticosti-Gaspe, Quebec.* Vol. II: Stratigraphy and Paleontology, 231–245.

Lu Yan-hao. 1959: *Subdivision and correlation of the Ordovician rocks of South China.* Proceedings of special summaries of Geological fundamental data of China, no. 2, 1–123. Science Press, Beijing.

Lu Yan-hao & Mu En-zhi. 1980: *Boundaries of the Ordovician System in China.* Scientific Papers on Geology for International Exchange prepared for the 26th International Geological Congress. 4. Stratigraphy and Palaeontology. Publishing House of Geology, Beijing.

Marek, L. & Havlicek, V. 1967: The articulata brachiopods of the Kosov Formation (Upper Ashgillian). *Vest. Ustr. ust. geol. 42,* 275–284.

McElhinny, M. W. & Luck, G. R. 1970: Paleomagnetism and Gondwanaland. *Science 168,* 830–832. New York.

Mikhajlova, N. F. 1970: On the discovery of *Glyptograptus persculptus* (Salter) in the *Dalmanitina* Beds of Kazakhstan. *Izv. Akad. Nauk Estonian SSR, Ser. Chem. Geol. 19,* 177–178.

Morel, P. & Irving, E. 1978: Tentative paleocontinental maps for the early Phanerozoic and Proterozoic. *J. Geol. 86,* 535–569.

Mu En-zhi. 1962: *Silurian System of China,* 1–95. Science Press, Beijing.

Mu En-zhi 1974: Evolution, classification and distribution of Graptoloidea and Graptodendroids. *Scientia Sinica 17* (2), 227–238.

Mu En-zhi & Ni Yu-nan. In press: Uppermost Ordovician and Lowermost Silurian graptolites from the Xainza area of Xizang (Tibet) with discussion on the Ordovician–Silurian boundary. *Palaeontologia Cathayana 1.*

Mu En-zhi, Zhu Zhao-ling, Chen Jun-yuan & Rong Jia-yu. 1978: The Ordovician strata in the vicinity of Shuanghe, Changning district of Sichuan. *Acta Stratigr. Sinica 2,* 105–121.

Nanjing Institute of Geology and Palaeontology, Academia Sinica, 1974: *The Handbook of stratigraphy and palaeontology in Southwest China,* 1–454, 202 pp. Science Press, Beijing.

Neuman, R. B. 1968: Paleogeographic implications of Ordovician shelly fossils in the Magog belt of the Northern Appalachian region. *In* Zen, E. A., White, W. S., Hadley, J. B. & Thompson, J. B., Jr. (eds.): *Studies of Appalachian Geology: Northern and Maritime,* 35–48. Intersience Publ., New York.

Ni Yu-nan, Cheng Ting-en, Cai Chong-yang, Li Guohua, Duan Yan-xue & Wang Ju-de. 1982: The Silurian rocks in Western Yunnan. *Acta Palaeont. Sinica, 21.*

Ni Yu-nan, Xu Han-kui & Cheng Ting-en. 1981: Boundary of Ordovician and Silurian in the Xainza area, Xizang. *Jour. Stratigr. 5,* 146–147.

Nikitin, I. F. 1972: *Ordovician of Kazakhstan. Pt. I. Stratigraphy.* Nauka Kazakh. SSR, Publ. House, Alma-Ata.

Nikitin, I. F. 1976: Ordovician–Silurian deposits in the Chu-Illi Mountains (Kazakhstan) and the problem of the Ordovician–Silurian boundary. *In* Bassett, M. G. (ed.): *The Ordovician System:* Proceedings of a Palaeontologifal Association Symposium, Birmingham, Sept. 1974, 293–300. University of Wales Press and National Museum of Wales, Cardiff.

Oradovskaya, M. M. & Sobolevskaya, R. F. (eds.) 1979: *Guidebook to field excursion to the Omulev Mountains, Tour VIII,* Problem: "The Ordovician–Silurian Boundary." XIV Pacific Science Congress, 1–100. Magadan.

Pickerill, R. K. & Brenchley, P. J. 1979: Caradoc marine benthic communities of the south Berwyn Hills, North Wales. *Palaeontology, 22,* 229–264.

Reed, F. R. C. 1915: Supplementary Memoir on new Ordovician and Silurian fossils from the Northern Shan States. *Palaeont. Indica (N.S.) 6,* 1–122.

Rickards, R. B. 1979: New information on some Ordovician–Silurian boundary sections in Great Britain. *Izv. Akad. Nauk Kazakh. SSR, Geol. ser. 4,* 103–107.

Rong Jia-yu. 1979: The *Hirnantia* fauna of China with comments on the Ordovician–Silurian boundary. *Acta Stratigr. Sinica 3,* 1–8.

Rukavishnikova, T. B., Tokmacheva, S. G., Salin, B. A., Sevriugin, N. N., Poltavtzeva, N. V. & Timush, A. V. 1968: New data on the Late Ordovician and Early Silurian stratigraphy in the Chu-Illi Mountains. *Dokl. Akad. Nauk SSSR, 183.*

Schönlaub, H. P. 1971: Palaeo-environmental studies at the Ordovician/Silurian Boundary in the Carnic Alps. *In* Colloque Ordovicien-Silurien, Brest, Sept. 1971. *Mem. Bur. Rech. Geol. Min. 73,* 367–378.

Scotese, C. R., Bambach, R. K., Barton, C., Voo, R. V. D. & Ziegler, A. M. 1979: Paleozoic base maps.

Jour. Geol. 87, 217–277.

Seslavinskiy, K. B. 1979: Ordovician and Siilurian climates and global climatic belts. *Internat. Geol. Rev. 21,* 140–152.

Sheehan, P. M. 1973: The relation of Late Ordovician glaciation to the Ordovician–Silurian changeover in North American brachiopod faunas. *Lethaia 6,* 147–154.

Sheehan, P. M. 1979: Swedish Late Ordovician marine benthic assemblages and their bearing on brachiopod zoogeography. *In* Gray, J. & Boucot, A. J. (eds.): *Historical Biogeography, Plate Tectonics, and the Changing Environment,* 61–73. The Oregon State University Press.

Sheehan, P. M. & Lesperance, P. J. 1981: Brachiopods from the White Head Formation (Late Ordovician–Early Silurian) of the Perce region, Quebec, Canada. *In* Lesperance, P. J. (ed.): *Subcommission on Silurian stratigraphy. Ordovician–Silurian Boundary Working Group. Field Meeting, Anticost, Gaspe, Quebec 1981. Vol. II. Stratigraphy and Paleontology,* 247–256.

Sheng, Xin-fu (Sheng, S. F.). 1964: Upper Ordovician trilobite faunas of Szechuan-Kweichow with special discussion on the classification and boundaries of the Upper Ordovician. *Acta Palaeont. Sinica 12.*

Stridsberg, S. 1980: Sedimentology of Upper Ordovician regressive strata in Västergötland. *Geol. För Stockh. Förh. 102,* 213–221.

Temple, J. T. 1965: Upper Ordovician braciopods from Poland and Britain. *Acta Palaeont. Polonica 10,* 379–450.

Temple, J. T. 1968: The Lower Llandovery (Silurian) bravhiopods from Keisley, Westmoreland. *Palaeontogr. Soc. Monogr. 122,* 1–58.

Whittington, H. B. & Hughes, C. P. 1972: Ordovician geography and faunal provinces deducted from trilobite distribution. *Phil. Trans. Roy. Soc. B. 263,* 235–278.

Williams, A. & Wright, A. D. 1981: The Ordovician–Silurian boundary in the Garth area of southwest Powys, Wales. *Geol. Jour. 16,* 1–39.

Wright, A. D. 1968: A westward extension of the Upper Ashgillian *Hirnantia* fauna. *Lethaia 1,* 352–367.

Zhang Ming-shao (Chang, M. S.) & Sheng Xin-fu (Sheng, S. F.) 1958: The Ordovician formations along the Szechuan-Kweichow border. *Acta Geol. Sinica 38,* 326–342.

Zhang Wen-tang, Chen Xu, Xu Han-kui, Wang Jungeng, Lin Yao-kun & Chen Jun-yuan. 1964: *Silurian of Northern Guizhou. Paleozoic rocks of northern Guizhou,* 79–110. Nanjing Inst. of Geol. and Palaeont., Academia Sinica.