CARBONIFEROUS AND PERMIAN ALGAL MICROFLORA, TARIM BASIN (CHINA)

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(6 figures)

ABSTRACT. Thirty eight algal genera have been observed in Tournaisian to Kungurian carbonates of the Tarim Basin (China). Floral assemblages permit identification of ten stratigraphic levels. Most of the widespread and common forms have a "cosmopolitan" distribution, although Calcifolium is recognized for the first time in the eastern part of the Tethys.

Key-words: Tarim basin, Carboniferous, Permian, algae, China.

RESUME. Trente-huit genres d'algues calcaires ont été reconnus dans le Paléozoïque Supérieur du Bassin de Tarim (Chine). Les assemblages de flores permettent l'identification de dix niveaux stratigraphiques locaux. La plupart des taxa ont une distribution "cosmopolite", à l'exception de Calcifolium qui est observé pour la première fois dans la partie orientale de la Téthys.

Mots-clés: Bassin de Tarim, Carbonifère, Permien, algues, Chine.

1. Introduction

This paper reports that extensive Carboniferous and Permian marine deposits in the Tarim Basin contain abundant calcareous algae. Previously, Mu (1985) reported in the Tienshan belt an Asselian to Artinskian flora with 13 genera ascribed to the Cyanophyta and the Chlorophyta. But little is known on the Carboniferous algae in this area, although they are present in many horizons. The material described here was collected by one of the authors, Zili Zhu, who joined the Upper Paleozoic research team organized by the Nanjing Institute of Geology and Paleontology, Academia Sinica in 1992-1994. Recent oil exploration has made the general geology and stratigraphy of the basin better understood (Wang et al., 1992, Zhou & Chen, 1992, Zhai & Sun, 1994, Zhu, 1995, Liao & Rodriguez, 1999).

2. General geology

The Tarim Basin (Fig. 1) is a Proterozoic plate separated from other terranes by the Tienshan belt to the north and the Kunlun belt to the south. From the late Precambrian to the Ordovician, the northeastern part of the plate formed a southwest-northeast trending platform-basin system. This pattern gradually disappeared during the Silurian, Devonian, Carboniferous time and in the Permian, it finally resulted in the welding of the Tarim Basin and the Kazakhstan-Dzungarian Block (southern part of the Asia plate) (Jia et al., 1992b). Consequently, the depositional center shifted to the western end of the basin in Carboniferous and Early Permian time (Wang, 1986). The marine history of the region ended in the Middle Permian (Early Guadalupian) (Zhou & Chen, 1992).

Major transgressions occur at three levels. The first is short and relatively local. In the Tournaisian, the sea invades the middle part of the basin to form the crinoidal limestone member of the Bachu Formation. This transgression comes from the north, and the southwestern part of the basin remains littoral. Open marine environments in the southwestern part of the basin are restricted to the upper part of the Kelitake Formation.

The second transgression is still local and begins in the early Visean when the sea invades the northwestern and southeastern margins of the basin. The transgression comes from the west and lasts up to the Serpukhovian. It ended with a major regression at the base of the Kalawuyi Formation.

The third transgression begins in the Bashkirian and open marine conditions prevail in the western and middle part of the basin in Moscovian time. In the Early Permian, open marine facies cover most of the western and middle part of the basin. Those marine conditions end in Early Guadalupian time. Groves and Brenckle (1997) suggest an additional important Sakmarian hiatus, that is not corroborated here by the fusulinid succession.

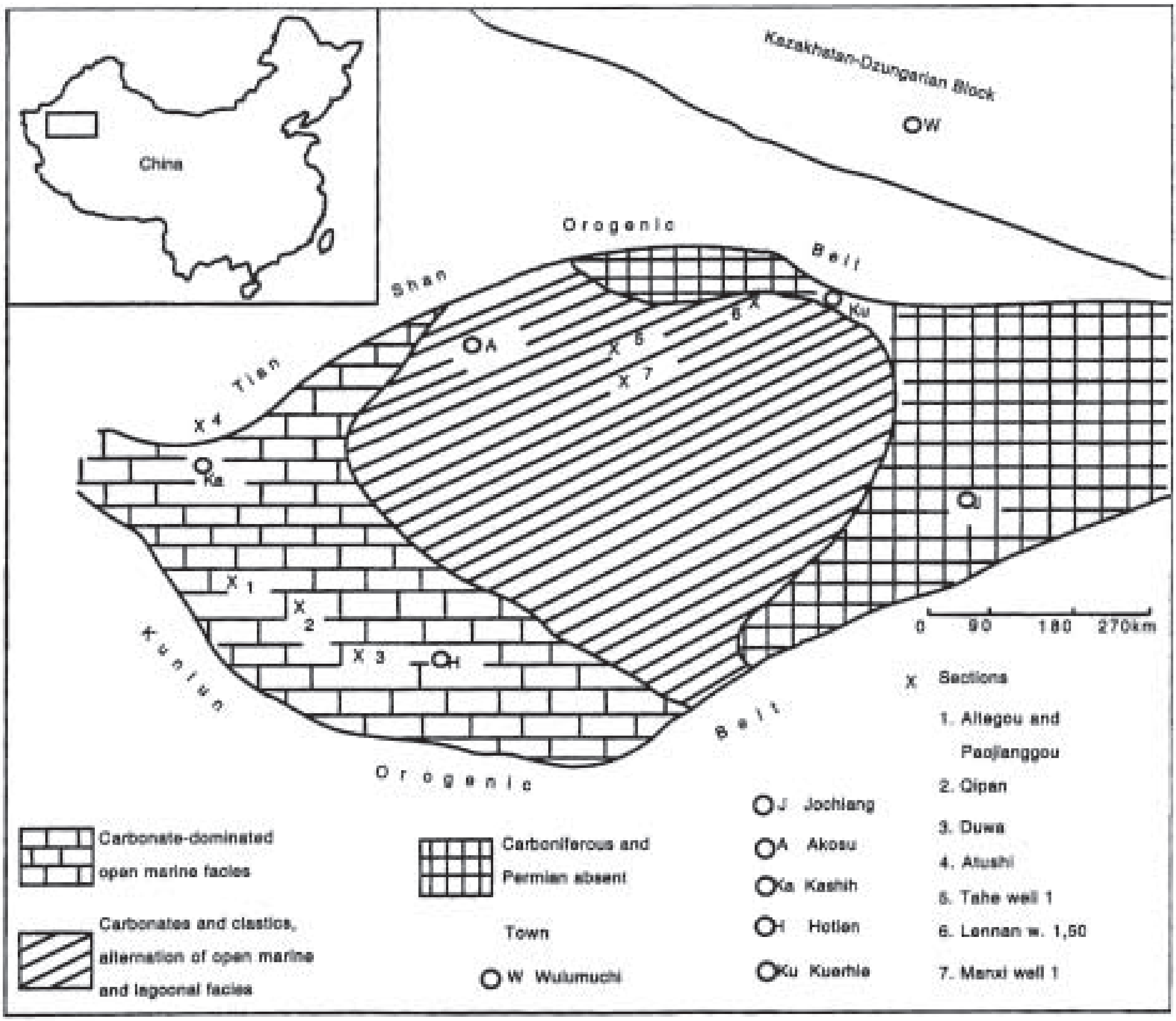

Figure 1. Carboniferous and Early Permian paleogeography, Tarim Basin. In Carboniferous and Early Permian time the eastern part of the basin was eroded, while the central part was occupied by alternations of supersaline lagoons and open marine ramps. The western part of the basin, in particular the southwestern and northwestern margins, was characterized by open marine environments. Subsidence was active and an extensive and thick marine sequence of nearly 2500m was deposited.

3. General stratigraphy

The thick marine sequences of the western part of the basin contain diverse fossil assemblages that have been recorded by Zhao et al. (1984), by the Institute of Geology, Xinjiang Geological Bureau & Institute of Geology, CAGS (1987), by Zhang & Gu (1991) and Liao et al. (1992). Recent oil exploration encouraged further studies of the basin and a fine framework of stratigraphy was established (Fig. 2). The southwestern margin of the basin, where an extensive marine succession from the basal Carboniferous to the Middle Permian is exposed, was extensively studied and used as a standard for regional correlations. Zhao et al. (1984) divided the succession into seven formations, in ascending order Kelitake, Heshilafu, Kalawuyi, Azigan, Tahaqi, Keziliqiman, and Qipan (Fig. 3).

The Kelitake Formation conformably overlies the upper Devonian terrestrial Qizilafu Formation and is divided in two parts. The lower part comprises dolomitic limestones and argillaceous limestones with Cyrtospirifer and Tenticospirifer. The upper part consists of oolitic limestones interbedded with lime mudstones. The Heshilafu Formation is composed of shales and sandstones with limestone intercalations. The base of the Viséan is marked by a coarse conglomerate. Brachiopods, corals and foraminifera are present. The Kalawuyi Formation has a somewhat similar rock composition but contains more limestone levels. No extensive conglomerates have been found except one layer of small pebbles, the base of which marks the Bashkirian widespread regression. One foraminiferal zone is missing at the base of the formation which may suggest an unconformity, although no obvious hiatus is recognized in the field. Fusulines, brachiopods

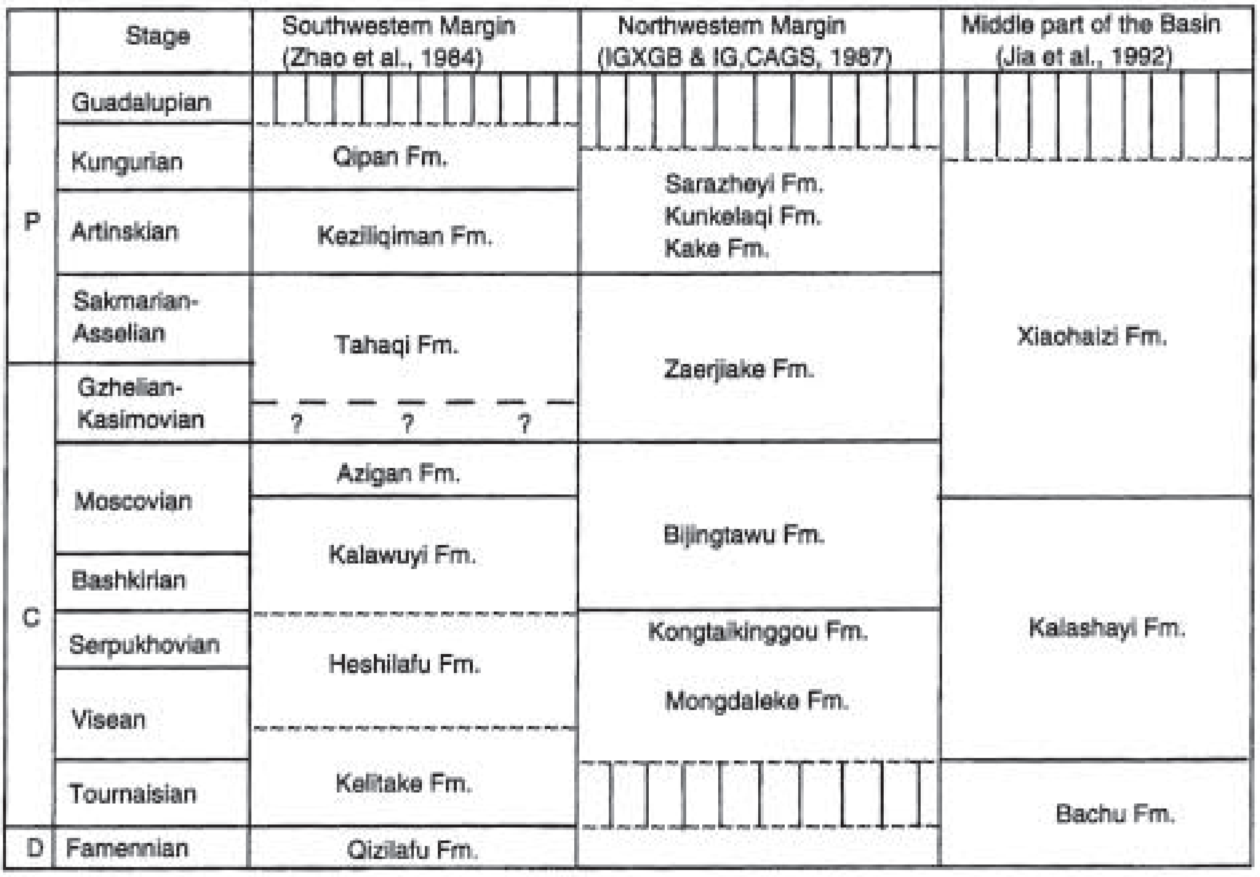

Figure 2. Carboniferous and Early Permian stratigraphy in Tarim Basin.

and corals are common. The overlying Azigan Formation includes light colored, massive limestones. Fusulines are abundant in the lower part but rare higher up. The Tahaqi Formation has essentially the same aspect and fusulines dominate the fauna. The Keziliqiman Formation yields thin limestone, dolomitic limestone and sandstone layers. Brachiopods, fusulines and fenestellid bryzoans are the main fossils. The Qipan Formation is composed of alternations of thin limestone, shales and sandstone with abundant bryozoans, bivalves and brachiopods.

4. Microfacies and foraminifers

The following is a concise description of the microfacies and the associated foraminifers ("endothyrids" and "fusulinids"). Foraminiferal zones are those of Mamet (1974).

4.1. Kelitake Formation (also transliterated Kelitag Formation)

Thin-bedded, black, shaly, dolomitic limestones. Black, thin-bedded argillaceous mudstones. Light gray, pelloid grainstones. Medium- to thick-bedded bioclastic-oolitic packstones. Some evaporites. Mainly restricted facies with few foraminifers and abundant calcispheres at the base. Marine ramp at the top.

Tournaisian (probably Zone 7?): Brunsia, Septaglomospiranella, Tournayella, Tournayellina.

Early Visean (Zone 11) : Brunsia, Dainella, Earlandia, Globoendothyra, Latiendothyra, Priscella, Pseudoammodiscus.

4.2. Heshilafu Formation

Fine-grained conglomerates and sandstones, overlain by black, thin-bedded bioclastic grainstones. Dark shales with minor black, thin-bedded, sandy grainstones. Black, thick-bedded, cherty grainstones/packstones, with abundant corals and brachiopods (Liao & Rodriguez, 1999). First levels of oncolites.

Middle Visean (Zone 13): Archaediscus, Brunsia, Endothyra, Endothyranopsis, Eostaffella, Mediocris, Planoarchaediscus, Priscella, Pseudoammodiscus.

Latest Visean (or slightly younger?)(Zone 16) : Archaediscus, Climacammina, Endothyra, Endothyranopsis, Eostaffella, Neoarchaediscus, Palaeotextularia, Planospirodiscus, Pseudotaxis, Tetrataxis.

Serpukhovian (Zone 18) : Asteroarchaediscus, Biseriella, Climacammina, Earlandia, Endothyra, Endothyranopsis,

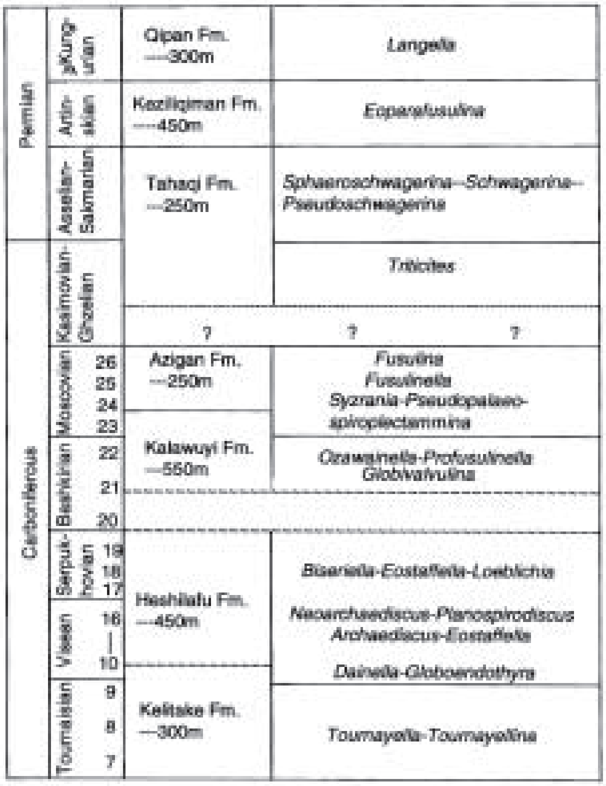

Figure 3. Detailed stratigraphy of the southwestern Tarim Basin, microfacies and foraminifers. The zones of the seven formations are based on small foraminifers and fusulines. The lower and middle part of the Carboniferous yield rather precise zones that can be correlated with other basins of the Tethys (Mamet, 1974; Pinard & Mamet, 1998). The Permian has no formal foraminiferal zonation and only stages or series can be recognized.

Eostaffella, Globoendothyra, Loeblichia, Neoarchaediscus, Omphalotis, Palaeotextularia, Planospirodiscus, Pseudoammo-discus, Pseudoendothyra, Pseudotaxis, Tetrataxis.

4.3. Kalawuyi Formation

At the base, fine- to coarse-grained sandstones interbedded with thin foraminiferal grainstones. Then, massive alternations of sandstones and limestones. Few algal bafflestones. At the top, massive fusuline grainstones. Mainly detrital, grading to open marine ramp.

Late Bashkirian (Zone 21 and 22: no evidence of zone 20 which is probably missing): Bradyina, Climacammina, Endothyra, Endothyranella, Eoschubertella, Globivalvulina, Ozawainella, Palaeotextularia,Profusulinella, Pseudoendothyra, Pseudostaffella, Tetrataxis, Verella.

Early Moscovian (Zone 23): Aljutovella, Biseriella, Bradyina, Bradyinelloides?, Climacammina, Deckerella, Eofusulina, Globivalvulina, Ozawainella, Palaeotextularia, Profusulinella, Pseudobradyina,Pseudopalaeospiroplectammina, Pseudostaffella, Syzrania.

4.4. Azigan Formation

Light-colored, homogeneous, massive packstones. Then interfingerings of dark/white limestones. Massive grainstones with boundstones at the top.
Middle Moscovian (Zone 24 and 25) Beedeina, Bradyina, Bradyinelloides, Climacammina, Endothyranella, Fusulinella, Globivalvulina, Hemidiscus, Pseudopalaeospiroplectammina, Pseudobradyina, Tetrataxis.
Late Moscovian (Zone 26): Bradyina, Bradyinelloides, Climacammina, Fusulina, Fusulinella, Tetrataxis.

4.5. Tahaqi Formation

Thin-bedded varsicolored grainstones and dolomites, massive oncolithic grainstones.
Kasimovian-Ghzelian (no typical Kasimovian fusulines identified) : Bradyina, Climacammina, Quasifusulina, Carbonoschwagerina, Triticites.
Asselian-Sakmarian: Climacammina ,Nodosinelloides, Protonodosaria, Pseudoschwagerina, Schwagerina, Sphaeroschwagerina, Zellia(at top).

4.6. Keziliqiman Formation

Light-colored, massive, oolitic, oncolithic grainstones, thin-bedded evaporites, dolomites, black, thin-bedded wackestones.
Artinskian: Eoparafusulina, Geinitzina, Nankinella, Nodosinelloides, Protonodosaria, Staffella, Syzrania.

4.7. Qipan Formation

Thin-bedded wackestones, high-energy grainstones with oncolithes interbedded with minor shales, sandstones and bindstones.
Kungurian (or slightly younger): Climacammina, Geinitzina, Globivalvulina, Langella, Nodosinelloides, Protonodosaria, Syzrania.

5. Algal microflora (Fig. 4)

Algae are too facies sensitive and too long-ranging to permit the establishment of a precise stratigraphic zonation. Carboniferous and Permian stratigraphy must rely on ammonoids, corals, conodonts or foraminifers. However, on a local basis, the Tarim microflora allows recognition of 10 assemblages that are locally useful. When the fauna is scarce or absent, the algal flora proves to be an important addition to the stratigraphy.

5.1. The calcisphere flora (Fig. 6A)

Abundant and diversified calcispheres (Fig. 6A) characterize the Tournaisian part of the Kelitake Formation. Cal-

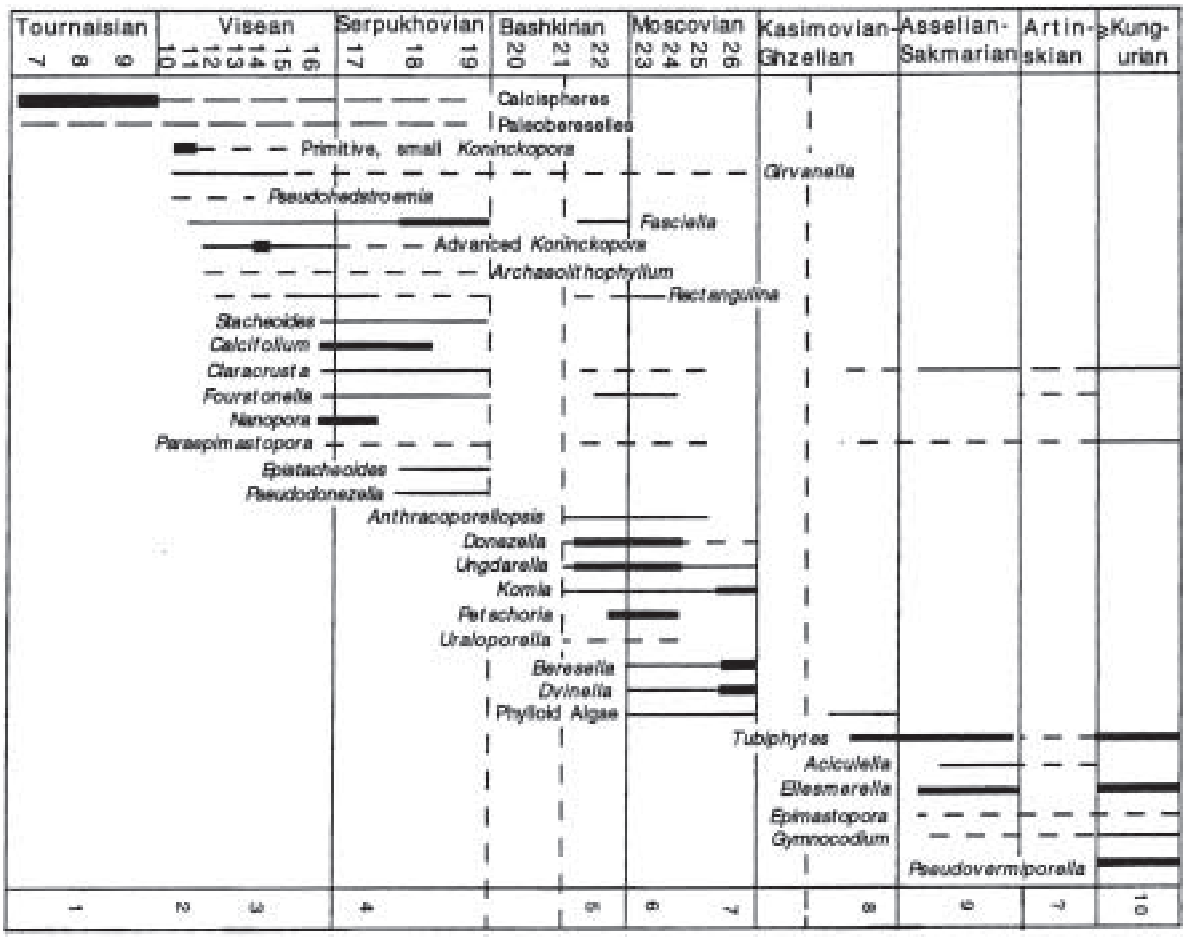

Figure 4. Detailed stratigraphic distribution of calcarous algae and incertae sedis, with numbered algal floras, in the Tarim Basin, subdivided according to stages and foram zones.

cispheres are algal spore kysts and proliferate in lagoons. They are cosmopolitan in the Paleozoic world and range from Devonian to Carboniferous (Mamet, 1991, 1998).

5.2. The primitive Koninckopora flora (Fig. 5G)

First representatives of the dasycladale Koninckopora are small with a poorly calcified cortex (Nakai & Kato, 1981). Although Wright (1981) has challenged the validity of the concept, it appears however quite constant and synchronous on a world-wide basis. It may be used to underline the early Visean.

5.3. The advanced Koninckopora flora

Massive, well-calcified, double-layered Koninckopora are observed in all Middle-Late Visean shallow-water open-marine grainstones. They form an essential part of the "oolite factory". In Europe the taxon peters out at the end of the Visean, but in the Tarim Basin, it is still observed in the Serpukhovian. A similar situation is known in South China, where Koninckopora grainstones are observed in the Serpukhovian, Zone 18, Luocheng Formation, near Liuzhou, Guangxi (Anonymous, 1987).

5.4. The Nanopora-Calcifolium flora (Figs 5 A, D)

The Calcifolium algal microfacies is well documented in Skompski (1996). While Nanopora normally ranges from the Visean to the Serpukhovian (Fig. 5 A), Calcifolium (Fig. 5 D) is restricted to the latest Visean-Serpukhovian. Together, they are good markers for that level in the Tarim Basin, and they are quite common. Up to now, Calcifolium was known only from the occidental part of the Tethys, its easternmost report in Asia being the Tadzikhistan (Mamet, 1991). It has also been recognized in South China (Luocheng Formation, Qiaotoucun, Guangxi) (Mamet, unpublished).

5.5. The Donezella flora (Figs 6 B, C)

Donezella is a Paleosiphonocladale (Shuisky & Schirschova, 1985) that has caused considerable controversy (Riding 1979, Della Porta et al, 2002). As it is cosmopolitan and very abundant in the Northern Hemisphere, its role has intrigued many researchers and the taxon has been attributed to foraminifers, sponges, pseudosponges (Riding, 1979; Vachard, 1981). Although fragile, Donezella forms bafflestones, which usually crumple unless the thalli are

Figure 5. The following two figures illustrate widespread algae and characteristic algal microfacies. U. of M. stands for University of Montréal. A. *Nanopora fragilissima* (Maslov, 1939). Equatorial and longitudinal section in a well-sorted pellet-foraminifer (*Neoarchaediscus*) grainstone. U. of M. 924/12, Heshilafu Formation, Aitegou section, AET730, latest Visean Zone 16 (or slightly younger), X85. B. Diagenetically altered *Fasciella* strands on a brachiopod valve. U. of M. 924/10, as A, but X 22. C. *Paraepimastopora* sp. U. of M. 925/20, Tahaqi Formation, Paojianggou section, AET 355, Ghzelian, X 25. D. *Calcifolium okense* Shvetsov & Birina, 1935. U. of M. 924/11, as A. E. *Girvanella problematica* Nicholson & Etheridge, 1878. U. of M. 926/17, Atushi section BG 4, Visean, X85. F. *Petschoria elegans* Korde, 1951 (showing the lateral tubes). U. of M. 926/13, Lennan well 1, core 8, Bashkirian, X 54. G. *Koninckopora minuta* Weyer, 1968. U. of M. 924/21,Kelitake Formation, Aitegou section, AET 601, Early Visean Zone 11, X 25. H. *Rectangulina tortuosa* (Antropov, 1950). U. of M. 924/25, Kalawuyi Formation, Aitegou section, AET 745, Serpukhovian Zone 18, X70. I. *Claracrusta catenoides* (Homann, 1972). U. of M. 925/27, Qipan Formation, Qipan section, Kungurian (or younger), X 25. J. *Aciculella* sp. U. of M. 926/4, Manxi well 1, core 21, Asselian-Sakmarian, X 54. K. *Petschoria elegans* Korde, 1951 (showing the branching). U. of M. 926/10, Kalawuyi Formation, Lennan well 1, core 8, as F, but X 25. L. *Fourstonella? johnsoni* (Flügel, 1966). U. of M. 924/32, as H. M. *Beresella* ex. gr. *B. polyramosa* Kulik, 1964. U of M. 925/9, Azigan Formation, Aitegou section, AET 774, Moscovian Zone 24, X25. N. *Pseudodonezella tenuissima* (Berchenko, 1982). U. of M. 924/27, as H. O. *Petschoria elegans* Korde, 1951 (showing the medullary tubes). U. of M. 926/12, Lennan well 1, core 8, Bashkirian, X 25. P. *Beresella erecta* Maslov & Kulik, 1956. U. of M. 925/8, Kalawuyi Formation, Aitegou section, AET 774, Moscovian Zone 24, X 35. Q. *Anthracoporellopsis machaevii* Maslov, 1956 (showing conceptacles). U. of M. 925/3, Kalawuyi Formation, Aitegou section, AET 754, Bashkirian? or early Moscovian? Zone 22-23, X54.

solidified by early marine cementation (see Figs 6 B, C). The sedimentary role of that algal incertae sedis has been recently discussed by Della Porta et al, 2002.

5.6. The Petschoria flora (Figs 5 F, K, O)

Petschoria has a wide dispersion. While it is known from the Urals, China, Yukon Territory and New Mexico, it is usually scarce. The taxon is well displayed in the Bashkirian-Moscovian limestone, well 1, Lenan (Figs 5 F, K, O).

5.7. The Beresella-Dvinella flora (Figs 5 M, P)

This duo is one of the most prolific "reef" builders (bafflestone) in Carboniferous-Early Permian time and is cosmopolitan in the Northern Hemisphere flora (Morin et al, 1994, Granier & Grgasovic, 2000). As the thalli have an outer mucilagenous coating fossilized as a continuous early cement layer, they are less susceptible than Donezella to crumple, and the bafflestones in the mud-mounds are usually better preserved. For taxonomy, refer to Granier & Grgasovic, 2000 or Forke & Samankassou, 2000 for upper Carboniferous microfacies. In the Tarim Basin, these bafflestones are restricted to the late Moscovian Azigan Formation.

5.8. The Tubiphytes flora? (Fig. 6, F,G)

This cosmopolitan algal? incertae sedis has been attributed to various phylla ranging from the hydrozoans to the cyanobacteria. Recent studies of Senowbary-Daryan & Flügel (1993) suggest a polygenetic origin for this problematicum. It was illustrated from Permian Chinese carbonate sections by Mu (1982, 1985).
Whatever its origin (Vachard et al., 2001), Tubiphytes is a common encruster associated in the Tarim Basin with bryozoans and sponges. It extends higher up associated with the Ellesmerella and Pseudovermiporella floras. In other parts of the world, Tubiphytes is usually associated with phylloid algae (Eugonophyllum, Ivanovia), but these are uncommon in the Tarim carbonates.

5.9. The Ellesmerella flora (Fig. 6,E,H)

Originally described from the Early Permian of the Canadian Arctic (Mamet et al., 1987), the flora has a great dispersion (Carnic Alps, Oman, Iran, China, Bolivia). It is probably the most prolific alga observed in the Permian limestones of the Tarim Basin. It is a common encruster of Gymnocodium (Fig.6,H).

5.10. The Pseudovermiporella flora

This is another controversial cosmopolitan alga. It has been excluded from the Dasycladales by Granier & Deloffre (1994) and transferred to the Thaumatoporelles. It has been repeatedly illustrated from China (Zhang & Wang, 1974; Zhao et al., 1981; Mu, 1981: Yang & Jiang, 1981; Mu, 1982; Yang et al., 1984; Lin, 1986; Wu, 1991, Riding & Guo, 1991; Sha et al., 1992).

6. Conclusions

The Late Paleozoic algal flora of the Tarim Basin is quite prolific . The most important taxa are "cosmopolitan" in the Northern Hemisphere. The only exception is that of Calcifolium which is reported here for the first time in the oriental part of the Tethys. Ten characteristic local algal assemblages are recognized from the Tournaisian to the Kungurian. They permit the establishment of a crude, local biostratigraphy at the stage level.

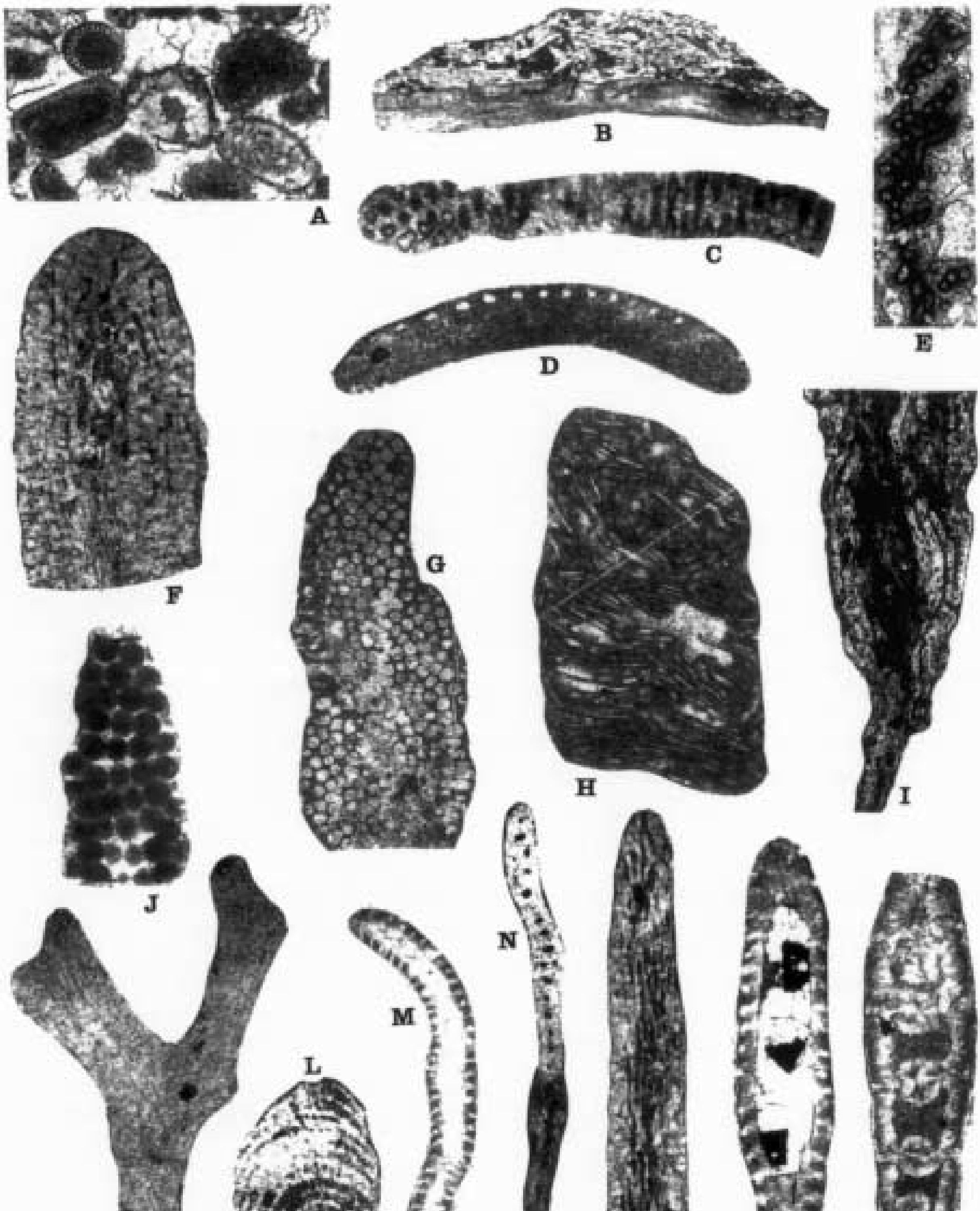
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Figure 6. A. Well sorted pellet-calcisphere packstone with patches of grainstone. Calcispheres are mostly *Calcisphaera laevis* Williamson, 1881 with a few *Archaesphaera* sp. Foraminifers are conspicuously absent. Environment is a restricted, quiet lagoon. U. of M. 928/0, Kelitake Formation, Lennan well 50, core 9, Tournaisian, X 22. B. *Donezella* bafflestone. Intertwined, anastomosed network of *in situ* thalli, preserved by early marine isopachous cementation. Algae represent 15-20% of the volume and originally left an extensive porosity. Figured elements are scarce pellets, ostracods and molluscs. Marine facies, in euphotic zone, below wave action. U. of M. 926/8, Kalawuyi Formation, Tahe well 1, core 8, Bashikirian, X 22. C. Reworked *Donezella* bafflestone. Although there is little evidence of transport, the bafflestone (see B) is disarticulated and the thalli are fragmented. No evidence of early marine cementation. Marine facies, in euphotic zone, base of wave action zone. U. of M. 925/4, Kalawuyi Formation, Aitegou 1 section, AET 771, Moscovian, X 22. D. Strands of *Claracrusta catenoides* (Homann, 1972) encrusting fenestellid bryozoans fronds. Marine oncolite facies in high energy *Eoparafusulina* grainstone. U. of M. 925/33, Keziliqiman Formation, Duwa section , DW 34, Artinskian X22. E. *Ellesmerella* encrustations on dissolved mollusc shell. Marine oncolite facies in high-energy *Pseudoschwagerina* grainstone. U. of M. 925/32, Tahaqi Formation, Duwa section, DW 28, Asselian-Sakmarian, X22. F-G. Complex composite bindstones of *Tubiphytes obscurus* Maslov, 1956, fenestellid fronds, calcareous sponges, *Claracrusta catenoides* (Homann, 1972) strands and serpulopsids. *Tubiphytes* tissue encloses thin-shelled ostracods and sponge spicules. U. of M. 925/29 and 925/30, Qipan Formation, Qipan section, no number, Kungurian or younger, X 22. H. *Ellesmerella* encrustation on *Gymnocodium* in a *Sphaeroschwagerina* high-energy grainstone. *Ellesmerella* is the most abundant alga in the Early Permian of South China, while the *Gymnocodium* flora is usually developed in the upper part of the Permian. U. of M. 925/22, Tahaqi Formation, Paojianggou section, AET 375, Asselian-Sakmarian, X 22.

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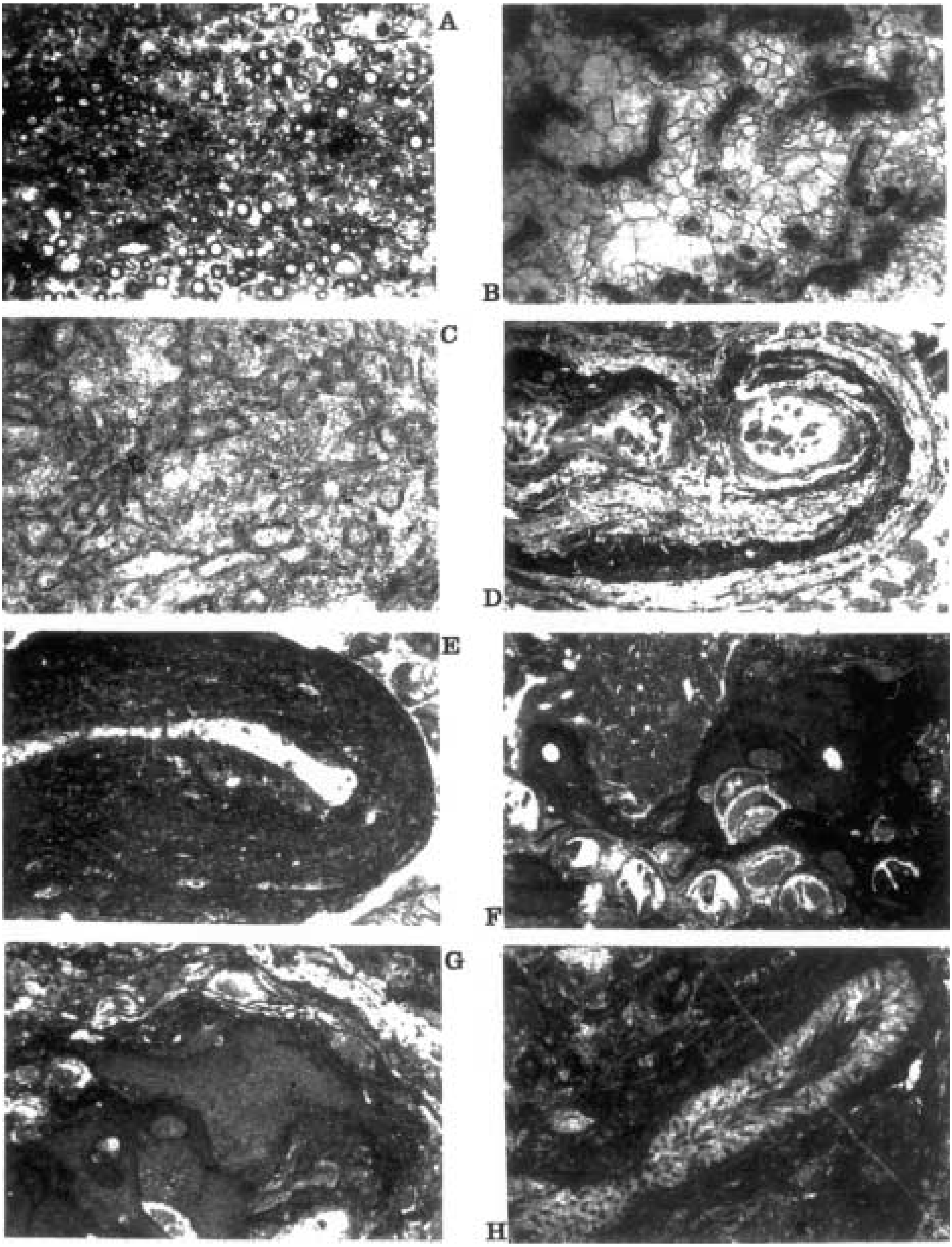
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