Annales de la Société géologique de Belgique, T. 116 (fascicule 2), 1993, pp. 359-378 Octobre 1994

BIOSTRATIGRAPHY AND SEQUENCE STRATIGRAPHY AT THE DEVONIAN-CARBONIFEROUS TRANSITION IN SOUTHERN CHINA (HUNAN PROVINCE). COMPARISON WITH SOUTHERN BELGIUM

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(12 figures)

ABSTRACT. In southern China, the Devonian-Carboniferous transitional strata are well exposed in several sections representative of different sedimentary environments. The siliciclastic-carbonate deposits have been investigated in the Oujiachong, Malanbian and Sujiaping sections situated in central Hunan. The Devonian-Carboniferous boundary coincides with the boundary between the Menggongao and the overlying Malanbian Formation. Study of different fossil groups (conodonts, foraminifera, ostracods, spores, brachiopods, rugose and tabulate corals) gives coherent biostratigraphical results which form the framework for reconstruction of the sedimentological evolution. Strong similarities are observed with southern Belgium allowing biostratigraphical and sequence stratigraphical correlations between the two distant sedimentary basins.

KEYWORDS: Devonian-Carboniferous boundary, S-China (Hunan), S-Belgium, biostratigraphy, conodonts, foraminifers, spores, ostracods, brachiopods, rugose and tabulate corals, sedimentology, sequence stratigraphy

RESUME. Dans le Sud de la Chine, les couches de passage du Dévonien au Carbonifère sont bien exposées dans de nombreuses coupes qui reflètent des environnements sédimentaires différents. Les dépôts mixtes carbonatés-siliciclastiques ont été étudiés dans les coupes de Oujiachong, Malanbian et Sujiaping situées dans le centre du Hunan. La limite dévono-carbonifère coïncide avec la limite entre les Formations de Menggongao et de Malanbian. L'approche biostratigraphique par des groupes fossiles différents (conodontes, foraminifères, spores, ostracodes, brachiopodes, coraux rugueux et tabulés) a donné des résultats cohérents qui servent de support pour retracer l'évolution sédimentaire. De fortes similitudes sont observées avec le Sud de la Belgique, permettant d'établir des corrélations stratigraphiques et séquentielles entre ces bassins sédimentaires très éloignés.

MOTS-CLES: Limite Dévono-Carbonifère, S-Chine (Hunan), S-Belgique, biostratigraphie, conodontes, foraminifères, spores, ostracodes, brachiopodes, coraux rugueux et tabulés, sedimentologie, stratigraphie séquentielle.

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1. INTRODUCTION

In the context of a cooperation between the Chinese Academy of Geological Sciences and the Belgian Geological Survey, the Devonian-Carboniferous (D-C) transitional strata have been investigated in the Ouijiachong, Malanbian and Sujiaping sections, situated in the Hunan Province (southern China; Fig. 1): This area was characterized by siliciclastic-carbonate deposits representing a nearshore environment south of the Jiangnan Oldland (Fig. 2; Hou, 1991). The aim of this study is to discuss the biostratigraphy of the D-C transitional strata and to compare their sedimentary evolution with that of the classic Dinant area in southern Belgium (Fig. 3).

The D-C boundary is identified by the first appearance of the conodont *Siphonodella sulcata* within the evolutionary lineage from *Siphonodella praesulcata* to *Siphonodella sulcata* (ICS, Working Group on the Devonian-Carboniferous boundary, 1979). In southern China, this criterion has been applied with success in the Muhua section (Hou *et al.*, 1985; Ji, 1987a) and in the Nanbiancun section (Yu *et al.*, 1987), both displaying pelagic facies. Unfortunately, the index conodont species are absent or extremely scarce in nearshore and platform facies. Moreover, the D-C boundary can not satisfactorily be drawn in these facies using the appearance of other guide fossils. On an eurasian scale, the platform and nearshore deposits of the D-C transition are biostratigraphically characterized by a rapid extinction of Devonian-type fossils. The colonization by the Carboniferous taxa is slow and generally occured after a period which was extremely unfavorable for the main fossil groups (Simakov *et al.*, 1983; Conil *et al.*, 1986; Conil *et al.*, 1988; Gilissen, 1988; Van Steenwinkel, 1988, 1993). Clearly, the distribution of the fauna around the D-C transitional deposits is related to sea-level fluctuations. A better understanding of the stratigraphy can thus only be achieved by an integrated biostratigraphical and sedimentological approach. Particularly, the use of relative sea-level curves appears to be an efficient tool for correlations (Van Steenwinkel, 1988, 1990, 1992).

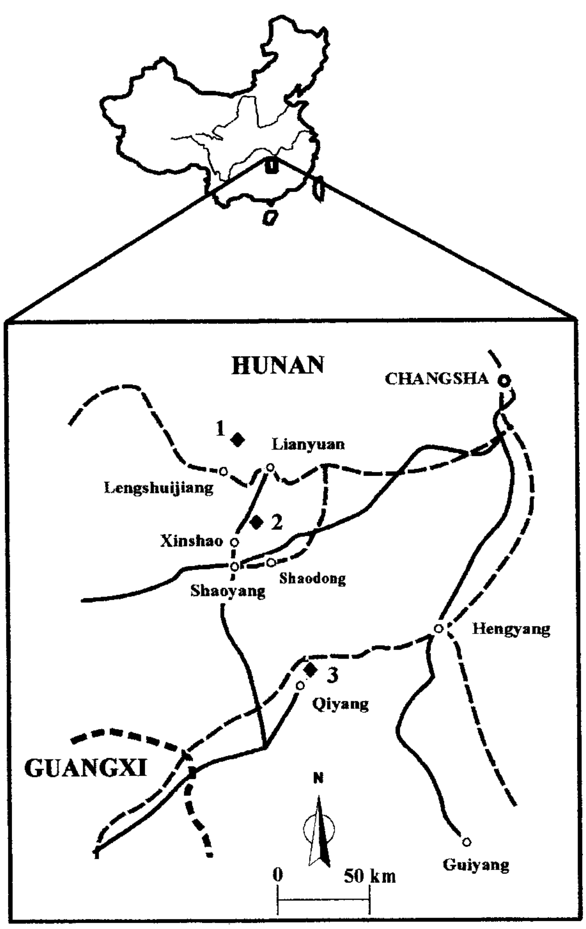

Figure 1. General location of the sections investigated. Main roads and railways are indicated respectively by continuous lines and pecked lines. 1. Oujiachong section; 2. Malanbian section; 3. Sujiaping section.

In Hunan, the position of the D-C boundary has been a matter of discussion for almost thirty years. The different opinions are summarized in figure 4. In the more recent papers, there has been disagreement between the results obtained from brachiopods, corals and foraminifers on the one hand, and from spores on the other hand. The first group indicated that the Menggongao Formation (*Cystophrentis* zone) was of late Devonian age (Tan *et al.*, 1987). Spores suggested a Lower Carboniferous age (post-*lepidophyta* assemblage; Streel, 1986; Gao, 1990).

2. LITHOSTRATIGRAPHY

In the Famennian and Tournaisian mixed siliciclastic-carbonate succession of central Hunan, ten lithostratigraphical units have been recognized (fig. 5). The Famennian includes, from bottom to top, the Changlongjie Shale, Tuzitang Limestone, Nitangli iron-bearing bed, Magunao Limestone, Oujiachong Sandstone, Shaodong and Menggongao Formations. The Malanbian, Tianeping and Doulingao Formations compose the Tournaisian. In southern Hunan, Tuzitang, Nitangli and Magunao merge into the Xikuangshan Formation and the Oujiachong Formation is reduced to a few metres. The Shaodong, Menggongao and Malanbian Formations are grouped into the Guiyang Formation forming a thick limestone sequence. Northward, in the Changsha-Ningxiang area, along the oldland, siliciclastic sediments dominate and lithostratigraphy is different.

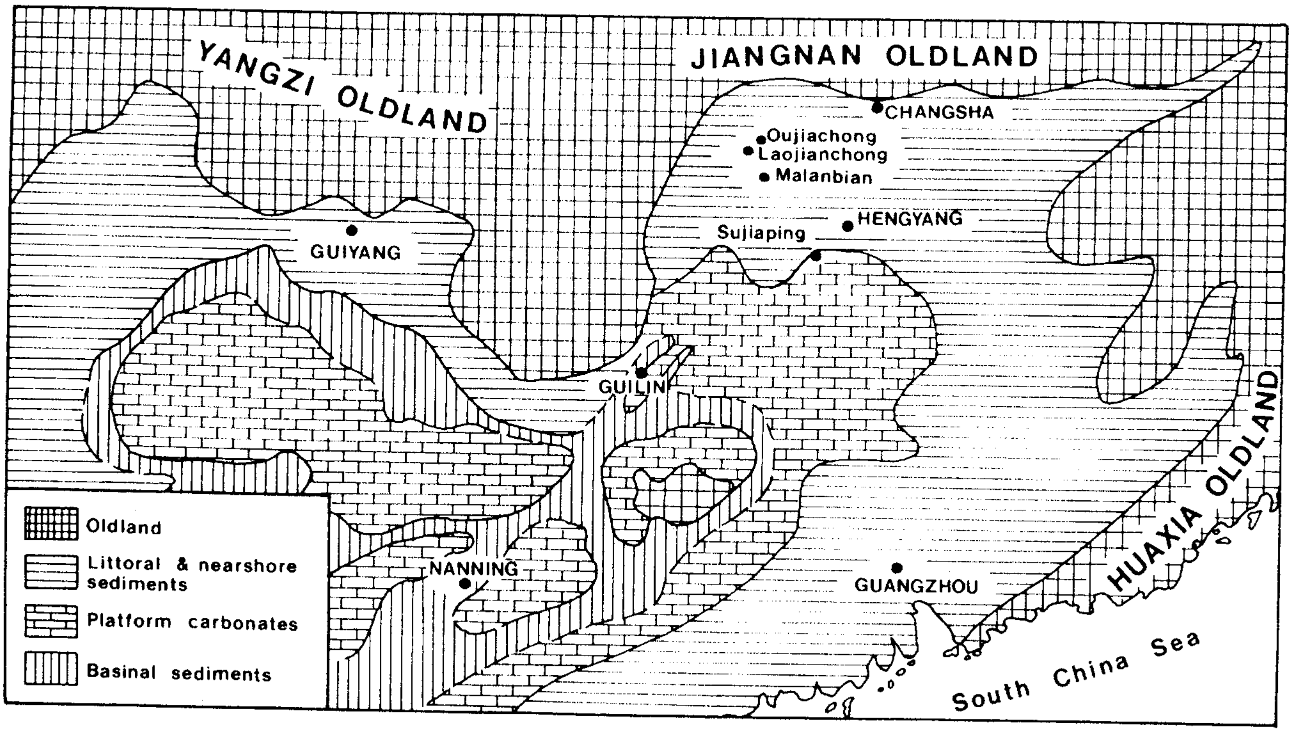

Figure 2. Paleogeographical map of southern China at the end of Devonian time (after Hou, 1991).

This paper will focuse mainly on the Menggongao and Malanbian Formations and partly on the underlying Shaodong and Oujiachong Formations and on the overlying Tianeping and Doulingao Formations.

The lithostratigraphical scheme has undergone important modifications in the past 30 years, which are partially reflected in figure 4. Several unit names have changed of stratigraphical rank. A synthesis of these changes is given by Tan *et al.* (in press) who specify the reference sections and document the lithological characters, extension, lateral variation and age of each formation. The text hereafter point out the main lithological characters and thickness observed in the investigated sections. A petrographical description will be given by Muchez (in press).

2.1. SHAODONG FORMATION

In the current sense, the Shaodong Formation has a thickness of about 44 m at Malanbian and 97 m at Oujiachong. It consists mainly of bioturbated siltstones, micaceous sandstones and shales, which incorporate thin beds and lenses of limestones. Macrofauna includes crinoids, echinoid spines, brachiopods, bivalves, bryozoans and solitary rugosa. The Shaodong Formation can easily be distinguished from the underlying Oujiachong Sandstone, which is more shaly and almost devoid of limestone. It is overlain by the Menggongao Formation in which limestones beds are numerous.

The Shaodong Formation is restricted to the Xikuangshan, Xinshao and Shaoyang areas in central Hunan. South of Qiyang, it merges into the lower part of the Menggongao Formation.

2.2. MENGGONGAO FORMATION

The Menggongao Formation, as defined by Tan *et al.* (1987) is an alternation of shales and limestones bounded by the Shaodong and Malanbian Formations. Its thickness in the reference section of Malanbian (Xinshao County) is 145 m. At Sujiaping, the Guiyang Formation which overlain the Oujiachong Formation (Tan *et al.*, 1987), can in fact be divided into the Menggongao (including the lateral equivalent of the Shaodong Formation) and Malanbian Formations. These terms are therefore prefered to the traditional undivided Guiyang Formation.

The Menggongao Formation consists of fining-upward limestone-shale sequences, graded limestone sequences, nodular and burrowed limestones, dark burrowed shales and siltstones. Brachiopods are common in shales. The carbonate content increases gradually from north to south.

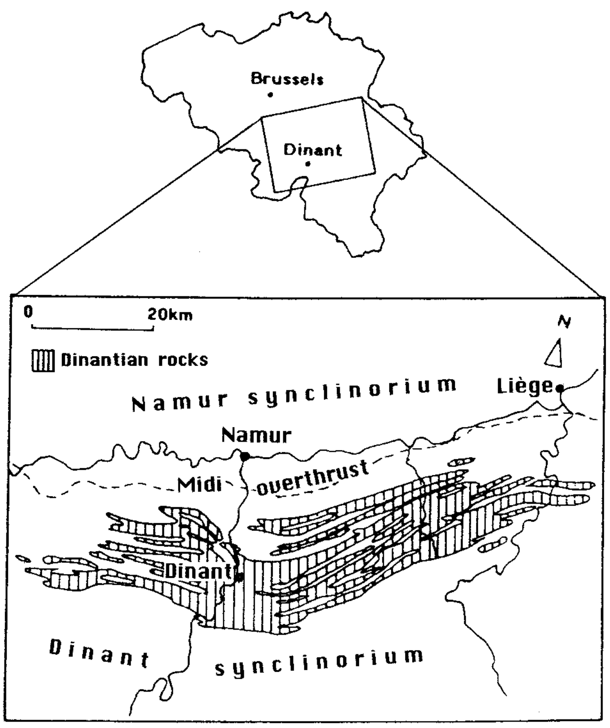

Figure 3. Location of the Dinant synclinorium in southern Belgium

In the Malanbian and Oujiachong sections, the Menggongao Formation is capped by a siliciclastic horizon and in the Sujiaping section, by a fenestral limestone bed.

2.3. MALANBIAN FORMATION

The Malanbian Formation is very well exposed in the type section of Malanbian (M), Xinshao County (Tan *et al.*, 1987) and in the Sujiaping section (S). Both sections have a similar thickness of about 65 m. It can be divided into three members which are not formally designated.

- The lower member (M, 40 m; S, 32 m) consists of poorly fossiliferous, thick bedded limestones with graded bedding. Oncoids and clasts are locally abundant. Some levels are strongly bioturbated. Burrows are dolomitized, forming a striped appearance of alternating limestones and dolomites. This feature can easily be recognized in the whole area, even in Guangxi.

- The middle member (M, 8 m; S, 11 m) is formed by an alternation of undulating thin bedded limestones and shales. Abundant macrofauna includes crinoids, rugose and tabulate corals and bivalves.

- The upper member (M, 18 m; S, 22 m) consists mainly of thick bedded limestones locally developing fining-upward sequences. Millimetre thick, irregular, shaly intercalations are present in the lower and middle part of this member. Crinoids, rugose and tabulate corals, gastropods, bivalves and oncoids are abundant. Bioturbation is locally important and affected by dolomitization.

2.4. TIANEPING FORMATION

The Tianeping Formation (Tan *et al.,* 1987) is poorly exposed in the Malanbian section where the thickness is about 39 m. In the Sujiaping section, its lowermost part is composed of calcareous shales, 2.2 m thick, overlain by a 7.5 m thick limestone bed. It is followed by an alternation of calcareous shales with thin bedded and lenticular argillaceous and dolomitic limestones. Macrofauna is represented mainly by crinoids, bivalves and bryozoa. Some rugose corals have been found in the Malanbian section where bed 119 has also yielded abundant tabulate corals. Sandstones and siltstones are generally predominant in the upper part of the Tianeping Formation.

2.5. DOULINGAO FORMATION

In the Malanbian section, the Doulingao Formation (Tan *et al.,* 1987) is very well exposed with a thickness of about 65 m. The following lithological characters have been recognized, from bottom to top :

- shales alternating with crinoidal dolomites and bioclastic fine-grained limestones;
- fine-grained dolomites and burrowed limestones;
- graded and burrowed limestones alternating with argillaceous dolomites; symmetrical ripples and hummocky-cross stratifications are locally developed; bivalves, rugose and tabulate corals and gastropods are abundant;
- fenestral fine-grained limestones.

3. BIOSTRATIGRAPHY

3.1. CONODONTS (Groessens, E.)

Conodonts are very rare in the D-C transition beds in the Hunan and Dinant area due to unfavourable facies. About hundred samples from the Malanbian, Oujiachong and Sujiaping sections have been collected and analysed by the authors and other investigators (Tan *et al.*, 1987), however only a limited amount of data has been obtained. Our knowledge

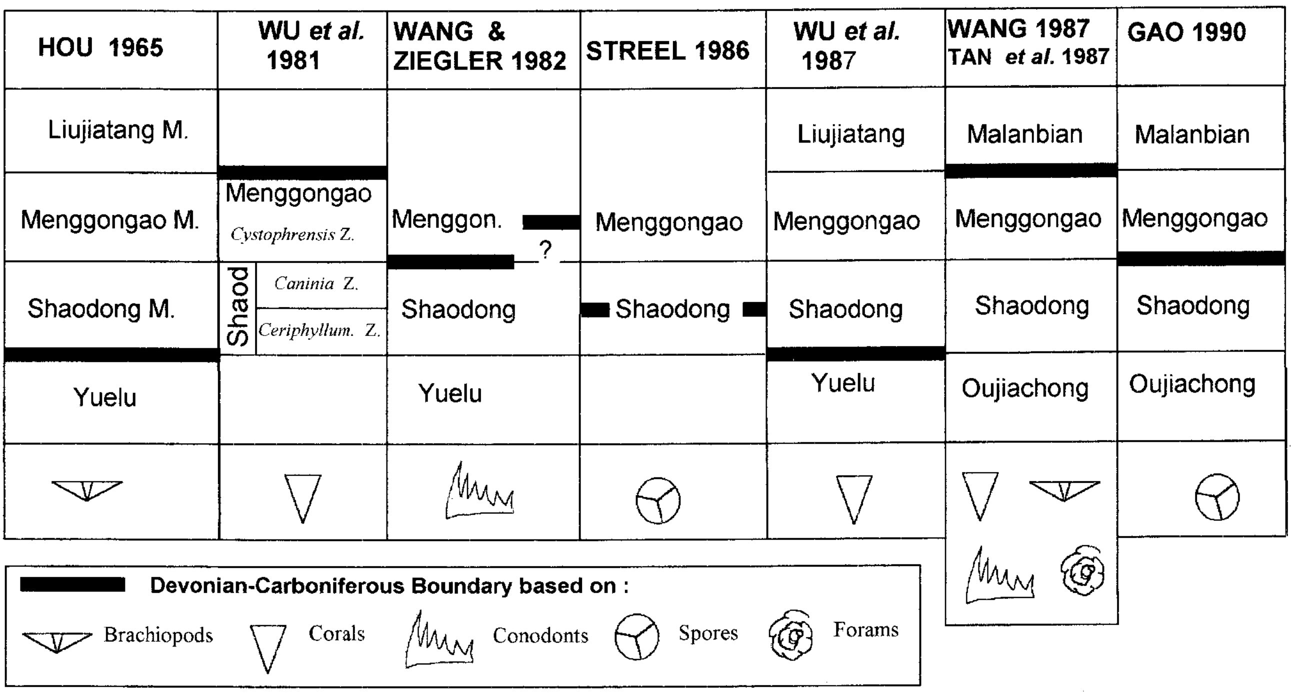

Figure 4. Overview of the literature on the position of the Devonian-Carboniferous boundary in southern China. Note that Wu *et al.* (1981) have recognized the Strunian age of the Shaodong Formation but consider that Strunian belongs to the Carboniferous system.

of the conodonts of Hunan relies largely on the publication of Tan *et al.* (1987) and two other papers (Ji, 1987b; Ji & Ziegler, 1992). The following conodont data have been summarized from literature and completed with new investigations. They are nevertheless useful in dating the D-C transitional strata.

No palmatolepid conodonts have been found in the Shaodong and Menggongao Formation. *Polygnathus obliquicostatus* appears at the base of the Menggongao Formation in the Malanbian section and occurs associated with *Spathognathus stabilis*, *S. planiconvexus*, *S. strigosus*, *Apatognathus varians*, *Hindeodella subtilis*, *H. croca*, *Ozarkodina immersa*, *Drepanodus circularis*, ... The species *Polygnathus obliquicostatus* is known to range from the *postera* to the *expansa* Zone in western Europe. The representative of the genus *Icriodus*, *I. costatus*, *Apatognathus varians*, *Ozarkodina* sp., *Spathognathodus* sp. and *Hindeodella* sp. occur approximately 40m below the top of the Menggongao Formation at Malanbian and 11.5m below the fenestral limestone at Sujiaping. *I. costatus* is believed not to range into the Carboniferous. Therefore, the limited conodont data indicate that the Menggongao Formation should be assigned to the Devonian.

As in the Dinant Basin, there exists a biostratigraphical interval near the D-C boundary without any significant fossil but characterized by the presence of calcispheres and the foraminifer *Earlandia*. The first *Siphonodella* of shallow water facies occurs in different stratigraphic positions above the siliciclastic beds or fenestral limestones at the top of the Menggongao Formation in the different sections. This specific *Siphonodella* group, different from that of pelagic facies, is characterized by an orally ornamented platform with a typical pseudokeel on the aboral side. It has been widely recognized in southern China. Dong (*in* Tan *et al.*, 1987) proposed a *Siphonodella levis* Zone based on the development of *Siphonodella levis* (Ni) in Malanbian and Sujiaping. This zone can be subdivided into three subzones. The first one is defined by the first occurrence of *Siphonodella levis*, 6m above the fenestral limestone in the Sujiaping section (bed 57). The second subzone is characterized by the appearance of *Siphonodella sinensis* Ji about 21.7 m above the siliciclastic beds in the Malanbian section and 8m above the fenestral limestone in Sujiaping. The third subzone is defined by the disappearance of *Siphonodella sinensis* and the co-occurrence of *S. levis*, *S. eurylobata*, *S. isosticha*, *S. qiyqangensis*, *Polygnathus* cf. *inornatus*, *P. inornatus rostratus*, *P. lobata* and *Dinodus* sp.. The appearance of the *Siphonodella levis* Zone is considered as a marker of the Carboniferous in shallow water facies and has been correlated with the *duplicata* to *isosticha-upper crenulata* Zones of the pelagic facies by Dong. In 1992, Ji and Ziegler studied in detail the phylogeny

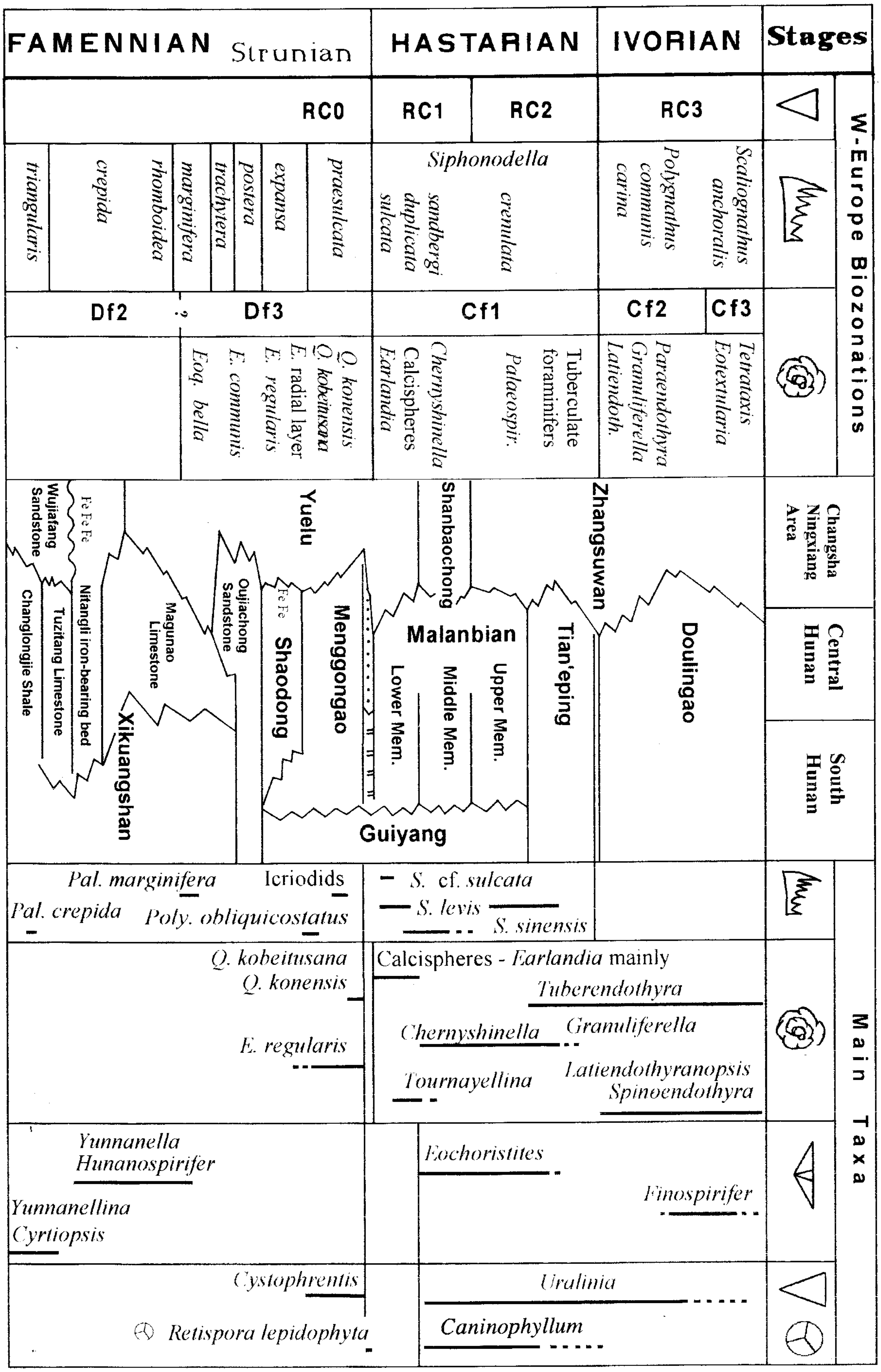

Figure 5. Upper Devonian and Lower Carboniferous stratigraphy in central Hunan.

and zonation of *Siphonodella* in shallow water facies. Their work is mainly based on material from southern China and Russia. Six *Siphonodella* zones have been proposed in southern China and have been correlated with those of the standard *Siphonodella*-based zonation (from *sulcata* to late *crenulata*). Doubtless, the discovery and zonation of the shallow water *Siphonodella* are very useful in dating and correlating the earliest Carboniferous shallow water facies.

Field work carried out in 1990 and 1991 has provided new data on the above discussed sections. The only good sample collected at Sujiaping (bed 73), almost 30m above the base of the Malanbian Formation contains *Polygnathus inornatus*, *Bispathodus aculeatus aculeatus* and *Siphonodella levis*. In the Oujiachong section, the uppermost part of the Menggongao Formation and the lower part of the Malanbian Formation have yielded only *Polygnathus communis communis*. Four metres above the base of the Malanbian Formation, an argillaceous level with limestone lenses contains in addition *Bispathodus plumulus*, *Clydagnathus cavusformis* and a fragmentary *Pseudopolygnathus*. *Siphonodella* cf. *sulcata* (a transition form showing transverse ridges on the anterior part of the platform) and other siphonodellids as well as *Polygnathus inornatus* have been recorded 3.6m higher. At Malanbian, the poor conodont fauna in the upper part of the Menggongao Formation is dominated by *Bispathodus aculeatus aculeatus*. *Siphonodella levis* has been found firstly about 40m above the base of the Malanbian Formation (bed 110).

3.2. FORAMINIFERS (Hance, L.)

Interesting foraminiferal assemblages have been found in the D-C transitional strata (fig. 6) giving important biostratigraphic constraints, helpful for correlations. These assemblages are documented in details by Hance (in press). Only the main elements are discussed hereafter.

In the lower part of the Menggongao Formation at Sujiaping, *Eoendothyra communis* (Rauzer-Chernousova, 1948) and *E. regularis* (Lipina, 1955) are associated with Tournayellinae and Septabrunsiininae. A specimen of *Rectoavesnella* has been found. In the upper part, *Quasiendothyra kobeitusana* (Rauser, 1948) and *Q. konensis* (Lebedeva, 1956) are present but scarce. The Menggongao Formation is capped by a fenestral bed, above which the lower 30 m of the Malanbian Formation have only yielded calcispheres and *Earlandia*. Very few plurilocular Foraminifera have been found in the upper part of the Malanbian Formation. They include *Chernyshinella glomiformis* (Lipina, 1948) and some *Septabrunsiina*. Only one specimen of *Palaeospiroplectammina* is reported from the uppermost part of the Malanbian Formation. A major change in the foraminiferal population is obvious in the lower part of the Tianeping Formation with the appearance of *Tuberendothyra* and *Granuliferella*.

In the Oujiachong section, the uppermost part of the Menggongao Formation has yielded an association dominated by Quasiendothyridae including *Q. kobeitusana*, *Q. konensis* and *Klubovella*. Tournayellidae are also well represented. The Menggongao Formation is capped by a sandstone bed. In the lower part of the overlying Malanbian Formation, only calcispheres and rare *Earlandia* are present.

At Malanbian, *E. communis* and *E. regularis* occur in the lower part of the Menggongao Formation. In the uppermost part of this formation, the foraminiferal population is dominated by Tournayellinae and Septabrunsiininae. *Latiendothyra parakosvensis* (Lipina, 1955) is common whereas representatives of the Quasiendothyridae are very rare and badly preserved as is *Avesnella*. The Menggongao Formation is capped by clastic sediments, 3,5 m thick, which have yielded the spore *Retispora lepidophyta* (see 3.3). Here also, the lower part of the Malanbian Formation is characterized by the abundance of calcispheres and *Earlandia* associated with a few specimens of *Tournayellina beata* (Malakhova, 1956). The upper part of the formation is richer with mainly Septabrunsiininae and Tournayellinae. At this level, fragments of large endothyrids with septal thickenings have been observed. The Tianeping Formation, badly exposed in this section has not yielded any biostratigraphic element. A much more diversified association occurs in the lower part of the Doulingao Formation including *Spinoendothyra*, *Granuliferella*, *Paraendothyra* and *Spinotournayella*.

The foraminiferal biostratigraphy of the three sections is summarized in figure 7 with references to the biozonation of Conil established in the Franco-Belgian Basin (CONIL *et al.*, 1977, 1991).

In the Sujiaping section, the lower part of the Menggongao Formation (including bed 33) can be assigned to the Df3γ subzone (guide : *E. regularis*). In the Oujiachong and Sujiaping sections, the uppermost part of this formation corresponds to the Df3ε subzone (guide: *Q. kobeitusana* and *Q. konensis*). The appearance of *Eoendothyra* with an incipient or incomplete hyaline radial layer has not been observed making the corresponding Df3δ subzone undetermined. In the Malanbian section, the upper part of the Menggongao Formation, below the clastic bed, displays a similar carbonate facies

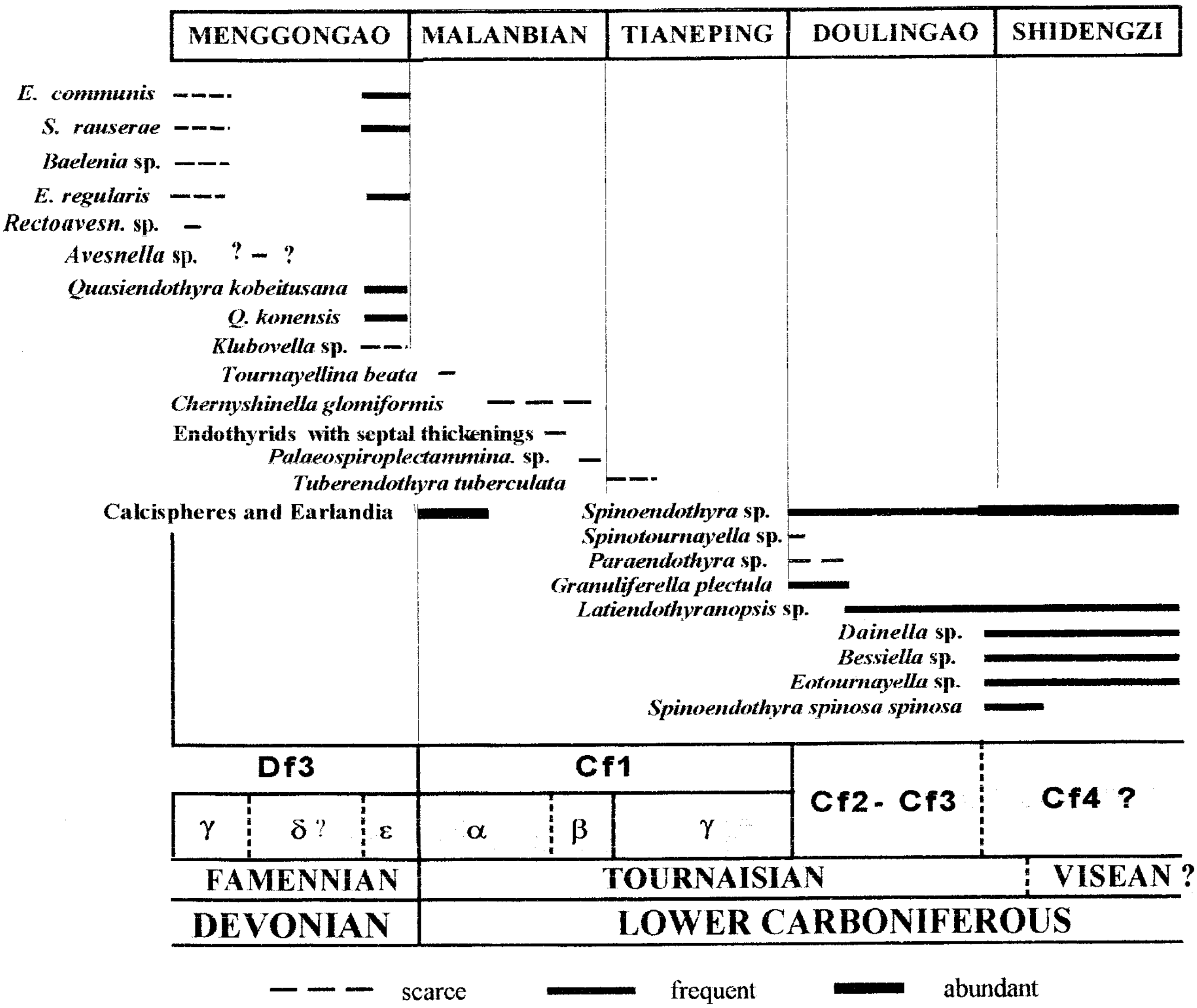

Figure 6. Distribution of the main foraminiferal elements in Upper Devonian and Lower Carboniferous formations of central Hunan. Foraminiferal zones Df3 to Cf4 from Conil *et al.* (1977, 1991).

but is probably older than Df3ε. *Q. kobeitusana* and *konensis* have not been recorded in spite of a great number of thin sections and moreover, *Avesnella* is present. In the Franco-Belgian Basin, this taxon seems restricted to the Df3δ subzone, but the very close genus *Rectoavesnella,* distinguished by its biserial development, is known from the Df3γ subzone (Conil & Lys, 1970, 1977) and has been found at this level at Sujiaping. The stratigraphical lower range of *Avesnella* could therefore also be Df3γ. A stratigraphical gap is suspected at Malanbian, which could include the Df3δ and part of the Df3ε subzones. Additional sampling in the middle and upper part of the Menggongao Formation is however required to confirm this hypothesis and to specify the correlations with the two other sections.

The Malanbian Formation covers the Cf1α and β subzones, testified by the presence of *T. beata*, *C. glomiformis* and *Palaeospiroplectammina*. The appearance of tuberculate foraminifers in the lower part of the Tianeping Formation indicates a Cf1γ subzone and can be compared with the *Tuberendothyra tuberculata* zone of North America (Brenckle & Groves, 1987).

A correlation can easily be made with other section situated in a similar palaeogeographical setting, to the west, in the Guangxi Autonomous Region and Guizhou Province (Conil *et al.*, 1988). In both regions, the quasiendothyrid population dissapears abruptly. Recolonization by plurilocular foraminifers is very slow and starts within an interval dominated by calcispheres and *Earlandia*. Fewer elements of the Cf1β-γ and Cf2 foraminiferal fauna have been recorded in the investigated sections of Hunan than in Guangxi and Guizhou where facies are more suitable for foraminifers.

The prolongation of the quasiendothyrid population into the Lower Carboniferous, documented in

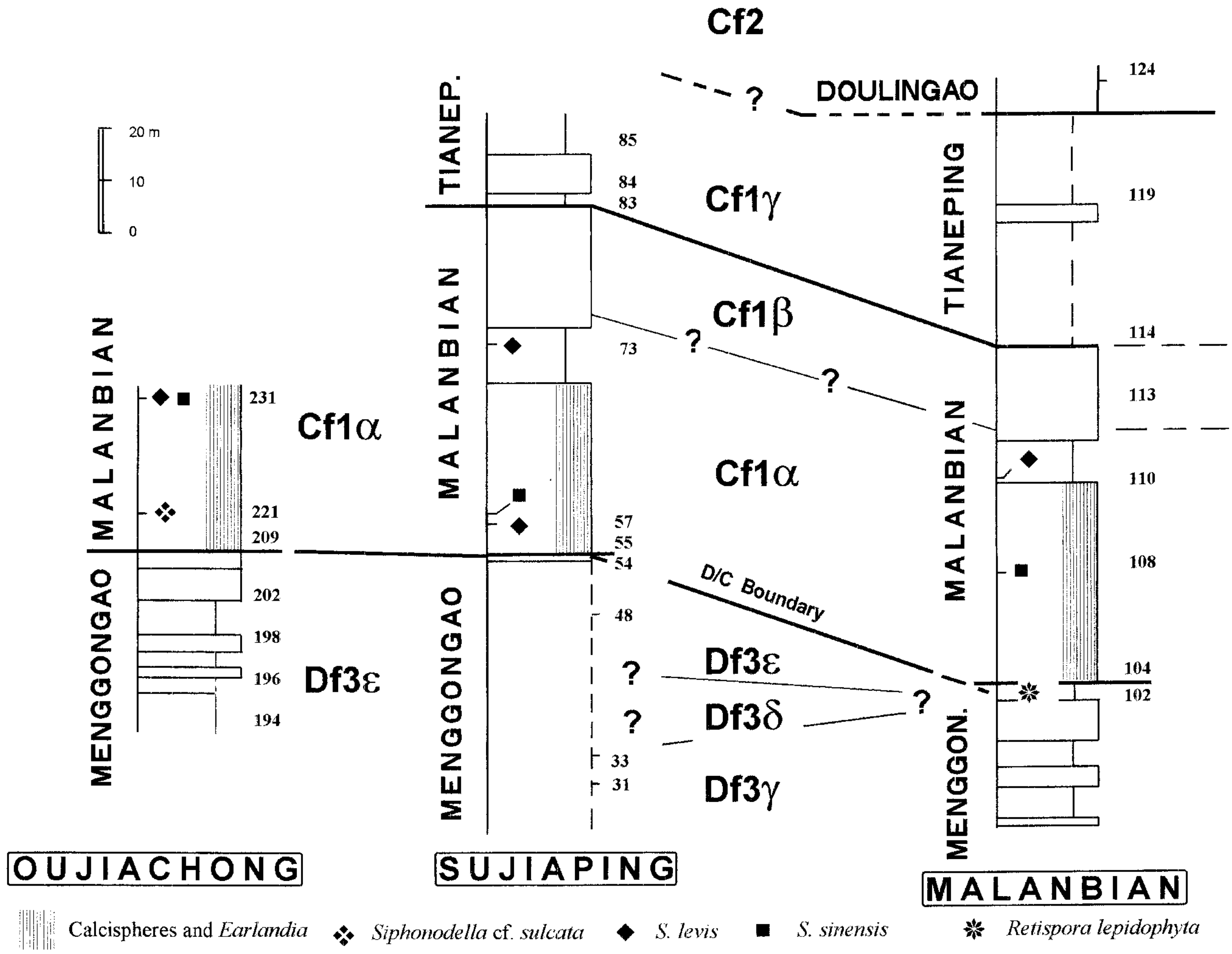

Figure 7. Correlation of the D-C transitional strata in Hunan.

the Omolon area of northeast Russia (*sandbergi* zone; Bushmina and Simakov, 1979; Conil *et al.*, 1982; Simakov *et al.*, 1983) and in Moravia of Czechoslovakia (*duplicata* zone; Kalvoda & Kukal, 1987), can not be confirmed in southern China. The closest relation between foraminifers and conodonts is given by Wang *et al.* (1987) in the Xiakou section c (Yishan County, Guangxi Autonomous Region), where *Quasiendothyra konensis* dissapears 20 cm below the incoming of *Siphonodella sulcata.* The simultaneous occurence of a post *lepidophyta* spore assemblage with stromatoporoids in the Baihupo section (Dushan County, Guizhou Province; Streel, 1986) suggested a parallelism with the Omolon and led Conil to suspect that quasiendothyrids also extended into the Lower Carboniferous (Conil *et al.*, 1988, fig. 2). Nevertheless, as most of the specimens of *Retispora lepidophyta* reported from the litterature are confused with an older taxon (see 3.3), the above mentioned assemblage could also be pre-*lepidophyta*.

A comparison between the D-C transitional strata in southern China (Hunan) and southern Belgium (Dinant area) based on foraminiferal biostratigraphy is proposed in figure 8 as working hypothesis. As already suggested by Hou (1965), the Menggongao Formation must be compared with the Etroeungt Formation. The Malanbian Formation corresponds to the Hastière (except lowermost part), Pont d'Arcole and Landelies Formations, whereas the Tianeping Formation can be considered as an equivalent of the Maredsous Formation.

3.3. PALYNOLOGY (Steemans, P., Streel, M. & Fang, X.-S.)

About 200 palynological samples have been collected from the studied sections. Most of the samples have yielded spores. Unfortunately the association displays a large predominance of miospore species which are known only from southern China. This indicates that a strong endemism affected the

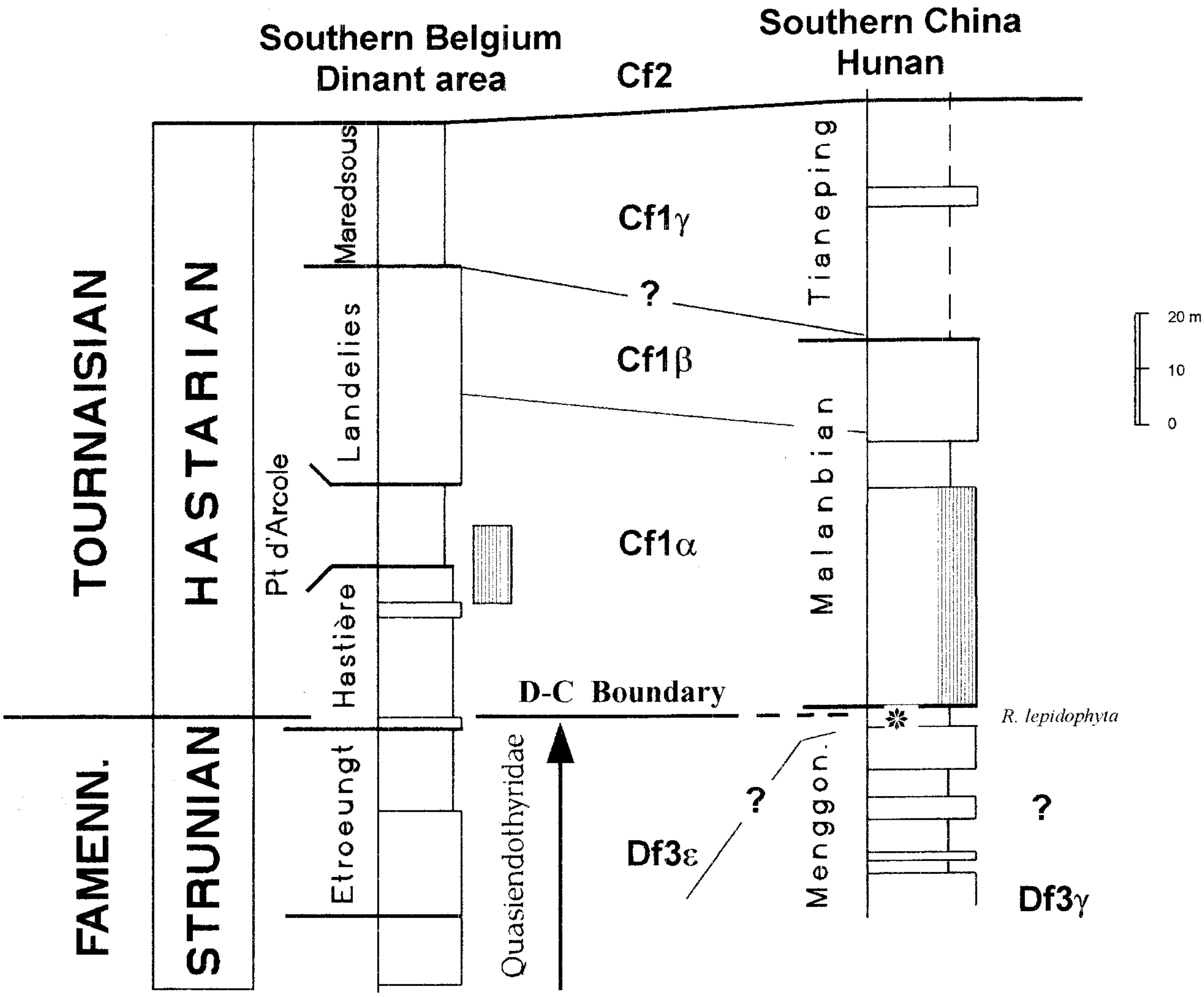

Figure 8. Tentative correlation of the D-C transitional strata of southern China and southern Belgium.

vegetation in this area during the Upper Devonian. Only in the Malanbian section, the palynological data allow a biostratigraphic correlation.

The main criteria for a biostratigraphic correlation is the presence of the species *Retispora lepidophyta* (Kedo) Playford 1976 in the 3.5m thick siliciclastic beds at the top of the Menggongao Formation (Fig. 9). The species has only been found in the first fifty centimeters of these siliciclastics. Below these beds, we have studied thirty samples from the Menggongao, Shaodong, Oujiachong and Magunao Formation. All samples lack *R. lepidophyta*. However, we determined many specimens of a miospore which corresponds to a new species which is morphologically very similar to *R. lepidophyta* but which belongs to a new monolete genus. The description of the new taxon will be given by Steemans *et al.* (in press).

This new species occurs firstly in the Oujiachong Formation and is very abundant in the Shaodong Formation. In the Menggongao Formation it becomes rare. In the lower part of the siliciclastic beds, this new species is absent. In the upper part it has been recognized in one sample (Fig. 8; Lazarus taxon or reworked palynomorphs). The latter sample is very rich in spores, but *R. lepidophyta* is absent. The new species has also been observed in the Oujiachong and Shaodong Formations in the Oujiachong section, in the Shaodong Formation in the Shaodong section and in the Oujiachong Formation in the Sujiaping section.

The absence of *R. lepidophyta* in these last formations invalidates the conclusions proposed by Streel (1986), which were mainly based on the publications by Gao (1981) and Hou Jipeng (1982).

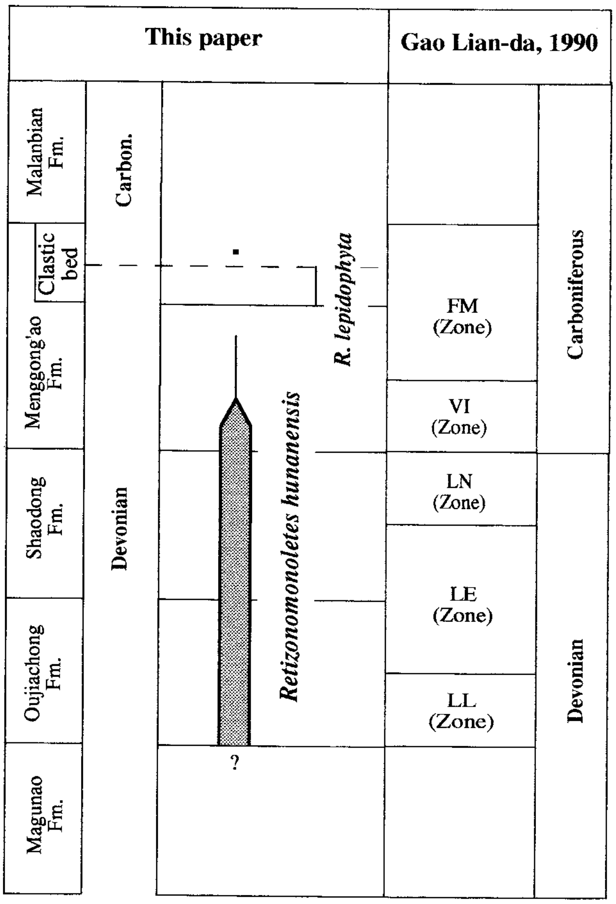

Figure 9. Biostratigraphical extensions of the species *Retispora lepidophyta* (Kedo) Playford 1976 and of the new Genus new species in the Malanbian section.

Retispora lepidophyta is known only from the upper part of the Devonian, i.e. the Strunian or approximately Wocklumian (Streel *et al.*, 1987). The base of the Oppel Zone LV is characterized by the first appearance of *R. lepidophyta* followed by *Apiculiretusispora verrucosa*. *R. lepidophyta* is also characteristic for the younger biozones LL, LE and LN. It disappears close to, but below the Devonian-Carboniferous boundary. Parallel with this biozonation, the evolution of the size of *R. lepidophyta* is a useful biostratigraphic criterium (Streel, 1966). The measured diameter ranges between 48 and 65µm with a mean of 57µm. This is close to the values of the «D zone» which corresponds to the LL-LE biozones. However, there are too few specimens of *R. lepidophyta* (10 specimens) to draw a reliable histogram of the spore sizes in the siliciclastic beds of the Malanbian section.

Although these results have to be treated carefully, we suggest that the basal part of the siliciclastics at the top of the Menggongao Formation belongs to the *lepidophyta* range-zone and probably to the LL-LE biozones. Therefore, these beds have a Strunian (Wocklumian) age. The disappearance of *R. lepidophyta* in the middle part of the siliciclastics would further suggest that the Devonian-Carboniferous boundary is situated within these beds. It also seems that the new species has been confused with *R. lepidophyta* in other sections in southern China, which led to a misinterpretation of the biostratigraphy (Fig. 8; Gao, 1990).

3.4. OSTRACODS (Coen, M.)

Ostracods corroborate the zonation based on conodonts, foraminifers and spores. Especially interesting is the occurrence of two species of Thuringian ecotype in the lower part of the Malanbian Formation (bed 215 and 216) in the Oujiachong section: *Amphissites blumenstengeli* Gründel 1962 = *A. similaris* Morey 1936, and *Villozona villosa villosa* (Gründel 1961).

Amphissites blumenstengeli is here considered as a junior synonym of *A. similaris* because of the similar unequal development of the lateral carinae. *A. blumenstengeli* ranges in Thuringia from the *Wocklumeria* to the *Gattendorfia* Stage. *A. similaris* was first described from the Chouteau Formation of Missouri, U.S.A. It is also known from the Banff Formation of Alberta, Canada (Green, 1963) and from the Bastakh Suite of the Lena delta, Yakutia, northern Siberia (Bushmina, 1970b). The Banff and the Chouteau Formations can be correlated (Green, 1963). The latter in turn correlates with the Upper Hastarian (Middle Tournaisian) of the Ardenne (Conil *et al.*, 1977; Webster & Groessens, 1991). The Bastakh Suite has a higher range (Bogush & Yuferev, 1991).

Villozona villosa villosa is an index fossil of the *Gattendorfia* Stage. Further comparisons can be made with *Kirkbya magna* Roth sensu Wang (1988a) from the Early Carboniferous Wangyou Formation at Baping, Guangxi (*sulcata* zone), *Kirkbya* sp. Green 1963 from the Banff Formation, Alberta, and *Kirkbya parva* Bushmina 1975 from the Kolyma and Omolon successions, NE Siberia. Conflicting evidences between conodonts and foraminifers make the Siberian data difficult to use. Faunal affinities are worth mentioning, however, as well as those derived from European and North American occurrences quoted previously. All the above evidences point to a Hastarian age (Cf1) for the lower part of the Malanbian Formation in the Oujiachong section. This is reinforced by the occurrence of *Pseudoleperditia* gr. *venulosa* in a lateral section. Only the right single valve of a juvenile specimen has been recovered. Precise comparison is thus difficult. However, the marked velar bend along the free margin makes that specimen resemble closely *P. poolei* Sohn in Wang

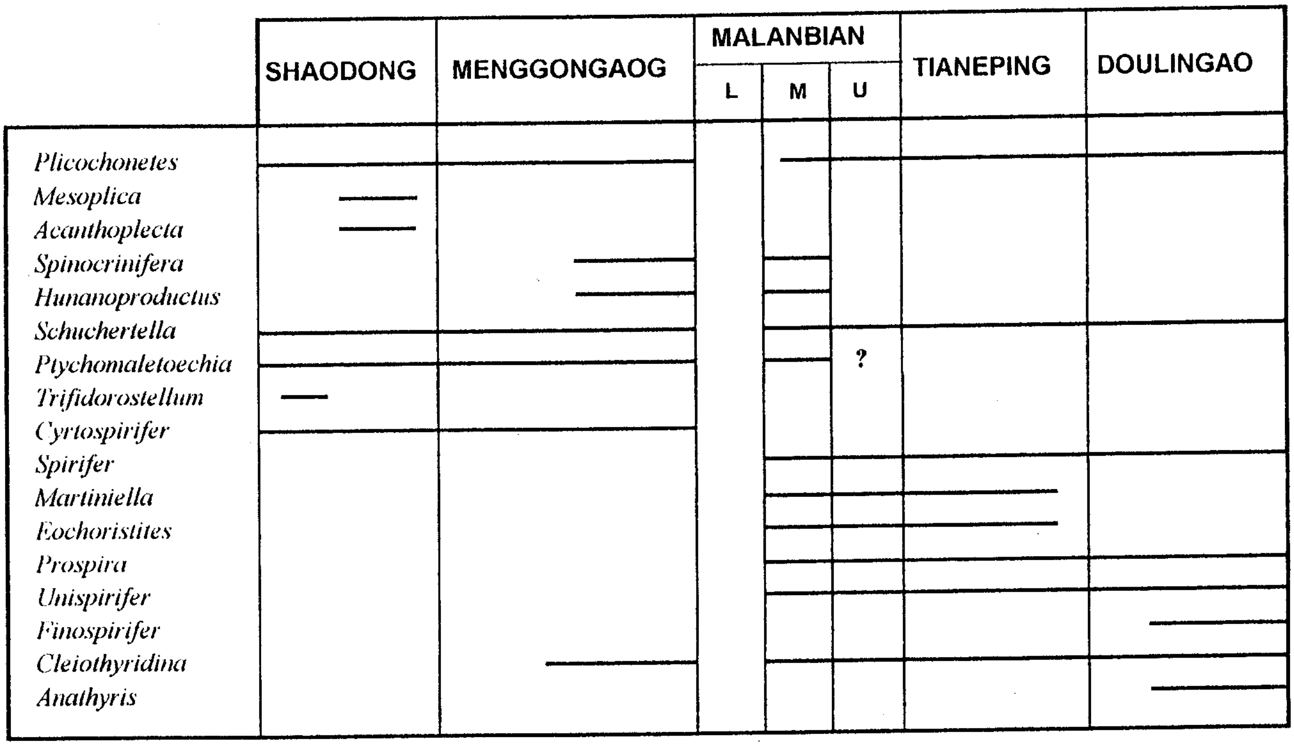

Figure 10. Distribution of the brachiopods in the Upper Famennian and Tournaisian strata of central Hunan.

(1988b) from the *duplicata* to *crenulata* zones at Nanbiancun.

Amphissites similaris has also been observed in the Tianeping Formation (bed 117) in the Malanbian section. *Villozona* are no longer present at this level suggesting that the Tianeping Formation can be correlated with the upper part of the Bastakh Suite of Siberia.

Another occurrence of potential interest is that, in bed 100 at Malanbian, of *Acratia insolita* Bushmina 1970a. *A. insolita* is known from the Devonian-Carboniferous transitional beds (Chingis Formation) in the Eltsov synclinorium, SW Siberia. *A.* cf. *evlanensis* sensu Wang (1988b) from the Middle *praesulcata* zone at Nanbiancun most probably represents the same species. It thus fits with the Devonian age of the Menggongao Formation as constrained by the occurrence of *R. lepidophyta* in the overlying strata.

3.5 BRACHIOPODS (Hou, H. & Tan, Z.)

Brachiopods are the most common megafossils in central Hunan and therefore they have widely been used for dating and correlating the Devonian and Carboniferous strata. Among the three studied sections, the brachiopods are abundant in the Malanbian section, rare in the Sujiaping section because of relatively unfavourable facies, and poorly preserved in the Oujiachong section. The distribution of the brachiopods in the Upper Famennian to Tournaisian strata of central Hunan is given in figure 10.

At the base of the Shaodong Formation in the Malanbian section, a fossiliferous bed has yielded *Trifidorostellum longhuiensis*. It has been designated as the *T. longhuiensis* acme zone by Tan *et al.* (1987) and led Sartenaer and Xu (1989) to define a worldwide upper Famennian *Trifidorostellum* Zone, based on species found in Canada, USA, Russia and China. However, the genus has not been reported from western Europe. In the upper part of the Shaodong Formation, the productids *Mesoplica* and *Acanthoplecta* dominate and seem restricted to this stratigraphical interval in Hunan.

No brachiopod guides have been found in the Menggongao Formation. Common elements include *Plicochonetes* sp., *Schuchertella* sp., *Ptychomalatoechia kinlingensis*, *Hunanoproductus hunanensis*, *Spinocrinifera dushanensis* and *Cleiothyridina* sp.. Most of the species range into the overlying Malanbian Formation displaying transitional aspects from Devonian to Carboniferous. *Cyrtospirifer* is present in the Menggongao Formation. As in the Etroeungt Formation of southwestern Belgium, the genus *Cyrtospirifer* disappears at the top of the Devonian. The use of cyrtospiriferids in biostratigraphy is currently hindered by taxonomic problems.

The main brachiopod guides for the Strunian in the Franco-Belgian Basin, including *Sphenospira julii, Eobrachythyris struniana, Araratella moresnetensis* and *Whidbornella caperata* (Conil *et al.*, 1986), do not occur in Hunan. *Yangunia* of southern China is likely a synonym of *Spinocrinifera* of the Dinant area. They have the same stratigraphical distribution: from the uppermost Devonian to the lowermost Tournaisian.

The brachiopods from the Malanbian Formation are quite different from those of the Menggongao Formation and are widespread in southern China. The association is called the *Martiniella-Eochoristites* Assemblage Zone characterized by a rich population of *Martiniella chinglungensis, M. elongata, Eochoristites neipentaiensis* which is associated with *Spinocrinifera dushanensis, S. tenuiplicata, Hunanoproductus hunanensis, Ptychomalatoechia kinlingensis, Spirifer jielingensis* and *Unispirifer* cf. *tornacensis*. They mainly occur in the middle part of the Malanbian Formation at Oujiachiong, Malanbian and Sujiaping, coinciding with the first major relative sea-level rise in the Carboniferous. In fact, the first appearance of *Eochoristites* and *Martiniella* is earlier, i.e. in the lower part of the Malanbian Formation (bed 109). *Ptychomalatoechia kinlingensis, Hunanoproductus* and *Spinocrinifera* are present in the Menggongao Formation and disappear in the middle part of the Malanbian Formation. *Eochoristites* and *Martiniella* can range into the overlying lower part of the Tianeping Formation. The study of spiriferids, which are the main elements of the Tournaisian brachiopod association, needs refinements in the Dinant area for comparison with the Hunan Province. However, spiriferids with a prismatic shell and denticulation are present in the Malanbian Formation in Hunan and in the Hastarian of Dinant and are good Carboniferous indicators.

The brachiopods in the Upper Tournaisian Doulingao Formation are referred to the *Marginatia-Finospirifer* Assemblage Zone, which is characterized by the development of *Spirifer, Unispirifer, Prospira, Celsifornix* and *Punctospirifer*. The genus *Anathyris* is very abundant in central Hunan and it appears in Malanbian equivalent beds in Guizhou. *Marginatia* and *Ovatia* seem to occur in this zone. The genus *Levitusia*, which occurs widely in the Lower Visean in Belgium has not been found in southern China.

3.6. RUGOSE CORALS (Poty, E. & Xu, S.)

Rugose corals occur relatively abundantly in the Uppermost Devonian and the Lower Carboniferous of Hunan. They have been investigated in the Malanbian and Sujiaping sections (fig. 11). They are uncommon at Oujiachong.

The upper part of the Shaodong Formation (Malanbian section) and the lower part of the Menggongao Formation (Malanbian and Sujiaping sections) have yielded coral species which are characteristic of the *Caninia dorlodoti* zone of Wu *et al.* (1981) renamed here *Eocaninophyllum yizhangense* zone because «*Caninia*» *dorlodoti* has been misinterpreted and does not exist in China (Poty & Xu, in press). *Cystophrentis kolaohoensis*, one of the typical species of the *Cystophrentis* zone, occurs firstly in bed 69 of the Menggongao Formation in Malanbian and in bed 40 of the same formation in Sujiaping. *Cystophrentis* species are the only corals which have been found in that zone, except for *Eocaninophyllym yizhangense* in bed 78 at Malanbian. *Cystophrentis* disappears at the top of the formation just below the D/C boundary. None of the species which have been found during this work in the Shaodong and Menggongao Formations, or none of other ones previously described, are known in the Famennian or in the Carboniferous in Europe (where the so called *Caninia dorlodoti* occurs). Therefore, neither comparison nor correlation are possible at this level and the Strunian age of the beds has to be established by the mean of other fossils. Of the Chinese species, only one (*Smitiphyllum antiquatum*) belongs to a genus known before the Frasnian/Famennian crisis; all the others are restricted to the Strunian.

The lowest part of the Malanbian Formation has yielded almost no corals, except two specimens doubtfully assigned to the genus *Kizilia*. Corals occur commonly from bed 110 of the formation in the Malanbian section and from bed 69 in the Sujiaping section. The presence of *Uralinia tangpakouensis* in these levels marks the base of the *Uralinia* (=*Pseudouralinia*) zone and is separated from the *Cystophrentis* zone by the *Cystophrentis/ Pseudouralina tangpakouensis* interval zone of Tan (*in* Tan *et al*, 1987). The base of the zone approximately matches the boundary between the Cf1α and Cf1β Foraminifera subzones (Hance, this paper). The species found here belong to genera which are known outside China (*Uralinia, Caninophyllum* and ? *Lophophyllum*), or are closely related to a widespread genus (*Stelechophyllum*). In Belgium, the first representatives of *Uralinia* appears in the upper part of the Cf1α Foraminifera subzone-RC1γ Coral subzone (in the Pont d'Arcole Formation) and those of *Lophophyllum* in the top of the same foraminiferal zone and at the base of the RC2 Coral zone. However, *Caninophyllum* is not known below the Cf2 Foraminifera zone and is one of the type species of the RC3 Coral zone (Poty, 1985; Conil *et al.*, 1991). *Stelechophyllum*, which possibly has given rise to *nov.* Genus A (Poty & Xu, in press) is characteristic of the Northwestern

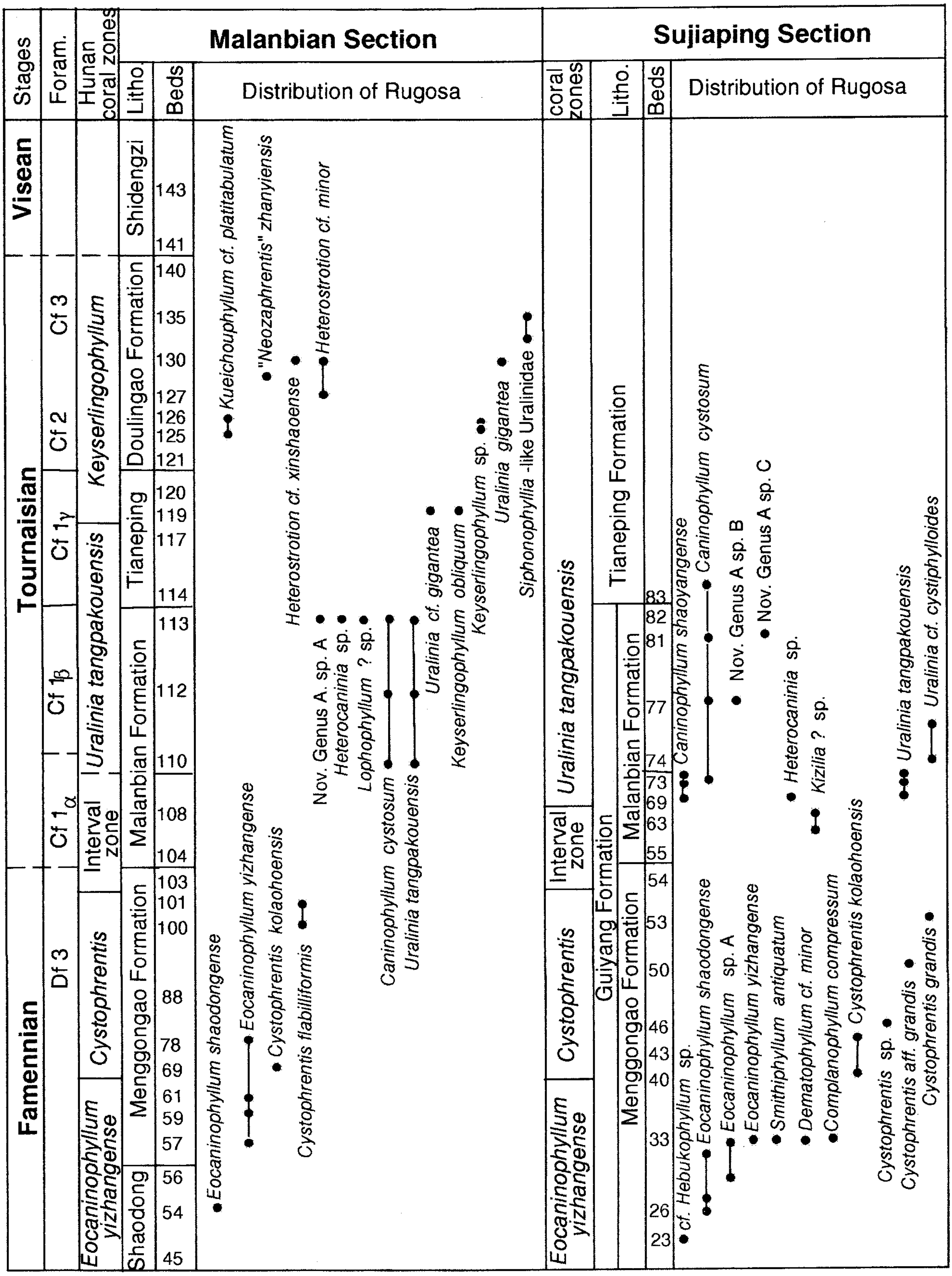

Figure 11. Distribution of rugose corals at the Devonian-Carboniferous transition in the Malanbian and Sujiaping sections.

American Coral zone II of Sando & Bamber (1985), whose base is situated in the Cf1α zone.

In the Malanbian section, which displays higher levels than at Sujiaping, the coral fauna discussed above stops at the top of the Malanbian Formation and is replaced in the Tianeping and in the Doulingao Formations by species belonging mainly to *Uralinia, Keyserlingophyllum, Heterostrotion* (="*Donophyllum*" of the Chinese palaeontologists ; Poty & Xu, in press), and the oldest species of *Kueichouphyllum*. Some representatives of this assemblage, such as *Keyserlingophyllum obliquum* or *Uralinia gigantea*, or species closely related to them, are common in the Upper Tournaisian (Cf2-Cf3 Foraminifera zones, RC3 Coral zone) in the Eurasian realm. In Belgium, species near *Uralinia gigantea* and *Heterostrotion* (Poty, 1989) occur in the Yvoir Formation (Cf2 zone, RC3α subzone).

The revision of the Strunian-Tournaisian corals of the Malanbian and Sujiaping sections (Poty & Xu, in press) has established that most of the assignations to European taxa were in error. Therefore, because of their relatively low diversity and the endemism of many of them, especially the Strunian species, Rugose corals do not allow a detailed correlation with Europe without the help of the foraminifers and conodonts.

3.7 TABULATE CORALS (Tourneur, F.)

In the Oujiachong and Malanbian section, the tabulate coral fauna is strongly dominated by syringoporids. Most of the species have already been illustrated by Jia *et al.* (1977).

Two distinct populations have been recognized in the Menggongao Formation. The first assemblage, already present in the lower part of the Menggongao Formation, is characterized by a syringoporid coral with subparallel corallites (diameter close to 1.5mm or slightly larger) and with some spines. This coral belongs to the genus *Fuchungopora* and we will name it provisionally *Fuchungopora* sp. A. The second assemblage is present in the uppermost part of the Menggongao Formation. It is dominated by *Fuchungopora* sp. B with smaller corallites (diameter inferior to 1mm) and rare spines. This species is always associated with a commensal cylindrical organism without skeleton (annelid ?). The latter organism lies at the origin of the gaps in the regular organization of the tabulate coral. Additionally we identified a larger species with closely spaced corallites, sometimes nearly cerioid, a strong development of spines and cystose tabulae. It probably belongs to the genus *Chia*. These forms are also present in the Sujiaping section. In the uppermost part of the Menggongao Formation in this section, *Fuchungopora* sp. A and B, *Chia* (?) sp., a very strange Micheliniid coral with aphroid growth stages, and a very rich stromatoporoid fauna have been recognized.

Tabulate corals are rather rare in the Malanbian Formation at Oujiachong and Malanbian. In the Malanbian and Tianeping Formations of the Malanbian section, a few *Syringopora*, a small specimen characterized by eccentric syrinx belonging to the genus *Pleurosiphonella* and a unique colony of a Micheliniid coral with very flat tabulae (probably *Protomichelinia*) have been found. Higher in the section large cystose Syringoporids, small colonies with very thick walls belonging to the Multithecoporids and strange pseudocolonies of probably an annelid (close to the Trypanoporids) are present. In the upper part of the Malanbian Formation in the Sujiaping section we have collected a micheliniid coral with very large corallites (diameter close to 1cm), small cystose tabellae (*Cystomichelinia*) and a colony with regularly spaced connections (*Gorskyites*).

In summary, the tabulate coral fauna of the studied sections contains mostly endemic forms which are useful to establish correlations between the sections, but which are difficult to apply at a larger scale. They are typical for the South Chinese Province defined by Lin (1985) and show some similarities with other Chinese faunas of the same age (Lin, 1963a, b).

4. SEDIMENTOLOGY AND SEQUENCE STRATIGRAPHY OF THE DEVONIAN-CARBONIFEROUS TRANSITIONAL STRATA (Muchez, Ph. & Van Steenwinkel, M.)

4.1. HUNAN PROVINCE

In central Hunan, the D-C transitional sedimentation took place during 6 time units which are easy to distinguish and useful for long distance correlations (for more details see Muchez in press; Fig. 12).

Unit 1, the upper part of the Menggongao Formation, consists of fossiliferous shales, siltstones, peloidal wackestones and packstones with crinoids, bivalves, bryozoa, moravamminids, sponge spicules, echinoid spines, corals, ostracods, foraminifers, algae and gastropods. It has been deposited in an open marine environment below wave base.

Unit 2, the uppermost part of the Menggongao Formation, is represented by siliciclastic beds or a fenestral bioclastic wackestone. The siliciclastics and the fenestral limestones have been deposited in response to a significant lowering of sea-level. In the Sujiaping section, the limestones are followed by peloidal wackestones (3m thick) with mainly calcispheres and algae. The wackestone texture and the restricted biota indicate deposition in a lagoonal environment.

Subsequently, peloidal wackestones with clasts, micritized and aggregate grains occur in the Oujiachong section and bioclastic grainstones with peloids, micritized and aggregate grains and intraclasts (**unit 3**) in the Malanbian and Sujiaping area. The wackestones have been deposited below wave base, however the presence of peloids, aggregate and micritized grains and clasts suggests a shallower setting than in the Menggongao Formation (see also Hennebert & Lees, 1991). The grainstones represent sedimentation above wave base at shallow depth. The aggregate grains are characteristic for a shallow depositional environment with an uneven water turbulence and a low sedimentation rate (Purdy, 1963; Winland & Matthews, 1974). In the Sujiaping area, the grainstones point to a migration of a high energy facies over the lagoonal setting.

In the Malanbian and Sujiaping section, **unit 4** consists of shallowing-upward sequences of bioclastic wackestones and peloidal bioclastic pack- to grainstones. The wackestones contain a fully open marine biota and often peloids. The pack- to grainstones are characterized by micritized and aggregate grains, clasts and peloids. Unit 4 is capped by a massive grainstone bed. The wackestones have been deposited below wave base and indicate a drowning of the coarse-grained facies and a rise of sea-level. When sedimentation rates were high and able to fill the space created by the relative sea-level rise, pack- to grainstones were deposited.

The lower part of the Malanbian Formation is overlain by clay-rich wackestones without micritized and aggregate grains, peloids and clasts **(unit 5)**. These sediments formed due to the fact that the sedimentation rate could not longer keep up with the deepening environment and drowning was the result.

Unit 6, the upper part of the Malanbian Formation, again consists of shallowing-upward sequences of bioclastic, peloidal wackestones and pack- to grainstones with peloids, micritized and aggregate grains and clasts. It formed during a slowing down of the relative sea-level rise.

4.2. DINANT SYNCLINORIUM

The Etroeungt Limestone (Fig. 12) and the laterally equivalent Comblain-au-Pont Formation are characterized by open-marine, lower-ramp limestone-marl rhythms and storm deposits (Van Steenwinkel, 1992). The boundary between the Etroeungt Formation and the overlying Hastière Limestone is abrupt and followed by a lithoclastic bed. The main part of the Hastière Limestone consists of small-scale shallowing-upward cycles of crinoidal wackestones to grainstones. The upper part of the Hastière Limestone is characterized by a sudden deepening followed by an increasingly deeper-water facies and by the open-marine Pont d'Arcole Shale.

The stratigraphic succession of the Etroeungt-Comblain-au-Pont Formations, Hastière Limestone, Pont d'Arcole Shale and Landelies Limestone (Fig. 11) around the Devonian-Carboniferous transition are interpreted as the sedimentary response to six particular time units (Van Steenwinkel, 1990). Each time unit corresponds to a certain trend of relative sea-level. The following summary is based on the work of Van Steenwinkel (1988).

Unit 1 (Etroeungt Limestone) represents a time interval during which eustatic sea-level fell slowly, at a rate lower than that of subsidence. The net effect was a relative rise. This relative sea-level rise created new space available for the sedimentation of the Etroeungt Limestone and the equivalent Comblain-au-Pont Formation. Referring to the terminology used in seismic stratigraphy (Vail, 1987), unit 1 reflects the Highstand Systems Tract.

Time **unit 2** is represented by a sequence boundary which terminated the deposition of the Highstand Systems Tract of unit 1. As the increasing rate of eustatic sea-level fall outpaced the rate of subsidence, a relative fall of sea-level resulted. The space available for sedimentation disappeared. In a carbonate setting, this resulted in non-deposition and submarine erosion. The final record of this relative sea-level fall in the Dinant synclinorium is a sharp contact between relatively deep water highstand deposits of unit 1 and shallow-water deposits of unit 3.

Unit 3 (basal part of the Hastière Limestone) represents conditions of eustatic sea-level fall slower than subsidence, creating new space for sedimentation. This means that the relative fall had changed into a rise, despite the fact that eustatic sea-level was falling. It was a phase of renewed sedimentation after a period of almost non-deposition. In the near-shore environment, an oolite bank migrated over the lagoonal muds.

Unit 4 (main part of the Hastière Limestone) forms the prograding complex of the Shelf Margin Systems Tract. When eustatic sea-level fall changes into a rise, the rate of relative rise increased. This speedened up relative rise resulted in a drowning of the shallow water carbonate environment and a generally deeper water setting. In the offshore areas, deposition of storm

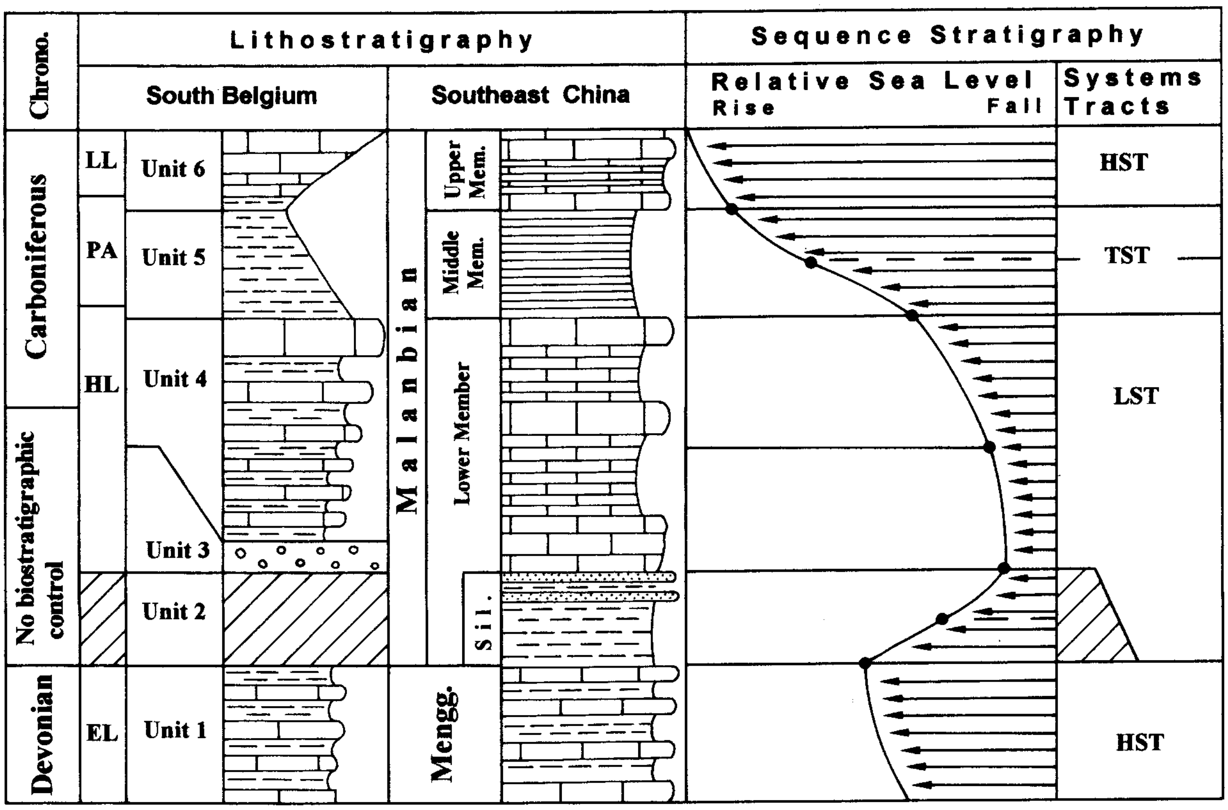

Figure 12. Comparison between the Devonian-Carboniferous transitional strata in southern Belgium and southern China (partly after Van Steenwinkel, 1990). Mengg. Fm.: Menggongao Formation; Sil.: siliciclastics; EL: Etroeungt Limestone/ Comblain-au-Pont Formation; HL: Hastière Limestone; PA: Pont d'Arcole Shale; LL: Landelies Limestone; HST: Highstand Systems Tract; TST: Transgressive Systems Tract; LST: Lowstand Systems Tract.

sands derived from the crests of the original banks occurred, and this with generally high sedimentation rates. This resulted in the fill of the space that was created for sedimentation by the relative sea-level rise, and consequently in the levelling of the uneven topography by progradation. Sedimentation would have stopped at the top of the shallowing-upward sequences if there were no subsequent relative sea-level rises.

Unit 5 (lower part of the Pont d'Arcole Shale) corresponds to the steepest part of the rising limb of the eustatic curve. It started when eustatic sea-level rise increased to such an extent that carbonate sedimentation no longer kept pace. This caused the overall drowning of the platform. Unit 5 represents the Transgressive Systems Tract, the base of which is at the top of the most prominent shallowing-upward sequence. This top is defined as the Transgression Surface.

Unit 6 (upper part of the Pont d'Arcole Shale - Landelies Limestone) is characterized by a slowing down of the eustatic sea-level rise. The rate of eustatic rise has decreased so that sedimentation could again outpace the relative rise and shoreline transgression eventually gave way to regression. In seismic stratigraphy, this point is termed the Maximum Flooding Surface.

4.3. COMPARISON BETWEEN THE HUNAN PROVINCE AND THE DINANT SYNCLINORIUM

A comparison between the Devonian-Carboniferous transitional strata in southern China and southern Belgium is given in figure 12. A striking similarity in the sedimentary evolution exists between the two areas.

The open marine muds of the Etroeungt Limestone and the Menggongao Formation were deposited at the end of the Devonian, during a highstand period. Time unit 2 in southern China and southern Belgium represents the sequence boundary at the top of the Highstand Systems Tract of unit 1. The siliciclastic sediments above the sequence boundary in south China form the lowstand deposits characteristic for such a setting (Posamentier & Vail, 1989; Posamentier *et al.*, 1989). The basal part of the Hastière Limestone and the lower part of the Malanbian Formation formed at the beginning of relative sea-level rise. During the further rise of relative sea-level the main part of the Hastière and unit 4 of the Malanbian Formation were deposited. The unit 5 in the Hunan Province and in the Dinant synclinorium represents conditions when relative sea-level was fastly rising. In both areas this unit starts just above the most prominent shallowing-upward sequence. Finally, sedimentation of unit 6 occurred when sedimentation could again outpace the relative rise.

5. CONCLUSIONS

The integrated biostratigraphical and sedimentological approach to study of the Devonian-Carboniferous transitional strata in Hunan (southern China) allows a better comparison with the type succession of southern Belgium.

In Hunan, the D-C boundary coincides with the base of the Malanbian Formation which has yielded the foraminifers *Tournayellina beata* and *Chernyshinella glomiformis* and the conodonts *Siphonodella* cf. *sulcata, S. levis* and *S. sinensis*. Typical elements of the Devonian fauna disappear in the upper part of the underlying Menggongao Formation, including cyrtospiriferid brachiopods, stromatoporoids, quasiendothyrid foraminifers and the spore *Retispora lepidophyta*. Foraminifers provide additional elements which indicate that the Malanbian Formation covers the Cf1α-β subzones whereas the Tianeping Formation corresponds to the Cf1γ subzone of Upper Hastarian age. The lower part of the Doulingao Formation has yielded a Cf2 foraminiferal association indicative of an Ivorian age. Its upper part could correspond to the Cf3 subzone. The Hastarian age of the Malanbian and Tianeping Formations is corroborated by ostracods, brachiopods and corals data. The latter are also consistent with the Ivorian age of the Doulingao Formation.

The sedimentary evolution of Upper Devonian and Hastarian strata of Hunan and southern Belgium is extremely similar, suggesting an eustatic controlled sea-level history and a comparable setting. This sedimentary history can be divided into six time units which allow long distance correlations to be made and which reinforce biostratigraphical comparisons.

6. ACKNOWLEDGEMENTS

The authors are most grateful to: the Chinese Academy of Geological Sciences at Beijing, the Bureau of Geology and Mineral Resources of Hunan and Guangxi and the Belgian Geological Survey for their scientific and financial support; and to G. Sevastopoulo for his helpful review of the typescript.

7. REFERENCES

BOGUSH, O.I. & YUFEREV, V.O., 1991. Foraminifers and problems at the Tournaisian-Visean boundary in Siberia and Northeast USSR. *Cour. Forsch.-Inst. Senckenberg*, 130: 61-63.

BRENCKLE, P.L. & GROVES, J.R., 1987. Calcareous Foraminifers from the Humboldt Oolite of Iowa: Key to Early Osagean (Mississippian) Correlations between Eastern and Western North America. *Palaios*, 1: 561-581.

BUSHMINA, L.S., 1970a. Ostracodes from the Devonian-Carboniferous transition beds of the Eltsov synclinorium (SW Siberia). *Akad. Nauk SSSR, Siberian branch, Trans. Inst. Geol. Geophys.*, 71: 60-76.

BUSHMINA, L.S., 1970b. Carboniferous ostracodes of the lower Lena river. *Akad. Nauk SSSR, Siberian branch, Trans. Inst. Geol. Geophys.*, 125.

BUSHMINA, L.S., 1975. Early Carboniferous ostracodes of the Kolyma massif. *Akad. Nauk SSSR, Siberian branch, Trans. Inst. Geol. Geoph.*, 219.

BUSHMINA, L.S. & SIMAKOV, K.V., 1979. Correlation of the Upper Famennian-Lower Tournaisian deposits of different facies in the central Fore-Kolyma area by the aid of microfossils. Field Excursion Guidebook Tour IX, XIV Pacific Science Congress, Khabarovsk 1979, Suppl. 8: 71-90.

CONIL, R., DREESEN, R., LENTZ, M.-A., LYS, M. & PLODOWSKI, G., 1986. The Devono-Carboniferous transition in the Franco-Belgian basin with reference to foraminifera and brachiopods. *Ann. Soc. géol. Belg.*, 109: 19-26.

CONIL, R., DE PUTTER, TH., HOU, H.-F., WEI, J.-Y. & WU, X.-HE, 1988. Contribution à l'étude des foraminifères du Strunien et du Dinantien de la Chine Sud-Orientale. *Bull. Soc. belge Géol.*, 97: 47-62.

CONIL, R., GROESSENS, E., LALOUX, M., POTY, E. & TOURNEUR, F., 1991. Carboniferous guide Foraminifera, Corals and Conodonts in the Franco-Belgian and Campine Basins: their potential for widespread correlation. *Courier Forsch.-Inst. Senckenberg*, 130: 15-30.

CONIL, R., GROESSENS, E. & PIRLET, H., 1977. Nouvelle charte stratigraphique du Dinantien type de la Belgique. *Ann. Soc. géol. Nord*, 96: 363-371.

CONIL, R. & LYS, M., 1970 . Données nouvelles sur les Foraminifères des couches de passage du Famennien au Tournaisien dans l'Avesnois. *Coll. Stratigraphie Carbonifère, Liège, avril 1969, Congr. U.Lg*, 55: 241-265.

CONIL, R. & LYS, M., 1977. Les transgressions dinantiennes et leur influence sur la dispersion et l'évolution des foraminifères. *Mém. Inst. géol. Univ. Louvain*, 29: 9-55.

CONIL, R., POTY, E., SIMAKOV, K.V. & STREEL, M., 1982. Foraminifères, spores et coraux du Famennien supérieur et du Dinantien du massif de l'Omolon (Extrème-Orient soviétique). *Ann. Soc. géol. Belg.*, 105: 145-160.

GAO, L., 1981. Devonian spore assemblages of China. *Rev. Palaeobotany & Palynology*, 34: 11-23.

GAO, L., 1990. Miospore zones in the Devonian-Carboniferous boundary beds in Hunan and their stratigraphical significance. *Geol. Rev.*, 36: 58-70.

GILISSEN, E., 1988. Etude de l'Hastarien, premier étage du Carbonifère dans le bassin franco-belge. Biozonation par foraminifères et parallélisme avec l'Amérique du Nord et l'Extrême-Orient. *C.R. Acad. Sci. Paris*, Série II, 1297-1300.

GREEN, R., 1963. Lower Mississippian ostracodes from the Banff Formation, Alberta. *Bull. Research Council Alberta*, 11.

GRÜNDEL, J., 1961. Zur Biostratigraphie und Fazies der Gattendorfia-Stufe in Mitteldeutschland unter besonderer Berücksichtigung der Ostracoden. *Freiberger Forschh.*, C111: 53-173.

GRÜNDEL, J., 1962. Zur Taxionomie der Ostracoden der Gattendorfia-Stufe Thüringens. *Freiberger Forschh.*, C151: 51-105.

KALVODA, J. & KUKAL, Z., 1987. Devonian-Carboniferous boundary in the Moravian Karst at Lesni Lom Quarry, Brno-Lisen, Czechoslovakia. *Cour. Forsch.-Inst. Senckenberg*, 98 : 95-117.

HANCE, L., in press. Foraminiferal biostratigraphy of the Devonian/Carboniferous boundary and Tournaisian strata in central Hunan Province, South China. *Mém. Inst. Géol. Univ. Louvain*, 36.

HENNEBERT, M. & LEES, A., 1991. Environmental gradients in carbonate sediments and rocks detected by correspondence analysis: examples from the Recent of Norway and the Dinantian of southwest England. *Sedimentology*, 38: 623-642.

HOU, H., 1965. Early Carboniferous brachiopods from the Mengkungao Formation of Gieling, Central Hunan and discussion of the lower boundary of the Carboniferous. *Prof. Papers, Acad. Geol. Sci. Ser. B*, (1): 116-146.

HOU, H., 1991. An outline of Famennian stratigraphy of South China. *Stratigr. Paleont. China*, 1: 49-69.

HOU, H., JI, Q., WU, X., XIONG, J., WANG, S., GAO, L., SHENG, H., WEI, J. & TURNER, S., 1985. Muhua section of Devonian-Carboniferous boundary beds. Geol. Publ. House, Beijing, 226p.

HOU, J., 1982. Some spore assemblages of the Devonian-Carboniferous transition from Xikuangshan District. Central Hunan. *Bull. Chinese Acad. Geol. Sc.*, 5: 81-92.

HUANG, D. X., 1978. On the subdivisions of «Xuefengshan Sandstone» and a supplement to the concept of «Shaodong Member». *Prof. Paper Symp. Dev. Syst.S China.* Geol. Publ. House, Beijing, pp 90-97.

JI, Q., 1987a. New results from Devonian-Carboniferous boundary beds in South *China. Newsl. Strat.*, 17: 155-167.

JI, Q., 1987b. The boundary between the Devonian and Carboniferous systems of shallow-water facies as viewed in the light of conodont studies. *Acta Geol. Sinica*, 61(1): 10-20.

JI, Q. & ZIEGLER, W., 1992. Phylogeny, speciation and zonation of *Siphonodella* of shallow water facies (Conodonta, Early Carboniferous). *Courier Forsch.-Inst. Senckenberg*, 154: 223-251.

JIA, H., XU, S., KUANG,G., ZHANG, B., ZUO, Z. & WU, J., 1977. Corals. In: Hubei Provincial Geological Science Research Institute (ed.), Atlas of the Paleontology of South Central Regions of China, Late Paleozoic. Geological Publishing House, Beijing, pp. 97-270.

KALVODA, J. & KUKAL, Z., 1987 - Devonian-Carboniferous boundary in the Moravian Karst at Lesni Lom Quarry, Brno-Lisen, Czechoslovakia. *Cour. Forsch.-Inst. Senckenberg*, 98 : 95-117.

LIPINA, O.A., 1948. - Textulariidae de la partie supérieure du Carbonifère inférieur du Versant sud du bassin de Moscou. *Akad. Nauk SSSR, Trudy Inst. Geol. Nauk*, Geol. Ser. 19, publ. 62 : 196-215.

LIPINA, O.A., 1955. - Foraminifera of the Tournaisian stage and uppermost Devonian of the Volga-Ural region and western slope of the central Urals . *Akad. Nauk SSSR, Trudy Inst. Geol. Nauk*, Geol. Ser. 163, publ. 70 : 1-96 (in russian).

LIN, B., 1963a. Some Tabulata from the Carboniferous and Permian strata of Southern China. *Acta Palaeont. Sinica*, 11: 579-596.

LIN, B., 1963b. Lower Carboniferous tabulate corals from Nanling Range. *Prof. Papers Chinese Acad. Geol. Sci., Minist. Geol., ser. B, Strat. Paleont.*, 4: 75p.

LIN, B., 1985. A preliminary study of the stratigraphical distribution and zoogeographical provinces of the Carboniferous tabulate corals of China. *Mem. Geol. Paleont.*, 12: 27-46.

MALAKHOVA, N.P., 1954. Foraminifera from the Carboniferous rocks of the western slope of the northern and central Urals (in Russian). *Akad. Nauk SSSR, Uralskii filial*, Trudy v. 24 : 72-155 (in russian).

MUCHEZ, P., in press. Sequence stratigraphy at the Devonian-Carboniferous transition in southern China. *Mém. Inst. géol. Univ. Louvain*, 36.

POSAMENTIER, H.W. & VAIL, P.R., 1989. Eustatic controls on clastic deposition, II. Sequence and systems tract models. In: Wilgus, C.K., Hastings, B.S., Posamentier, H., Van Wagoner, J., Ross, C.A. & Kendall, C.G. (eds.): Sea Level Changes - An Integrated Approach. *Soc. Econ. Paleont. Miner., Spec. Publ.*, 42: 125-154.

POSAMENTIER, H.W., JERVEY, M.T. & VAIL, P.R., 1989. Eustatic controls on clastic deposition, I. Conceptual framework. In: Wilgus, C.K., Hastings, B.S., Posamentier, H., Van Wagoner, J., Ross, C.A. & Kendall, C.G. (eds.): Sea Level Changes - An Integrated Approach. *Soc. Econ. Paleont. Miner., Spec. Publ.*, 42: 109-124.

POTY, E., 1985. A Rugose Coral biozonation for the Dinantian of Belgium as a basis for a coral biozonation of the Dinantian of Eurasia. *C.R. X Congr. Int. Strat. Géol. Carbonifère, Madrid 1983*, 4: 29-31.

POTY, E., 1989. Distribution and paleogeographic affinities of Belgian Tournaisian rugose Corals. *Mém. Assoc. Australas. Palaeontol.*, 8: 267-273.

POTY, E. & XU, S.C., in press. Rugosan biostratigraphy of the Devonian-Carboniferous transition in Hunan (SW - China). *Mém. Inst. Géol. Univ. Louvain*, 36.

PURDY, E.G., 1963. Recent calcium carbonate facies of the Great Bahama Bank. 2. Sedimentary facies. *J. Geol.*, 71: 472-497.

RAUZER-CHERNOUSOVA, D.M., 1948. Foraminiferal fauna of the Carboniferous deposits of central Kazakhstan. *Akad. Nauk SSSR, Trudy Inst. Geol. Nauk*, Geol. Ser. 21, publ. 66 : 119-176 (in Russian).

SANDO, W.J. & BAMBER, E.W., 1985. Coral zonation of the Mississippian system in the Western Interior Province of North America. *U.S. Geol. Survey Prof. Paper*, 1334: 1-61.

SARTENAER, P. & XU, H., 1989. The Upper Famennian rhynchonellid genus *Trifidorostellum* Sartenaer, 1961 from China, North America and USSR. *Bull. Inst. Roy. Nat. Belg.*, 59: 49-59.

SIMAKOV, K.V., BLESS, M.J.M., BOUCKAERT, J., CONIL, R., GAGIEV, M., KOLESOV, Y., ONOPRIENKO, Y.I., POTY, E., RAZINA, T.P., SHILO, N.A., SMIRNOVA, L., STREEL, M. & SWENNEN, R., 1983. Upper Famennian and Tournaisian deposits of the Omolon region (NE URSS). *Ann. Soc. géol. Belg.*, 106: 335-399.

STEEMANS, P., FANG, X. & STREEL, M., in press. Miospore stratigraphy around the Devonian-Carboniferous boundary, Hunan Province, China. *Mém. Inst. géol. Univ. Louvain*, 36.

STREEL, M., 1966. Critères palynologiques pour une stratigraphie détailée du Tn1a dans les bassins ardenno-rhénans. *Ann. Soc. géol. Belg.*, 89: 65-95.

STREEL, M., 1986. Miospore contribution to the Upper Famennian-Strunian event stratigraphy. *Ann. Soc. géol. Belg.*, 109: 75-92.

STREEL, M., HIGGS, K., LOBOZIAK, S., RIEGEL, W. & STEEMANS, P., 1987. Spore stratigraphy and correlation with faunas and floras in the type marine Devonian of the Ardenno-Rhenish regions. *Rev. Palaeobot. Palynol.*, 50: 211-229.

TAN, Z., DONG, Z., JIN, Y., LI, S., YANG, Y. & JIANG, S., 1987. The late Devonian and early Carboniferous strata and Palaeobiocoenosis of Hunan. Regional Geological Surveying Party, Bureau of Geology and Mineral Resources of Hunan Province. Geological Publishing House, Beijing, 200p.

TIEN, C. C., WANG, H. C. & HSU, Y. T., 1933. The Geology of Changsha, Hsiangtan, Hengshan, Hengyang, Hsiangsiang and Shaoyang Districts, Central Hunan. *Geol. Sur. Hunan, Bull.* 15, Geol. 2, 47p.

VAIL, P.R., 1987. Seismic stratigraphy interpretation using sequence stratigraphy. *In*: Bally, A.W. (ed.): Atlas of Seismic Stratigraphy. *Am. Assoc. Petrol. Geol., Stud. Geol.*, 27: 1-10.

VAN STEENWINKEL, M., 1988. The sedimentary history of the Dinant Platform during the Devonian-Carboniferous transition. Unpubl. Ph. D. Thesis, K.U.Leuven: 173p.

VAN STEENWINKEL, M., 1990. Sequence stratigraphy from «spot» outcrops - example from a carbonate-dominated setting: Devonian-Carboniferous transition, Dinant Synclinorium (Belgium). *Sediment. Geol.*, 69: 259-280.

VAN STEENWINKEL, M., 1992. The Devonian-Carboniferous boundary: comparison between the Dinant synclinorium and the northern border of the Rhenish Slate Mountains. A sequence-stratigraphic view. *Ann. Soc. géol. Belg.*, 115: 665-681.

VAN STEENWINKEL, M., 1993. The Devonian-Carboniferous boundary in southern Belgium: biostratigraphic identification criteria of sequence boundaries. In: Posamentier, H.W., Summerhayes, C.P., Haq, B.U. & Allen, G.P. (eds.): Sequence Stratigraphy and Facies Associations. *IAS Spec. Publ.*, 18: 237-246.

WANG, C. & ZIEGLER, W., 1982. On the Devonian-Carboniferous boundary in South China based on conodonts. *Geol. Paleont.*, 16: 151-162.

WANG, C., YIN, B., WU, W., LIAO, W., WANG, K., LIAO, Z., MU, X., QIAN, W. & YAO, Z., 1987. Devonian-Carboniferous boundary section in Yishan area, Guangxi. *In*: Wang, C. (ed.): Carboniferous boundaries in China. Sci. Press, Beijing, 22-43.

WANG, S.Q., 1988a. Ostracode faunas from the Early Carboniferous Wangyou Formation in Nandan of Guangxi and their paleoecotype. *Mem. Nanjing Inst. Geol. Pal.*, 24: 269-315.

WANG, S.Q., 1988b. Ostracodes. *In* : Yu, C. M. (ed.), Devonian-Carboniferous boundary in Nanbiancun, Guilin, China. Sci. Press, Beijing: pp. 209-244.

WEBSTER, G.D. & GROESSENS, E., 1991. Conodont subdivision of the Lower Carboniferous. Cour. Forsch.-Inst. Senckenberg, 130: 31-40.

WINLAND, H. D. & MATTHEWS, R. K., 1974. Origin and significance of grapestones, Bahama Islands. *J. Sedim. Petrol.*, 44: 921-927.

WU, W., ZHAO, J. & JIANG, S., 1981. Corals from the Shaodong Formation (Etroeungt) of South China. *Acta Paleont. Sinica*, 20: 1-14.

WU, W., ZHANG, L., ZHAO, X., JIN, Y. & LIAO, Z., 1987. Carboniferous Stratigraphy in China. *In* Zhang, L. (Ed.), Contr. 11th Intern. Congr. Carb. Strat. Geol., 1987, Beijing, China. Sci. Press Beijing, 160p.

YOH, S. & HOU, H., 1962. On the Devonian-Carboniferous boundary and the existence of «Etroeungt» in South China. *Acta Sci. Nat. Uni. Peking*, 8(3): 276-295.

YU, C., WANG, C., RUAN, Y., YIN, B., LI, Z. & WEI, W., 1987. A desirable section for the Devonian-Carboniferous boundary stratotype in Guilin, Guangxi, South China. *Sci. Sinica (ser. B)*, 30: 751-764.