European frameworks for the selection of Palaeozoic palaeobotany Geosites

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Abstract. Frameworks for the selection of palaeobotanical Geosites should be developed around four criteria: palaeofloristics, palaeoecology, fossil preservation and biostratigraphy. For the Silurian and Devonian, there is a relatively low degree of provincialism, so comparisons have to be made on a global basis. As there is a more marked provincialism in the Carboniferous and Permian floras, European palaeobotanical sites must be compared mainly with others in the same low palaeolatitudes. Especially in the European Lower Devonian and Lower Carboniferous, there are two main habitats reflected in the plant fossil record: fluvio-deltaic and volcanogenic terrains. This palaeoecological distinction is also partly reflected through differences in preservation, with the floras in fluviodeltaic deposits being mainly adpressions, and those in volcanogenic deposits mainly petrifactions. The plant macrofossil biostratigraphy is well developed in the European Palaeozoic and so provides a useful temporal background to the fossil record. By integrating these four sources of data, it is possible to develop the frameworks for a reliable assessment of the European palaeobotanical sites.


Key words: palaeobotanical geosites, criteria for palaeobotanical geosites, Palaeozoic fossil plant

Introduction

The underlying philosophy behind the Geosites programme (Wimbledon, 1996; Wimbledon et al., in press) was intended to ensure that the voices of individual geologists would be heard in the site-selection process. National working groups are being asked to collate the views of geologists within their country and submit the resulting list to regional or continental working groups, who in turn will submit their collated lists to a global Geosites working group. However, against this background, there are specialist groups that can help to provide a global perspective in certain fields. The role of such specialist groups will vary, but will be of most significance in fields which are not totally familiar to most geologists. One such group has been organised for palaeobotany, that for historical reasons has tended to be regarded as more the remit of botanists and the life-sciences, rather than of geologists and the earth sciences.

The two authors of this paper have been asked to co-ordinate the palaeobotany Geosites specialist group and we have been canvassing for opinions on both selection framework criteria and specific site proposals among the palaeobotanical community. The canvassing has so far been mainly through the International Organisation for Palaeobotany and the IUGS Subcommission on Carboniferous Stratigraphy, including the web pages of the former (Cleal & Thomas, 1996 b, 1997). In this paper, we will summarise the results of the work by the palaeobotany specialist group, especially as it relates to the Palaeozoic of Europe.

Selection frameworks

As with all of the Geosites selection programmes, it has been essential to establish the frameworks within which the comparative analyses can be made. There is no point in comparing, for instance, a Lower Permian boreal flora with a Middle Devonian tropical flora (we should perhaps point out that we are using the term flora here to refer to an assemblage of plant fossils, rather than an assemblage of plants; the significance of this difference will be-
come evident later). We must be comparing 'like with like' if the comparative analysis is to have any significance.

Plant fossils can provide four main types of information to the palaeobotanists and these control the frameworks within which sites can be meaningfully compared.

1. Palaeofloristics. The broad pattern of geographical distribution of plant fossils is probably the single most important factor in delineating the Geosites selection frameworks for palaeobotany. The best analysis of palaeofloristics remains that of Meyen (in Vakhrameev et al., 1978), with shorter reviews provided by Meyen (1987) and Cleal (1991). In such analyses, a nested hierarchy of palaeofloristic 'zones' or phytocoria are recognized, in descending rank palaeokingdoms, palaeoarea and palaeoprov-

2. Palaeoecology. Environmental conditions and intraspecific interactions are obviously major factors in determining the distribution of plants. However, as only a relatively narrow band of mainly lowland habitats is usually sampled in the fossil record, palaeoecology tends to be of less important for selecting frameworks. This is not to say that palaeoecological studies should be ignored because, for instance, in the case of the fossil record of the Late Carboniferous tropical swamp forests there are two quite different and mutually exclusive vegetational habitats: the lycopsid dominated back-swamp communities and the more diverse, fern/pteridosperm levee communities (Cleal & Thomas, 1994). In such examples as this, the case for treating the two, or more, communities separately is compelling.

3. Preservation. This controls the type of information that a fossil reveals: adpressions sensu Shute & Cleal (1986) normally provide the best morphological data, whilst petrifications sensu Bateman (in Cleal, 1991) are best for anatomical studies. Hence the same original vegetation could be represented by sites in two quite different frameworks: one for adpression floras and one for petrification floras. The preservational divide may also partly mirror differences in habitat. In the above quoted Late Carboniferous example, the backswamp vegetation is mainly represented by the coal-ball petrifications, whereas the levee vegetation is mainly reflected in the adpersion record in the clastic deposits.

4. Biostratigraphy. This reflects the progressive development of vegetation with time. For convenience, the stratigraphical column is divided into a sequence of biozones based on this changing pattern of fossil occurrence. Various schemes have been proposed, but that most widely adopted in Europe today is summarized in Cleal (1991).

Silurian

Other than the Baragwanathia found in Australia (Lang & Cookson 1935; Tims & Chambers 1984), about whose age there are still some doubts, Silurian floras are mainly dominated by simple rhynophytoids such as Cooksonia. The best known examples are found in the British Isles (reviewed by Cleal & Thomas, 1995), but on the whole their preservation is not as good as the slightly younger floras from the basal Devonian. The only Silurian site that has therefore been regarded as being sufficiently important as a palaeobotany Geosite is in Tipperary, Ireland, which has yielded the oldest known (Wenlock) examples of Cooksonia and represent the earliest known macrofossil evidence of land vegetation (Edwards et al., 1983).

Devonian

The Devonian palaeobotanical record reflects the progressive early development of land plants, from their early rhynophytoid beginnings to the early seed plants. Most of the well documented floras are from Europe and North America. There is possible evidence of global provincialism in Devonian floras, but this is based on assemblages from places such as Kazakhstan and China which have not been as extensively studied as the European and North American assemblages. Until these other floras have been more extensively studied, the comparative analysis of Devonian palaeobotanical sites has to be in global frameworks, divided primarily on preservation.

Europe has proved especially important in the study of Early Devonian palaeobotany. The United Kingdom and Belgium have the best available sites for the study of the two Lower Devonian plant biozones: sites in the Clee Hills for the Zosterophyllum Zone, Craig-y-Fro and Llanover quarries for the lower Psilophyton Zone, and sites on the northern margins of the Dinant Basin for the upper Psilophyton Zone. The only Lower Devonian site outside of Europe which is of equivalent significance is Gasp, in Canada, which has yielded a classic flora of the upper Psilophyton Zone (Gensel & Andrews, 1984). For the lower Middle Devonian Hyenia Zone, the diverse floras of Elberfeld in Germany and Vesdre in Belgium clearly stands out as the best in the world. The European record for the overlying Svalbardia and Archaeopteris Biozones in the upper Middle and lower Upper Devonian is much poorer and no sites can match those in North America, notably in the Catskill Mountains (Banks et al., 1985). However, for the topmost Devonian biozone, the Rhacophyton Biozone, Belgium again includes some of the best sites near the northern margins of the Dinant Basin,
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<tr>
<td>Tipperary</td>
<td>Ireland</td>
<td>Oldest known example of Cooksonia</td>
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<td>Clee Hills</td>
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<td>Best examples of Zosterophyllum Zone floras including anatomically preserved Cooksonia</td>
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<td>Classic Lower Devonian petrifications</td>
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<td>Stockmans</td>
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<td>Glynneath- Ammanford</td>
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<td>Classic middle Stephanian petrified peat, especially important for ferns and sphenophytes</td>
<td>Gallier &amp; &amp; Scott (1981) and Gallier &amp; Phillips (1985)</td>
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which complement the Bear Island flora in the Arctic (Schweitzer, 1967, 1969).

Standing quite separate from this main global framework is the classic Rhynie Chert flora. The assemblage is totally different from any other known assemblage, being chert petrifications representing the vegetation in a volcanic terrain. It should not therefore be interpreted within the same frameworks as the other Devonian sites, which preserve fluvio-deltaic vegetation as adpressions or other, less perfect types of petrifaction.

Lower Carboniferous

The Lower Carboniferous reveals the first well-documented evidence of floristic provincialism, most notably in the distinctive Angaran floras from Siberia (Meyen, 1982). Elsewhere, there is a less marked provincialism, which was recognized by Cleal & Thomas (in Cleal, 1991) as four palaeoareas: Gondwana, Cathaysia, Kazakhstan and Europe (which also includes North America and parts of north Africa) (Fig. 1).

Within this Europe Palaeoarea, at least three quite separate sets of palaeobotanical sites occur, which have to be assessed within their own frameworks: sites yielding adpressions from fluvio-deltaic vegetation, sites yielding petrifications from fluvio-deltaic vegetation, and sites yielding petrifications from volcanic terrains.

There are several good Lower Carboniferous adpression sites in Europe, especially in the UK and Germany (see Cleal & Thomas, 1995, for a review of the former). However, none match the North American sites for diversity and fine preservation: the Price and Pocono Formations exposed in north-western Virginia (Read, 1955), and Horton Bluffs in northern Nova Scotia (Bell, 1960).

In contrast, Europe has by far the best petrifaction sites. For the Tournaisian, the Scottish sites in Berwickshire and East Lothian have yielded the most diverse and well preserved petrifications, and are especially important for early gymnosperms; nowhere else has been found such a diverse range of structurally-preserved early seeds. Within this area, both fluvio-deltaic and volcanic-terrain vegetation is preserved, providing two contrasting views of the Tournaisian tropical vegetation of this time. In addition, there is the classic floras from the phosphatic nodules within the Lydienne Formation, Montagne Noire. These petrifications reveal yet another type of Tournaisian vegetation, with a much higher proportion of ferns and lycophytes.

In the Visean, the classic Pettycur site stands out as the most important for petrifications. Prior to the discovery of the Rhynie Chert, Pettycur had yielded the oldest known structurally-preserved plant fossils and was pivotal for developing our understanding of early plant evolution. The Pettycur fossils are pre-

![Fig. 1. Phytogeographical map for the Lower Carboniferous. Thick solid line separates the named palaeokingdoms. Thick dashed line separates the unnamed palaeoareas in the Eurameria Palaeokingdom (Europe, Gondwana, Kazakhstan, Cathaysia). Adapted from Cleal (1991, fig. 4.2)
served in limestones caught-up in a volcanic deposit and seems to represent the vegetation growing in a volcanically disturbed habitat. In contrast, the Visean deposits of the Kilpatrick Hills, near Glasgow, represent vegetation that grew in more tranquil conditions and is more typical for floras of this age, including abundant gymnosperms and progymnosperms. The Kilpatrick Hills sites (especially Loch Humphrey Burn) is of particular interest as it has yielded some impressions together with the petrifactions, and thus has gone some way to helping correlate the plant remains preserved in these two modes of preservation.

Upper Carboniferous

The floristic provincialism recognised in the Lower Carboniferous becomes even more marked in the Upper Carboniferous (Fig. 2), mainly through global climatic cooling and high-latitude glaciation. The high-latitude Angaran and Gondwanan floras are quite distinct and belong to their own palaeokingdoms (Meyen, 1982; Rocha Campos & Archangelsky, 1985). The plant fossils found in Europe belong to the Euramerica Palaeokingdom, which represents the tropical vegetation of the time, exemplified during the Westphalian Epoch by what has been referred to as the Coal Forests.

Within the Euramerica Palaeokingdom, four palaeoareas have been recognized (Thomas & Cleal in Cleal, 1991): Oregon and Cordillera Palaeoareas in western North America, Cathaysia Palaeoarea in the Far East, and the rest (mainly Europe and eastern North America) referred to as the Europe Palaeoarea. The European sites must therefore be assessed within the context of this Europe Palaeoarea. Unlike the Lower Carboniferous, there is not the range of volcanogenic deposits containing plant fossils, and so the Upper Carboniferous sites can be more or less assessed within two frameworks: petrification sites, mainly representing backswamp vegetation, and adpression sites mainly representing vegetation growing on clastic substrates (e.g. levee banks).

There has been much work on Upper Carboniferous petrifications, we have encountered problems in developing a comprehensive network of suitable sites. The only European sites that could merit selection as a Geosite is the middle Stephanian Grand' Croix. In North America, there is also the Washington County site for the lower Namurian (Taylor & Eggert, 1967), and the Stuebenville and Hamilton Quarries and for the middle-upper Stephanian (Rothwell, 1988; Mapes & Mapes, 1988). However, for the bulk of the Upper Carboniferous, including the classic lycophyte-dominated coal ball floras, it is virtually impossible to identify suitable candidates to act as Geosites.

Despite the extensive research that there has been on the Upper Carboniferous adpression floras, finding suitable surface exposures to represent them was far from easy; much of the work has been done on material from temporary exposures or underground workings. However, we have eventually been able to develop a network of sites which cover the adpressions of this age, many of which are in Europe: the Meeuse Valley (Arnsbergian to Yeadonian), Glynneath-Ammanford (Langsettian to Bolsovian), the Guardo Coalfield (uppermost Westphalian D and Cantabrian) and the Sabero Coalfield (upper Barruelian to Stephanian B).

These are complemented by a number of North American sites showing features not represented in the European sites, including Joggins Cliffs for the unrivalled that they give of stumps of the lycophyte forests (Ferguson, 1988), the beautifully preserved
cuticles from the lower Cantabrian of Point Aconi (Cleal & Zodrow, 1989), the lower Cantabrian nodule flora of Mazon Creek (Darrah, 1969), and the 'upland' vegetation represented at Rock Island (Leary, 1981). There is also the remarkable sequence of floras represented within the New River Gorge Section of West Virginia, which demonstrates the changes that were taking place in the tropical floras through the entire Late Carboniferous (Englund et al., 1979).

Permian

Although the polar glaciation disappeared towards the end of the Carboniferous or in the early Permian, floristic provincialism became even more marked (Fig. 3). This can be seen by the segmentation of both the Gondwana and Angara Palaeokingdoms into a series of palaeoareas, as the vegetation of the higher palaeolatitudes became more diverse. The tropical zone was also segmented into three quite distinct palaeokingdoms: the Cathaysia Palaeokingdom, which continued to support a flourishing a diverse tropical vegetation (Shen, 1995); the North America Palaeokingdom with its distinctive suite of mainly gymnosperms representing drier habitat vegetation (Read & Mamay, 1964; Mamay, 1976; Mamay & Watt, 1971); and the rump of the Euramerica Palaeokingdom, supporting a restricted, mainly conifer dominated vegetation that survived the effects of the Variscan tectonic uplift.

Only two European sites have yielded sufficiently diverse floras to justify designation as Geosites. The best Lower Permian site is the Saar-Nahe Rotliegend, which has yielded ferns, peltasperms, trigono-carpaileans, conifers and a possible early cycad. The assemblages clearly reflect their origin in the Late Carboniferous of the Euramerican Palaeokingdom, but with the addition of conifers and peltasperms. For the Upper Permian, the Kupferschiefer deposits of central Germany (e.g. Mansfeld site, Ilmenau, Gera, Richelsdorf) provide the best palaeobotanical evidence, representing the conifer-dominated vegetation surrounding the Zechstein Sea.

Discussion

The proposed candidate Geosites are not intended to be anything more than suggestions, that may be modified by the appropriate national working groups, as they see fit. As palaeobotany is an aspect of the earth sciences with which many geologists are less familiar, the suggestions should prove a useful basis on which to start their discussions. However, we would urge the adoption of our suggested selection frameworks, as they reflect the current thinking among the palaeobotanical community on palaeoecology, taphonomy and biostratigraphy. For the European Palaeozoic palaeobotanical sites they may be summarised as follows.

1. Silurian adpressions world-wide
2. Devonian adpressions world-wide
3. Devonian petrifications world-wide
4. Lower Carboniferous adpressions of the Europe Palaeoarea
5. Lower Carboniferous fluvio-deltaic petrifications of the Europe Palaeoarea
6. Lower Carboniferous volcanic-terrain petrifications of the Europe Palaeoarea
7. Upper Carboniferous adpressions of the Europe Palaeoarea
8. Upper Carboniferous petrifications of the Europe Palaeoarea

![Phytogeographical map for the Permian. Thick solid line separates the named palaeokingdoms. Thick dashed line separates the unnamed palaeoareas (for Gondwana, Nothoafroamerica, Australoindia, Palaeoantarctica; for Cathaysia, North and South China; for Angara, Kazakhstan, Pechora, Kuznetsk, Far East). Adapted from Cleal (1991, fig. 4.6)](image-url)
9. Permian adpressions of the Euramerica Palaeokingdom

Only by establishing a scientifically rigorous set of frameworks, such as outlined here, will it be possible to make a meaningful comparative analysis of the sites, which in turn is the only way that the Geosites programme will become a useable tool for conservation.

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