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The acritarchs of the South Chinese *Azygograptus suecicus* graptolite Biozone and their bearing on the definition of the Lower–Middle Ordovician boundary

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Abstract – In southern China, well preserved acritarch assemblages have been recovered from numerous sections in the Yangtze Platform and the Jiangshan–Changshan–Yushan (JCY) area crossing the interval where the Lower–Middle Ordovician boundary should be defined, i.e., roughly at the base of the Chinese *Azygograptus suecicus* graptolite biozone. The acritarch taxa *Aureotesta clathrata* and *Arbusculidium filamentosum* first appear below the *suecicus* zone, while the genus *Ampullula* and the species *Barakella felix* have their First Appearance Datum (FAD) in the *suecicus* zone. These latter taxa, that are also present in Baltica and peri-Gondwana, respectively, thus probably indicate the base of the Middle Ordovician. ***To cite this article: J. Li et al., C. R. Palevol 1 (2002) 75–81.*** © 2002 Académie des sciences / Éditions scientifiques et médicales Elsevier SAS

acritarchs / biostratigraphy / Yangtze Platform / South China / Lower–Middle Ordovician boundary

Résumé – Les acritarches de la biozone à graptolites *Azygograptus suecicus* et leur intérêt pour la définition de la limite Ordovicien inférieur–moyen. Dans le Sud de la Chine, des assemblages d'acritarches bien préservés sont décrits dans de nombreuses coupes de la plate-forme Yangtze et de la région Jiangshan–Changshan–Yushan (JCY). Ces coupes traversent l'intervalle dans lequel la limite Ordovicien inférieur–moyen devrait être définie prochainement, c'est-à-dire approximativement la base de la biozone à graptolites *Azygograptus suecicus*. Les taxons *Aureotesta clathrata* et *Arbusculidium filamentosum* apparaissent pour la premiére fois en dessous de la zone à *suecicus* ; en revanche, le genre *Ampullula* et l'espéce *Barakella felix* apparaissent dans cette zone. Ces derniers taxons, qui ont aussi été reconnus en Baltica et en péri-Gondwana respectivement, indiquent ainsi, probablement, la base de l'Ordovicien moyen. ***Pour citer cet article : J. Li et al., C. R. Palevol 1 (2002) 75–81.*** © 2002 Académie des sciences / Éditions scientifiques et médicales Elsevier SAS

acritarches / biostratigraphie / plateforme Yangtze / Chine du Sud / Ordovicien inférieur / Ordovicien moyen

Version abrégée

1. Introduction

Au cours de la dernière décennie, l'Ordovicien a été subdivisé en trois séries (inférieure, moyenne et supérieure), tandis que la majorité des limites des étages a été définie ou proposée par la sous-commission de stratigraphie de l'Ordovicien (IOS) (Fig. 1). Les stratotypes et les GSSP (*Global Stratotype Section and Point*) ont été approuvés pour la base du Darriwilien en 1997 et pour la base du Tremadocien (c'est-à-dire la limite cambro-ordovicienne) en 2000, tandis que les stratotypes des étages 2 et 5, dont les noms doivent encore être choisis, viennent d'être votés par l'IOS. La limite entre l'Ordovicien inférieur et l'Ordovicien moyen devrait prochainement être définie. Dans le Sud de la Chine, cette limite devrait correspondre approximativement à la limite inférieure de la bio-

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zone à graptolites *Azygograptus suecicus*. Des assemblages d'acritarches bien préservés sont décrits dans de nombreuses coupes de la plate-forme du Yangtze et de la région Jiangshan–Changshan–Yushan (JCY). Ces coupes traversent l'intervalle dans lequel la limite Ordovicien inférieur–moyen devrait être définie. Les successions d'acritarches rencontrées, qui se corrèlent partiellement avec les séquences de Baltica et de la bordure gondwanienne, y compris les successions britanniques, pourraient jouer un rôle important pour la localisation et la corrélation de cette limite Ordovicien inférieur–moyen.

2. Biostratigraphie de la biozone à graptolites *suecicus* et corrélation internationale

La Chine joue un rôle important dans la stratigraphie de l'Ordovicien. Le GSSP du Darriwilien se trouve dans la région JCY et un stratotype auxiliaire pour la base de l'Ordovicien supérieur a été choisie à Dawangou au Tarim, dans le Nord de la Chine. La biostratigraphie des groupes fossiles majeurs de l'Ordovicien a été révisée et la biozonation à graptolites est assez bien établie. La base de la biozone à graptolites *Azygograptus suecicus* devrait approximativement correspondre à la limite Ordovicien inférieur–moyen (Chen, comm. pers.). En termes de stratigraphie britannique, cette limite devrait se trouver au milieu du Whitlandien (étage local britannique), qui représente la partie moyenne de l'Arénigien (série locale britannique). Selon les plus récentes corrélations, la biozone à *suecicus* correspond à la partie supérieure de la biozone à *Didymograptus simulans* (précédemment *D. nitidus*) du Whitlandien [8, 12].

3. Les acritarches de la biozone à *suecicus* et de l'« Arénigien–Llanvirnien » du Sud de la Chine

De nombreux travaux sur les acritarches de l'Ordovicien inférieur et moyen ont été réalisés dans le Sud de la Chine. Les trois travaux majeurs sont les thèses de doctorat de Li [18], Xu [32] et Brocke [3]. La révision de la littérature montre que 39 articles scientifiques ont été publiés, dont 18 concernaient les acritarches de la biozone à *suecicus*. Dans cette zone, 39 genres sont décrits, dont trois nouveaux. Concernant le nombre d'espèces, 111 taxons ont été cités, 26 nouvelles espèces sont décrites et 35 autres restent actuellement sous nomenclature ouverte. Les localités décrites dans la littérature se trouvent sur la carte de la Fig. 2. Une liste complète de la littérature est donnée dans Li et al. [20].

4. Paléoécologie et paléogéographie

La paléogéographie et la paléogéoécologie du Sud de la Chine sont aujourd'hui assez bien connues. Les roches essentiellement carbonatées de la plate-forme Yangtze passent progressivement vers le sud/sud-est aux faciès de schistes à graptolites du Jiangnan Belt, qui, dans la région JCY, peuvent inclure des intercalations de calcaires. Les assemblages d'acritarches de la biozone à *suecicus* reflètent ce changement graduel de lithofaciés dans une direction NW–SE. Dans les eaux peu profondes de l'Ouest de la plate-forme Yangtze, les assemblages sont pauvres, avec une diversité et un nombre de spécimens limités. L'abondance et la diversité des acritarches augmentent dans des eaux plus profondes du Nord de la province Guizhou et du Sud de la province Sichuan, c'est-à-dire dans les coupes de Shuanghe, Guanyinqiao, Honghuayuan, Wangjiazai et Datianba. Les assemblages de la région de Yichang dans la province Hubei (localités Jianyangping, Huanghuachang et Daping) montrent également des assemblages riches et diversifiés, mais de compositions différentes. En position plus distale vers la région JCY, la diversité diminue de nouveau et la préservation des spécimens n'est que médiocre. La différence de composition des assemblages reflète donc très probablement un gradient *inshore–offshore*, et ne doit pas nécessairement être attribuée à des changements paléogéographiques, comme certains auteurs le suggéraient [30].

Selon les derniers modèles paléogéographiques [21], le Sud de la Chine se trouvait dans des latitudes intermédiaires et/ou basses, proches de l'équateur. Le présent travail n'a pas pour but de revoir la paléobiogéographie des acritarches de la Chine en détail. Néanmoins, il est important de rappeler que les assemblages du Sud de la Chine contiennent aussi bien les taxons typiques de la province d'eaux chaudes de Volkova [31] que les espèces typiques de la province de la bordure gondwanienne définie par Li [16]. Ces assemblages ont ainsi le potentiel d'être utiles pour les corrélations avec tous les autres paléocontinents.

5. Biostratigraphie et signification pour la définition de la limite Ordovicien inférieur–moyen

La révision de la distribution stratigraphique des acritarches dans les coupes des 16 localités étudiées montre que les premières apparitions (FAD) de certains taxons peuvent avoir une grande signification pour la localisation et la corrélation de la limite Ordovicien inférieur–moyen (Fig. 3).

Les taxons *Aureotesta clathrata* et *Arbusculidium filamentosum* apparaissent en Chine pour la première fois en dessous de la zone à *suecicus*, c'est-à-dire probablement en dessous de la limite Ordovicien inférieur–moyen, limite qu'il reste à définir précisément. En revanche, le genre *Ampullula* et l'espèce *Barakella felix* apparaissent dans la zone à *suecicus*. Ces derniers taxons pourraient donc être des indicateurs de la base de l'Ordovicien moyen. *Ampullula* a également été reconnu en Baltica dans la partie supérieure de l'étage baltique de Volkhov (correspondant également à l'« Arénigien » moyen), tandis que *Barakella* et un bon nombre d'autres taxons trouvés dans les assemblages du Sud de la Chine sont largement répandus dans la bordure du Gondwana, permettant des corrélations biostratigraphiques.

1. Introduction

In the 1990s, significant progress was made in Ordovician series and stage boundary definitions. A tripartite division of the Ordovician System named Lower, Middle and Upper Ordovician Series has been accepted and it was decided that the base of the six global stages will be defined on the basis of the occurrences of either graptolite or conodont species (Fig. 1). The first stage that was approved by the International Union of Geological Sciences (IUGS) and the International Commission on Stratigraphy (ICS) in early 1997 is the second global stage of the Middle Ordovician Series, named Darriwilian, with its Global Stratotype Section and Point (GSSP) near Huangnitang, Changshan, SE China. The Executive Committee ratified the GSSP of the base of the first stage of the Lower Ordovician Series, named Tremadocian, at Green Point, Newfoundland, in January 2000. Two other GSSP have been voted recently by the Ordovician Subcommission (IOS) and are under the procedure of approval by the ICS and of formal ratification by IUGS: the GSSP of the second stage of the Lower Ordovician Series at the Diabasbrottet section at Mt. Hunneberg, Sweden, and the GSSP of the first stage of the Upper Ordovician Series at Fågelsång, Scånia, Sweden. The IOS will not choose a proper name for the second stage of the Lower Ordovician until the boundary of the stage (= the base of the Middle Ordovician Series) has been formally defined. However, selection of this latter GSSP for the base of the Middle Ordovician may prove to be contentious. The defining biohorizon (first appearance of the conodont *Tripodus laevis*) and the candidate stratotype section at Whiterock Narrows, Nevada, USA, need to be re-evaluated. Little progress has been made on the lower boundary for the upper stage of the Upper Ordovician Series, which is to be defined on the FAD of either the conodont *Amorphognathus ordovicicus* or the graptolite *Dicellograptus complanatus*.

After proving to be useful for long distance correlations and having a high potential for the definition of Ordovician boundaries, such as the base of the second stage of the Lower Ordovician Series (= the Tremadocian–'Arenigian' boundary) [26], acritarchs may play an essential role for the definition and correlation of the base of the Middle Ordovician Series of which the GSSP still needs to be chosen.

In southern China, acritarchs have been recovered from many localities from the Yangtze Platform and from the Jiangshan–Changshan–Yushan (JCY) area, providing an almost continuous succession from the Tremadocian to the Darriwilian. This acritarch succession can be partly correlated with the sequences observed for Gondwana, including the former Ordovician-type localities of the British Isles. Of particular interest are the acritarchs recorded in the *Azygograptus suecicus* graptolite biozone of southern China. The base of this biozone may roughly correspond to the Lower–Middle Ordovician boundary, which has to be defined in the next years.

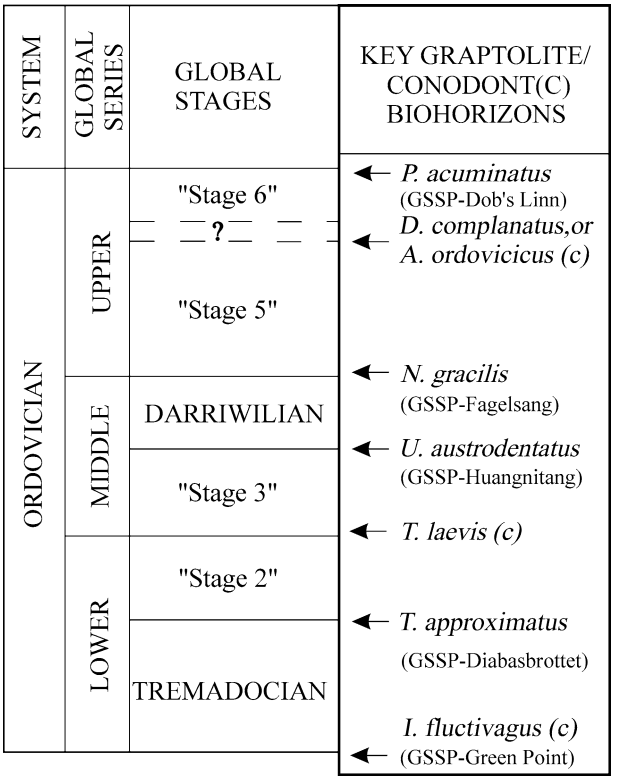

Figure 1. Diagram showing the stratigraphic location of biohorizons approved by the IOS as defining the base of global Ordovician stages and series.

Figure 1. Diagramme montrant la position des biohorizons approuvés par l'IOS pour définir la base des étages et séries globaux de l'Ordovicien.

The present paper deals with the acritarch succession crossing the *suecicus* biozone and with the palaeoecology, palaeobiogeography, and biostratigraphy of the assemblages. It is documented here that some selected, easily recognisable acritarch taxa may be useful, not only for the recognition of the Lower–Middle Ordovician boundary, but also for its correlation, at least between localities from peri-Gondwana and southern China, but probably also with Baltica.

2. Biostratigraphy of the *suecicus* biozone and international correlation

During the Palaeozoic, China was constituted by a series of palaeocontinents, of which the three major elements were the North China (Sino-Korean), Tarim and South China Plates. In the last years, China played an essential role in the reconsideration of the global Ordovician stratigraphy. For example, the GSSP of

the Darriwilian Stage lies in the JCY area in South China, and an auxiliary stratotype section for the base of the Upper Ordovician Series has been proposed at Dawangou, in western Tarim.

Recent revisions of the Ordovician of China makes that the biostratigraphy of the major fossil groups (graptolites, conodonts, trilobites, brachiopods) is today well known and can easily be integrated in the international standard [8]. The tripartite division of the Ordovician is accepted in China and the global stage names that have been approved are formally used in China. Only two regional stage names, the Yushanian and the Dawanian, still remain. They can roughly be correlated with the global 'stages 2' and '3', which still need to be defined and named. The Ordovician graptolite succession of these stages is today known in detail, although some international correlation problems still exist. Of particular interest for the definition and international correlation of the Lower–Middle Ordovician boundary is the *Azygograptus suecicus* biozone, which constitutes the base of the regional Dawanian stage [8]. The base of this biozone may roughly correspond to the Lower–Middle Ordovician boundary (Chen, pers. comm.), which has to be defined in the next years by the IOS. According to the British chronostratigraphy, this boundary should be defined in the middle part of the British Arenig series, in the middle of the British Whitlandian stage [12]. According to the most recent correlations, the Chinese *A. suecicus* biozone roughly corresponds to the upper part of the British *Didymograptus simulans* (formerly *D. nitidus*) biozone, which occupies most of the Whitlandian [8, 12].

3. The acritarchs of the *suecicus* biozone and of the 'Arenig–Llanvirn' of southern China

Over 50 publications deal with Ordovician acritarchs of China, of which only few concern material from North China and Tarim [20]. Most investigations were focused on the Lower and Middle Ordovician of southern China, i.e., from the Yangtze Platform and from the JCY area, mostly from levels between the Late Tremadocian and the Early Darriwilian. The major part of the palynological investigations is based on three PhD theses by Li [18], Xu [32] and Brocke [3]. In addition, a total of 39 publications have been published, of which 18 deal with acritarchs of the *suecicus* zone. A revision of this literature shows that 39 acritarch genera are described from the *suecicus* zone; among them three have been newly established. Some 111 acritarch species, among them 26 newly described taxa and 35 species remaining in open nomenclature have been reported and described from this interval so far.

The sections from which acritarchs of the *suecicus* zone have been described are located on the map in Fig. 2. Fang [10], Li [18] and Li and Yuan [19] investigated the acritarchs of the *suecicus* zone from Ningqiang in the Shaanxi Province (Fig. 2, locality 1). Fang [10] also studied a section nearby, at Guangyuan in northern Sichuan (Fig. 2, locality 2). The investigated sections from southern Sichuan are those at Shuanghe (Fig. 2, locality 3, [18]), Guanyinqiao (Fig. 2, locality 4; Li, unpublished), Wangjiazai (Fig. 2, locality 5, [2, 5, 28]), and Datianba (Fig. 2, locality 6, [2, 3, 5, 6, 11, 28]). Three sections are located in the Guizhou Province: Honghuayuan (Fig. 2, locality 7, [15]), Huanghuachong (Fig. 2, locality 8, [18]) and Sandu (Fig. 2, locality 9, [18, 32]). Two localities from the Yunnan Province were investigated by Fang [9] (Luquan, Fig. 2, locality 10) and by Gao [13] (Wuding, Fig. 2, locality 11). Li [17] described the acritarchs from a locality in the Hunan Province (Jishou, Fig. 2, locality 12). Three sections including the *suecicus* biozone are investigated in Hubei. The first section, at Jianyangping (Fig. 2, locality 13) was investigated by Brocke et al. [2, 3, 6]. The section at Huanghuachang (Fig. 2, locality 14) was investigated by numerous workers, first by Lu [22] and Li [18, 19] and later by Yin, Tongiorgi et al. [30, 33]. The latter authors also investigated a section at Daping, close to Huanghuachang (Fig. 2, locality 15, [29, 30]). One locality from the Jiangxi Province, at Chenjiawu was investigated by Huang et al. [14] (Fig. 2, locality 16). This latter locality is belonging to the JCY area; all other localities are belonging to the Yangtze Platform. The above-cited references constitute the major works. For a complete list of publications, the reader is referred to Li et al. [20].

4. Palaeoecology and palaeobiogeography

The palaeogeography and the palaeoecology of southern China are today fairly well understood. The carbonate dominated rocks from the Yangzte Platform (between Kunming in eastern Yunnan and Yichang in Hubei, Fig. 2) change gradually to the south–southeast into the graptolitic shale facies of the Jiangnan Belt, which includes locally some beds or lenticular intercalations of limestone, such as in the JCY area [7].

The acritarch assemblages of the *suecicus* biozone from the different localities clearly reflect this gradual lithofacies change in a NW–SE direction by showing different abundances and diversity patterns. In the shallow-water part of the western Yangtze Plat-

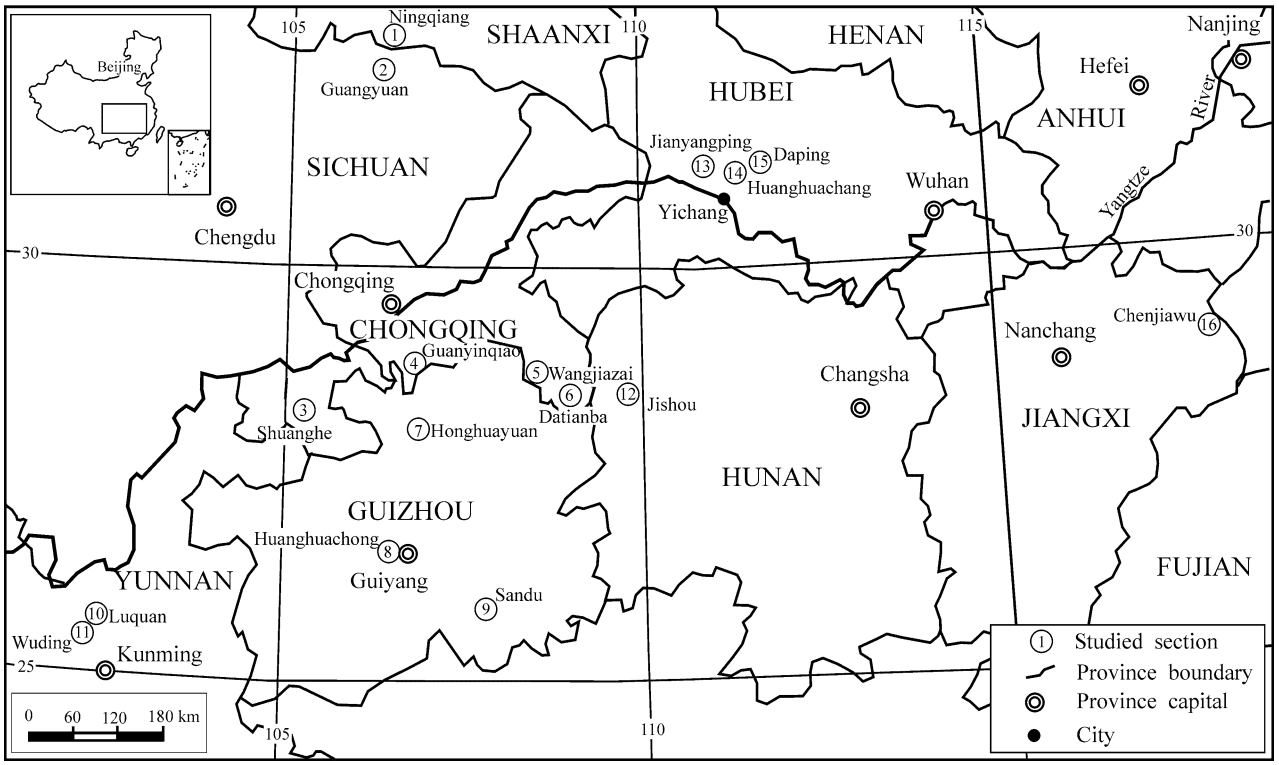

Figure 2. Location map of the sections in southern China from which acritarchs of the *suecicus* graptolite biozone have been described.

Figure 2. Carte de localisation des sections en Chine du Sud, dans lesquelles des acritarches de la biozone à graptolites *suecicus* ont été décrits.

form in the Kunming–Luquan area in eastern Yunnan, the acritarch assemblages are not abundant and are poorly diversified. Deeper-water conditions present in northern Guizhou and southern Sichuan, i.e., in the sections from Shuanghe, Guanyinqiao, Honghuayuan, Wangjiazai and Datianba show acritarch assemblages of much higher diversity. Other deeper-water areas, observed around Yichang in the Hubei Province in the localities Jianyangping, Huanghuachang and Daping are also highly diversified, but show a different composition from the previous area. By going deeper into the basin, i.e., towards the JCY area, the diversity diminishes again, with generally a poor preservation of the acritarch assemblages. The difference of acritarch composition in the *suecicus* zone therefore probably partly reflects a facies-dependence and an inshore–offshore trend in the distribution of taxa, and not only palaeogeographical changes, as suggested by Tongiorgi et al. [30], whose investigations were limited to the Yichang area.

According to the most recent palaeogeographical reconstructions, e.g., by Li and Powell [21], South China was located at intermediate to low latitudes. It is beyond the scope of this paper to completely review the palaeobiogeography of the acritarchs of southern China. Nevertheless, it is important to remind that the assemblages of the Yangtze Platform include both acritarch taxa that are typical of the warm-water province of the Late Tremadocian defined by Volkova [31] and typical elements of the 'Arenig' peri-Gondwanan province defined by Li [16]. The acritarch assemblages of southern China thus bear a potential for global correlations with not only the cold-water areas from peri-Gondwana, but also with localities at intermediate latitudes, such as Baltica, and warm-water areas, such as Laurentia, Australia and northern China.

5. Biostratigraphy and significance for the definition of the Lower–Middle Ordovician boundary

Previous publications already documented the biostratigraphical importance of the acritarchs at the Tremadocian–'Arenig' [1] and at the 'Arenig–Llanvirn' [6] boundaries in southern China. The revision of the biostratigraphical distribution, and especially of the First Appearance Datum (FAD) of selected acritarch taxa in the sections from the 16 investigated localities, now also allows to recognise the boundary between the Yushanian and the Dawanian stages, i.e., the interval where the Lower–Middle Ordovician boundary should be defined. Additionally, the strati-

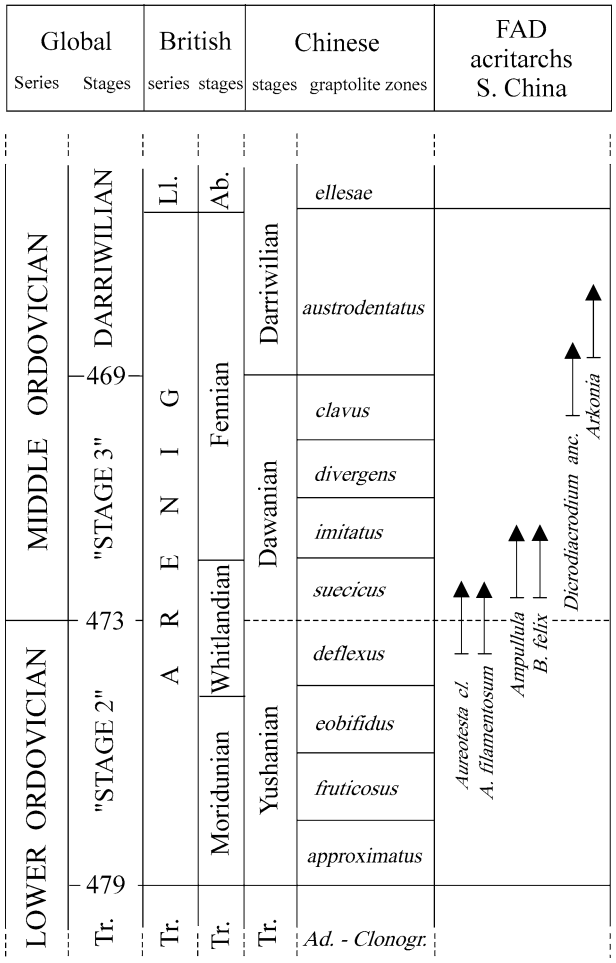

Figure 3. First appearance data (FAD) of selected acritarch taxa in southern China. Global Ordovician chronostratigraphy and correlations after Paris [27]. Regional series and stages of the British Isles according to Fortey et al. [12]. Chinese regional stages and graptolite zones according to Chen et al. [8].

Figure 3. Premières dates d'apparition (FAD) dans le Sud de la Chine de taxons d'acritarches sélectionnés. Chronostratigraphie globale et corrélations d'après Paris [27]. Séries et étages régionaux britanniques selon Fortey et al. [12]. Étages régionaux et zones à graptolites selon Chen et al. [8].

graphical distribution of some of these taxa also allows a correlation with the distribution of taxa in other areas of peri-Gondwana, including the British Isles, and Baltica.

The FAD of the biostratigraphically important taxa are given in Fig. 3. The species *Aureotesta clathrata* (with both its varieties *clathrata* and *simplex*) first appears in the *deflexus* graptolite biozone [4, 5], together with *Arbusculidium filamentosum* [4, 11], i.e., in the uppermost part of the Yushanian, which can be considered as the uppermost part of the Lower Ordovician.

However, the acritarch genus *Ampullula* first appears in the *suecicus* biozone, with FAD's of both *A. erchunensis* and *A. simplex* [2, 6]. Together with the species *Barakella felix*, that also first appears in the *suecicus* biozone [6], these taxa may thus be important indicators of the base of the Middle Ordovician. Other important taxa that have been reviewed in detail in recent years and which are known to occur first in the middle and upper parts of the 'Arenig' are the species *Dicrodiacrodium ancoriforme*, which first appears in southern China in the *clavus* (formerly *sinodentatus/nexus*) biozone [28], and the genus *Arkonia*, which first appears in the *austrodentatus* biozone [18], thus indicating the base of the Darriwilian.

Most of these occurrences are of great importance for the understanding of the acritarch biostratigraphy in peri-Gondwana. As the reviews of the taxa *Arbusculidium filamentosum* [11], *Arkonia* [25], *Aureotesta clathrata* [5], and *Dicrodiacrodium ancoriforme* [28] have shown, these taxa are widespread in peri-Gondwana and southern China; they should therefore be useful to identify the Lower–Middle Ordovician boundary.

The FAD of the genus *Ampullula* may also be of great importance. This taxon, which probably indicates the basis of the Middle Ordovician in southern China is also recorded from the Baltica continent in the upper part of the Baltoscandian Volkhov stage of Öland [23, 24], in levels that can be considered as slightly younger than the Chinese *suecicus* zone. However, the FAD of the genus in Baltica is not yet known, as the sediments below the upper Volkhov did not provide palynomorphs in northern Öland [23].

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