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An extraordinary peat-forming community on the Falkland Islands

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Most of Beauchêne Island in the South Atlantic is covered by tussac, the tussock-forming grass *Poa flabellata* (Lam.) Rasp., which has produced a deep accumulation of exceptionally dense peat during ~12,500 yr. The basal peat is lignitic, yet it is several hundred times too young to be a true lignite. During an ecological survey of the island in December 1980[1], one of us (R.I.L.S.) sampled an 11-m high peat face. The age against depth profile in the peat is consistent with a constant proportional rate of decay of $1.1–2.2\times10^{-4}$ yr^{-1} and a constant rate of addition of dry matter to the peat of 430–720 g m^{-2} yr^{-1}. This rate of decay is within the range recorded for peats in corresponding latitudes in the Northern Hemisphere, but the rate of addition of dry matter is about 10 times as great. This is not easy to accommodate within current hypotheses about peat formation. An unusual combination of biological, physical and chemical circumstances may be the cause. As the island is difficult to visit and no more information can be obtained in the near future, we now report these results, incomplete though they are.

Beauchêne Island[1,2] (lat. 52°54′ S, long. 59°04′ W) is the most southerly and isolated of the Falkland Islands in the South Atlantic Ocean. It is ~187 hectares in area, rises to 82 m altitude and is 60% covered by continuous closed tussac grassland. Individual plants, at a density of 600–700 per hectare, reach 3.5 m in height, including a peaty pedestal 1.0–1.5 m tall, and 2 m in diameter, and have a canopy up to 4.5 m across; a skirt of dead foliage extends from the side of the pedestal and interlaces with the skirts of adjacent plants. This is an almost truly monospecific plant community with almost no ground flora.

A further 35 hectares are occupied by dense mixed colonies of about 300,000 pairs of rockhopper penguins (*Eudyptes chrysocome*) and 160,000 pairs of black-browed albatrosses (*Diomedea melanophrys*).

The grassland grows on a deep mantle of peat composed of *Poa flabellata* litter. Along about one-third of the main bird colony the western edge of the tussac grassland is eroded into a steep and often near-vertical peat cliff (Fig. 1) along which the maximum recorded depth was 13.3 m.

Beauchêne Island has a cool temperate oceanic climate similar to, but probably cooler, drier and windier than, that of Port Stanley (Fig. 2) on the east side of East Falkland Island. It is similar to that of Tierra del Fuego. Compared with Moor House in the North Pennines of England, which has extensive blanket bog, the temperature regime is more equable with little frost, and the precipitation is much lower. Other regions of the Northern Hemisphere, such as Ireland, have extensive peat bogs with as equable a temperature regime as Beauchêne Island but even larger precipitation than Moor House. Yet others, such as continental Europe, North America and north Eurasia, have peat bogs with a much less equable temperature regime and similar precipitation.

The concentrations of inorganic species in leaves of one *Poa flabellata* plant and in three samples of surface peat from Beauchêne Island were determined[2]. These values are compared with some for North German surface peats (Table 1). The influence of sea spray is clear in the values for Na, but not in Mg. The cation exchange and chelating capacities of the Beauchêne Island peat are smaller than those of the North German peats, and this may reduce selectivity for higher valence ions. The absence of soil dust may partly account for the lower values of Ca, Fe and Al: the island rock is quartzite. Inorganic and total N are high in the Beauchêne Island peat, probably a consequence of the close proximity of so many nesting birds, but PO_4 concentrations are not very high. In the live plant there are higher concentrations (than in the peat) of NH_4 and especially of K. In general there seem to be no obvious deficiencies in the live plants, but the concentration of K in the peat may perhaps limit the activities of microorganisms, particularly at pH 3.7 which now prevails near the surface (Fig. 3).

The physical properties of the peat are unusual. The water content was measured on samples of peat stored for about 2 weeks in sealed polythene bags. The dry bulk density of air-dried peat was measured much later, but the results showed that during air-drying the peat had shrunk considerably. The dry bulk density of fresh peat was therefore measured indirectly by two methods. A sample was heated in water at 98 °C for 24 h. The peat was strongly coherent. Its volume was determined by displacement. The surface was blotted and the rehydrated fresh mass measured. Then the sample was put into a 'specific gravity' bottle whose mass was measured. Finally the sample was dried

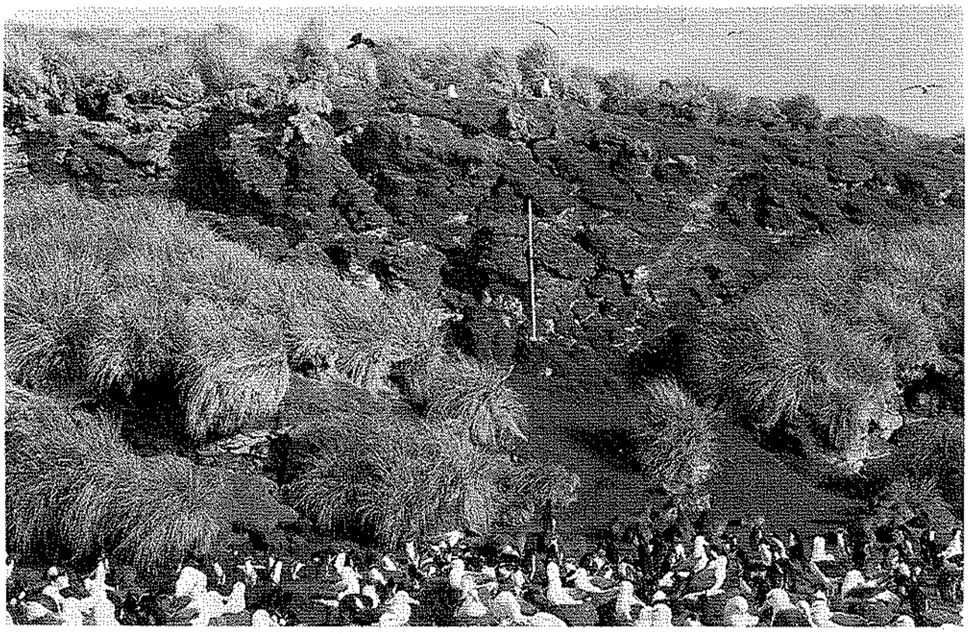


Fig. 1 An eroded cliff in the western edge of peat formed by tussac (*Poa flabellata*) grassland on Beauchêne Island in the South Atlantic. The birds in the foreground are part of a breeding colony of rockhopper penguins and black browed albatrosses. This is the site where our samples were taken. The white stake is 2.80 m long and the depth of peat from the base of the grass tussocks to the bedrock is 11.3 m. At the north-east edge of the island is a similar cliff in 5 m of peat.

Table 1 Concentration of some inorganic species (μmol g^{-1}) and loss on ignition (%) on a dry mass basis

	Beauchêne Island		North Germany[9]
	Poa flabellata green leaf mid-lamina	Surface tussac peat: range of three values	Surface peat inter-quartile range
Na	160	120–150	2–10
K	490	2–10	10–60
$\frac{1}{2}$Ca	60	110–490	200–500
$\frac{1}{2}$Mg	70	83–130	160–800
$\frac{1}{3}$Fe	10	80–90	100–300
$\frac{1}{3}$Al	10	80–90	170–1,100
PO_4-P	180	6–120	30–650
NO_2+NO_3-N	0.5	0.8–5.4	<0.01–0.01
NH_4-N	240	9–27	1–15
Total – N	1,700	2,500–4,900	700–1,800
Loss on ignition	95	78–85	50–95

at 105 °C for 24 h and its mass measured. From the 'specific gravity' measurement the dry matter density, and then the volume of dry matter, were calculated. This, together with the fresh and dry mass, gave the wet volume of the rehydrated peat. The results agreed to within 5% with the direct measurements of volume. Next it was assumed that the difference in water content of the rehydrated sample and of the original wet peat gave a direct measure of the loss of volume from the peat in the fresh state and so, finally, the dry bulk density. The second method used the fact that the density of the dry matter (not the dry bulk density) changed approximately exponentially from 1.44 g cm^{-3} at 75 cm depth to 1.62 at 1,100 cm depth. With this information and the water content of the original wet peat, assumed water saturated, the minimum value of the dry bulk density was calculated. For nine samples below 125 cm deep, this calculation gave results within 3% of those obtained by the first method. This close agreement probably indicates that the dry bulk density values are sufficiently accurate and that the peat below 125 cm depth is water-saturated and hence probably anaerobic. The first method gave higher values than the second for the two topmost samples: 0.29 compared with 0.25 g cm^{-3} at 75 cm; 0.34 compared with 0.30 at 125 cm. This is consistent with some gas in the fresh peat at these depths, or with bias in the first method applied to these markedly less-coherent peats. Whatever the explanation it does not seriously affect the use of the dry bulk density values for the assessment of the peat accumulation process (Fig. 3). In the absence of measurements of redox potential, however, we do not know the extent to which the surface layers are aerobic, and this is crucial in any attempt to understand the decay processes[3].

The bulk density of dry matter is unusually high for bog peat and the loss in mass on ignition was high (89–95%) so the high bulk density cannot be attributed to the presence of large amounts of inorganic matter. The bottom 150 cm of the peat are lignitic. Where this peat is exposed to the air it becomes black, rock-like, and breaks with a conchoidal fracture[2]. The

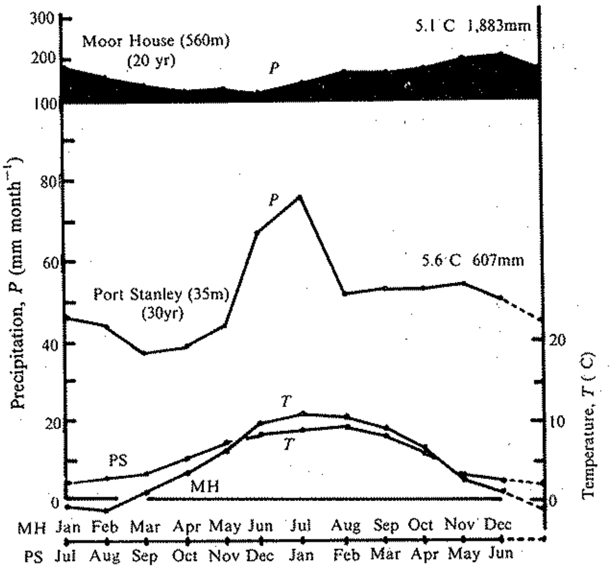
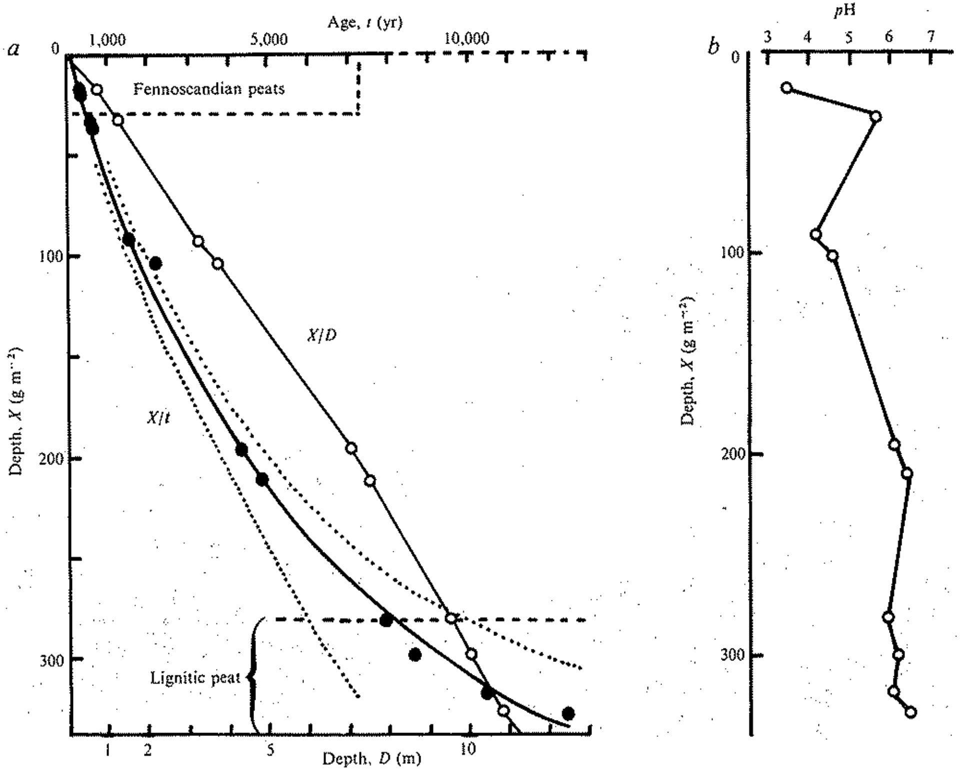


Fig. 2 Klimadiagramms (superimposed) for Port Stanley (PS), East Falkland Island and Moor House (MH), North Pennines, England.

Fig. 3 *a*, Age, *t*, against depth as cumulative mass, *X*, and depth as distance, *D*, against depth as cumulative mass for a *Poa flabellata* peat profile on Beauchêne Island, South Atlantic. The 'true' age, *t*, of samples with ^{14}C age up to 6,500 yr was calculated using a dendrochronological calibration[10]. For the oldest thousand years of this calibration the deviation between ^{14}C and dendrochronological age is approximately constant and this deviation has been assumed to hold for older samples also. On this plot a constant rate, *p*, of addition of plant mass to the peat would give a straight line, and if there is decay in the peat a hollow curve results[3,4]. If the proportional rate of decay, α, is constant, and the peat is formed of a single component, then $X=(p/\alpha)(1-e^{-\alpha t})$. The fitted curve[4] is for $p=620$ g m^{-2} yr^{-1} and $\alpha=0.00017$ yr^{-1}. The estimated value of *p* is largely determined by the general slope of the line, and of α by the concavity. Dotted lines show 95% confidence limits. The box at the top left shows the approximate region occupied by peats in Fennoscandia[4]. *b*, *p*H against depth.



field water content of this material is ~30% (of the dry mass) but about 1 m in from the peat face the water content is ~200% and the peat has a very hard cheesy texture. True lignite is chemically altered by geothermal heat and is $> 10^6$ yr old, yet ^{14}C dating shows that the lignitic peat is younger by several hundred-fold. The compressive stress at the base of a water-saturated peat may be quite small, because the effective weight is produced only by that part of the dry matter with density greater than that of water. Thus for a 10-m depth of water-saturated peat of dry bulk density 0.3 g cm^{-3} and with dry matter density 1.5 g cm^{-3}, the pressure will be $(1.5–1.0) \times 0.3 \times 1{,}000 = 150$ g cm^{-2}.

The ^{14}C-age of 10 samples spaced down the peat profile was measured (Fig. 3) and is consistent with a rate of addition of dry matter of $p = 520–720$ (95% confidence limits) g m^{-2} yr^{-1} and of proportional rate of decay of $\alpha = 1.2 \times 10^{-4} - 2.2 \times 10^{-4}$ yr^{-1}. The asymptotic limiting depth, p/α, is 360 g cm^{-2} (there is ~330 g cm^{-2} at present). If the dry bulk density of this matter were ~0.35 g cm^{-3} then the limiting depth would be ~14 m. The position of the lowest two points may be seriously inaccurate because of the ^{14}C calibration extrapolation, and because they are in the lignitic peat which may affect the assumption of no more than two constant processes. So the topmost eight points alone were fitted too. They gave $p = 430–630$ g m^{-2} yr^{-1}, $\alpha = 1.1 \times 10^{-4} - 1.7 \times 10^{-4}$ yr^{-1}, and an asymptotic depth of 15 m.

These results are similar to those found for Fennoscandian peats[4] in that (1) depth, as cumulative mass, versus age curves appear to fit the single component, constant rate of addition, constant proportional rate of decay hypothesis surprisingly well; (2) independent of assumptions about the rate of decay, the rate of addition of dry matter has been nearly constant over thousands of years in spite of probable climatic changes; (3) the rate of decay of Beauchêne Island peat is within the range $(0.7–5) \times 10^{-4}$ yr^{-1} for Fennoscandian peats; (4) the rate of addition, p, of dry matter to Beauchêne Island peat is about 10 times as great as the rate (35–78 g m^{-1} yr^{-1}) for Fennoscandian peats[4] (Fig. 3). The quoted Fennoscandian values of p are the rate of addition to the anaerobic peat and are ~10% of the net productivity of the vegation there. If the same were true on Beauchêne Island then net productivity would be about 5,500 g m^{-2} yr^{-1} which is an implausibly (but not impossibly) large value: the relative growth rate of *Poa flabellata* tillers in experiments[5,6] over the 24-week austral summer was 0.13 g g^{-1}, and a capital of 240 g m^{-2} invested with this growth rate would be sufficient to produce 5,500 g m^{-2} in 24 weeks. The dry green biomass in a site close to a seal wallow on South Georgia was 16,000 g m^{-2}.

It is difficult to account for the Beauchêne Island peat. The concentration of inorganic elements in the plants reveals little about what limits the productivity of *Poa flabellata*. The species favours organic soils and is highly tolerant of sea-spray and biotic disturbance. Its luxuriance and productivity are enhanced wherever there are breeding populations of seals and seabirds. It is not known why the plant matter does not decay as rapidly as it forms. Populations of bacteria, yeasts and other fungi in the peat are high[2]. The temperature is not so low as to restrict decay in general. At the much colder sub-Antarctic South Georgia tussac peat accumulates to several metres in depth[7] yet decomposition of other organic matter proceeds quite rapidly[8]. Why then does peat accumulate on Beauchêne Island at all? And why is the rate of input to it so high at the same time as the decay rate is low? Part of the reason must be that the large input of volatilized nitrogenous compounds from the adjacent massive seabird colonies promotes rapid growth of the grass. In contrast, decomposition may be slow because of the low rainfall and high evaporation rates, caused by the almost perpetual strong winds, which together maintain a fairly dry substrate moisture regime in the surface layer of peat. In Arctic tundra peats a moisture content <300% inhibits microbial activity and decomposition rates. The water content of surface peat on Beauchêne Island is 250–350%. Potassium may also be deficient. The Beauchêne Island *Poa flabellata* peat raises fundamental issues about how peat forms, and would repay detailed study.

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