PLANT SUCCESSION AND RE-EXPOSED MOSS BANKS ON A DEGLACIATED HEADLAND IN ARTHUR HARBOUR, ANVERS ISLAND

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Abstract. A substantial part of Bonaparte Point, Arthur Harbour, Anvers Island, has been deglaciated by the retreat of the high ice cliff of the Marr Ice Piedmont. The area was visited briefly in February 1977 and notes made of the succession of pioneer plants within 100 m of the present ice margin. Relict banks of the turf-forming mosses *Polytrichum alpestre* and *Chorisodontium aciphyllum*, exposed by the receding ice piedmont, were discovered close to the ice cliff. Radiocarbon dates for three samples of peat, probably representing the base of the former moss banks, taken from between 25 cm and 10–12 m from the ice margin, range from 425±40 to 630±50 years B.P. It is suggested that these moss banks were identical to existing healthy *Polytrichum–Chorisodontium* stands beyond the maximum advance of the ice, which may have occurred during the Little Ice Age of about A.D. 1750–1850. An attempt has been made to correlate mean annual and summer air temperatures with recent glacier activity in the area and its consequent effect on the local vegetation.

Arthur Harbour (lat. 64°46′S, long. 64°05′W) lies between the ice-free headlands of Norsel Point and Bonaparte Point on the south-west of Anvers Island and a group of small islands, the largest of which are Torgersen, Litchfield and Humble Islands which lie up to 1 km offshore (Fig. 1). The western end of the two promontories and Litchfield Island are extensively vegetated and have a fairly rich cryptogamic flora (Smith and Corner, 1973). The much lower Torgersen and Humble Islands have large penguin rookeries and the vegetation is much less diverse and extensive.

Sheltered north-facing rocky slopes support locally extensive communities of the moss-turf sub-formation with stands of the *Polytrichum alpestre*–lichen sociation predominating but with the *Chorisodontium aciphyllum*–lichen and *Polytrichum alpestre–Chorisodontium aciphyllum*–lichen sociations also frequent and the *Chorisodontium aciphyllum*–lichen sociation occurring on Litchfield Island. Turves exceeding 30–35 cm in depth possess a permafrost below about 25–30 cm. Moist rock basins and depressions are occupied by the moss-carpet sub-formation with the *Drepanocladus uncinatus* sociation occurring on the drier soils and the *Calliergidium austro-stramineum* sociation (given as *Brachythecium* cf. *antarcticum* in Smith and Corner (1973)) in the wetter situations. Dry rocky substrata are colonized by a wide range of sociations in the fruticose lichen and moss-cushion sub-formation and the crustose lichen sub-formation; stands dominated by species of *Alectoria*, *Umbilicaria* and *Usnea* predominate on areas of block scree, especially on Norsel Point. *Deschampsia antarctica* is locally common and widely scattered, forming closed swards on Litchfield and Torgersen Islands and to a lesser extent on Norsel and Bonaparte Points. *Colobanthus quitensis* is much more restricted.

The southern part of Anvers Island is covered by the Marr Ice Piedmont and the only ice-free areas near sea-level are occasional headlands such as those in Arthur Harbour. It is clear from the diversity of plant species and the extent of stands of vegetation that the seaward ends of Norsel and Bonaparte Points and Litchfield Island (and Hermit and Laggard Islands about 4 km to the south-east; see Smith and Corner (1973)) must have been ice-free for at least several hundred years. However, it is obvious from the sparseness of the vegetation and the freshness of the rock surfaces (see Corner and Smith, 1973) towards the landward end of the two headlands that the snout of the ice piedmont has been considerably farther forward than its present position.

Of particular interest is the promontory of Bonaparte Point, on which there is a fairly distinct boundary, about 300 m beyond the present ice cliff, separating the more or less barren deglaciated area from that supporting long-established mature vegetation comprising small stands of *Drepanocladus uncinatus* and *Calliergidium austro-stramineum* carpets, shallow banks of *Polytrichum alpestre*, small aggregations of *Deschampsia antarctica* and occasional *Colobanthus quitensis*, and a variety of lichen communities on the rock surfaces and boulders. The

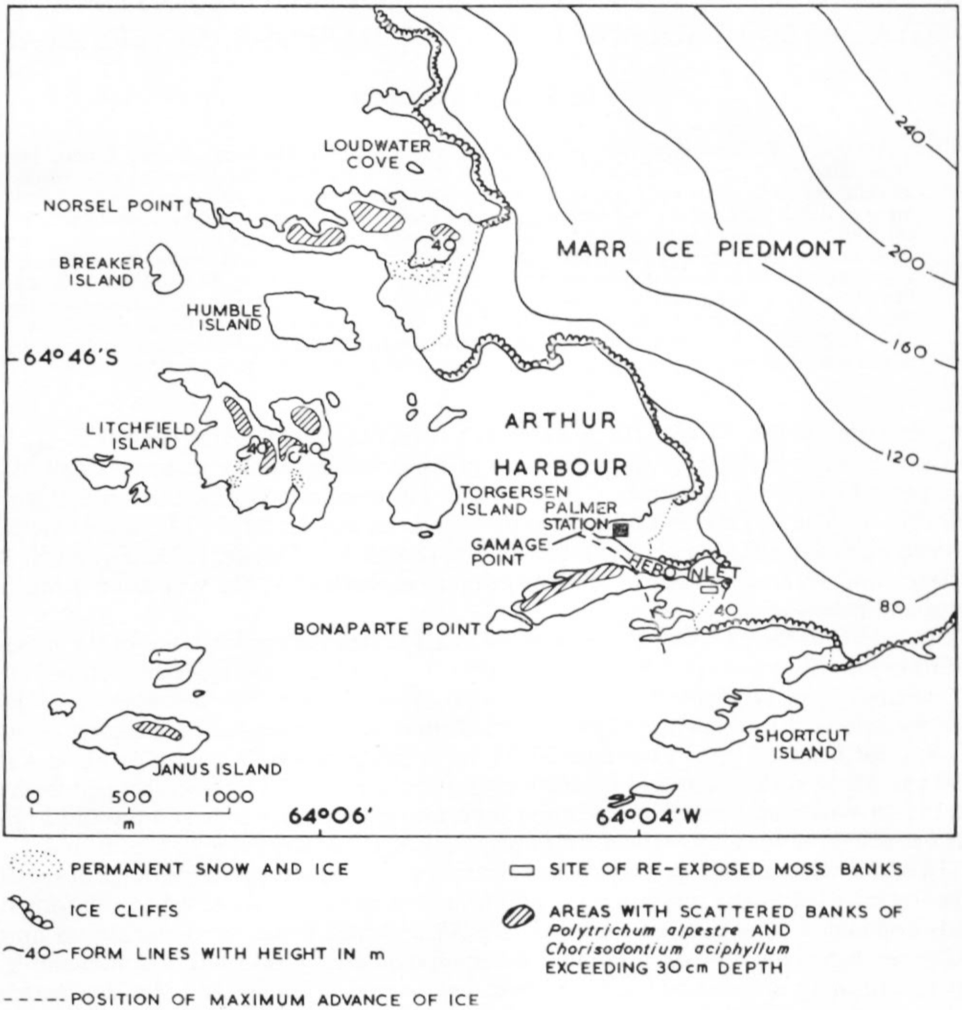

Fig. 1. The Arthur Harbour area of south-western Anvers Island.

large thalli of both fruticose and crustose lichens and the depth of the moss-turf banks (up to 50 cm) suggest that this sector of the headland has been unaffected by glacier ice for at least several hundred years. However, inland from a line trending north-west to south-east and commencing approximately due south of Palmer Station on Gamage Point, the vegetation exhibits a succession of colonizing species which become progressively more sparse towards the ice cliff of the Marr Ice Piedmont at the head of the promontory. Although there is no distinct terminal moraine marking this boundary, the terrain bears many signs of glaciation, e.g. the ground is littered with boulders, gravel, sandy till and glacial flour, outcrops are rounded and their surfaces are covered with parallel striations.

Rundle (1974), as part of his detailed glaciological survey of the Marr Ice Piedmont in 1965–67, studied the gently sloping ice ramps on Norsel and Bonaparte Points. The present author's observations reported here are substantiated by Rundle (1974, p. 33–34), who noted "On the Bonaparte Point promontory, extending outward from the present ice edge for 10–20 m, there is evidence of a very recent glacial recession, but the area is very small. Striated boulders and chatter marks are abundant and fresh rock flour is visible on many of the larger boulders. The localization of this retreat is remarkable and suggests a local meteorological phenomenon as its possible cause. No such evidence exists at the edge of the Norsel Point ramp." The present author noted that the apparently recently deglaciated zone extended about 40 m from the present ice cliff, indicating recession of a further 20 m since Rundle made his observation. He added that "On both promontories, extending outward for 100 to 150 m, is old evidence of glaciation. Most of this is faint and though the degree of erosion has not reached that on Litchfield Island, plant colonization is well advanced. K. R. Everett (personal communication) has suggested that these rock surfaces have been exposed for at least 100 years and possibly for 150 years. There is no evidence of a former ice cover beyond about 150 m from the present ice edge." There is also evidence of recent ice recession on Litchfield Island, where a semi-permanent snow patch had built up over the lower slope of a hill covering the lower part of an extensive *Polytrichum alpestre* bank. The snow must have persisted for several years or even decades and has recently melted back to reveal a zone, up to 5 m wide, of black moribund *Polytrichum* peat.

Plant Succession on the Deglaciated Section of Bonaparte Point

The succession of pioneer plants occurs almost entirely on the north-facing side of the deglaciated area with virtually no re-colonization on the south side which still retains late or semi-persistent snow patches. Within about 40 m of the ice cliff no living plants were noted. At about 40 m and at 50 m there were scattered small cushions and short turves of *Bryum algens*, *Ceratodon* cf. *grossiretis* and *Pohlia nutans*, all typical pioneer species of moraines and soils recently exposed by receding glaciers (Smith, 1972, p. 59). Small (<1 cm diameter) circular thalli of a black crustose lichen, possibly *Lecidea* sp., occurred on some of the boulders and outcrops. There were also a few small non-flowering plants of *Deschampsia antarctica*. At about 60 m the same bryophytes occurred but were more abundant and colonies had frequently coalesced to form small patches of 5–10 cm across; there were also occasional cushions of *Andreaea regularis*. By 75 m these species increased further in abundance and extent of their colonies and there was also a circular stand of *c.* 50 cm diameter formed by *Polytrichum piliferum*. The size and density of ? *Lecidea* sp. thalli also increased and the grass was more frequent. About 100 m from the ice edge *Ceratodon*, *Bryum* and *Pohlia* (the latter two being found with sporophytes) were frequent in pure and mixed open communities covering 1–4 m^2, and *Drepanocladus uncinatus* and *Prasiola crispa* were also occasionally present. A shallow (5–10 cm) turf of *Polytrichum alpinum*, *c.* 1 m^2, had also become established. *Deschampsia* was locally frequent forming scattered aggregations of plants. Several crustose lichens, including occasional thalli of *Acarospora macrocyclos*, *Lecania brialmontii* and *Caloplaca* sp. occurred on rocks used as bird perches. Between here and the boundary of the deglaciated area all the above species increased in frequency and several other unidentified crustose lichens and *Usnea antarctica* made their first appearance. However, this area was not examined in detail.

A similar succession was noted on Gamage Point, a small rocky snow-free promontory separated from Bonaparte Point by the narrow Hero Inlet. This area has also been entirely covered by ice but is now littered with glacial debris. Pockets of sandy and clay soil, especially on the north and west sides of the headland, are colonized by sparse colonies of *Bryum*, *Ceratodon* and *Pohlia*, and occasional crustose lichens and a few small thalli of *Usnea antarctica*. Scattered plants of *Deschampsia* are not infrequent. However, the development of vegetation over much of the promontory has been arrested due to the construction of Palmer Station and the extensive use of tracked vehicles.

Although *Deschampsia antarctica* is a pioneer species on moraines and recently deglaciated soils on South Georgia in the sub-Antarctic, it rarely colonizes such sites in the South Orkney and South Shetland Islands; its success as a pioneer species in the Arthur Harbour area is probably due to its greater fertility and seed viability here than in the latter two maritime Antarctic regions (Greene and Holtom, 1971).

Re-exposed Moss Banks on Bonaparte Point

Evidence that the entire promontory of Bonaparte Point has been vegetated at one time was provided by the discovery of moss peat lying in hollows and against the side of rock outcrops facing away from the ice cliff, indicating that former moss banks had occurred here but had been removed by the advance of the ice piedmont.

The ice cliff of the piedmont snout at the head of the promontory is about 20 m high. Pockets of black moss peat about 10 cm deep comprised compressed intact shoots of *Polytrichum alpestre* with associated *Chorisodontium aciphyllum* and occasional *Pohlia nutans*, each of which was clearly identifiable without the aid of a hand lens, but which were confirmed microscopically. These were recorded in several positions up to 25 m from the ice margin on the gently sloping terrace on the north side of the promontory about 12–15 m above sea-level, and also on the steep rocky north-facing slope, 2–3 m above the shore of Hero Inlet, about 5 m from the ice margin.

Samples of peat from positions on the terrace 0.25, 5–6 and 10–12 m from the glacier snout were radiocarbon dated as 630±50, 425±40 and 501±40 years B.P. (Before Present = before A.D. 1950), respectively. *Polytrichum* banks up to 50 cm deep occur on the north side of the seaward end of the promontory at about 5–15 m above the shore, and also at about 10–20 m altitude on the seaward end of Norsel Point and on a steep north-facing rocky slope at about 35–40 m altitude in the north-east corner of Norsel Point. The latter habitat, which is quite close to the ice cliff, is very similar to that of the re-exposed banks on Bonaparte Point. It is likely that these relict peat deposits represent the base of moss banks which avoided abrasion and removal by the advancing glacier and therefore the radiocarbon dates of 385–680 years B.P. (absolute range) provide an indication of when these banks began development, i.e. between A.D. 1270 and 1565. This compares with 495±85 years B.P. for the base (47.5 cm deep) of the extensive *Polytrichum* bank referred to above, on Litchfield Island, and 721±105 years B.P. for near the base of a small deep (maximum 170 cm on the eroded down-hill face) *Chorisodontium* bank on Galindez Island, Argentine Islands.

The dates give no indication when the ice advanced and destroyed the moss banks and, unfortunately, it is not possible to detect the present rate of recession of the glacier. Comparison between an air photograph of the Arthur Harbour area, taken from 13 000 ft (4 030 m) in December 1956 and the author's observations made in February 1967 (when no re-exposed moss banks were seen) and February 1977 cannot reveal any substantial recession during the past 20 years. However, in 1956 much of the area where the re-exposed moss banks occur was covered by what appeared to be an extensive deep ramp of snow drifted against the ice cliff but this is thought to be a late or semi-persistent snow patch which may exist each season until late summer.

The Bonaparte Point ice ramp is clearly visible in an air photograph (Rundle, 1974, fig. 2) of the Arthur Harbour–Marr Ice Piedmont area taken between 1965 and 1967. In 1977 there was no such ramp, indicating substantial recession to form the present very steep ice cliff, although Rundle reported no change had occurred during the previous 10 years according to inspection of air photographs. It is possible that the ice piedmont advanced during the Little Ice Age which affected Fuegian–Patagonia and South Georgia during the period of A.D. 1750–1800 (Mercer, 1970; Clapperton, 1971) or as late as 1875 at South Georgia according to Smith (1960). However, Lamb (1964) indicated that "latitudes south of about 45°S seem to have largely escaped the 'Little Ice Age' until 1800 to 1830". It therefore seems that the moss banks could have been growing for about 400–500 years before being destroyed.

An investigation of peat accumulation in the Argentine Islands has indicated a growth rate for *Polytrichum alpestre* about 2.5 mm year^{-1} and, taking into account compression before the peat enters the permafrost, the rate of peat accumulation has been calculated to be about 1.3 mm year^{-1} (Fenton, 1980 *a*). From these data it is estimated that the Bonaparte Point banks may have been approximately 50–70 cm deep when they were destroyed. However, the close proximity of the vast ice piedmont and its influence on the local climate near sea-level would probably have reduced the growth rate and therefore bank depth. This is substantiated by the maximum age of around 800 years B.P. so far recorded for moss banks in this area of the Antarctic Peninsula; although most banks are about 50 cm deep, a few exceed 1 m on their down-hill side (Fenton and Smith, 1981) and may give a false impression of their age in the absence of radiocarbon dates.

Recent Climatic Trends and their Possible Influence on Glacier Activity and the Perturbation of Vegetation

Re-exposed moss banks have also been reported from the South Orkney Islands, especially Signy Island (Collins, 1976; Fenton, 1981). Collins (1976) has summarized the recent literature relating to climatic change and glacier fluctuations in the Southern Hemisphere, particularly in the Magellanic–maritime Antarctic region. Evidence from radiocarbon dating of re-exposed peat suggests that, on Signy Island, there were ice advances towards the end of the fifteenth century, between 1750 and 1900, and from 1950 to 1960 (Fenton, 1981).

Limbert (1974) has indicated a strong positive correlation between the temperature regime of the South Orkney Islands and the Argentine Islands (the latter generally being 1–3° C colder), based on climatic data for the period 1947–71, and this has been substantiated by data for shorter periods for other west Antarctic Peninsula stations. He suggested that it should be possible to correlate the long sequence of temperature data from Laurie Island (1904–46) and Signy Island (1947–present), in the South Orkney Islands, with extreme conditions in the Antarctic Peninsula region. The Laurie and Signy Islands mean annual air temperatures indicate periods of cooling between approximately 1909 to 1915, 1918 to 1930 and 1956 to 1959, and periods of warming between 1915 to 1918, 1930 to 1956 (with minor fluctuations) and 1959 to the early 1970's. These minor climatic trends have been fairly consistent throughout the Antarctic Peninsula, South Shetland Islands and South Orkney Islands region (Limbert, 1974; unpublished data). This has been substantiated to some extent by Koerner (1964), who has provided one of the few accounts of recent glacier activity in the Antarctic Peninsula region. He reported that Depot Glacier, Hope Bay, in the extreme north-eastern tip of the peninsula (where the climate is less maritime than on the west coast), receded little between 1903 and 1945, but between 1945 and 1960 the margins of the snout retreated 75–90 m. One of the major outflows of the nearby Arena Glacier retreated about 130 m between 1955 and 1959, one of the coldest periods in recent times; however, this glacier advanced considerably during the winters then calved back very substantially during the summers. Victoria and Russell East Glaciers, farther south on the colder north-east coast, showed very little change during this period. The glaciers of the Patagonian ice cap showed several recessional re-advances following the eighteenth-century maximum. The most recent was in the early 1940's with some glaciers still advancing until 1958–59, although during the following decade all were receding (Mercer, 1970). Glaciers on South Island, New Zealand, reached their maximum advance "before about 1620, 1780, and 1830, and though retreat has prevailed subsequently, it has been interrupted by minor advances between 1890 and 1920, and in the 1930's, early 1950's, and mid 1960's" (Wardle, 1973).

Assuming that air temperatures in the Arthur Harbour area are similar to those recorded at the Argentine Islands (Fig. 2) about 75 km farther south, there was a substantial increase in mean annual temperature from −7.5° C in 1953 to −1.9° C in 1956, falling sharply to

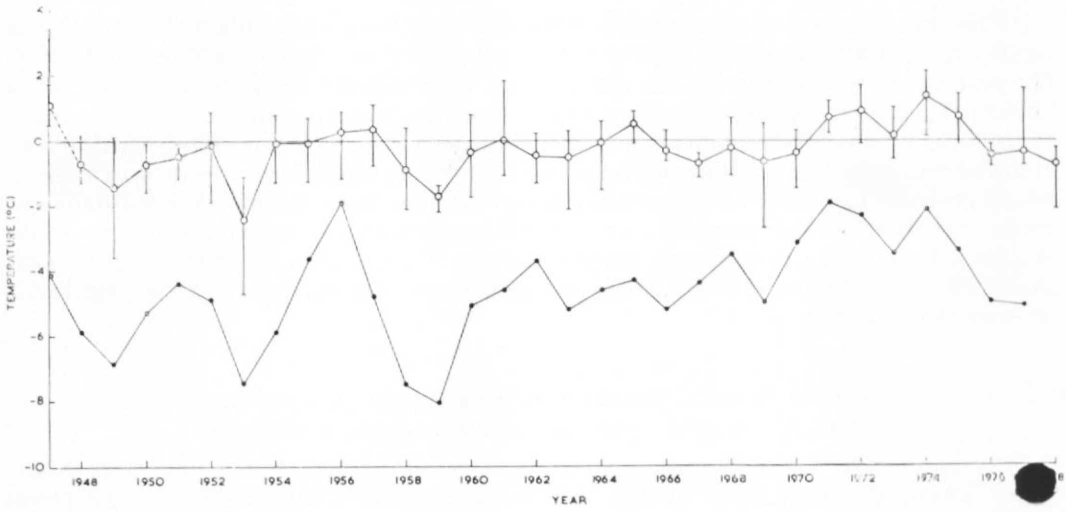

Fig. 2. Mean annual and summer (December–March) air temperatures for the Argentine Islands, 1947–78.

−8.1° C by 1959. From 1959 there has been a fairly steady increase until 1974 (−2.1° C), followed by a decline in the past few years. However, the period of critical temperatures, which will determine whether a glacier makes a net advance or retreat during a year, will be the summer (December–March) when temperatures are frequently above 0° C and föhn winds and low relative humidity are quite frequent. During the past 30 years mean summer air temperatures at the Argentine Islands have been close to or above 0° C for more than two consecutive years on only two occasions, i.e. 1954–57 and 1971–75 (Fig. 2). It was during this latter period that mean annual temperatures recorded at the Argentine Islands were higher than those at Signy Island, South Orkney Islands, due mainly to higher winter temperatures resulting from a change in the atmospheric circulation pattern over the south-eastern Pacific Ocean (Schwerdtfeger, 1976). It seems probable that glacier and ice-cap retreat will have been enhanced during these two warm periods, the latter possibly accounting for the recent re-exposure of moss banks at Bonaparte Point, Anvers Island, which would suggest a retreat of perhaps 10–15 m or more.

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