PALYNOLOGICAL STUDIES IN SOUTH GEORGIA: IV. PROFILES FROM BARFF PENINSULA AND ANNENKOV ISLAND

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Abstract. Pollen analyses are presented for three South Georgia post-glacial peat deposits, two from the northern side of the island (on Barff Peninsula) and one on an offshore island (Annenkov Island) lying a little to the south of the mainland. Surface analyses from one site (Ocean Harbour) indicate that *Sphagnum fimbriatum* appears to fruit under present environmental conditions, although it has never been observed with sporophytes. Because of the lack of diversity of native pollen production it has been possible to isolate numerous exotic grains, notably of *Nothofagus* spp., derived from southern South America or the Falkland Islands.

As with other sites analysed the pollen diagrams are dominated by grass and *Acaena* pollen. At levels where there are significant peaks in grass pollen this is interpreted as possibly representative of a cool dry phase, while peaks in *Acaena* may indicate wetter conditions, but little reliance can be placed upon the relative abundance of these two plant groups as climatic indicators. It is concluded from these palynological studies on South Georgia peat deposits that by 10 000 yr B.P. post-glacial conditions on the island were favourable enough for the development of locally extensive vegetation and peat formation, and that conditions have changed little during the past 9 500 years. There is no clear indication of neoglacial cooling, between about 5 000 and 4 500 yr B.P., as has been reported from some other sub-Antarctic islands.

Pollen analyses of material from organic deposits in Sphagnum Valley, Cumberland West Bay (Sites 1 and 2), and in a valley on the south side of King Edward Cove, Cumberland East Bay (Sites 3–5), South Georgia, have already been reported by Barrow (1978, 1983) and by Barrow and Smith (1983). In this third account of the fossil record of pollen and spores of this sub-Antarctic island, the results of three ancillary sites are reported. These were located in Sörling Valley, Cumberland East Bay, and at Ocean Harbour, both on Barff Peninsula, and on Annenkov Island off the south-west coast of South Georgia (see fig. 1 in Barrow and Smith, 1983).

Study Areas and Site Descriptions

Site 6, Sörling Valley

This site is a *Rostkovia magellanica*–bryophyte bog situated near a stream flowing across a coastal plain regarded by Clapperton (1971) as 'lower raised beach' deposits. It lies about 200 m from the shore and about 150 m from the edge of the coastal tussock *(Poa flabellata)* zone, at an altitude of 3–5 m; it is also about 50 m seaward from a wave-cut cliff.

The bog is dominated by relatively dense *Rostkovia* (*c.* 60% cover) with *Acaena magellanica* (30–40%) and *Phleum alpinum* (10%); *Deschampsia antarctica, Festuca contracta, Galium antarcticum, Juncus scheuchzerioides* and *Ranunculus biternatus* occurred as scattered plants in the closed understorey of bryophytes (mainly *Tortula robusta*). *Colobanthus quitensis, C. subulatus, Montia fontana* and the alien grass *Poa annua* grew nearby and the only hummock of *Sphagnum*

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fimbriatum known in this region of the island occurred a few hundred metres distant. *Poa flabellata* with its typical associate, *Callitriche antarctica*, was frequent on the seaward side of the bog, but the grass was severely grazed by the introduced reindeer (Kightley and Smith, 1975; Leader-Williams and others, 1981). The drier slopes inland from the bog supported *Festuca contracta* grassland.

Site 7, Ocean Harbour

This site was situated on the lower slope of the south side of a valley, about 200 m from the shore at an altitude of 9–10 m above present sea level. It is close to a derelict whaling station which ceased operations in 1920.

The wet slope on which the sample site was situated is dominated by *Rostkovia magellanica–Tortula robusta* mire. The rush afforded about 20% cover and *Acaena magellanica* about 5%; there were numerous scattered plants of *Callitriche antarctica, Festuca contracta, Phleum alpinum* and *Ranunculus biternatus* amongst the continuous understorey of *Tortula robusta* with locally extensive mounds, often continuous, of *Sphagnum fimbriatum*. Nearby, *Deschampsia antarctica, Montia fontana* and the aliens *Cerastium fontana, Poa annua* and *Rumex acetosella* were present; several other adventive species occur in the environs of the former whaling station (see Walton and Smith, 1973). The site is influenced by reindeer although their grazing activity in *Rostkovia* bogs is minimal (Kightley and Smith, 1975; Leader-Williams and others, 1981; Pratt and Smith, 1982).

Site 8, Annenkov Island

Annenkov Island lies about 15 km off the mid-south-west coast of South Georgia; it rises to *c.* 700 m but lacks permanent snow or ice (Pettigrew, 1981). Although there is tussock peat (see Smith, 1981) in excess of 2 m deep on an erosion platform at about 20–25 m above sea level at the south-east of the island, the samples taken were not analysed because there was considerable seal and burrowing seabird disturbance. A radiocarbon date of 1010 ± 160 yr B.P. was obtained for the base of such a deposit at 1.50 m (Harkness and Wilson, 1979), confirming the relatively rapid rate of accumulation of *Poa flabellata* peat compared with that of valley bog peat (Smith, 1981).

The site which was sampled and analysed in the present study was in one of the few *Rostkovia*–bryophyte bogs and was situated at about 80 m a.s.l. in the north-west of the island. *Rostkovia* afforded about 20% cover and there was a continuous understorey of *Tortula robusta*; associated species include *Acaena magellanica, Deschampsia antarctica, Ranunculus biternatus* and *Marchantia berteroana*. *Poa flabellata* was abundant all around the bog.

Material and Methods

Collection of material

At Site 6 a sampling hole was dug through the bog revealing peat to a depth of 1.5 m overlying the well-rounded pebbles of the raised beach. The peat darkened in colour shortly after being exposed to air. Thirty samples were taken, as described by Barrow and Smith (1983), at 5-cm intervals, but only 15 were analysed. The Site 7 samples were taken using a Hiller corer to a depth of 1.6 m; the section was predominantly peat with narrow layers of stones, gravel and clay. Twenty-eight samples were taken at 5-cm intervals and 16 analysed. At Annenkov Island ten samples (eight analysed) were taken at 5-cm intervals from a cleaned erosion scar to about 50 cm depth; below this the stream which had cut the exposure prevented sampling of the remaining 30 cm of peat, which overlay stones. The stratigraphy of the three profiles is illustrated diagrammatically in Figs. 1, 2 and 3 respectively.

To obtain an indication of modern sporomorpha deposition a few grams of surface litter were collected from 20 randomly located 1-m^2 quadrats within a 25-m^2 plot centred on the sampling section at Site 7. No surface samples were taken at Sites 6 and 8, although surface samples have been analysed for a site in south-east Annenkov Island (Barrow, 1977, p. 100).

All sample material was stored at − 10°C as soon as possible after collection and kept frozen until required for analysis in the UK.

Analytical procedure

Standard pollen analytical techniques were employed for each set of samples (see Barrow and Smith 1983). All analyses included acetolysis treatment but hydrofluoric acid was used to remove soluble silica only from the Site 7 surface samples. The microscopic examination and counting procedures were the same as those described by Barrow and Smith (1983), while the identification of sporomorpha was as described by Barrow (1976) and Barrow and Smith (1983). The analyses are presented as relative frequency histograms with the abundance of each taxon expressed as a percentage of the total pollen sum (excluding spores) in each sample. Pollen sums averaged about 200 grains in most samples, but at Site 8 the numbers were invariably less.

RESULTS

The pollen, spore and micro-fossil contents of the three sites are presented in Figs. 1, 2 and 3.

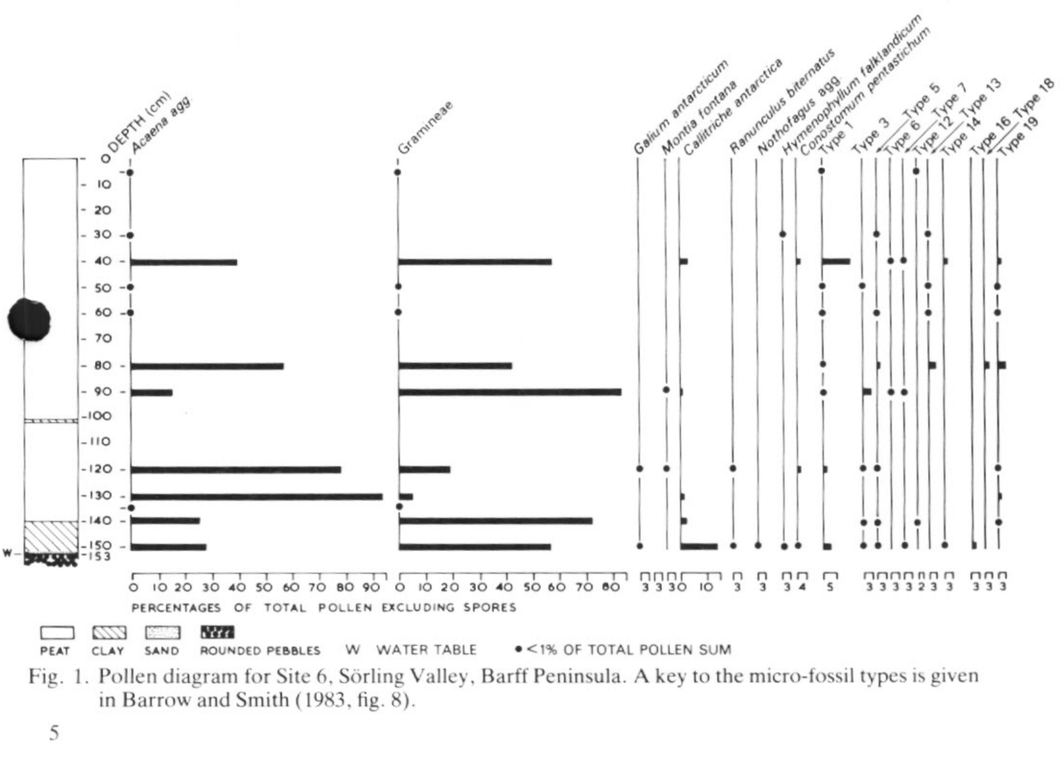

Fig. 1. Pollen diagram for Site 6, Sörling Valley, Barff Peninsula. A key to the micro-fossil types is given in Barrow and Smith (1983, fig. 8).

Site 6, Sörling Valley (Fig. 1)

The sporomorpha content of this section was erratic, ranging from abundant to very sparse (e.g. 1081 pollen grains counted in the sample from 90 cm depth while in several samples the maximum count was less than 200 grains). There were, however, no obvious signs of corrosion of the pollen, but it is difficult to determine whether this variation in pollen content reflects lithological control (the peat at 90 cm depth was wet and little humified) or fluctuations in actual pollen production.

The grass values varied from virtually no record to over 80% and little clear trend can be distinguished. It seems likely that nearby tussock stands have contributed the bulk of this pollen, supplemented perhaps by locally derived *Deschampsia* and *Phleum* grains. *Rostkovia* rhizomes and leaf remains were apparent throughout the peat to a depth of 1.40 m.

The suffruticose herb record, considered to be derived mainly from *Acaena magellanica*, is also variable reaching 93% of the total pollen sum at 1.30 m depth while barely registering at several other depths. Of the forbs *Galium antarcticum* pollen occurs in small quantities at 1.20 and 1.50 m although the species was not noted in the immediate vicinity of the section but did occur on *Acaena*-dominated scre[e] about 20 m away. *Montia fontana* pollen was isolated at 90 cm and 1.20 m. It grows i[n] wet flushes seaward of the sample section on the inland fringe of the tussock zone. *Callitriche antarctica* pollen is abundant at 1.50 m and was isolated sporadically to 40 cm below the present surface. This prostrate herb is common amongst the tussock grassland seaward of the site. *Ranunculus biternatus* pollen was recovered from 1.20 and 1.50 m depth but was not abundant.

Ferns were not noted in the vicinity of the site but *Cystopteris fragilis, Hymenophyllum falklandicum* and *Polystichum mohrioides* grew farther inland on higher, drier ground. The only pteridophyte spores recovered were those of *Hymenophyllum* at 30 cm and 1.50 m. Of the bryophytes, *Conostomum pentastichum* spores are usually the most abundant and readily detectable in the samples at all other sites, but here only a few were isolated and these show no significant trend. While common in the *Festuca* grassland farther inland, *Conostomum* was not present in the bog vegetation. The only other bryophyte spores recovered (at 1.50 m depth) are believed to belong to the liverwort genus *Schistochila*.

The uppermost sample (5 cm depth) was quite rich in diatoms (types A, D, F and two unidentified taxa), but only in peat from 40 cm have any been isolated (type F). Desmids were present but not very common. A large micro-fossil (type 22) was recovered at 1.30 m depth. Although the basidiocarps of macro-fungi were present close to the section few septate spores belonging to fungi have been recovered from the peat. Type 6 sub-reticulate patterned spores, probably of an ascomycete, a[re] present only in small quantities at 40 cm, 90 cm and 1.50 m, all levels at which grass pollen dominates.

The remains of tardigrades (type 13) and mite fragments were the only micro-faunal remains recognized from the section.

Site 7, Ocean Harbour (Fig. 2)

The results of the surface litter analysis are included in Fig. 2 (0 cm depth). The floristic composition of the sample plot was predominantly *Sphagnum fimbriatum* (about 70% cover), *Tortula robusta* (30%) *Rostkovia magellanica* (20%), *Acaena magellanica* (10%), with occasional *Festuca contracta, Phleum alpinum* and *Ranunculus biternatus*. Nearby, the adventives *Cerastium fontanum* and *Rumex acetosella* were present as scattered plants. The pollen count was typically dominated by grass (probably mainly *Poa flabellata* but possibly including *P. annua*

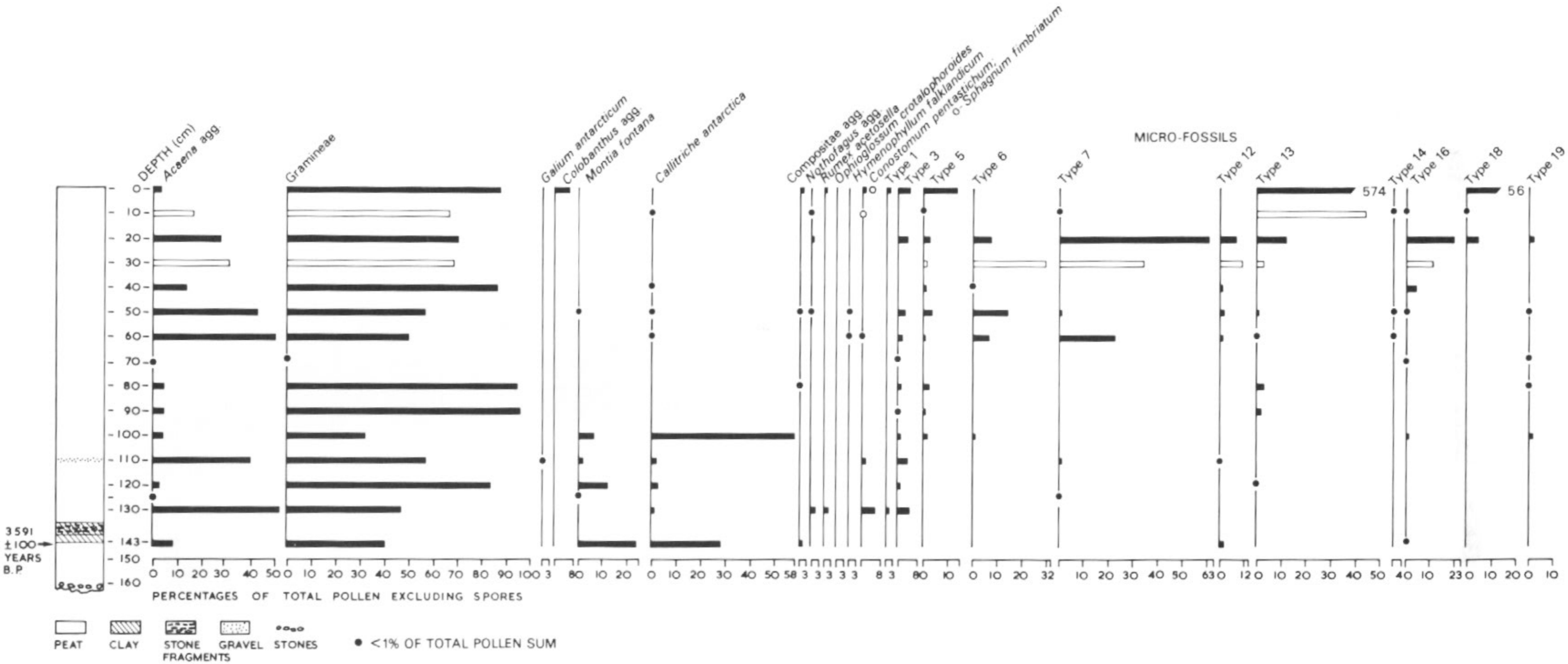

Fig. 2. Pollen diagram for Site 7, Ocean Harbour, Barff Peninsula. Open bars indicate a total of < 200 pollen grains isolated. A key to the micro-fossil types is given in Barrow and Smith (1983, fig. 8).

which is very abundant nearer the shore). There was an unusually small number of *Acaena* grains. Pollen of *Colobanthus quitensis* and *C. subulatus,* which are quite common in the vicinity, was recorded as frequent in the surface sample. Although *Cerastium* pollen was not isolated (it is distinguishable from that of *Colobanthus*) that of *Rumex* was and grains of Compositae which may have belonged to *Taraxacum officinale* which grows and flowers several hundred metres to the north of the site in the former whaling station. The only fern spores noted were of *Hymenophyllum falklandicum*, a species occurring in nearby rock crevices. The occurrence of 29 *Sphagnum fimbriatum* spores provides strong evidence that the species does, in this locality at least, fruit under present conditions, although fertile plants have never been found on South Georgia (personal communication from R. I. Lewis Smith).

The pollen diagram for the profile samples is dominated by Gramineae, but the curve is rather erratic, ranging from 96% of the total pollen sum at 90 cm depth to 31% only 10 cm farther down the section (discounting the very low count at 70 cm where the total pollen sum was very low). It seems very probable that nearby coastal tussock stands had contributed the majority of this pollen. The grass curve shows distinct peaks and troughs which might be interpreted in terms of climatic fluctuations.

Acaena (probably *A. magellanica*) pollen is relatively less abundant at this site than at all other sites analysed (Barrow, 1983; Barrow and Smith, 1983). Values are variable, ranging from 2 to 51% of the total pollen sum at each level. *Galium antarcticum* pollen was isolated only from 1.10 m, but *Callitriche antarctica* and *Montia fontana* occurred sporadically throughout the profile. The high values of these two species at certain of the lower levels may indicate wetter conditions and possible seal disturbance close to the site in the past. *Colobanthus* pollen was not recorded below the surface litter. All of these forbs occurred beyond the immediate proximity of the sample site but were not noted above or close to the section. Similarly, no *Ranunculus biternatus* pollen was recovered although plants were present near the section.

The ferns *Hymenophyllum falklandicum, Ophioglossum crotalophoroides* and *Polystichum mohrioides* all grew within 100 m of the collection site but only the former two are represented in the peat. *Conostomum pentastichum* was not common in the vicinity of the site although it is frequent in the drier *Festuca* grassland higher up the valley. This is probably reflected in the limited occurrence of its spores in the peat. *Polytrichum alpestre* formed a large moss bank about 10 m from the section but no spores of this moss were recovered from the peat. Besides their occurrence in the surface samples two spores of *Sphagnum fimbriatum* were recorded at 10 cm depth and remains of the moss were visible to below 1.00 m in the peat. Spores of another bryophyte, possibly of the liverwort genus *Schistochila*, were recognized at 80 and 90 cm, while spiral filaments resembling elators, possibly from this or other hepatic taxa (which are often abundant in mires and bogs), were common at 20 cm depth.

Diatoms and desmids are particularly abundant and diverse at 20 cm where eight forms of the latter were recognized. The diatoms comprised types D and F at 20 cm and type D at 1 m depth. A large (over 100 μm diameter) unidentified micro-fossil (type 22) was present in several samples. Although apparently absent from the surface litter, fungal spores (types 6 and 7) were frequent between 20 and 60 cm depth.

Type 6 spores comprised 30% of the total pollen count at 30 cm and at 20 cm type 7 reached 60%. Other lichen or fungus spores were few; uni-septate spores were found at 20 and 30 cm and uni-septate *Buellia*-like spores at 60 cm. Micro-fossil types 7, 16 and 18 show increased abundance towards the surface in the upper 30–40 cm, while types 6 and 12 appear to decline slightly.

Micro-fossil type 13, believed to be the egg cases of tardigrades (possibly *Macrobiotus* sp.), show a marked increase in the upper 30 cm; no other invertebrate fragments were recorded.

Site 8, Annenkov Island (Fig. 3)

Preservation in the *c.* 40 cm depth of peat sampled was good with *Acaena* and grass being the dominant pollen types. Although *Deschampsia antarctica* is present as scattered plants in the study area it is unlikely that it has made much impression on overall pollen deposition at a site which is surrounded by extensive tussock grassland. Grass pollen, probably mainly that of *Poa flabellata*, exceeds 80% of the pollen total at three levels.

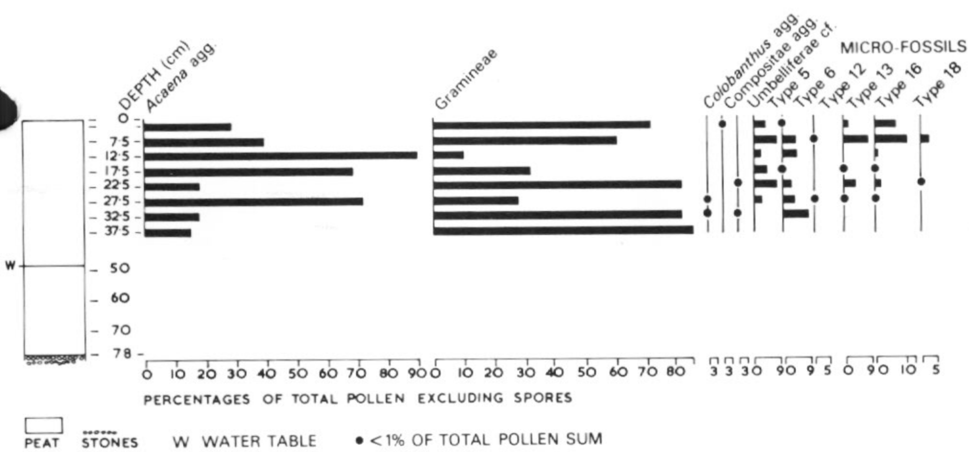

Fig. 3. Pollen diagram for Site 8, Annenkov Island. A key to the micro-fossil types is given in Barrow and Smith (1983, fig. 8).

Acaena pollen reaches 89% at one level, implying that *A. magellanica* may at times become locally dominant in terms of pollen production. Dense *A. magellanica* herbfield is frequent in sheltered situations in this part of north Annenkov Island. None of the other vascular species noted in the vicinity were represented in the analysis. However, *Colobanthus* spp. are frequent in the fellfield and rock face communities higher up on the island, and pollen of this genus registers in the lower part of the section. Similarly, no pteridophyte or bryophyte spores were recovered although *Hymenophyllum falklandicum* and *Conostomum pentastichum* grow abundantly on the rockier parts of the island. What may be elators of the liverwort genus *Schistochila* were found at 7.5 cm depth.

Desmids were not common but diatoms were recovered from 5 cm (type F), 12.5 cm (types F, C and an unidentified taxon), 17.5 cm (type F and an unidentified taxon) and from 22.5 cm (unidentified type). Lichen-like spores were few and were isolated only from 32.5 cm depth. Type 6 fungal spores do, however, show trends in this section and reach 8% of the total pollen sum at 32.5 cm.

In the lowermost sample analysed, despite a count of over 200 pollen grains, only *Acaena* and grass grains were recovered, together with a few mite fragments.

Sporomorpha of non-South Georgian origin

Nothofagus cf. *fusca* agg. pollen was the most common of the non-South Georgian types recovered. At Site 6 a single grain was recorded in the 1.50 m sample while at Site 7 they were isolated from four levels with seven grains (comprising 1.6% of the total pollen sum for that level) recovered from 1.30 m depth. All Compositae grains were of the tubuliflorae type, similar to that of *Baccharis* sp. which is a common dwarf shrub in the Falkland Islands and Fuego–Patagonia; single grains were recovered from three levels in the peat and two from the surface litter at Site 7, and one from 2.5 cm at Site 8. A Celestraceae grain resembling *Maytenus* sp. was also recovered from the surface litter at Site 7 and single grains resembling Umbelliferae were isolated at two separate levels at Site 8. Five unidentified tricolpate grains were found, three in the peat and two in the surface litter, at Site 7.

Discussion

The impression given by the analysis of the Site 6 (Sörling Valley) section is that pollen preservation is poor. The peat overlies rounded 'lower raised beach' pebbles and the upper 1.20 m may drain during drier periods in summer; this may cause oxidation and loss of pollen within the peat. Peat development at this site appears to have begun with wet flush conditions which supported *Callitriche antarctica* and *Montia fontana*, or a typical coastal zone of *Poa flabellata* in which the former species is almost always associated, probably after a fall in sea-level exposed the rounded pebbles as a raised beach (mapped by Clapperton, 1971, as the 2.5–3.5 m 'lower raised beach'). It is tempting, but somewhat speculative, to compare Site 6 and Site 2 (Sphagnum Valley, see Barrow and Smith, 1983). At both sites peat accumulation was probably initiated after the 2.5–3.5 m 'lower raised beach' was exposed (Clapperton, 1971). Of Sites 6, 7 and 8, Site 7 is the only one to have been radiocarbon dated and is therefore of greater value in the interpretation of the pollen analysis as the results can be related to a time factor.

Peat development at Site 7 (Ocean Harbour) appears to have begun also under wet flush or tussock zone vegetation, with *Callitriche* and *Montia* growing in the immediate vicinity. It is tempting to compare this site with Site 5 (on the south side of King Edward Cove) (Barrow, 1983), as both are situated at low altitudes close to the sea, both peat bases lie close to the 5.5–7.5 m 'upper raised beach' (Clapperton, 1971; Stone, 1974), and peat accumulation at both sites was initiated around 4000–3500 years ago. Human influence during the 20th century is registered by the pollen of *Rumex acetosella* and possibly *Taraxacum officinale* (Compositae) in the surface litter; these and several other alien vascular species occur around the former whaling station nearby (Walton and Smith, 1973).

Perhaps the most striking features of the Site 7 pollen diagram are the low *Acaena* values between 1.00 m and 70 cm depth; over this period of peat accumulation grass pollen production and deposition was high (except at 70 cm where all sporomorpha were very low). *Callitriche antarctica*, a typical associate of tussock grassland, also peaked with the grasses and the flush species *Montia fontana* was also prominent (at 1.00 m). If a climatic cause can be inferred (which is by no means certain) the indications might be of a wet phase (gravel layer at 1.10 m depth, followed by high *Callitriche* at 1.00 m) followed by a cool dry phase (low *Acaena*, high grass, absence of *Callitriche* and *Montia*) making its greatest impact on pollen production or preservation by 70 cm depth, after which conditions ameliorated. It is possible that the exceedingly low grass pollen production at 70 cm was caused by a dominance of *Festuca contracta*, a species of relatively dry habitats and which is typically cleistogamous; most of the other grasses, besides *Poa flabellata*, are low pollen producers.

Surface litter analysis at Site 7 suggests that most pollen is derived from plants growing close to the collection site, and that the grass pollen sum is probably composed mainly of *Poa flabellata* grains, certainly the greatest pollen-producer on the island, rather than of species typical of the drier grassland and fellfield communities (*Festuca contracta* and *Phleum alpinum*) or mesic coastal grassland (*Deschampsia antarctica* and the adventive *Poa annua*). The importance of tussock grass as the dominant pollen-producer was confirmed by an analysis of surface litter in a virtually pure *P. flabellata* stand in south-east Annenkov Island. About 99% of the total pollen sum was Gramineae (almost exclusively *P. flabellata*), with no *Acaena* and only single grains of *Colobanthus* and *Nothofagus*. Although the Site 7 plot was within a mire community, grass pollen predominated and *Acaena* was again very low. The reliance upon relative abundance of grass and *Acaena* pollen as climatic indicators is thus fraught with danger. *A. magellanica* and *Poa flabellata* are the most prolific pollen producers in the present-day flora of the island. *Poa flabellata* grains almost certainly dominate the Gramineae pollen record but its production of pollen may have been influenced by cyclical flower development and survival, depending on winter temperatures (the inflorescences are pre-formed in the previous summer and overwinter in an immature state), fluctuations in rust infection, which seems to increase in warmer drier summers (personal communications from R. I. Lewis Smith), or changes in sea level which displace the tussock zone and create gaps in the distribution of the grass and hence in its pollen deposition throughout the Quaternary history of the island's vegetation.

The Site 8 (Annenkov Island) pollen record is limited due to the shallow depth of peat sampled. However, it reflects the local vegetation cover, indicating conditions have altered little during the period of formation of almost 40 cm of peat (possibly only a few hundred years). The type 6 fungal spore present in the section seems to fluctuate independently of either grass or *Acaena* pollen, and *Rostkovia magellanica* is present. If this fungus is a parasitic species, it is therefore tempting to consider whether one of these plants is its host, for example *Rostkovia magellanica* or one of its associated bryophyte taxa. The search for the identity of the type 6 spore might be best directed towards an examination of rust and other micro-fungi associated with *Rostkovia* or certain associated species. If the fungus can be identified and is host-specific, it would be a useful palynological indicator species.

Because of the sparsity and limited variety of the native pollen production, it is easy to recognize in analyses exotic pollen derived form southern South America. *Nothofagus* spp. pollen is the most abundant of these. Species of the *N. fusca* agg. group produce similar pollen and the most likely sources include *N. antarctica, N. betuloides, N. dombeyii* and *N. pumilio*. The bulk of *Nothofagus* pollen recovered in South Georgia peat and litter has six pores; much of the remainder has five pores and a few grains have seven pores. Conifer pollen and the spores of southern South American pteridophytes do not seem to disperse to South Georgia as readily as *Nothofagus* pollen, or the pollen of *Ephedra* spp. or Compositae, which also occur in the island's deposits.

It is possible to draw the following general conclusions from an assessment of all the pollen diagrams available from the eight sites at South Georgia (see also Barrow, 1983; Barrow and Smith, 1983) with reasonable confidence. By 10 000 yr B.P. post-glacial conditions in South Georgia were favourable enough to allow peat formation. Although a period of Neoglacial cooling (between 5 000 and 4 500 yr B.P.) has been reported from some sub-Antarctic islands, it is not marked in the South Georgia pollen diagrams. Indeed, during the last *c.* 9500 years conditions have only slightly influenced the abundance of *Acaena* and other elements of the island's flora. Many elements of the present flora, including the forb *Montia fontana* – once regarded as a recent immigrant (Moore, 1963) – were flowering soon after the major ice retreat.

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