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Spore assemblages from the Lower Devonian 'Lower Old Red Sandstone' deposits of Arran, Scotland

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ABSTRACT: Dispersed spore assemblages have been recovered from the Am Binnein Sandstones from the upper part of the 'Lower Old Red Sandstone' sequence on the island of Arran, Scotland. The spore assemblages belong with the *Emphanisporites annulatus–Camarozonotriletes sextantii* (AS) Spore Assemblage Biozone (SAB), indicating an Early Devonian, Emsian (but not earliest Emsian or latest Emsian) age. This is the first reliable age constraint for the 'Lower Old Red Sandstone' of Arran, and enables correlation with the more extensive sequence developed on the mainland in the Midland Valley of Scotland. The Am Binnein Sandstones are confirmed as correlatives of the Strathmore Group.

KEY WORDS: Emsian, Am Binnein Sandstones, Strathmore Group, early land plants

The island of Arran off western Scotland is a classic area for the study of geology, and generations of geologists have undertaken fieldwork on this small island. Over the years they have begun to unravel its complex geological relationships, and many of their findings have played an important role in the historical development of the science. This includes early work by James Hutton (reviewed in Tyrell 1928). To this day Arran remains a popular destination for field excursions, as it provides an excellent training ground for students of geology. However, much remains to be discovered, and the 'Lower Old Red Sandstone' deposits are a case in point. Hitherto they have lacked reliable age constraint and their relationship with the classic 'Lower Old Red Sandstone' deposits developed on the mainland Midland Valley of Scotland has remained uncertain. This paper reports on dispersed spore assemblages recovered from the 'Lower Old Red Sandstone' deposits of Arran that provide the first reliable age constraint for these deposits and enables reliable correlation and geological interpretation with respect to their better understood correlatives on the mainland.

1. Geological setting

During the Lower Devonian the Caledonian Mountains were situated along the southeast margin of the Old Red Sandstone continent on the Euramerican plate. They were uplifted during the complex tectonic movements associated with the closure of the Iapetus Ocean and the amalgamation of Laurentia, Baltica and Avalonia. This is believed to have taken place largely during the Silurian, with the accretion of numerous terranes, through strike-slip (reviewed in Bluck 2003). Material weathered from these terranes, combined with volcaniclastic deposits, provided the detritus that formed the Late Silurian–Early Devonian 'Lower Old Red Sandstone' deposits of the Midland Valley and adjacent regions (reviewed in Trewin & Thirlwall 2003). The nature of terrane amalgamation and the extent to which they moved with respect to one another is widely debated, with evidence provided by studies of clast provenance and the distribution of volcanic rocks. Whatever the extent of later fault movements, it is clear from the volcanic rocks that this region remained geologically active well into the Lower Devonian.

The extensive 'Lower Old Red Sandstone' deposits of the northern Midland Valley of Scotland essentially follow a northeast–southwest-trending strip parallel to the Highland Boundary Fault. They consist of terrestrial fluviatile-lacustrine sediments, with some prominent interbedded lavas. These deposits occur in three distinct basins that have been structurally assembled (Marshall *et al.* 1994). The Stonehaven Group (as redefined by Marshall 1991 and Wellman 1993a) is a distinct basin fill of late Wenlock–?early Ludlow age that rests unconformably on the Highland Border Complex. It crops out only in the northeast corner of the Midland Valley in a narrow fault slither adjacent to the Highland Boundary Fault. The Carron Formation, Dunnottar Group and Crawton Group form a separate basin fill, probably of Late Silurian–?earliest Devonian age, although firm evidence for this is lacking. Again the deposits of this basin are confined to the northeast of the Midland Valley, where they crop out in a narrow fault-bounded basin. These two basin fills are overstepped by the remainder of the 'Lower Old Red Sandstone' (Arbuthnott, Garvock and Strathmore groups of the Strathmore Basin) that form an extensive outcrop along the northern margin of the Midland Valley. They are 3–5 km in thickness (Marshall *et al.* 1994), apparently thinning in a southwesterly direction. Fossils indicate a Lochkovian age for parts of the Arbuthnott Group (spores, plants, fish: Richardson 1967; Ford 1971; Richardson *et al.* 1984; Trewin & Davidson 1996; Lavender & Wellman 2002) and an Emsian age for the Strathmore Group (spores, plants: Richardson 1967; Ford 1971; Rayner 1983, 1984; Richardson *et al.* 1984). Additional evidence for age is provided by radiometric dating (reviewed in Trewin & Thirlwall 2003).

The 'Lower Old Red Sandstone' deposits of Arran are generally considered to represent a westerly extension of the Arbuthnott, Garvock and Strathmore groups of the

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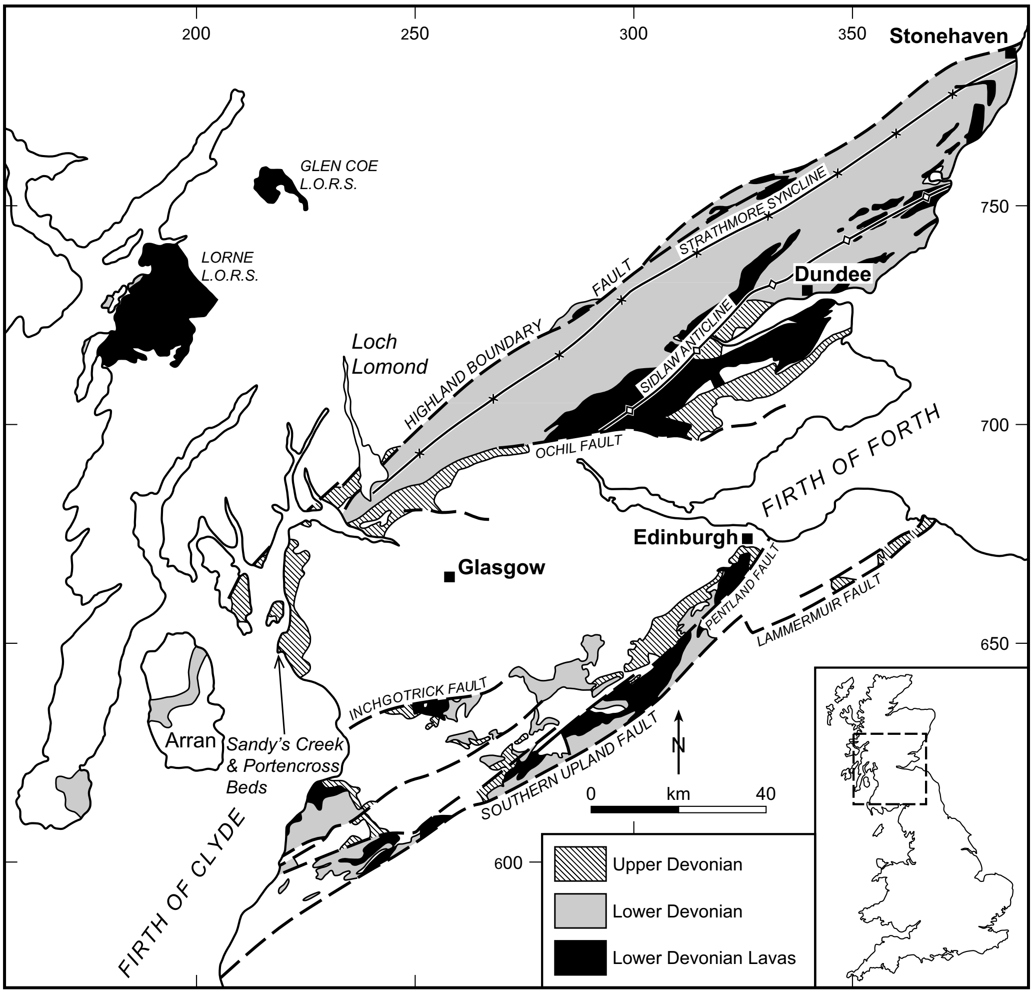

Figure 1 Geological map illustrating the outcrop of Silurian–Devonian 'Lower Old Red Sandstone' and 'Upper Old Red Sandstone' deposits in the Midland Valley of Scotland and adjacent regions.

Strathmore Basin. They crop out in an arc around the southern and eastern margin of the prominent Northern Granite of Tertiary age (Fig. 1). These deposits are up to 1500 m in thickness. However, they are difficult to map and, consequently, the stratigraphical sequence and the nature of the upper and lower contacts have long been contentious. Early mapping by the Geological Survey (Tyrell 1928) suggested that the lower contact with the Dalradian Schists (and, in a very few places, with the Northern Granite) is everywhere faulted and the upper contact with the 'Upper Old Red Sandstone' is most likely unconformable, although there is no direct evidence for this. More detailed mapping by Friend *et al.* (1963) enabled the stratigraphical sequence to be determined in different parts of the island. It became evident that the situation was complex, and their findings are illustrated in Figure 2. These workers also clarified that the lower boundary was a step faulted unconformity with the Dalradian Schists. Morton (1979) concurred with much of Friend *et al.*'s findings, but further suggested that the Glen Sannox Conglomerate correlated entirely with the Allt an Brighide Siltstone and Creag Mhor Conglomerates. Browne *et al.* (2002) proposed new lithostratigraphical correlations that differed substantially from those of Friend *et al.* (1963) and modified the stratigraphical terminology accordingly (outlined in Figure 3). Various workers have also attempted to correlate the Arran sequence, purely on lithological grounds, with the mainland sequence (e.g. Morton 1979; Browne *et al.* 2002; Trewin & Thirlwall 2003).

The Arran sequence has traditionally been regarded as 'Lower Old Red Sandstone' based on its stratigraphical position and lithological similarities with the classic 'Lower Old Red Sandstone' sequences of the Midland Valley of Scotland. The only direct evidence for its age is plant fossils recovered from the Am Binnein Sandstones by Geikie in 1882 and Macconochie and Tait in 1897 (reviewed in Tyrell 1928). Kidston identified some of these as *Psilophyton princeps* var. *ornatus* Dawson, a plant first described from the Lower Devonian of eastern Canada. Unfortunately these specimens can no longer be located (Friend *et al.* 1963), so a modern taxonomic consideration is not possible.

2. Palynology

2.1. Methods

During the course of several fieldtrips, numerous siltstone horizons were sampled from throughout the 'Lower Old Red Sandstone' sequence of Arran. The siltstones were processed using standard palynological techniques: HF–HCl–HF acid maceration followed by heavy liquid separation using zinc chloride. Recovered organic residues were sieved using a 20-μm mesh, oxidised for varying periods of time using Schultz solution, and strew mounted for light microscope analysis. Only two samples yielded palynomorphs: both from the Am Binnein Sandstones in the central-southeast section of 'Lower Old Red Sandstone' (see Appendix). The assemblages are rich

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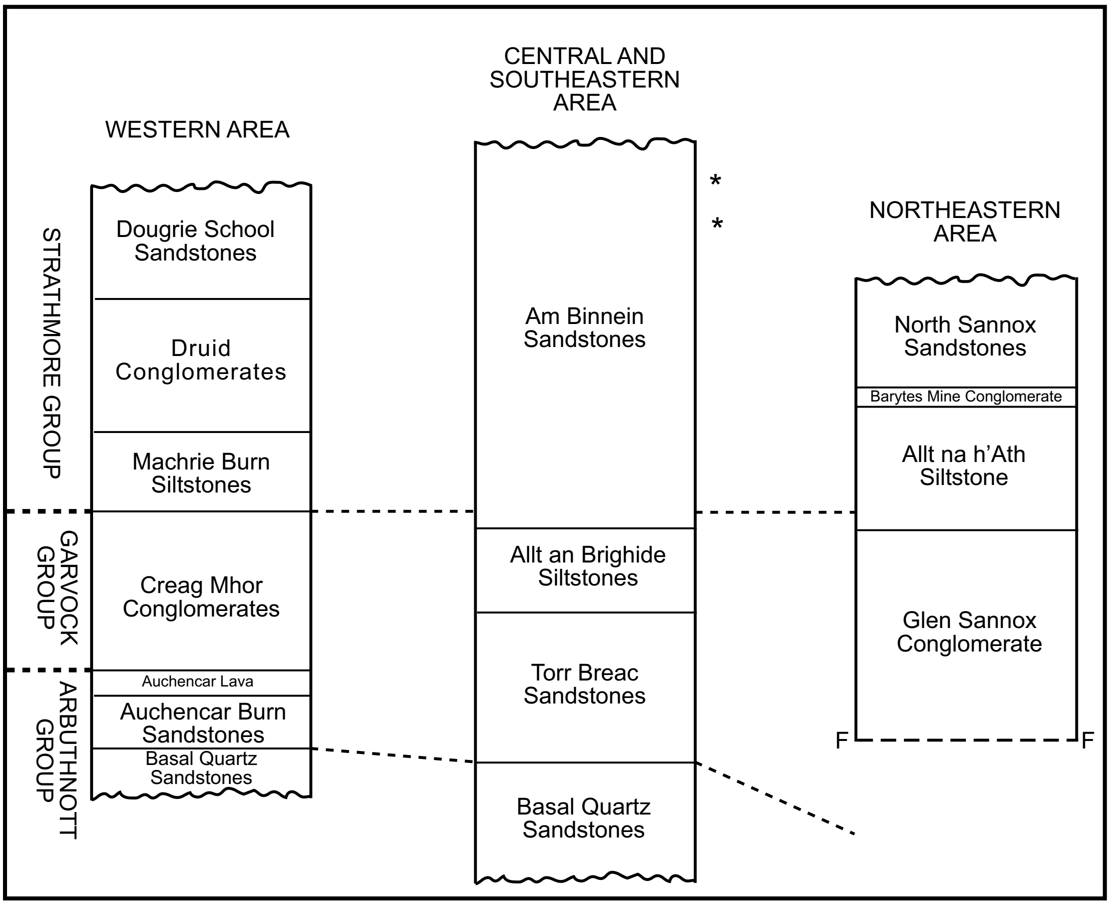

Figure 2 Stratigraphical successions of the 'Lower Old Red Sandstone' developed on Arran. Stratigraphical nomenclature and lithostratigraphical correlations of Friend *et al.* (1963). Correlation with the mainland sequence (groups on left hand side of figure) from Trewin & Thirlwall (2003). Asterisks illustrate position of palynomorph assemblages considered in this present paper.

in palynomorphs that are of moderate preservation and high thermal maturity. Treatment for 30 minutes in Schultz solution cleared the spores to a workable translucent dark orange–pale brown colour. All materials (samples, residues, slides) are housed in the collections of the Centre for Palynology of the University of Sheffield.

2.2. Description of spore assemblages

Both productive samples essentially yield identical palynomorph assemblages (see Table 1; Fig. 4). They contain only dispersed spores and palynodebris (cuticle-like sheets and tubular structures). The dispersed spores are dominated by laevigate retusoid spores (*Retusotriletes* spp.) (Fig. 4a, d) and apiculate retusoid spores with a sloughing extra-exosporal layer that bears the ornament (*Apiculiretusispora* spp. and possibly *Rhabdosporites minutus*) (Fig. 4b, c, e). Many of the *Retusotriletes* have thickenings (triangular or annular) associated with the trilete mark and extra-exosporal material adhering to them (Fig. 4a). Similarly, some of the *Apiculiretusispora* have a triangular thickening associated with the trilete mark (Fig. 4c, e). Other apiculate retusoid spores have biform sculpture (*Dibolisporites* spp., including *D. eifeliensis*) (Fig. 4f, j). The distinctive retusoid, reticulate spore ?*Dictyotriletes emsiensis* is also present (Fig. 4i). Laevigate crassitate (*Ambitisporites* spp.) (Fig. 4g) and patinate (*Archaeozonotriletes* spp.) spores occur in both samples but are relatively uncommon. Very rare ornamented forms are present, including apiculate forms (e.g. Fig. 4l), murornate forms (e.g. Fig. 4k) and foveolate forms placed with *Brochotriletes* spp. (Fig. 4h).

The highly distinctive spore *Amicosporites streelii* is identified (form with a single large distal verrucae). Spores with proximal radial ribbing are relatively common in both samples and include *Emphanisporites rotatus*, *E. erraticus* and *E. annulatus*. (Fig. 4o–s). Zonate spores are present but are too poorly preserved to identify even to generic level. A complete list of identified spore taxa is provided in Table 1.

2.3. Age determination

The described spore assemblages are correlated with the *Emphanisporites annulatus–Camarozonotriletes sextantii* (AS) Spore Assemblage Biozone (SAB) of Richardson & McGregor (1986), based on the presence of one of the nominal species (*E. annulatus*) and the general characteristics of the assemblage in terms of morphotypes present and their general abundances. The preceding and succeeding zones are precluded by, among other observations, the presence of *E. annulatus* and the absence of spores with grapnel-tipped spines, respectively. The age of the AS SAB is Early Devonian Emsian (but not earliest Emsian or latest Emsian). In the spore zonation scheme of Streel *et al.* (1987) the AS SAB is equivalent to the AB and FD Oppel Zones. It is difficult to correlate the Arran assemblages with the Streel *et al.* scheme due to the absence of certain species characteristic of the Ardenne–Rhenish region. However, based on the possible presence of *Rhabdosporites minutus*, the Arran assemblages may be tentatively correlated with the FD Oppel Zone (Min Interval Zone), which is equivalent to the upper part of the AS SAB, indicating a mid to early-late Emsian age.

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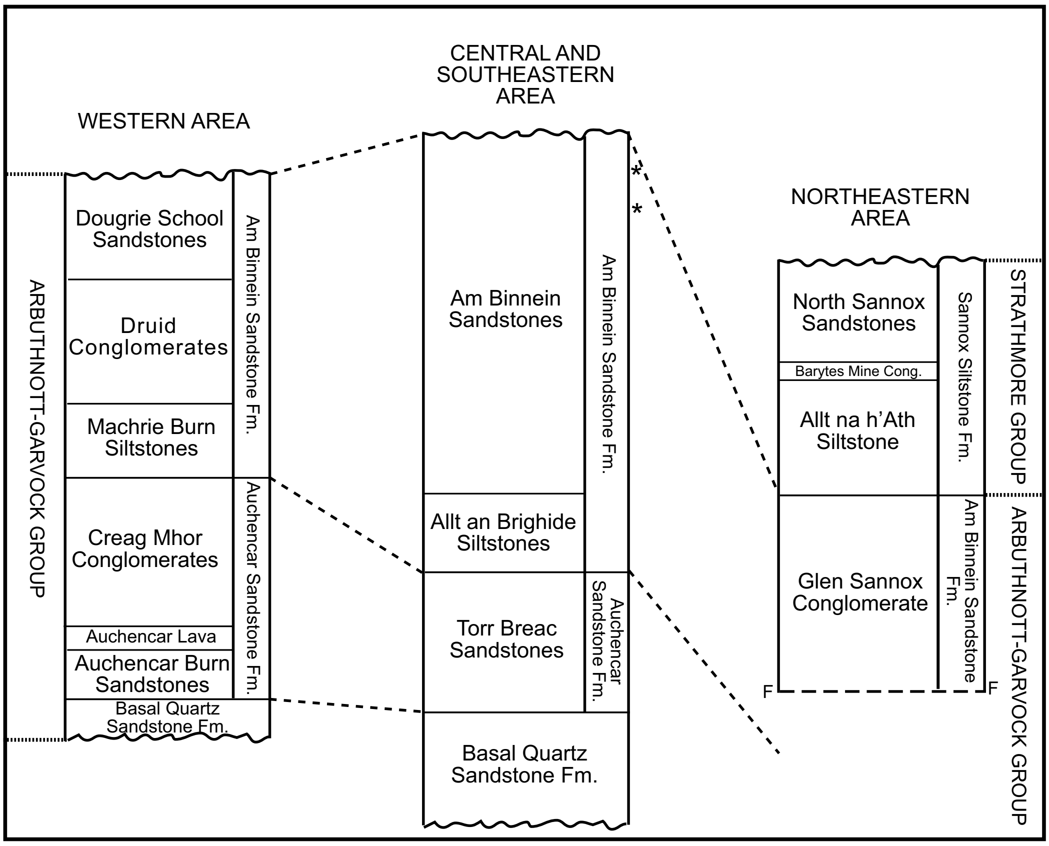

Figure 3 Stratigraphical successions of the 'Lower Old Red Sandstone' developed on Arran. Stratigraphical nomenclature and lithostratigraphical correlations of Browne *et al.* (2002). The units of Friend *et al.* (1963) have been formally identified as formations, or reduced to member status and incorporated into newly identified formations. Lithostratigraphical correlation is very different from that of Friend *et al.* (1963), particularly with respect to correlation with the Arbuthnott, Garvock and Strathmore groups of the mainland, and is not supported by the new age data reported in this present paper. Asterisks illustrate position of palynomorph assemblages considered in this present paper.

2.4. Palynofacies analysis

The palynomorph assemblages contain only land derived forms. That is disarticulated plant parts, spores derived from the plants and rare fungal hyphae. The disarticulated plant parts include cuticles and conducting tissues of land plants. There are also rare banded tubes similar to those produced by nematophytes. The nature of the palynomorph assemblages suggests accumulation in a non-marine environment. This strongly supports previous interpretations of these deposits, based on sedimentological observations and correlation with 'Lower Old Red Sandstone' deposits of the mainland, as accumulating in typical 'Lower Old Red Sandstone' terrestrial fluviatile-lacustrine environments.

2.5. Thermal maturity

The spores are of high thermal maturity (Thermal Alteration Index 3+ from chart provided in Traverse 2007). This is clearly a consequence of their complex geological history and may reflect a number of heating events that are difficult to disentangle. These included earth movements associated with the late stages of the Caledonian Orogeny, subsequent movements along the Highland Boundary Fault, emplacement of Tertiary granites, etc. However, Friend *et al.* (1963) suggested that deformation of the 'Lower Old Red Sandstone' was largely the result of the intrusion and uplift of the Tertiary granites.

Figure 4 Light microscope images of dispersed spores from the Am Binnein Sandstones of Arran, Scotland. Scale bar = 20 µm: (a) *Retusotriletes* cf. *triangulatus* (Streel) Streel, 1967, slide BAR9.8, E. F. No. (O49); (b) ?*Rhabdosporites minutus* Tiwari & Schaarschmidt, 1975 (possibly an *Apiculiretusispora brandtii* in which the exoexospore has been artificially separated and expanded due to swelling during oxidation), slide BAR10.2, E. F. No. (P40); (c) *Apiculiretusispora brandtii* Streel, 1964, slide BAR10.4, E. F. No. (P32/7), exoexosporal layer partially degraded and sloughing; (d) *Retusotriletes* sp., slide BAR10.4, E. F. No. (U47/2); (e) *Apiculiretusispora brandtii* Streel, 1964, slide BAR10.3, E. F. No. (Y30), note sloughing exoexosporal layer; (f) *Dibolisporites* sp., slide BAR9.7, E. F. No. (O30/2/4); (g) *Ambitisporites* spp., slide BAR10.6, E. F. No. (H46/1); (h) *Brochotriletes* sp., slide BAR10.3, E. F. No. (K46/4); (i) ?*Dictyotriletes emsiensis* (Allen) McGregor, 1973, slide BAR9.7, E. F. No. (D44); (j) *Dibolisporites eifeliensis* (Lanninger) McGregor, 1973, slide BAR9.9, E. F. No. (T48/3); (k) Crassitate-patinate, murornate spore, slide BAR9.7, E. F. No. (T45); (l) *Aneurospora* sp., slide BAR10.6, E. F. No. (S42); (m) *Amicosporites streelii* Steemans, 1989, slide BAR9.7, E. F. No. (Q45); (n) Tetrad, sample BAR10.3, E. F. No. (C39/3); (o) *Emphanisporites rotatus* McGregor, 1961, sample BAR 9.8, E. F. No. (J49/4); (p) *Emphanisporites erraticus* (Eisenack) McGregor, 1961, sample BAR 9.9, E. F. No. (F28/2); (q) *Emphanisporites erraticus* (Eisenack) McGregor, 1961, sample BAR 9.7, E. F. No. (N47/3/4); (r) *Emphanisporites annulatus* McGregor, 1961, sample BAR 9.7, E. F. No. (N39). (s) *Emphanisporites annulatus* McGregor, 1961, sample BAR 10.2, E. F. No. (E41/3/4).

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Table 1 Identified spore taxa.

Taxon	Sample BAR09	Sample BAR10
Retusotriletes cf. *triangulatus* (Streel) Streel, 1967	X	X
Retusotriletes spp.	X	X
Apiculiretusispora brandtii Streel, 1964	X	X
Apiculiterusispora plicata (Allen) Streel, 1964	X	X
Apiculiretusispora arenorugosa McGregor, 1973	X	X
Apiculiretusispora spp.	X	X
?*Rhabdosporites minutus* Tiwari and Schaarschmidt, 1975	X	X
Dibolisporites spp.	X	X
Dibolisporites eifeliensis (Lanninger) McGregor, 1973	X	X
?*Dictyotriletes emsiensis* (Allen) McGregor, 1973	X	
Ambitisporites spp.	X	X
Aneurospora sp.	X	X
Emphanisporites rotatus McGregor, 1961	X	X
Emphanisporites erraticus (Eisenack) McGregor, 1961	X	
Emphanisporites annulatus McGregor, 1961	X	X
Brochotriletes spp.		X
Amicosporites streelii Steemans, 1989	X	
Archaeozonotriletes chulus (Cramer) Richardson & Lister, 1969	X	X
Unidentifiable Zonate spores	X	X

3. Geological implications

The new age data suggest that the Am Binnean Sandstones are correlatives of the Strathmore Group of the main 'Lower Old Red Sandstone' sequence of the Midland Valley. Both contain virtually identical dispersed spore assemblages. This supports the lithostratigraphical correlations of Friend *et al.* (1963) rather than those of Browne *et al.* (2002) (see Figs 2–3). Hence, the stratigraphical nomenclature of Friend *et al.* (1963) is retained, because that of Browne *et al.* (2002) implicitly implies the rejected correlations (Figs 2–3). It is possible that the Am Binnean Sandstones may be correlated with the mainland sequence via the 'Lower Old Red Sandstone' deposits on the mainland coast at Portencross (Portencross Sandstone Formation) and around the southern shores of Loch Lomond in the Ardmore/Balmaha area, although spores have yet to be recovered from these sequences. However, the diminutive fault-bounded sequence faulted into the Portencross Beds on the mainland coast (Sandy's Creek Mudstone Formation) are older. Wellman (1993b) demonstrated that they are Lochkovian in age and most likely represent an allochthonous slither of the Arbuthnott Group. The 'Lower Old Red Sandstone' deposits in the Grampian Highlands to the north of the Midland Valley are generally older. Spore assemblages from Lorne are latest Silurian–earliest Devonian (most likely earliest Devonian, early Lochkovian) in age (Marshall 1991; Wellman & Richardson 1996), those from Glencoe are of Lochkovian age (Wellman 1994) and those from the Rhynie outlier are of Pragian–earliest Emsian age (Wellman 2006). However, spore assemblages from at least some of the basement beds of the Orcadian Basin (e.g. Strathpeffer) are very similar (Richardson 1967).

4. Palaeobotanical implications

The Arran dispersed spore assemblages are very similar in composition to those described from the Strathmore Group on the mainland (Ford 1971). The spore assemblages are not particularly diverse and are dominated by a small number of morphotypes: laevigate retusoid spores characteristic of zosterophylls (and certain lycopsids) and retusoid spores with a sloughing apiculate exoexine that are characteristic of trimerophytes. Coeval spore assemblages from elsewhere also tend to be characterised by these morphotypes. Often, however, they are more diverse, e.g. those from the nearshore floodplain deposits of Gaspé, eastern Canada (McGregor 1973, 1977) and nearshore marine deposits of the Ardennes–Rhenish region (Steemans 1989). This probably reflects the fact that the Scottish assemblages accumulated in an inland intermontaine basin and are dominated by spores derived from the local (possibly restricted) flora of this basin, whereas the nearshore floodplain and marine assemblages represent spores derived from throughout an entire drainage basin. Interestingly, a similar situation was noted by Richardson and Rasul (1978a, b), where AS SAB spore assemblages from the terrestrial-fluviatile floodplain deposits of southern Britain are of rather low diversity.

Plant megafossils have long been known from the Strathmore Group (summarised in Henderson 1932 and Lang 1932). The most recent treatment is by Rayner (Edwards *et al.* 1982; Rayner 1982, 1983, 1984). Two plants dominate the assemblages: the zosterophyll *Sawdonian ornata* (Dawson) Hueber (synonymous with *Psilophyton princeps* var. *ornatum* Dawson), and the lycopsid *Drepanophycus spinaeformis* Göppert (synonymous with *Arthrostigma gracile* Dawson). *In situ* spores of *S. ornata* are of *R.* cf. *triangulatus*-type while those of *D. spinaeformis* are unknown. It is likely that zosterophylls, lycopsids and trimerophytes dominated the flora of the drainage basin, producing the *Retusotriletes* spp. and *Apiculiretusispora* spp. spores that dominate the dispersed spore assemblages. It is rather surprising that trimerophytes such as *Psilophyton* have yet to be recorded from the Strathmore Group, as such plants often dominate coeval deposits in eastern Canada (the previous reports of *Psilophyton princeps* var. *ornatum* from the Midland Valley 'Lower Old Red Sandstone', including that from Arran, are almost certainly all *Sawdonia ornata*).

5. Acknowledgements

This research was funded by the NERC. I would like to thank Philippe Steemans for helpful discussions regarding spore identifications.

6. Appendix. Sampling details

SAMPLE	GRID REFERENCE	FORMATION	LOCATION
BAR09	1988/6364	Am Binnein Sandstones	Siltstone in bank of Glenshurig Burn just west of confluence with Allt Mor
BAR10	1989/6364	Am Binnein Sandstones	Siltstone in bank of Allt Mor 10 m south of junction with Glenshurig Burn

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