PALYNOLOGICAL STUDIES IN SOUTH GEORGIA: III. THREE PROFILES FROM NEAR KING EDWARD COVE, CUMBERLAND EAST BAY

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Abstract. The sporomorpha records of three sections of post-glacial organic deposits in a valley in Cumberland East Bay, South Georgia, are presented. Two of the analyses are the longest record of Quaternary plant history so far provided for South Georgia. These indicate that conditions, at least at low altitude, seem to have ameliorated by *c.* 10 000 yr B.P. By 9 500 yr B.P. many elements of the present day South Georgia flora were flourishing, and conditions since then have not prevented flowering. The analyses are dominated by *Acaena* (presumably *A. magellanica*) pollen while the grass component is generally low. Since there are few levels in the profiles with distinct pollen peaks, the detection of possible climatic, and consequently floristic, fluctuations is not obvious. There are no clear indications of Neoglacial (*c.* 5 000–4 500 yr B.P.) cooling in the pollen record. Pollen derived from South America (*c.* 2 000 km distant) occurs in the deposits, in the main being that of *Nothofagus* spp.

In this second account of the fossil record of pollen and spores in South Georgia organic deposits, three profiles in an unnamed valley† on the south side of King Edward Cove, Cumberland East Bay, have been analysed in detail (see also Barrow, 1978). A corresponding series of samples from two profiles (Sites 1 and 2) in Sphagnum Valley, Cumberland West Bay, about 6 km west-north-west of the King Edward Cove sites has been reported by Barrow and Smith (1983).

Study Area

The valley (Figs. 1 and 2 and fig. 1 in Barrow and Smith, 1983) was selected for palynological investigation because (a) it has a continuous cover of vegetation dominated by bog and mire communities, (b) there are several relatively deep organic deposits, and (c) its geomorphology is relatively simple and already mapped (Clapperton, 1971). The valley lies within the area selected for a range of botanical and environmental studies during the International Biological Programme Tundra Biome investigations carried out on South Georgia (Smith and Walton, 1975). Much of the Cumberland Bay region appears to have been deglaciated longer than most other areas on the island.

The broad shallow glaciated valley lies on the south side of King Edward Cove and extends from a wide raised beach for about 1 km west and north-west from the shore to the northern slope of Brown Mountain. The northern side of the valley is steep rising to a low ridge only about 30–50 m a.s.l.; the southern side has a fairly gentle slope which grades into the steep scree slope of Brown Mountain which rises to 250–300 m. Towards the seaward end of the valley there is an extensive level plain at about 10 m a.s.l. separated from the raised beach area by a low, steep, wave-cut cliff. The floor of the upper part of the valley is at about 30–40 m a.s.l. Besides the small stream running the length of the valley there is little other surface water although

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† Unofficially referred to as 'Gun Hut Valley' because of the remains of a Second World War gun emplacement and associated huts on the ridge between the shore and the main part of the valley.

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Fig. 1. General view of the south side of King Edward Cove, Cumberland East Bay. The positions of Sites 3–5 are indicated in the broad shallow valley. The western end of Brown Mountain rises above the valley to about 300 m. The darker vegetation near the shore is mostly *Poa flabellata* tussock grassland, the greyish vegetation is mainly *Rostkovia magellanica–Tortula robusta* mires, and the light coloured vegetation on the slopes is *Festuca contracta* grassland. (Photograph: R. I. Lewis Smith.)

several deep sink holes penetrate the peat to the mineral substratum 1.0–2.5 m below the surface draining surface water into subterranean channels. About 500 m from the shore the valley narrows and becomes longitudinally terraced with the lower terrace lying only a few metres below the upper. Further up, the valley is transversely stepped with at least six abrupt falls of about 1 m each and separated from the next by a terrace about 30 m wide; these steps have possibly been formed as solifluction lobes capped by peat. For about half the distance between each fall the stream flows through wet mire and bryophyte flushes and for the other half, extending from the base of each step, the stream flows in a narrow gully up to 1 m deep, cut through the peat to the till and coarser debris beneath.

The main vegetation types in the valley and adjacent area are indicated in Fig. 3. The valley floor and south side are dominated by an extensive soligenous mire community of closed *Tortula robusta* with relatively open *Rostkovia magellanica* and *Juncus scheuchzerioides,* vegetation typical of such nutrient rich seepage slopes (Smith, 1979, 1981). *Acaena magellanica, Galium antarcticum, Festuca contracta, Deschampsia antarctica, Phleum alpinum* and *Uncinia meridensis* are sparsely associated. The peat is deepest on the valley floor and generally shallow on the slope. The plain is less well drained and the community is more typical of a *Rostkovia*–bryophyte ombrogenous bog (Smith, 1979, 1981). Here, *Rostkovia* is much denser than in the mire community and *Calliergon sarmentosum, Drepanocladus uncinatus*

Fig. 2. The valley looking west. Sites 4 and 5 are indicated; Site 3 is close to the bottom left. *Rostkovia magellanica–Juncus scheuchzerioides–Tortula robusta* mire dominates much of the valley floor and lower slope of Brown Mountain (left); *Acaena magellanica* (light grey) dominates the mire in mid-ground centre to left. (Photograph: R. I. Lewis Smith.)

and the more mesophytic moss *Chorisodontium aciphyllum* with *Blepharidophyllum densifolium, Riccardia georgiensis* and other liverworts often abundant locally dominate the bryophyte understorey. *Acaena magellanica* is sparse and other vascular species are generally absent. On the raised beach between the mouth of the valley and the shore is a very wet *Rostkovia*–bryophyte (mainly *Calliergon*) bog with frequent large hummocks of *Sphagnum fimbriatum.* Stands of dense *Acaena* often with a closed understorey of *Tortula robusta* occur near the periphery of the mire and bog areas and on drier slopes, especially above the raised beach. Close to the shore tussock grass *(Poa flabellata)* forms a distinctive coastal zone inhabited by wallowing elephant seals; the principal associated species are *Callitriche antarctica, Deschampsia antarctica* and *Poa annua.* Small stands or individual plants of tussock grass also occur sporadically among the *Festuca* grassland which dominates the higher and drier slopes of the valley; here *Acaena, Phleum, Uncinia, Galium* and, in one locality, *Lycopodium magellanicum,* together with various bryophytes and foliose and fruticose lichens, are also frequent. On the more exposed roches moutonnées and ridge crests on the north side of the valley *Festuca, Phleum, Deschampsia, Acaena tenera* and *A. magellanica* and various cushion forming mosses form a very open fellfield. Of the ferns *Polystichum mohrioides* is frequent on the screes and ledges of Brown Mountain above the south side of the valley. *Cystopteris fragilis* and *Hymenophyllum falklandicum* are also present but *Grammitis kerguelensis* is rare, occurring more commonly on the north side of King Edward Cove about 1 km away. *Ophioglossum crotalophoroides* occurs sporadically on a few moist banks and in shallow gullies.

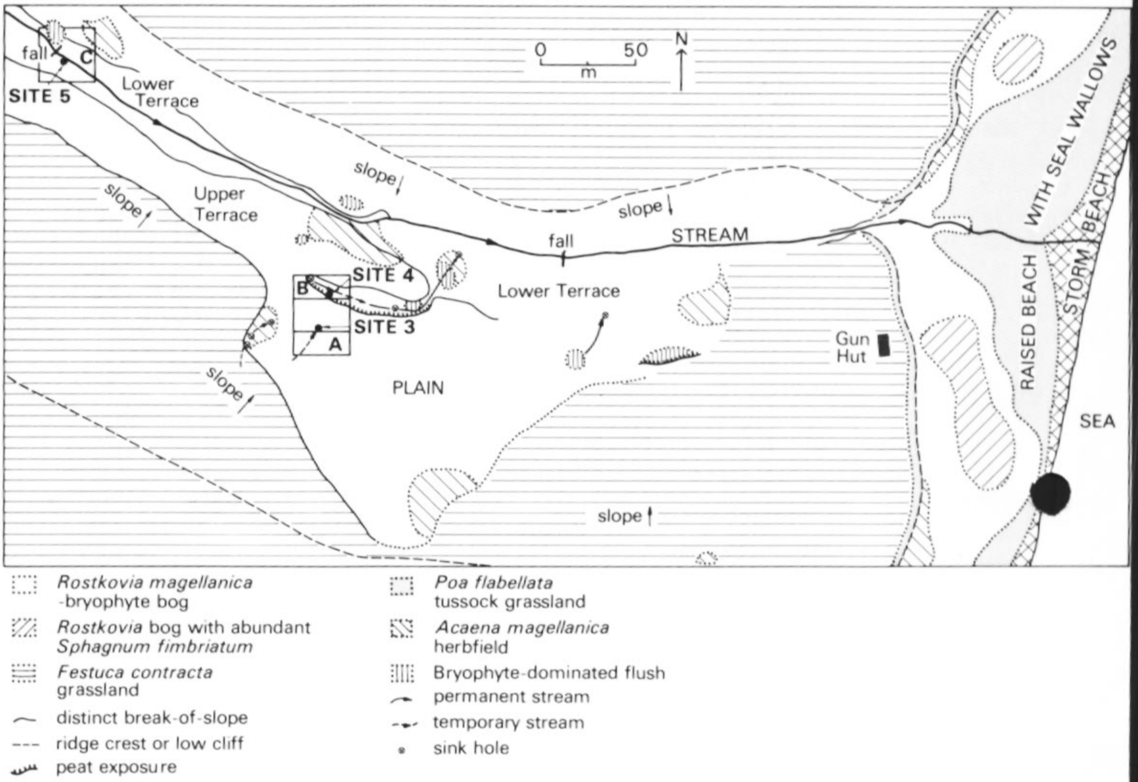

Fig. 3. The valley bog complex indicating the major vegetation types and location of Sites 3–5. Surface litter was sampled from Plots A–C.

Site Descriptions

Sites 3 and 4

These two sites are situated about 20 m apart on the gently sloping ground rising from the plain, about 400 m from the shore and at an altitude of about 21 m a.s.l. (Fig. 3). Site 3 samples were collected from the wall of a pit dug through a *Rostkovia*–bryophyte mire down to the underlying grey stony clay at a depth of about 1.7 m. Site 4 in the same mire, was sampled to 2.6 m depth from a section dug out of the face of an erosion scar caused, presumably, by meltwater action. It appears that about a metre of peat has been eroded from the upper part of Site 3, so that its present surface may correspond with Site 4 at a depth of about 1 m.

Site 5

Site 5 is situated in a similar mire about 200 m up-valley at an altitude of about 36 m a.s.l. in a narrow, 1-m-deep gully cut through a terrace and about 5 m from a stream fall (Fig. 3). The section was cut into the face of the gully to a depth of 1.05 m.

Stratigraphy of peat profiles

Sites 3 and 4 consisted of compact peat with only occasional layers of inorganic material (Fig. 4). Site 3 was underlain by morainic debris of stones and fine clay. The

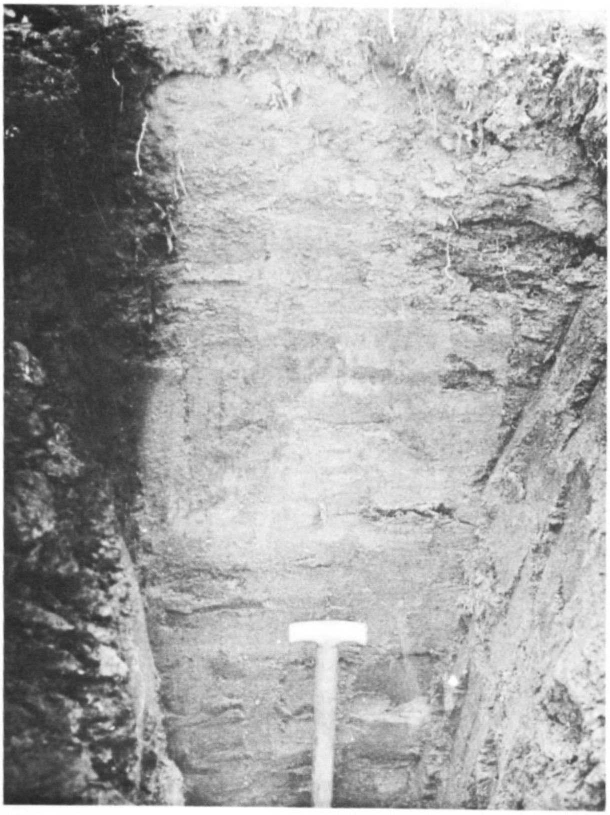

Fig. 4. Stratigraphy of section at Site 4. There is no visible stratification but occasional fibrous plant remains (roots and rhizomes) protrude from the homogeneous peat. Total depth of section is 2.60 m although the lowermost *c.* 80 cm is not visible here.

colour of the peat at Site 4 altered from red-brown to dark brown in the upper part of the profile when exposed to air and had a strong smell of hydrogen sulphide. Although this profile did not extend to the mineral substrate, probing with a Hiller sampler proved the peat was underlain by grey stony clay. A sink hole, about 1.8 m deep, close by in the lower part of the erosion scar revealed a stone and clay substrate similar to that at Site 3. A further section (not analysed) dug about 35 m down-valley and on the same erosion scar, exposed a stratigraphy similar to that at Site 4. The compact peat in the Site 5 profile was interrupted by two thin layers of sandy material; the basal peat lay on coarse morainic debris ranging from fine clay to boulders. Diagrammatic representations of each profile are given in Figs. 6–8.

MATERIAL AND METHODS

Collection of material

Sections were cut into cleaned erosion faces at each site and the profiles prepared and sampled as described by Barrow and Smith (1983). Thirty-three samples were taken from Site 3 (18 of which were analysed), 52 from Sites 4 (27 analysed) and 20 from Site 5 (11 analysed). To obtain an indication of modern sporomorpha deposition a few grams of surface litter were collected from 20 1-m^2 quadrats located randomly within a 25-m^2 plot centred on each site profile. Thus plot A was centred on Site 3, Plot B on Site 4 and Plot C on Site 5. Material was also collected from a quadrat of 100 cm^2 directly above the Site 4 profile, within Plot B, and is designated Plot B′.

An assessment of the principal plant species in the plots was also made. All material was stored at − 10°C within a few hours of collection and kept frozen until required for analysis.

Analytical procedure

Standard pollen analysis techniques, as described in detail by Barrow and Smith (1983), were employed for samples from Sites 3 and 4. All analyses included acetolysis treatment, but hydrofluoric acid was used to remove soluble silicates in the samples from 0.7 m depth at Site 3 and from 2.6 m depth at Site 4. For samples from Site 5 an 'absolute' analytical technique (see Peck, 1974) was used so that numbers o[illegible] individual taxa could be expresed as a concentration rather than as a percentage frequency as in the more commonly used technique; the more sophisticated and costly alternative absolute method, which provides an indication of annual pollen deposition, was not attempted.

The advantage of 'absolute diagrams' compared with 'relative or percentage frequency diagrams' is that they allow each component taxon in the diagram to be considered independently, thereby preventing the distortion which fluctuations in a major taxon can cause in frequency analyses. Absolute diagrams can also provide an indication of pollen concentration or actual pollen production in the past (Davis, 1963, 1965). Samples were prepared using the Jørgensen (1967) 'sub-sample by weight' method and the concentration expressed as number of sporomorpha per taxon per gram of dry sample. The extraction procedures were the same as those used in the 'relative' analyses, with the following differences. Each sediment sample (*c.* 1–3 ml) was oven-dried for 24 h at 90°C then processed (without sieving) in the standard manner until ready for transfer to the silicone mountant fluid. The sample, suspended in warm tertiary butyl alcohol, was rinsed from the centrifuge tube with warm tertiary butyl alcohol into a cleaned 5-ml glass vial and weighed (together with a glass stirring rod). A little silicone fluid was added and the vial left in a warm oven (85°C) for 24 h for the tertiary butyl alcohol to evaporate. The sample and mountant were then thoroughly mixed and slides prepared immediately. Re-weighing the vi[illegible] rod and remaining sample plus mountant enabled the calculation of the weight of t[illegible] sample plus mountant on the slides. The addition of silicone fluid to a slide too dense to count does not affect the calculation, nor is the option of counting additional slides precluded.

The prepared slides were examined (under No. 0 cover slips) and the number of grains of each taxon per gram of dry weight of sediment calculated using:

$$N \times A \times W_t/W_s \times 1/W_d$$

N = number of grains of taxon
A = total area of coverslips examined
W_t = total weight of sample + mountant + vial
W_s = weight of sample and mountant placed on slides
W_d = dry weight of sediment used in preparation

Microscopic examination and counting procedure

The slide preparations were examined using a Nikon Apophot 35-mm photomicroscope equipped with Nikon HKW × 15 eyepieces, a Nikon Apoplan × 1000 oil-immersion objective (numerical aperture 1.30) and Nikon Apo × 10, × 20 and × 40 objectives. Other details together with those regarding the counting procedure are given by Barrow and Smith (1983).

While the numbers of pollen grains per sample were exceedingly low (around 100) from the two profiles in Sphagnum Valley (Barrow and Smith, 1983), the pollen sums averaged 200 grains per sample at Sites 4 and 5 and 500 grains per sample at Site 3. The latter are the highest counts obtained for a profile on South Georgia; the second longest Quaternary record of the island's vegetation is therefore statistically the most reliable.

Identification of sporomorpha

Sporomorpha, including undetermined material and pollen of aggregate taxa, from the profiles are identified or described according to Barrow (1976) and Barrow [illegible]nd Smith (1983).

Presentation of data

The analyses for Sites 3 and 4 are presented as frequency histograms for each taxon with the abundance of pollen being expressed as a percentage of the total pollen sum in each sample level. Data for the Site 5 absolute analysis are presented as a concentration diagram with each taxon expressed as number of grains per gram of sample prepared.

RESULTS

Cranwell (1965) considered a pollen sum of around 200 grains per sample was probably adequate for analysis of South Georgia material, and that this sum should register the low-pollen producers. Fredskild (1973), working on comparable Greenland tundra deposits, found that counts of 100–150 grains per level were often all that he could provide. Few analyses with close-spaced samples from the southern high latitudes have been based on pollen counts of much above 200 grains per sample. In comparatively pollen-productive regions of temperate Southern Chile, Heusser (1964, 1966, 1974) counted from 150 to 500 grains per sample while Godley and Moar [illegible]973) made counts in Chilean coastal peats of only about 100 pollen grains per sample. Young and Schofield (1973) based their pollen diagram for Iles Kerguelen on counts of 150 pollen grains per sample and Schalke and van Zinderen Bakker (1971) averaged 300 grains per sample for their analysis of Marion and Prince Edward islands peats. Higher counts are certainly possible in the more temperate islands and temperate southern South America, e.g. Hafsten (1960) maintained counts of 1 000 grains (up to 2 000 at pollen-rich levels) in his Tristan da Cunha and Gough Island analyses. The highest counts in the colder sub-Antarctic are those of Bellair (1967), whose counts for Iles Kerguelen peats range from 300 to 2 266 grains per sample, and van Zinderen Bakker (1972) who provided counts of 1 000 grains per sample for Iles Crozet peats. In each case, statistical reliability was improved at the cost of detail since only seven and four levels, respectively, were sampled; also, each sum included spores of pteridophytes and fungi while in the present study, all spores were excluded from the total pollen sum.

Present sporomorpha deposition

The general floristic composition of the three plots from which the surface litter samples were collected was as follows:

Plot A comprised predominantly *Rostkovia magellanica* (*c.* 20% cover), *Juncus scheuchzerioides* (20%) and *Acaena magellanica* (10%), with a closed understorey of *Tortula robusta* (possibly including *T. serrata*). Other species included scattered plants of *Deschampsia antarctica, Festuca contracta, Phleum alpinum, Galium antarcticum* and *Ranunculus biternatus*; both *Polytrichum alpestre* and *Conostomum pentastichum* were present with abundant sporophytes.

Plot B, which overlapped Plot A to some extent, was dominated by *Rostkovia* (30%), *Juncus* (20%) and *Acaena* (10%), again with a closed understorey of *Tortula* although *Polytrichum alpestre* formed a continuous turf along the margin of the erosion scar. *Galium, Festuca, Phleum* and *Ranunculus* were occasional associates. The single small quadrat (Plot B′) directly above the sampling section was composed mainly of *P. alpestre* with no vascular plants included.

Plot C was dominated by *Rostkovia* (30–35%), *Acaena* (30%) and scattered plants of *Deschampsia, Festuca, Juncus, Montia fontana, Ranunculus* and frequen[illegible] *Tortula* spp. and *Marchantia berteroana*, while in drier places *Galium* was quite common.

The results of the surface litter analysis of the sample plots at each site are presented in Fig. 5. However, conclusions from so few surface analyses must be limited. In general, pollen and spores are derived from plants growing close to the sample plots. Bartley (1967), in his study of several Arctic sites, warned that, 'Because the influence of the vegetation is so local there are very great variations in the composition of the pollen rain falling on surface sites only a few metres apart. This leads to considerable difficulty in the interpretation of pollen diagrams and points to the value of having a number of diagrams from a small area since only consistent changes are likely to be of major significance.' Birks (1973) stated that, 'observed differences in pollen percentages and pollen composition in surface samples collected from the same [Arctic tundra] community are as great as the differences in pollen percentages and composition between samples from different communities, but that the broad zonal vegetation types can be consistently characterized by modern pollen spectra'.

As with the Sphagnum Valley sites (Barrow and Smith, 1983), the modern pollen 'rain' is dominated by *Acaena* and Gramineae, the former constituting 82–85%. The grass pollen count is rather low considering the abundance of grassland adjacent to the sites; however, the main pollen producer, *Poa flabellata,* is mainly to the leeward of the sites, while the dominant grass to the windward of the site is the cleistogamo[illegible] *Festuca contracta*. Spores of *Conostomum pentastichum* reach high values at Sites 3 and 4 but are surprisingly low at Site 5, despite the close proximity of all sites. This moss is common and usually fertile in the nearby *Festuca* grassland. While it is likely that the bulk of the grass pollen isolated is that of *P. flabellata,* the pollen of *Deschampsia antarctica* and *Phleum alpinum* is probably also present. Several introduced grasses occur close to the former whaling station, Grytviken, about 1 km to the west (Walton and Smith, 1973) and *Poa annua* is frequent near the shore at the mouth of the valley. The pollen of this species is distinguishable from that of the native grasses (Barrow, 1976) although, morphologically, there may be some overlap with smaller grains of certain native grasses. Grains of *P. annua* have been recorded only from the surface litter and none was detected in any layers of the underlying peat, confirming its status as an adventive species introduced during the nineteenth century (Walton and Smith, 1973). Because of the proximity of the

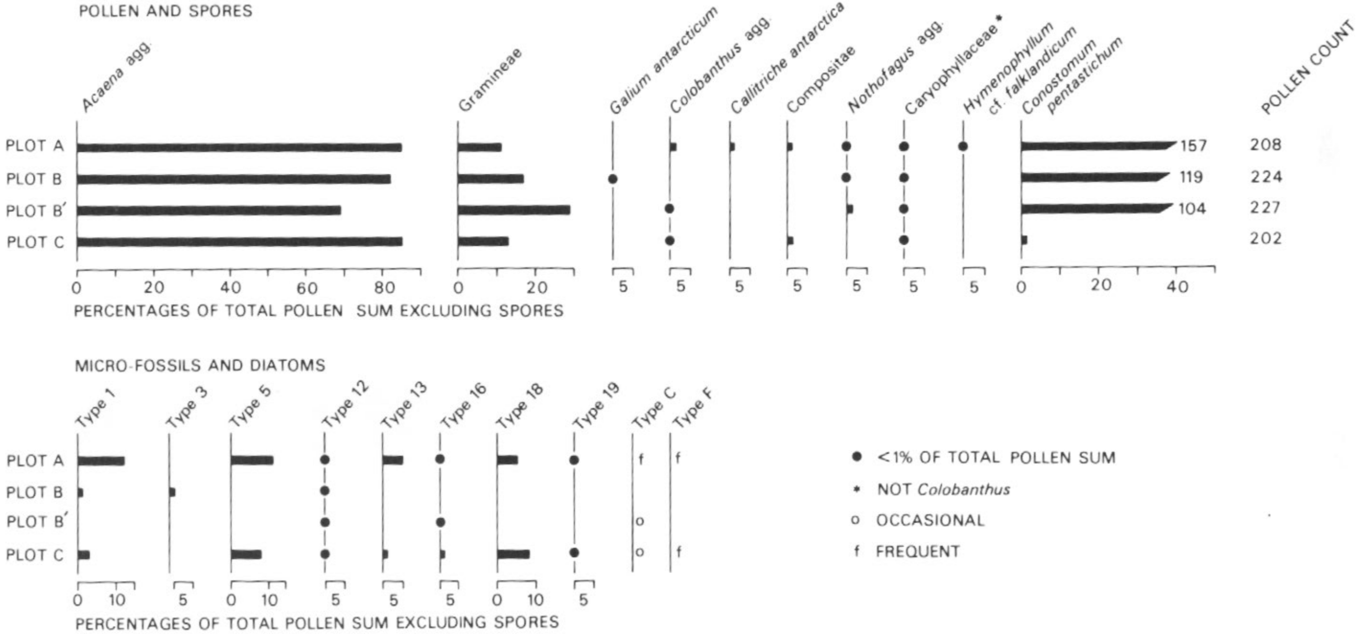

Fig. 5. Pollen diagram for surface plots in the valley south of King Edward Cove. (A key to the micro-fossil types is given in Barrow and Smith, 1983, fig. 8.)

former whaling station the King Edward Cove area has suffered more human interference than the Sphagnum Valley locality (Barrow and Smith, 1983) and was at times this century grazed by introduced livestock.

Besides several micro-fossil types (see Barrow and Smith, 1983) isolated, diatoms were also recorded from the surface litter collection.

Fossil sporomorpha record

The pollen and spore diagrams are presented in Figs. 6, 7 and 8. The material analysed from the three sections contains pollen and spores broadly representative of the species growing at present in the immediate vicinity of each site. Certain species (e.g. *Montia fontana, Ranunculus biternatus* and *Galium antarcticum*) are relatively low pollen-producers and occur only as scattered plants or are localized in occurrence; the pollen record for these species generally reflects this situation.

Graminoids

In all three diagrams the Gramineae curve fluctuates, but it is most striking in the Site 4 section. In neither of the two relative diagrams (Figs. 5 and 6) does grass pollen exceed 60% of the total at any one level, while at Site 4 the values are often below 10%. Quantities at the base of both diagrams are not very dissimilar from those of the present-day grass deposition at that locality (see Fig. 5). The pollen concentration data for Site 5 (Fig. 8) indicate that during the last *c.* 3000 years grass pollen deposition has ranged from less than 400 grains to over 100000 per gram of dry sediment. Although small-sized Gramineae pollen was examined to check for the possible occurrence of *Poa annua,* none of the other grass pollen was determined to generic level; no *Uncinia meridensis* pollen was recovered.

The rhizomes of *Rostkovia* occur in all three sections, the deepest visible being in Site 4 at 1.5 m depth. A seed of this rush was found at 1.6 m depth at Site 3.

Suffruticose herbs

Acaena pollen dominates all three peat analyses and the bulk is almost certainly *A. magellanica,* although some *A. tenera* and hybrid pollen may be present also. *Acaena* values do not fluctuate as markedly as those of the grass curves in the Site 3 and 4 diagrams, but maintain a fairly constant (generally $>75\%$) presence, particularly at Site 4. Short-lived fluctuations in deposition of *Acaena* pollen, suppressed in the relative diagrams, is indicated by the Site 5 analysis. However, in contrast to the relative analyses of Sites 3 and 4, peak *Acaena* deposition appears to occur concurrently with that of grass pollen.

Forbs

Forbs are generally much less abundant than *Acaena* and Gramineae. The most frequently recorded pollen belongs to *Colobanthus* spp. and occurs sporadically to the base of each site profile. Although the fossil caryophyllacean pollen is identical morphologically with that of present day *Colobanthus* spp., few of the grains isolated had a chord (= distance between adjacent pore centres): pollen grain diameter ratio (see McAndrews and Swanson, 1967) which fell within the range determined for fresh material (*C. quitensis* range for 40 grains from present day plants, 0.200–0.360, mean 0.268: *C. subulatus,* 0.185–0.320, mean 0.276; ratios for fossil grains range from 0.138 to 0.243, all but the latter being <0.205). *Galium antarcticum* pollen is sporadic and sparse (less than 1%) throughout the Site 3 section to a depth of 1.6 m (Fig. 6), but is little in evidence at Sites 4 and 5. However, the absence of *Galium* in

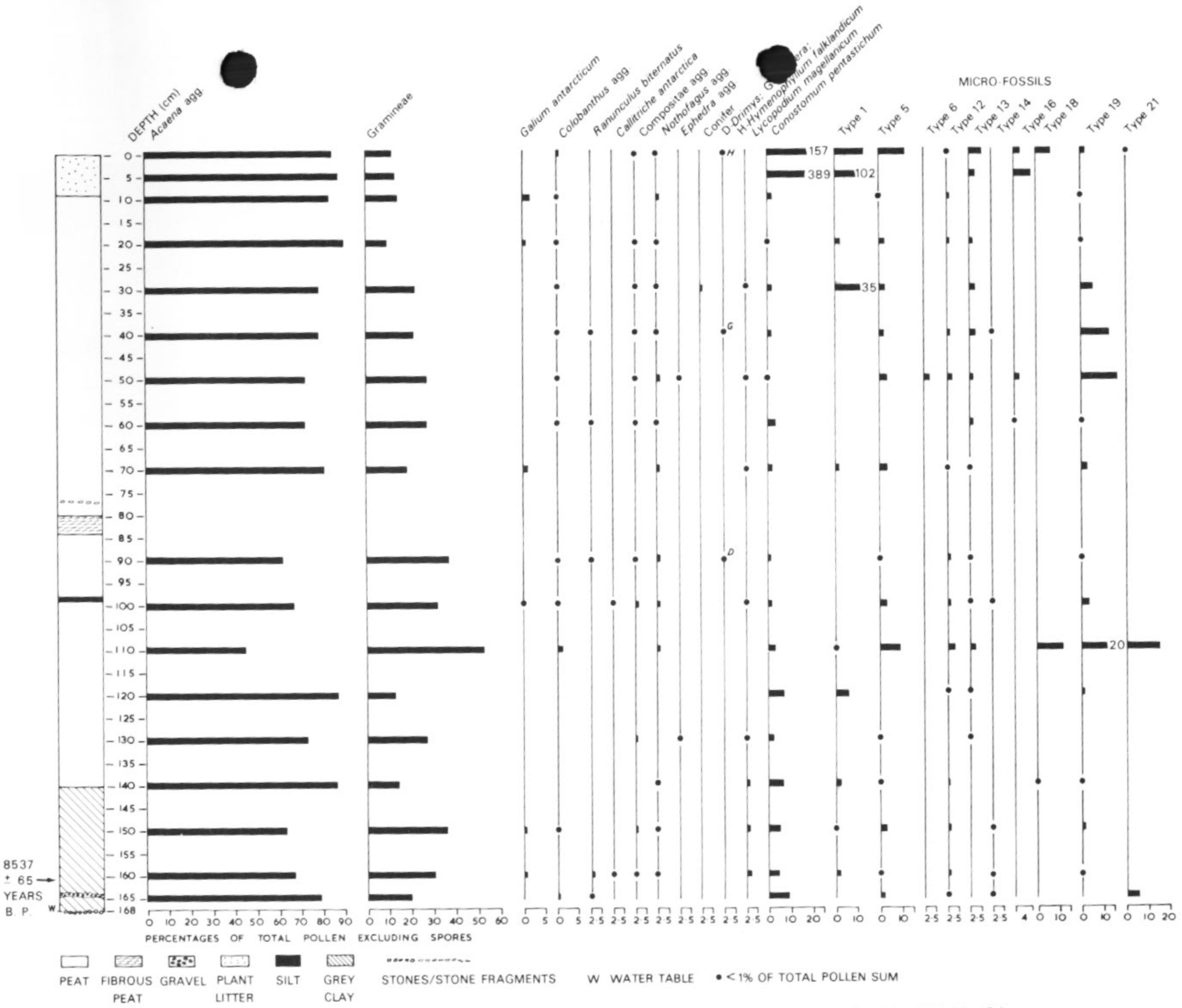

Fig. 6. Pollen diagram for Site 3. (A key to the micro-fossil types is given in Barrow and Smith, 1983, fig. 8.)

any diagram is not necessarily indicative that the species was absent from the past vegetation as the pollen seems under-represented.

Callitriche antarctica grains are infrequent but occurred near the base of Sites 3 and 5. Pollen deposition of this small, prostrate mainly coastal species is probably restricted to the close proximity of the plants. *Ranunculus biternatus* pollen was recorded low in the Site 3 profile, but the other flush species, *Montia fontana,* was not isolated.

Pteridophytes

Lycopodium magellanicum spores are present in small quantities down the Site 3 section to near the base, although it does not register in samples from Site 4 only 20 m away; its spores were found only at one level at Site 5. The only fern spore recorded was *Hymenophyllum falklandicum* recovered from the surface litter at Site 3.

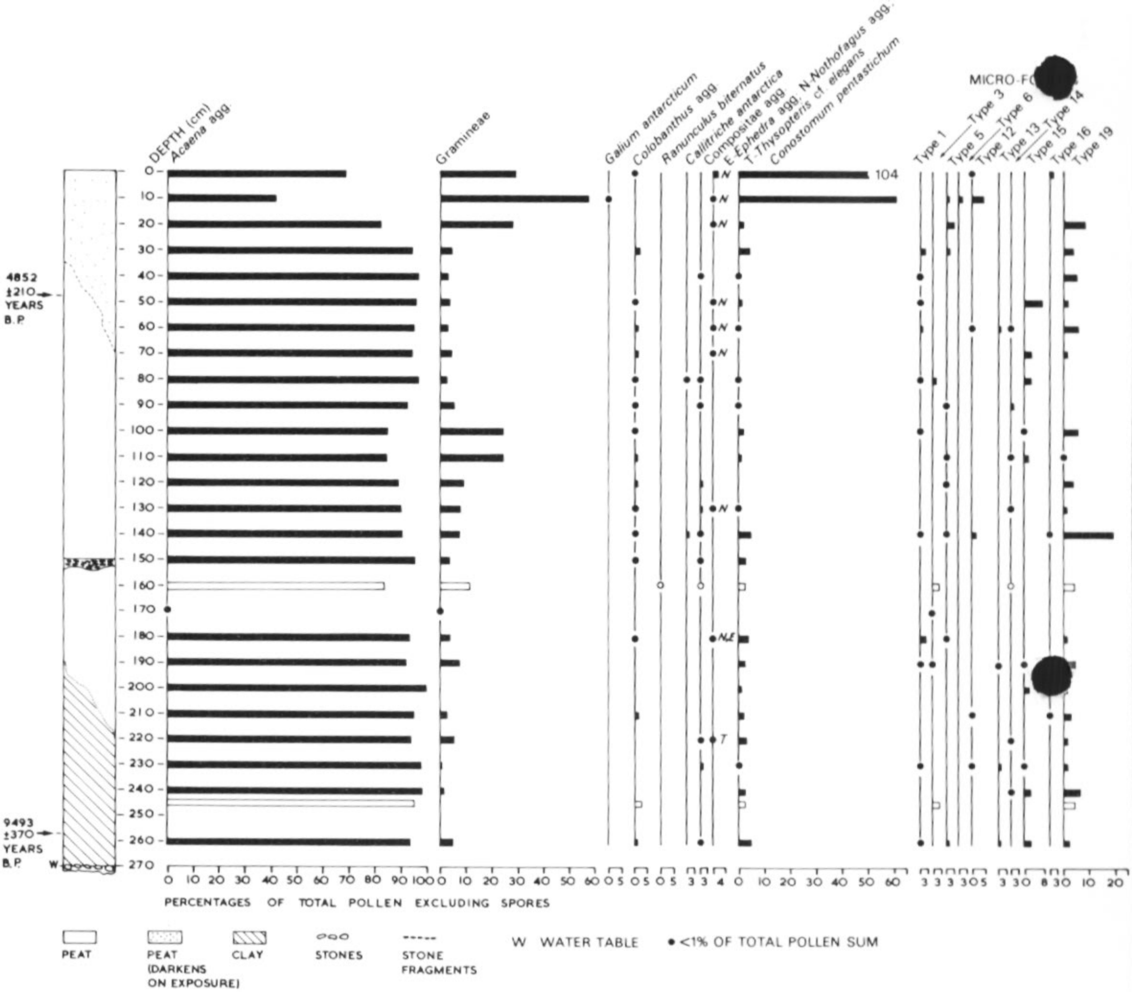

Fig. 7. Pollen diagram for Site 4. (A key to the micro-fossil types is given in Barrow and Smith, 1983, fig. 8.) Open bars indicate a total of < 200 pollen grains isolated.

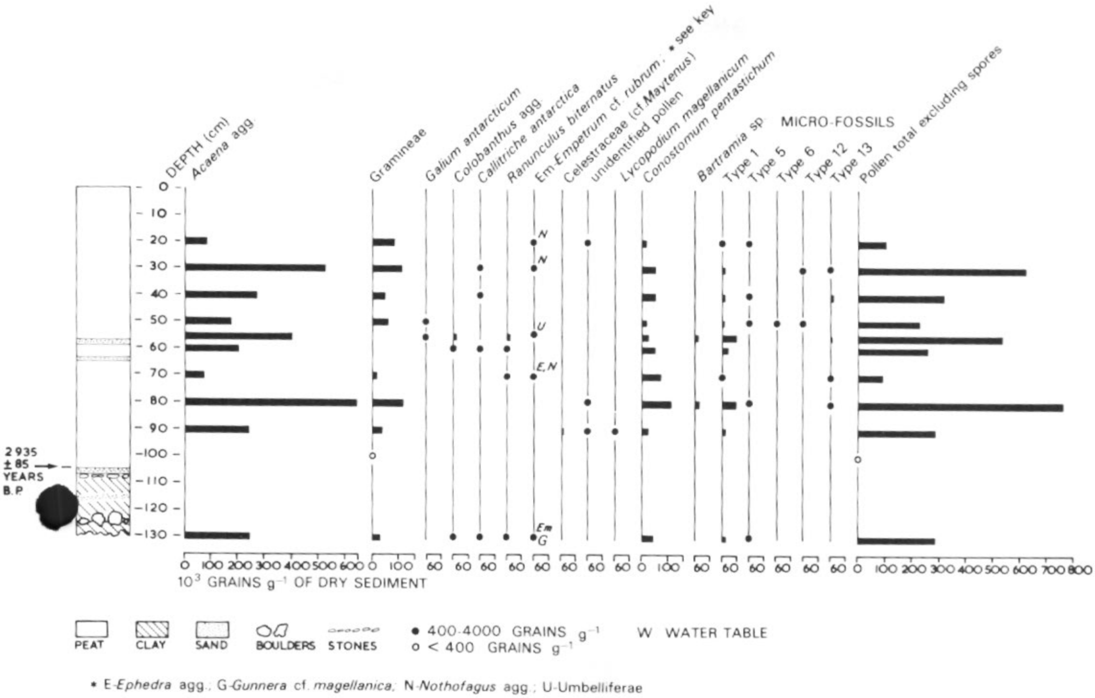

Fig. 8. Pollen diagram for Site 5. (A key to the micro-fossil types is given in Barrow and Smith, 1983, fig. 8.)

Bryophytes

The distinctive monolete spores of *Conostomum pentastichum* have been isolated from each of the three profiles and occur down to the basal peat at each site. Peak *Conostomum* values in Site 5 are at 80 cm depth and attain 4800 grains per gram of sediment. In Sites 3 and 4 values are highest between 0 and 20 cm depth, but the spores are present in lower quantities throughout the two sections. Fluctuations in the values at these two sites are fairly well defined.

The spores of another species of Bartramiaceae, *Bartramia* cf. *patens*, were recovered from Site 5 at 55 and 80 cm depth. Although fruiting *Polytrichum alpestre* abounds close to Sites 3 and 4, spores of this genus have not been recovered. *Sphagnum fimbriatum*, which grows a few hundred metres to the leeward of the sites (Fig. 3), was not recovered from the material analysed. Spores believed to be those of a chionophilous hepatic, *Schistochila* sp., were found at 1.5 and 2.6 m at Site 4.

Algae, fungi and lichens

A key to the various micro-fossil (including diatom) types recovered is provided by Barrow and Smith (1983). Generally, the assemblage recovered from Sites 3, 4 and 5 was similar to that from the Sphagnum Valley sites, except that there was a slightly greater diversity of desmid species and septate spores in the former locality. Many of the micro-fossil types occurred throughout each profile to the base. Diatoms were extracted from the Site 3 section at depths of 5 cm (types A, D and F), 10 cm (type C) and 20 cm (type A), from Site 4 at 2.4 m (unidentified due to corrosion), and from Site 5 at 30 m (type E) and 80 cm (types E and F). Type 6 sub-reticulate fungal spores, which are so abundant in the Sphagnum Valley profiles (Barrow and Smith, 1983), occur only sparsely in the Sites 3, 4 and 5 samples but have been isolated down to 2.3 m at Site 4.

Sporomorpha of non-South Georgian origin

The majority of non-South Georgian pollen isolated is that of *Nothofagus fusca* agg. Twenty-nine grains were isolated from the Site 3 profile, seven from Site 4 and three from Site 5. The number of *Nothofagus* pollen grains per gram of sample in relation to total pollen concentration at the latter site was 1:110000 in the 20-cm depth sample, 1:621000 in the 30-cm sample and 1:94000 in the 70-cm sample. The next most abundant alien pollen belongs to Compositae, all of the tubuliflorae type, with 14 grains isolated from Site 3 and 16 from Site 4. Some of these may be derived from species of *Baccharis* or *Senecio* which are common in the Falkland Islands and southern South America. Several grains belonging to Caryophyllaceae, but probably not of *Colobanthus* spp., were recorded in the profiles at Sites 3 and 4; four grains out of a total pollen concentration of over 291400 in the Site 5 section were of this family.

Pollen of several other species of South American origin occur at various levels in the profiles. Single grains of *Gunnera* cf. *magellanica* were isolated from Sites [illegible] (40 cm depth) and 5 (1.3 m depth) and of *Empetrum* (presumably *E. rubrum*) also from 1.3 m at Site 5. The Umbelliferae grain isolated from Site 5 may belong to *Azorella,* several species of which are common in the Fuego–Falkland Islands region. *Ephedra* pollen occurred very sporadically in each profile. Conifer pollen, which is very rare in all South Georgia samples analysed, was recovered from a depth of 30 cm at Site 3; the three grains resemble those of *Dacrydium* spp. A single grain of *Drimys* sp. occurred at 90 cm at Site 3. Several unidentified tricolpate grains were isolated from Site 5. An unidentified pteridophyte spore resembling *Thysopteris elegans* (Heusser, 1971) was recovered from 2.2 m at Site 4.

Invertebrates

Egg cases of a tardigrade, possibly *Macrobiotus* sp. (described as type 13) are fairly common in each profile, as are fragments of mites, and occur to a depth of 2.4 m at Site 4.

DISCUSSION

Radiocarbon dates have been determined for the base of the continuous peat profile at each site (Figs. 6–8), but the ages appear not to be correlated with depth and give no clear indication of the rate of peat accumulation. For example, at Site 4 [illegible] a sample from 50 cm depth was dated as almost 5000 years B.P., yet a sample from 255 cm was about 9500 years B.P. The apparent discrepancy cannot be explained by compression alone and other factors affecting the mire dynamics, such as differential growth and decomposition rates related to possible vegetational and climatic changes, and also erosion, may be partly responsible. Site 5, although at a slightly higher altitude than Sites 3 and 4, is situated on a lower terrace than the latter sites. The oldest dates are for Sites 3 and 4 (8537 ± 65 yr B.P. at 160 cm depth, and 9493 ± 370 yr B.P. at 255 cm depth, respectively), while the base of Site 5 was dated as 2935 ± 85 yr B.P. at 105 cm depth. Although the difference in altitude between the terraces is only a few metres, it is suggested that stream erosion has been responsible for lowering the valley floor sometime before 3000 yr B.P. The organic deposits at Sites 3 and 4, while at a lower altitude, may have escaped such erosion as they are situated 50–60 m from the stream. Possibly an eustatic fall caused the formation of a terrace *c.* 4500 to 3000 yr B.P. (Barrow, 1977). Such a change could have altered drainage at Sites 3 and 4.

The oldest radiocarbon date indicates that vegetation development was well advanced by about 9500 years ago, i.e. shortly after the recession of ice after the last glacial maximum (Clapperton and others, 1978; Smith, 1981). The date obtained for the base of the Site 4 profile is the oldest so far determined for a South Georgia organic deposit*, but an almost identical date of 9433 ± 120 yr B.P. was determined for the base (300 cm depth) of a similar *Rostkovia–Tortula* mire near Dartmouth Point (Smith, 1981), about 8 km south-east of Site 4. The Site 4 pollen diagram is therefore the longest record of Quaternary plant history so far provided for South Georgia.

The pollen diagrams for each site are dominated by *Acaena* (assumed to be predominantly *A. magellanica*), and in the Site 4 profile values for this taxon were below 80% of the total pollen count at only two levels (excluding the surface litter sample) over a time span of about 9500 years. There is a more marked fluctuation of values over 8500 years at Site 3. The diagram for Site 5 provides an indication of absolute pollen concentration during the past *c.* 3000 years and suggests greater and probably more realistic trends in *Acaena* pollen deposition. A striking feature of the Site 3 profile is the gap in the pollen record between 70 and 90 cm depth associated with a minor stratigraphic change (Fig. 6). Repeated attempts to isolate sporomorpha from the abundant organic material in the deposits between the mineral and fibrous peat layers were unsuccessful. A similar situation occurred between 160 and 180 cm in the Site 4 profile (Fig. 7). Repeated analyses of the dark peat yielded only a single grain each of *Acaena* and of a grass; only a single type 3 micro-fossil was recorded. The absence of pollen may have resulted either from very low production, in which case a few grains should have been recovered, or from a change in conditions which prevented the preservation of pollen, e.g. a decrease in substrate acidity or a drying of the peat leading to oxidation of the pollen. It is possible that a cooling of the climate caused much of low-lying South Georgia to be covered by a relatively short-lived (several centuries) non-mobile ice sheet causing minimal superficial erosion. The depth of the gap in the pollen record at Site 4 does not correlate with that at Site 3, but, as stated earlier, differential minor erosion in the valley may have removed about 1 m of peat from around Site 3. Thus the 70–90 cm level at this site would correspond approximately to the 160–180 cm level at Site 4.

The trends shown by the grass curves are more marked than those for *Acaena* but the values are very much less than those for the woody herb. The dominant pollen-producing grass is *Poa flabellata* (the other dominant grass, *Festuca contracta,* is generally cleistogamous), but even surface litter samples yielded a surprisingly low grass pollen content, perhaps because the stands of tussock grassland lie to the leeward of the sites. The fluctuations probably reflect the fortunes of *P. flabellata* but a proportion of the grass pollen probably comprises other local species such as *Phleum alpinum* and *Deschampsia antarctica.* As suggested by Barrow and Smith (1983) for the Sphagnum Valley sites, peaks in the Gramineae curves may indicate cool or cool-wet climatic conditions but it is not possible to correlate the peaks at the two adjacent sites (Sites 3 and 4) due to uncertainty regarding erosion at Site 3. However, if grass pollen peaks may be validly interpreted as indicating cool conditions, those prominent in the Site 4 profile around 10 cm and 1 m depth might reflect the 'Little Ice Age' (*c.* 100–250 yr B.P.) and the maximum post-glacial ice advance in

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* Since this was written R. I. Lewis Smith (personal communication) has obtained a radiocarbon date of 9700 ± 150 yr B.P. for a basal sample at 3.50 m depth taken by coring the mire peat about 15 m up-valley from Site 4 (see Fig. 2, sink-hole beyond erosion scar).

South Georgia around 6 500 yr B.P., respectively (see Clapperton, 1971; Markgraf, 1974; Clapperton and others, 1978; Burrows, 1979).

Although several forbs are present throughout the profiles, pteridophytes, with the exception of *Lycopodium magellanicum* at Site 3, appear to be absent. The moss *Conostomum pentastichum* abounds in the upper layers at Sites 3 and 4 and is frequent throughout each of the three profiles together with various unidentified micro-fossil types.

Because of the sparsity and the limited variety of the native pollen production, it is easy to recognize in analyses pollen derived from southern South America. *Nothofagus* pollen is the most abundant of the pollen types blown to South Georgia. Species of the *N. fusca* agg. group produce similar pollen and especially likely sources are *N. antarctica, N. pumilio, N. dombeyii* and *N. betuloides* all of which grow in southern South America. The bulk of this pollen found in South Georgia has six pores, the larger part of the remainder five pores, and a few grains seven pores. *Nothofagus* pollen predominated throughout much of a 165-cm-deep, 1 800-year-old, permanently frozen moss peat profile on Signy Island, South Orkney Islands (D. Churchill, pers. comm.). Detailed examination of the South Georgian surface samples revealed that of the 57 (35% of the total pollen sum) *Nothofagus* grains recorded, 26 belonged to *N. betuloides*, eight to *N. antarctica*, two to *N. pumilio* and one to *N. dombeyii*, while 20 were not determined beyond *N. ?fusca* agg. type. Conifer pollen and the spores of southern South American pteridophytes do not seem to disperse to South Georgia as readily as *Nothofagus* pollen, or that of *Ephedra* spp. or Compositae which also occur sporadically in the island's deposits.

The analyses presented here indicate that conditions on South Georgia have not prevented the flowering of a number of the present-day vascular taxa during at least the last 9 500 years. Furthermore, the high values for *Acaena* spp. pollen suggest that conditions were at least as warm over 9 000 years ago as they are at present. The oldest deposit so far analysed from South Georgia (Site 4, 9 493 ± 370 yr B.P.) has yielded pollen of *Acaena* spp., at least one grass species, *Colobanthus* sp., spores of *Conostomum pentastichum* and various unidentified micro-fossils. The slightly younger basal layer at Site 3, 20 m away, (8 537 ± 65 yr B.P.) contained sporomorpha

Fig. 9. *Galium antarcticum* pollen grain from 1.60 m depth at Site 3; the age of this level has been radiocarbon dated as 8 537 ± 65 yr B.P. In modern material grains of less than six colpi are rare. The grain is *c.* 26 μm in diameter.

of these taxa together with that of *Callitriche antarctica, Galium antarcticum* (Fig. 9), *Ranunculus* cf. *biternatus* and *Lycopodium magellanicum.* Both analyses revealed the presence of Compositae pollen and the latter site also contained *Nothofagus* pollen.

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