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WUFENGIAN (ASHGILLIAN) GRAPTOLITE FAUNAL DIFFERENTIATION AND ANOXIC ENVIRONMENT IN SOUTH CHINA

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Summary

A well-developed Wufengian (Ashgillian) graptolite fauna occurs in the central and south China areas which belong to the same plate, the South China Plate. The graptolite fauna of central China (Yangtze platform) was first studied by Mu (1945, 1954, 1974), who, together with his

* Both are contributors of results from their palaeontological and stratigraphic researches on the Upper Ordovician section at Guting, Chongyi County, south Jiangxi.

colleagues, is now carrying on a systematic palaeontological study of the Wufengian graptolites from all sections of the Yangtze platform. In the past twenty years, the writers have investigated and sampled many Upper Ordovician sections and localities in South China. On the basis of these sections which have been mostly published, the writers have summarized the Wufengian graptolite assemblages, the biofacies, lithofacies and confacies belts, the black shale and the anoxic paleoenvironment. Here illustrated are the Wufengian graptolites from Xing'an and Lingui Counties of Guangxi, Chongyi County of Jiangxi, and Jiangshan County of Zhejiang.

Distribution of the Wufengian Graptolite Fauna

The Wufengian graptolite fauna in the Upper Yangtze River Valley consists of 25 genera and more than 100 species (Mu and Lin, 1984), which 21 genera have been published or reported. This fauna is mostly of a high diversity, containing both cosmopolitan and endemic forms which extend from the *Dicellograptus szechuanensis* Zone (W_2) to the *Tangyagraptus typicus* Zone (W_3) of the Early to Middle Wufengian (Chen and Lenz, 1984), and only part of it has been described (Yin and Mu, 1945; Mu, 1945, 1954; Mu *et al.*, 1974; Mu and Lin, 1984; Wang *et al.*, 1983). Some contemporaneous graptolite faunas were recently described from Zhejiang and Anhui (southeast of the Yangtze platform), including the late Wufengian (Ashgillian) graptolites described by Yang Da-quan (1983) and Ge Mei-yu (1984) from the Yankou beds of northeastern Zhejiang, and the Wufengian (Ashgillian) graptolites described by Li Ji-jin (1984) from southern Anhui. The following graptolites are illustrated in Textfigures 1 and 2 as a supplement.

1. In Xing'an and Lingui Counties, Northern Guangxi:

There have been found from the flysch deposit of the Tianlingkou Formation *Dicellograptus szechuanensis* Mu, *D.* cf. *complanatus* Lapworth, *D.* ex gr. *complanatus arkansasensis* Ruedemann, *D. tenuiculus* Mu *et al.*, *D. excavatus* Mu, *Orthograptus intermedius* Elles and Wood, *Climacograptus latus* Elles and Wood, *C. longispinus supernus* Elles and Wood, *C. longispinus hvalross* Ross and Berry, *Amplexograptus suni* (Mu), *A. disjunctus yangtzensis* Mu *et al.*, and *Pararetiograptus sinensis* Mu, ranging from the *Amplexograptus disjunctus yangtzensis* Zone (W_1) to the *Dicellograptus szechuanensis* Zone (W_2) (Chen *et al.*, 1981).

2. At Guting, Chongyi County, Southern Jiangxi:

Dicellograptus cf. *complanatus* Lapworth, *Climacograptus longispinus supernus* Elles and Wood, *Orthograptus* cf. *amplexicaulis* (Hall) were collected from the Bed 7 of the Gaocaodi Formation (Upper Ordovician) which consists of silty slate with a few sandstone and conglomerate beds (Text-figs. 1—3).

3. At Changwu, Jiangshan County, Western Zhejiang:

Dicellograptus cf. *complanatus* Lapworth, and *Orthograptus* cf. *abbreviatus* Elles and Wood were identified by Lu and Mu (in Zhang, 1962) from the type locality in the Changwu Formation which comprises 280 m of yellow-greenish shale and thin sandstone beds. Recently, Han Nai-ren found *Climacograptus* sp. (Text-fig. 2) from the same locality. These graptolites indicate the *Dicellograptus szechuanensis* Zone (W_2) in age, and are associated with the trilobites *Corrugatagnostus*, *Telephina*, and *Ampyxinella*; and the brachiopods *Eospirigerina*, *Kassinella*, *Christiania*, *Sowerbyella*, *Strophomena*, *Oxoplecia*, and *Phynchotrema*. In a contemporaneous graptolite fauna from Lin'an, Anji, Dexing, and Chun'an Counties of western Zhejiang, there have been found *Dicellograptus ornatus* Elles and Wood, *Climacograptus* aff. *longispinus supernus* Elles and Wood, *C.* aff. *angustus* (Perner), *Orthograptus abbreviatus* Elles and Wood, *Paraorthograptus* sp., and *Amplexograptus* sp.

Biofacies, Lithofacies, and Confacies Belts

The concept of facies goes back to Gressly (1839) who used the term facies (Latin for aspects) to emphasize different but contemporaneous rock types and faunas. Dunbar and Rogers (1957) extended the sense of this term to define a definite stratigraphic unit both in lithologic and in biologic aspects, such as *lithofacies* and *biofacies*. The term biofacies also refers to some local larger live assemblage or biota which are more or less limited by environmental controls. Warme and Hantzschel (1979, in Faibridge and Jablonski, 1979) proposed that the term biofacies should be a special combination of species in every habitat, representing the result of adaptation to environmental conditions.

In the epicontinental sea which covered a large part of the sea in Ordovician, different lithofacies were arranged as adjoining belts in coincidence or partially in coincidence with the distribution of biofacies. Considering the interrelationship between lithofacies and biofacies, Jaanusson (1976, 1982) proposed the concept of a *confacies belt* with the following definition: "Each belt may represent a single, but, more commonly, several contemporaneous lithofacies, and within most belts there is a second-order faunal differentiation (biofacies) which mostly follows that of lithofacies. Confacies belts obviously reflect a broad ecologic zonation controlled by environmental factors which also influence the depositional conditions. Jaanusson and Bergstrom (1980) found that the pattern of differentiation, which relatively shares the boundaries between confacies belts, is similar in both the Baltoscandia and Appalachian regions. Mu (1974) suggested that the different types of graptolite faunas were the result from different modes of life in adapting to various past environments.

Therefore palaeoecological differentiation was the main factor which resulted in different faunal regions. Recently, Mu (1984) suggested three graptolite ecological differentiations in the Ordovician of China, among which the last differentiation, the Wufengian, was a moderate one. It seems that the ecological differentiation of Mu (1974, 1984), means the same thing as the biofacies concept of Dunbar and Rodgers (1957) and the second-order faunal differentiation of Jaanusson (1976, 1982).

The Wufengian graptolite fauna of South China was distributed in a sea basin restricted within the old land mass from the east, south and west. On the north, the South China Sea faced an open sea area. The geological map shows the North China Platform as an old land, in contact with the Yangtze Platform in Late Ordovician time. However, this configuration only reflects the collision of the South China plate with the Tarim-sino-korean plate, not indicating the existence of an old land in the north of the South China plate during the Ordovician; that is to say, the South China Sea was not bounded on the north by any land in this time.

There are three Wufengian confacies belts in south China: the Yangtze confacies belt (I), the Xiangwan (Hunan-Anhui) confacies belt (II), and the Zhegan (Zhejiang-Jiangxi) confacies belt (III). The Yangtze confacies belt covers a large area of the Yangtze River Valley, containing only one biofacies characterized by the high diversity Wufengian graptolite, lithologically with three lithofacies belts, namely, from east to west: the southwestern Sichuan marl facies belt (I_1); the Upper Yangtze River Black graptolitic shale belt (I_2) and the Lower Yangtze River graptolitic shale and chert belt (I_3). The Xiangwan confacies belt includes the southern and central parts of Hunan, most part of Jiangxi, southern Anhui and western Zhejiang, characterized by a low diversity Wufengian (Ashgillian) graptolite fauna containing only some cosmopolitan forms, lithologically in coincidence with a flysch facies belt, while the Zhegan confacies belt extends along the western edge of the Cathaysian land or along the area crossed by the Zhegan Railway. In latter belt, the biofacies is characterized by a shelly fauna with a few cosmopolitan graptolites at one locality (the Changwu Formation, Jiangshan County, Zhejiang), while the lithofacies belt-detrital facies with restricted carbonate rocks in Yushan (Jiangxi) and Jiangshan (Zhejiang) covers the same area as the biofacies (Text-fig. 4).

1. Yangtze confacies belt (I)

The Upper Yangtze belt (I_2) is characterized by a high diversity graptolite fauna including both cosmopolitan and endemic forms. A comparison of faunal diversities in the different lithofacies and confacies belts is shown in Textfigure 5. According to the study of the Benthic Assemblage (Rong, 1984), the brachiopod *Poliomena* fauna (pre-Wufengian) indicated a BA4—5 environment while the *Hirnantia* fauna indicated a BA2—3 environment. Analogically, the Wufengian graptolite fauna in I_2 corresponds to a GA3—4 environment (Chen and Qiu, 1986). The term of Graptolite Aseemblage (GA) was designated by Chen (1986) to define graptolite assemblages at different depths. The controlling factors of such a high diversity graptolite fauna in belt I_2 can be described as follows:

1) An enclosed or bay-like paleogeographic setting. The enclosed sea was a favourable environment for the development of reducing and stagnant water. Since the anoxic environment predominated at the bottom of the water mass, the benthic shelly fauna was almost non-existent. Only a few planktonic inarticulate brachiopods and swimming trilobites (*Triarthrus*) lived in the superficial water (the photic zone) with a rich graptolite and radiolarian fauna. The Wufengian *Triarthrus* is found in Hongya County of western Sichuan, Songtao County of northeastern Guizhou and Nanzheng of southern Shaanxi, all close to an old landmass (text-fig. 4). The planktonic graptolites in most graptolitic black shales in the Upper Yangtze River belt (I_2) are relatively well-preserved and crowded together on the bedding surfaces. There was no biodisturbance from the sea bottom because the shelly epifauna could not adapt itself to such an anoxic and reducing type of environment.

2) During the latest Ordovician, the old land mass emerged round the Upper Yangtze Sea (Mu *et al.*, 1981), providing fresh water (through rivers) for the sea basin resulting in low salinity superficial waters. Possibly, the low density of the superficial or fresh water layer isolated the bottom water.

3) Since the Upper Yangtze platform was rather stable during the Wufengian, the Wufeng Formation was the result of a rather deep and tranquil deposition with a low rate of sedimentation. The writers studied as many as 46 sections from the Upper Yangtze and found that the average thickness of the Wufeng Formation was 7.72 m. The black siliceous or carbonaceous shale and chert are very stable with no lithochange across the platform, and usually with horizontal lamination well-developed in the chert. All these indicate a very weak dynamical condition in the water mass. As stressed by Mu (1974), tranquility of sea water is indispensable for graptolites.

Southwest from Belt I_2, a Wufengian marl with a few black graptolitic shales (Daduhe Formation) was developed in the Lower Dadu River area, southwestern Sichuan (Luo and Yang, 1965). Cosmopolitan Ashgillian graptolites were dominant in this belt (I_1), such as *Climacograptus longispinus supernus* Elles and Wood, *Orthograptus abbreviatus* Elles and Wood, and *Dicellograptus szechuanensis* Mu. Lithologically, the Daduhe Formation changes rapidly across this belt. In Hongya and Hanyuan Counties, southwestern Sichuan, there are a few manganese beds to be intercalated in the marls. South from these counties, some detrital rocks occur in Meigu and Leibo Counties. Near the edge of the old land mass the Daduhe marls are absent, suggesting that the Daduhe Formation is indicative of a near-shore, shallow-water deposition. There the graptolites obviously lived in the superficial waters.

East from the Upper Yangtze belt (I_2), greyish, silty graptolitic shale and chert occur in the Lower Yangtze belt (I_3). The Wufengian Formation is still used to denote this rock unit. In comparison with the Upper Yangtze (I_2), the endemic forms decrease both in diversity and in abundance.

South from the Upper Yangtze the Wufengian black graptolitic shale thickens to 40 m along a line from Xiushui County in northwestern Jiangxi to Taoyuan and Anhua Counties in central Hunan, which might indicate the edge of the Upper Yangtze Belt (I_2).

2. Xiangwan confacies belt (II).

Southeast from the Yangtze confacies belt, a flysch facies belt occupies a large area from northern Guangxi to southern Anhui and western Zhejiang. This flysch deposit is more than 1,000 m in thickness, yielding only some cosmoplitan graptolites in a few thin black shale beds. At one locality (Ningguo County, southern Anhui), there also occurs *Diceratograptus* which is possibly on longer an endemic form since it has been reported by Chen and Lenz (1984) from Yukon, western Canada. In any case, the graptolite fauna of the Xiangwan belt belongs to a different species group or combination of species from the Yangtze faunas, and it also obviously indicates a different biofacies.

The variation in environments between these two confacies belts (Xiangwan and Yangtze) coincided with the graptolite faunal differentiation. Instead of the high diversity Wufengian graptolite fauna in the Yangtze belt (I), there occurs only a small number of cosmopolitan graptolites in the Xiangwan belt. This belt was located in a turbulent and highly dynamical environment characterized by a rapid flysch deposition. The endemic graptolites which were developed in the Yangtze confacies belt possibly adapted themselves to turbulent or high dynamical conditions. Only the cosmopolitan forms persisted because they had possesed a relatively high tolerance (unlike the stenohaline and stenothermal organisms) or a high intensity of the rhabdosome. These forms mainly include those of the *Dicellograptus complanatus* group, the *Orthograptus amplexicaulis* group, and the *Climacograptus longispinus* group, which adapted themselves not only to the South China turbulent slope and basin environments, but also to the contemporaneous deltaic environment in northern Appalacbians (Berry, 1977). They became adaptable to the turbidity of flysch depositional conditions in the Tasmaina Geosyncline (Victoria) (Hills and Thomas, 1953), and cottoned to the Ashgillian deep-sea basin environment in South Scotland.

Based on the study of the graptolitic facies in Victoria, Hills and Thomas (1953) suggested: "The graptolites, living in pelagic water at and near the surface, were killed by the cloud of turbid water laden with clay and fine silt, developed in the upper parts of the turbidity currents". Early in the fifties, Kuenen and Migliorini (1950) experimented with turbidity currents in reservoirs, and learned that while the major part of the load was transported along the bottom, the current was dispersed towards the top. This principle also serves to explain flysch deposition.

In the spring of 1984, Zhao Xiang-lin, Lin Yao-kun, Yang Da-quan and one of the writers (Chen Xu) studied the turbidity deposits of the Yuqian Formation (Upper Ordovician) in Lin'an County, northwestern Zhejiang, and found that a series of incomplete Bouma sequences were developed in this formation. Ashgillian cosmopolitan graptolites were present in thin-bedded black shale beds. The turbidity deposits of the Yuqian Formation belong to facies C and D of Richi-Lucci (1975)'s pattern (see Howell and Normark, 1982). Possibly, this kind of turbidity deposit was developed not only in the Yuqian Formation, but also in the Shikou Formation of southwestern Jiangxi and the Tianlingkou Formation of northern Guangxi. Morevor, some sedementary structures flow casts, and trace fossils (such as *Granularia yuqianensis, Helminthopsis tumluensis, Paleodictyon* cf. *inperfactum* and *Chondrites*) were also developed in the Yuqian Formation. These trance fossils were developed not only along the continental slope, but also at the platform edge or basin slop (Yang Shi-fu, personal communication, 1985).

3. Zhegan confacies belt (III).

This belt lithologically covers a rapid area. Two lithological types are developed in this belt. One type is a shallow water platform carbonate deposit (Sanjushan Formation) with reef limestone, biostromes and mudstones bearing brachiopods, among which the *Tcherskidium* and *Sowerbyella-Zygospira* communities indicate a BA 2—3 depth environment. Another type is a detrital deposit (Changwu Formation) (Chen Xu *et al.*, 1987), which was developed between the platform deposits and might have extended to the east slope of the Xiangwan basin.

4. Yunkai area.

A thick detrital deposit was developed in the Yunkai area and the mountains between Guangxi and Guangdong. These detrital rocks (Shanjian Formation) bear a few brachiopods such as *Sowerbyella* and *Strophomena*?. In northern Guangdong and central Guangxi, and the area between Yunkai and Zhegan, the Upper Ordovician is absent. Possibly, the Yunkai and Zhegan basins were separated by a continental area during the Late Ordovician when the Kangdian area (Yunnan-central Guizhou) and the Cathaysian old landmass were connected with each other.

Black Shale and Anoxic Environment

A review of the works on the lower Palaeozoic black shales has been made by Berry and Wilde (1978). Clarke (1904) suggested that the present-day Black Sea may serve as an appropriate model for the Early Palaeozoic black shale facies representing accumulations in deep and stagnant basins. Grabau (1917, 1929) considered the black shales to be lagoonal deposits, which were widespread in geological history; he also suggested that the graptolitic shales were formed in intertidal mud flats. Twenhofel (1939) postulated that the black shales were deposited in shallow shelf seas where the tidal range was slight and the lands were lying low. Ulrich and Ruedemann (1911) and Ruedemann (1947) suggested that the graptolites might have thrived in surface waters which were oxygenated and habitable. Beneath the surface water there was a sort of poison water beginning from 200 m below sea level. Strom (1939) considered that the organic-rich mud in the stagnant deep waters was accumulated under anaerobic conditions, black graptolitic shales were found not only in the land-locked waters, but also in the big seas or even in the oceans. He pointed out that in the tropical part of the present Atlantic Ocean, the water layers at depths from 50 to 1,200 m are anoxic.

Berry and Wilde (1978, 1982) extended Strom (1979)'s idea in combination with the Palaeozoic climatic fluctuations, and called their hypothesis the ventilation of the oceans with time. Wind-mixing resulted in a ventilated superficial layer of the ocean. Ventilation of deep ocean waters might have primarily resulted from high latitudes during the glaciation. Cold and oxygen-laden waters sank and spread towards the equator through deep oceans. By upward mixing, the midwaters might have been ventilated progressively. Loss of oxygen resulted from the decay and decomposition of organisms that lived in surface water and sank to the bottom after death. The minimum depth of oxygen would increase during the times of glaciation, but it would decrease during the non-glacial times. The Ordovician black shale was distributed worldwide during Caradocian, with the wide spread of the Huloan black graptolitic shale (the Hulo Formation in southeast China and the Miaopo Formation in central China). While the Silurian shale was distributed worldwide during the Early Llandoverian, with the deposition of the Lungmachian black graptolitic shale (the Lungmachi Formation of central China and the Lientan Formation of south China).

The Wufengian (Ashgillian) South China plate was situated in a low latitude area and enclosed by lands from which the oxygenated fresh water emptied into the basin. The superficial water might be ventilated from the intermixing fresh water, and the ventilated surface waters formed a suitable habitat for the rich graptolite fauna, radiolarians, planktonic inarticulate brachiopods, swimming trilobites and nautiloids. The Yangtze platform was restricted to and completely different from the open seas, with a depth not greater than 200 m. There was no deep water ventilated by deep cold water from a high latitude area. However, there was the shelly *Hirnantia-Dalmanitina* fauna in the Upper Yangtze in the latest Ordovician. The main controlling factor here would be the eustatic sea level lowering, with a large part of the Yangtze platform bottom coming up to the ventilated surface water layer. In the areas close to the old land mass such as Zunyi and Songtao Counties in northern to northeastern Guizhou, the *Hirnantia-Dalmanitina* beds first appeared from the late *Tangyagraptus typicus* Zone (W_3) during periods of sea-level lowering. Further, the *Hirnantia-Dalmanitina* fauna in the central Upper Yangtze occurred during the latest Wufengian, i.e., the *Diplograptus bohemicus* Zone (W_6). As an additional factor, the minimum oxygen compensation depth would increase during the latest Ordovician when the glaciation reached its climax. Even in the tranquil Upper Yangtze sea, the wind or wave mixing might be relatively strong. This also might have benefited surface water ventilation and led to the depth of oxygen minimum lowering.

Berry and Wilde (1978) believed that the anoxic condition in the shelf might be temporarily increased due to the upwelling during non-glacial intervals (Text-fig. 5). This would lead to a sudden mass extinction of the graptolites. Such a principle may explain the crowding of graptolites in local bedding planes separated by barren rocks. During the Ashgillian glaciation, the upwelling might not have been as strong as in the non-glacial intervals. However, it was valuable especially at the edge of the platforms and the troughs or basins. In the Upper Hartfell Shale of southern Scotland, the *D. complanatus* Zone consists of only two graptolitic bands, the *D. anceps* Zone five bands, and the *C. extraodinarius* Zone one band (Willams, 1982). In South China, especially in the Xiangwan belt (II), the thin-bedded graptolitic shales are intercalated with the thick flysch beds. Obviously, this sort of accumulation such as in southern Scotland and Belt II of south China has less value for correlation. That is why the writers believe that the Wufengian graptolite zones in the Upper Yangtze platform may serve as the world standard for international correlations.

讣 告

中国科学院地学部委员,中国古生物学会副理事长穆恩之教授因病于一九八七年四月八日在宁逝世,终年七十岁。

OBITUARY

It is helely announced that Professor Mu En-zhi, member of the Division of Earth Science, Academia Sinica, and Vice-President of the Palaeontological Society of China has passed away in Nanjing on April 8, 1987 because of heart disease.