# Analysis of timber weathering and wind velocity at Cape Adare, with comments on other historic sites in Antarctica

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ABSTRACT. At Cape Adare, there are three wooden historic huts in varying condition. Two are the first permanent structures erected in Antarctica for human habitation and were occupied in 1899 by the British Antarctic Expedition (1898–1900) led by C.E. Borchgrevink. The third hut was built in 1911 by the northern party of R.F. Scott's British Antarctic Expedition (1910–13) led by V.L.A. Campbell. Previous research has focused on the unusual wind regime at Ridley Beach, Cape Adare, with the use of an environmental wind tunnel to support field observations, and on the sequence of destruction by wind of the 1911 hut. The present paper focuses on the weathering of timber at some historic huts in Antarctica and presents observations and data collected on three visits to Cape Adare spanning 21 years. The results indicate that over 23% of the timber has been eroded from exposed board ends on one corner of Borchgrevink's 'stores hut' and further damage to the huts is being caused by wind blown sand and pebbles which, at two meters above the ground surface, can attain a velocity of 29–203 km/hr$^{-1}$. This has in places, resulted in severe degradation of the timber.

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## A conservation problem

The effects of wind on wooden huts, buildings and other structures, has an extensive literature. However, while this is a major conservation problem for historic huts in polar environments, the matter of timber degradation has received little attention.

In the Arctic, sharp wind-blown particles of volcanic sand has abraded wooden huts on Jan Mayen, 70° 59′N. and abrasion by wind-blown sand and ice particles is currently damaging huts in the Svalbard archipelago, 77°–80°N. (S. Barr, personal communication, 2004). Marslander regards wind as being the main threat of damage to Arctic sites (Marslander 2000).

In Antarctica, one site which has received considerable mention is that of Mawson's huts from the Australasian Antarctic Expedition (AAE) 1911–14, located at Cape Denison, 67°S., in Commonwealth Bay, East Antarctica. Here ice particles conveyed by katabatic winds off the polar plateau, with an average daily wind speed over the year of 71 km/hr (31.7 m/sec) (Godden Mackay Logan 2001), and a wind speed recorded during the AAE of some 250 km/hr (Mawson 1915, Maddigan 1929), have had a detrimental effect on the cladding of the huts.

Constructed from Baltic pine (*Pinus sylvestris*) with a density of 0.550 kg/m$^3$, south wall boards once 25 mm thick have been eroded by 5 mm and boards once 16 mm thick have been eroded by 4–5 mm, although Blunt has acknowledged that exact measurements are difficult to obtain (Blunt 1991). Hughes, however, maintains that for all the cladding, the total erosion had been about 2 mm in 75 years, that it was greater at ridges and corners (Hughes 2004), and that the rate of erosion for exterior wood was shown to be not constant (Hughes 1992, Farrell and others 2004).

Prior to restoration by the Australian Antarctic Programme (AAP) Mawson's Huts Foundation, the roof cladding constructed with boards 16 mm thick, had nails protruding up to 20 mm above the surface, although it was not established if this was due to movement of the roof, expansion, construction of the nails, or due to abrasion. In 1997 some boards were only 8 mm thick (Godden Mackay Logan 2001).

Hughes stated that the extent of erosion was grossly overestimated (Hughes 1986, 2004) and recent data indicates that the two main sections of the huts have weathered at a rate of approximately 1 mm every 10 years, while protected areas of the living section, have weathered more slowly, with a rate of 1 mm every 26–46 years (Godden Mackay Logan 2001; AAP 2000–2001). As Godden Mackay Logan (2001) note, abrasion resistance in timber is generally a function of timber density and timbers with a density greater than 800 kg m$^3$, have good abrasion resistance characteristics.

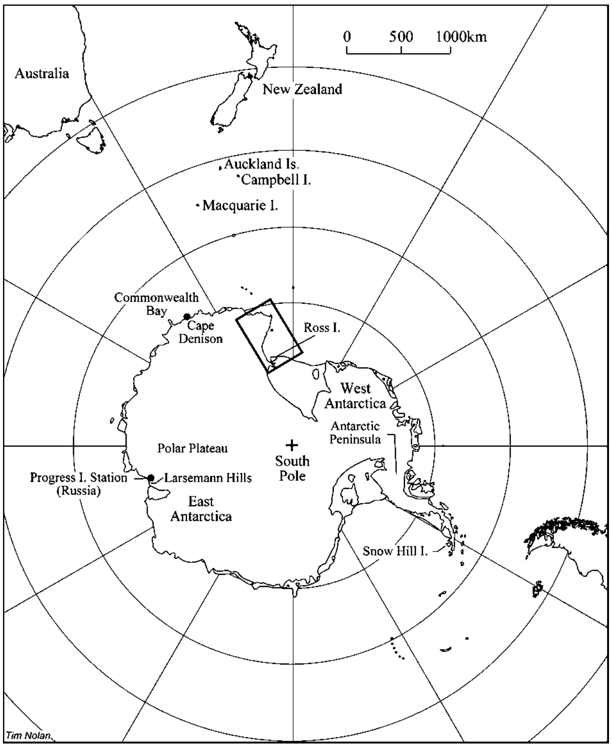


Fig. 1. Antarctica with localities referred to in text.

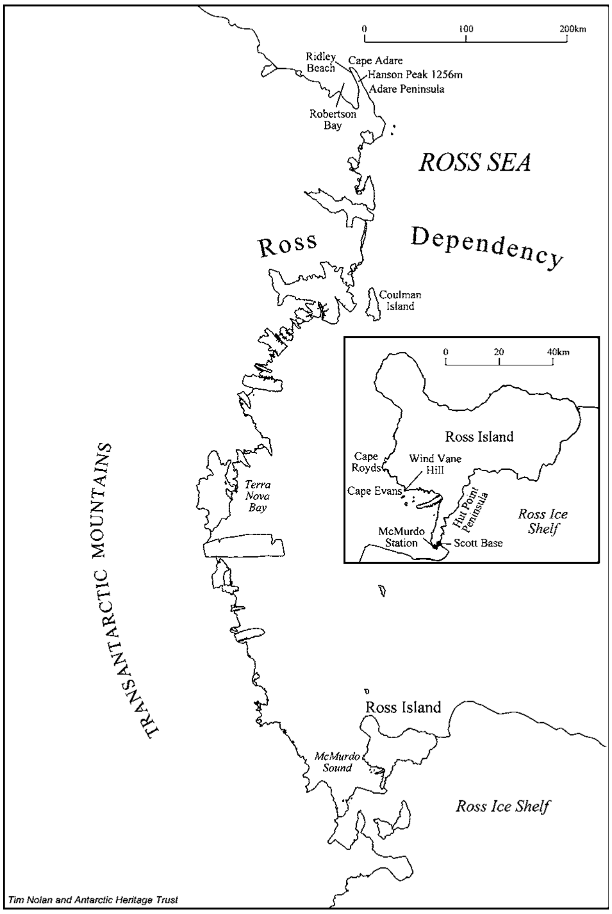


Fig. 2. Victoria Land coast and Ross Island, with localities referred to in text.

Nordenskjöld's hut from the Swedish South Polar Expedition 1901–04, at Snow Hill Island on the Antarctic Peninsula (Fig. 1) 64° 28′S., was erected in February 1902 on a level surface of unsorted glacial moraine exposed to very high winds. By late 1902, after the erection of their hut, a storm was experienced during which 'the velocity of the wind was about 20 metres per second . . . one could stand erect, but with difficulty, and the air was a thick whirling mass of fine snow-dust . . .' (Nordenskjöld 1905). The outside walls of the hut (probably of *Picea* sp.), were covered with tarred felt which in severe storms was perforated by flying stones and has been replaced and repainted on several occasions (Goldberg and others 2001) although according to Goldberg, no abrasion of timber has been observed (Goldberg, personal communication, 2004).

Regardless of their age, the huts erected in 1899 on Ridley Beach at Cape Adare, 71° 18′S. (Fig. 2), are not unusual in terms of damage by wind, although when compared to Mawson's huts, the weathering process primarily involves particles of rock.

## Physical Geography of Ridley Beach, Cape Adare

### Geomorphology

Ridley Beach is a cuspate foreland consisting of two suites of gravel ridges. A series of swales with stagnant meltwater ponds is orientated sub-parallel to South Beach while a recent series of ridges influenced by wave action and winter sea ice push, is oriented at right angles to the first and is sub-parallel with North Beach (Mabin 1982). Mabin suggests that the sets of beach ridges appear to be related to a complex interplay between sediment supply, wave climate, beach freeze-up processes, tectonic uplift and sea level fluctuations (Mabin 1982). Surveys by Cairns 1973, Mabin 1982 and Turner 1990, show that the elevation of the beach ridges varies from 4 to 6 m above sea level at the northern end and the swales from 2 to 4 m and that the dominant sediment supplies are to the south and south-east of the huts (Turner 1990). Much of the area is occupied by nesting Adélie penguins and guano binds any surface and underlying gravel. At the back of the foreland is a protalus rampart and behind this, are the steep cliffs of volcanic rock forming Cape Adare, rising to over 300 m.

### Climate

Ridley Beach is well known for its unusual wind regime. Depending on cyclonic development over the outer Ross Sea, a rapid fall in barometric pressure can be accompanied by a violent katabatic-type airflow off Cape Adare from the southeast or east-southeast. This strong gusting wind that can rapidly attain hurricane force often dissipates as quickly as it arrives (Harrowfield 1996). A possible explanation may relate to the flow of air along the east side of the Adare Peninsula including Hanson Peak, 1256 m, then with the west-sloping topography and the steady decrease in elevation from the peak to the north, the wind veers in a north westerly direction, until it reaches the cliff of the peninsula. The changed direction of patterns observed in 1982 on the snow surface on top of the peninsula, would tend to support this idea. The wind steadily increases in velocity until with the sudden decrease in height, the speed further increases and the wind is partially funnelled through low-lying swales and over the lagoons, until it attains the velocities recorded on Ridley Beach.

Historic accounts of such conditions describe how the huts were either showered with stones and/or suffered damage (Harrowfield 1996; King 1988) and in one instance, on 23 February 1899, Borchgrevink's ship *Southern Cross* while moored in Robertson Bay, received a shower of pebbles thought to be off the peninsula (Bernacchi 1899, Crawford 1998).

Similar winds have been observed at Cape Malea in southern Greece, and in southeast Alaska, the northeast 'Taku Wind' can exceed 50 m/sec with wind speeds of 40 m/sec not uncommon. This 'mountain induced wind storm' that arises from very cold air over an ice field, is highly dependent on terrain shape and the vertical structure of the atmosphere and can occur during cyclonic or anti-cyclonic events (Ecolman and Dierking 1992).

The violent nature of the gusts was experienced in January 1982 when basalt particles damaged a polar tent 12 m in the lee of Borchgrevink's 'stores hut' (Harrowfield 1984) and removed paint from a Munro totalising anemometer. In late December 2000, similar conditions to those experienced in 1982 destroyed an alpine tent erected in the lee of a polar tent 100 m southwest of the huts (Lambert and others 2001), with individual particles of beach sediment exceeding two grams, caught in the fabric.

In 1990 a new synthetic rubber cladding was attached to the roof of the 'living hut' at Cape Adare, and this was observed by Chaplin, in 1999, to be punctured by wind-blown stones and areas of the thin overlapping roof edge along the windward side were seen to be abraded away. Sediment had also accumulated along the 5.79 m high ridgeline. Along the east wall of the 'living hut' the ground surface is much higher than that beside the 'stores hut' and rises toward the northeast corner where guano covers jute bags of coal, blocks of coal and other items. A depression has partially formed along the base of the wall from the alleyway between the 'stores hut' and the 'living hut'. This rising surface that gently slopes in an eastward direction towards a swale probably facilitates airflow and can explain the eroded edge along the hut roof and deposition of sediment along the ridge line.

Ridley Beach is exposed to the south and can also be subjected to strong southerly airflow which passes over the 36 km (20 nm) fetch of Robertson Bay. This can deluge the huts with salt spray and ice. Such storms can be expected to occur perhaps two or three times during the summer months of December-January and become more frequent in autumn and winter. The huts are located on one of the innermost recent beach ridges and a shallow swale on each side is occasionally flooded from snow melt and possibly wave action during storms (Turner 1990).

### The historic huts

Borchgrevink's equipment included two prefabricated huts of Norwegian design, made by Strømmen Trevare-fabrikk near Christiania (Oslo) (Fig. 3). One was for stores and measured 5.2 $m^2$ and one was for accommodation and measured 6.4 $m^2$. Both were made from clean, mostly knot-free, tongue and grooved boards, 60–70 mm thick and 145 mm high and of 40–70 year Norwegian spruce (*Picea abies*) with a density of 368 $kg/m^3$ for a dried sample from Cape Adare (P. Fuller, personal communication, 2005). According to M. Morrison, conservation architect, the wood used was of 'extremely good quality'.

Fig. 3. Borchgrevink's huts, Cape Adare, viewed from the south east. January 1982.

The wall boards interlocking at the corners are tightened together by vertical steel hold-down bolts, inserted down pre-drilled holes and tightened from the bottom to provide good rigidity. The foundation beams were placed on the ground surface (Morrison 2004).

The two huts were aligned north-south and separated by an alleyway about three meters wide, which at the time of the expedition, was enclosed. On each hut the east-facing roof line was extended to ground level which over the past 106 years, has gradually built up with wind-blown pebbles and guano from nesting penguins. Today Borchgrevink's 'living hut' is in good condition although his 'stores hut', which had the roof removed in 1900, is in only fair condition.

Campbell's hut, 20 m north of Borchgrevink's huts, was British made and constructed of *Picea* sp. (Held and others 2003). It measured 6.09 m × 5.69 m and was orientated west-east. It was constructed using a conventional framework with A-frame trusses and with the wall framing attached to bearers laid on the ground surface (Morrison 2004). During the winter of 1911, the building began to disintegrate and today, with exception of the collapsed west and east walls and the floor, all are now largely covered with guano and only the cold porch remains. From this, the external weather boards are being steadily removed by wind (Harrowfield 1996).

## Observations on timber weathering

On Borchgrevink's and Campbell's huts, timber weathering over 105 and 93 years respectively includes the following

1. Abrasion of the soft (spring) wood in wall boards by wind-blown sand and granular particles. This is particularly evident in the protruding east-facing boards of the north wall of Borchgrevink's 'stores hut' and along the north wall in the alleyway, where abrasion of early wood is particularly noticeable at the east end (Harrowfield 1984).
2. Indentations caused by particles of granule to pebble size. Although bruising from impact of pebbles is noticeable on the east wall of both Borchgrevink huts, this is more evident on the 'stores hut' and may reflect closer proximity of particle sources or relate to ground terrain.
3. Embedding of coarse sand/small pebbles and larger angular sized particles and in some instances splitting.

Ice particles which at −30°C can assume the hardness of orthoclase feldspar (W.C. Le Masurier, personal communication, 1982), may have a significant effect during winter months (May–July).

Because wind gusting is not sustained, wind pressure is expected to have a lesser impact, although exposed end boards do show polishing of hard (autumn) wood. Wind pressure may have contributed to this but the impact of sand-sized particles is more likely.

## Sources of wind blown particles

There are two main sources of the wind blown particles that are having a direct effect on the huts. These are unconsolidated coarse basalt sand and gravel on South Beach, containing well rounded to sub-angular and fractured pebbles (a random sample had B-axes of 12–44 mm) and dried areas of guano with patches of large pebbles and nest sites of pebbles on ridge slopes and crests used by Adélie penguins.

In this context it should be noted that the B or intermediate axis of a particle greater than sand size (Folk 1965) is so stated, as this is the dimension at which the particle will pass through the mesh of a sieve; the movement a particle takes is around the B axis and this is the most stable position with minimal area presented to flow (Wentworth 1922).

The nearest deposit of loose particles is located 7 m beyond the southeast corner of Borchgrevink's 'stores hut' and covers an area of approximately 8 $m^2$. A further deposit is 70 m beyond this and the innermost beach margin of unconsolidated material is 80 m southeast of the hut. A deposit of medium-coarse sand is located on South Beach about 1km southeast of the huts. The pebbles cemented in guano, are in a swale about 10 m east of the 1911 hut porch.

In 1990, an examination of deposits on the top of the peninsula showed the material (large granules/small pebbles) to be poorly sorted angular products of freeze-thaw with some rounding of edges, perhaps due to distribution by wind or previous glacial meltwater.

## Field work

### 1899 'stores hut'

In 1982, measurements of the severely abraded northeast corner of the 'stores hut' were taken (Harrowfield 1984) and these observations were repeated in 1990 and 2003 to provide a weathering record over 21 years (Table 1; Fig. 4). The most severe weathering at the base of the wall corresponded to the rising surface of the beach ridge on which the huts were built. This was measured as 10° with two short, steep faces, of 45° at 52 cms from the base of the wall, and 65° at 3.3 m. Since 1982, there has been little change in the surface below the wall that is partly protected by an embedded row of four supply boxes, and this area receives only limited attention from nesting penguins.

On each occasion widths taken at 20 mm intervals up exposed ends of the north wall boards, were recorded using a vernier calliper and the extent of timber lost at each point was calculated. In one instance over 27% of the wood has been removed. In 1990, in order that wind transported particles could be related to the pattern of weathering, traps consisting of pvc pipe fittings with linen bags and logarithmically spaced, were mounted on an aluminium mast at ground level, 56, 72, 116, 156 cms and at 200 cms. Only one storm with wind of any consequence occurred from the east-southeast and the small quantity of

Table 1. Measurements for weathering of board ends from the northeast corner of the 'stores hut'. Beginning at lower part of board, readings were taken at 2 cm intervals up the board.

| Board No. Top of wall | Jan. **1982** Ave.loss cms | Jan. **1990** Ave.loss cms | Jan. **2003** Ave.loss cms | Ave.loss since 1982 cms | Total loss since hut built cms | Total thickness lost over points measured cms | % wood lost on board ends over 105 years. |
|---|---|---|---|---|---|---|---|
| 15 | 2.48 | 0.08 | 0.08 | 0.12 | 13.4 | 13.4 | 13.30 |
| 14 | 2.22 | 0.2 | 0.22 | 0.22 | 12.4 | 12.4 | 12.21 |
| 13 | 1.6 | 0.16 | 0.3 | 0.46 | 10.3 | 10.3 | 10.14 |
| 12 | 1.36 | 0.1 | 0.4 | 0.42 | 8.9 | 8.9 | 8.76 |
| 11 | 1.54 | 0 | 0.06 | 0.04 | 7.9 | 7.9 | 7.78 |
| 10 | 1.68 | 0.3 | 1.3 | 0.56 | 11.2 | 11.2 | 11.03 |
| 9 | 1.84 | 0 | 0.46 | 0.46 | 11.5 | 11.5 | 11.33 |
| 8 | 2.54 | 0.2 | 0.58 | 0.62 | 15.6 | 15.6 | 15.36 |
| 7 | 2.56 | 1.6 | 0.46 | 0.46 | 16.8 | 16.8 | 16.55 |
| 6 | 2.5 | 0.14 | 0.6 | 0.74 | 16.2 | 16.2 | 15.96 |
| 5 | 3.06 | 0.42 | 0.28 | 0.7 | 18.8 | 18.8 | 17.14 |
| 4 | 3.02 | 0.3 | 0.16 | 0.46 | 17.4 | 17.4 | 17.14 |
| 3 | 4.28 | 0.24 | 0.18 | 0.42 | 23.5 | 23.5 | 23.15 |
| 2 | 4.28 | 0.2 | 1.2 | 0.4 | 23.4 | 23.4 | 23.05 |
| 1 | 2.5 | 0.28 | 0.20 | 0.48 | 14.9 | 14.9 | 14.67 |

Fig. 4. Weathered northeast corner, Borchgrevink's 'stores hut' with coating of salt and sand particles. January 2003.

Fig. 5a. Weathered north wall boards, Borchgrevink's 'stores hut'. January 1982.

sediment collected was mostly organic material and with a tendency to show a decrease in overall particle weight up the wall.

On the north wall of the stores hut, a vertical profile of weathering was also obtained using sheet dental wax softened in boiling water on a Primus stove and applied with a 'release agent' of plastic film, to prevent the wax adhering to the wood while at the same time retaining the cast and the heights at which the most severe weathering occurred, were similar to the north-east corner (Figs. 5a, 5b).

In the alleyway, there is severe weathering to the east end of the 1899 carpenter's work bench positioned against the south wall of the 'living hut'. The maximum weathering of the most exposed bench support originally

Fig. 5b. Obtaining dental wax cast from north wall boards 'stores hut'. January 1990.

Fig. 6. Severely weathered end carpenter's work bench. January 1990.

55 × 67 mm has the 55 mm dimension now reduced at 54 cms above ground level to 19 mm. The bench top 73 cm above ground level is badly abraded at the east end (Fig. 6). This damage is probably associated with

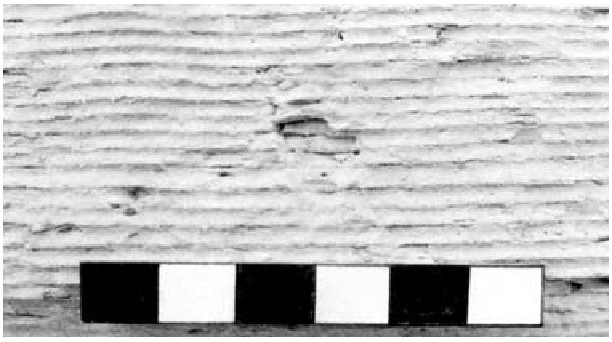

Fig. 7a. Bruising from beach pebble, east wall 'stores hut'. Each scale division 1 cm. January 1982.

Fig. 7b. Embedded part of basalt pebble, east wall 'stores hut'. January 1982.

higher wind speed at the base of a standing vortex system, identified by wind tunnel tests, field measurements and other observations (Harrowfield 1982, 1984).

Bruising by pebbles and embedded particles (Figs. 7a; 7b) along the east side of the 'stores hut' was measured using a vernier calliper and profile gauge, 33 cm from the southeast corner (Table 2). Parameters recorded for 38 indentations included; height above ground level (cms), maximum height (smallest diameter), width (largest diameter) and depth (mm) of each indentation and, by laying a sheet of acetate with a printed grid, the surface area ($mm^2$). The volume is calculated as,

$$V = k.a.b.d$$

Where V = volume; k is taken as 0.66; a, the largest diameter; b, the smallest diameter and d, depth of penetration (I.F. Owens, personal communication, 2005).

Most indentations in the profile were between 1.15 to 1.75 m above ground level and in boards 3–6 below the top of the wall. Like many beach pebbles they had a tendency to be oval in shape. The majority were aligned parallel with the grain of the wood and of the 38 sampled, 36% had a maximum depth of 2 mm and surface area of 20–30 $mm^2$. The largest indentation in the profile was at board 8, 93.5 cm above ground level and had a maximum depth of 1.5 mm and a surface area of 220 $mm^2$.

When the depth of indentations was contrasted with wall height, there was a marked increase with height and

Table 2. Examples of indentations recorded in vertical profile, south-east corner of 'stores hut'.

| Board number | Height above ground | Surface area | Vertical orientation | Horizontal orientation | Maximum depth | Volume |
|---|---|---|---|---|---|---|
| 3 | 166 cm | 130 mm$^2$ | 4.5 mm | 10.25 mm | 3 mm | 91.32 mm$^3$ |
| 3 | 160 | 108 | 8.5 | 12.5 | 2 | 140.25 |
| 3 | 160 | 162 | 7 | 18 | 2 | 166.32 |
| 4 | 152 | 72 | 6 | 6.5 | 2.5 | 64.35 |
| 4 | 153 | 91 | 12.5 | 18.5 | 4 | 610.5 |
| 4 | 142 | 84 | 6.5 | 8 | 2 | 68.64 |
| 5 | 130 | 35 | 3.75 | 11 | 2.25 | 61.25 |
| 6 | 123.5 | 18 | 5 | 5 | 3 | 49.5 |
| 6 | 123.5 | 82 (wood torn) | 9 | 8 | 4 | 190.08 |
| 6 | 123.5 | 18 | 5 | 5 | 3 | 49.5 |

impact points were concentrated between 50–200 cms. When the surface area of indentations was compared to height, impact points were <100 mm$^2$ in area and with the most significant concentration from 100–200 cms. While the actual size and shape of the particles that have caused the indentations is not known, it is assumed on the basis of observations in the field that those striking the hut wall were in most instances well rounded and left an impression with little variation in depth.

A 10 × 5 mm diameter core was collected from a large indentation, to establish the extent of deformation from impact. Using an Olympus stereomicroscope with 0.7 – 4x magnification, slight tearing was evident along the edges of autumn wood and also subsequent abrasion by fine particles.

Along the east wall, 63 particles were embedded in or between boards from 9 to 187 cm above ground level, with 29% having a B-axis of 3 mm. With the exception of one small pebble and an angular fragment, all were granules and appeared to be products of frost action and may have originated on the Adare Peninsula. 31 granules were embedded in the east-facing wall of the 'living hut' and the B-axis for all these particles ranged from 2–6 mm.

**1911 Hut**

The second expedition to winter on Ridley Beach, the 1911–12 northern party, experienced similar conditions to those of Borchgrevink's expedition. Raymond Priestley wrote,

> The blizzard, which we came to speak of as the 'ten days wind', began on the night of May 5th [1911], and my first knowledge of it came when I was waked by the noise of the wind at 4 a.m. In spite of the creaking and groaning of the hut, and the rattle of our gear that was hanging from the walls, I could make out definite gusts which appeared to be of terrific force, and which were accompanied by a rattling noise. My mind at once flew to Borchgrevink's account of showers of pebbles, and when I got outside the door on my way to take the eight o'clock [meteorological] observations there was no doubt about it. (Priestley 1914)

In 1990 a further examination was made of pebbles embedded between two vertically mounted boards at the south-east corner of the cold porch and positions were recorded for height above ground level and depth of penetration (Fig. 8). The particles were likely to have originated from the penguin nesting areas east of the hut.

Fig. 8. Pebbles embedded between boards of porch wall 1911 hut. January 1990.

Of 32 particles extracted (Table 3), with exception of three pebbles, all were fractured as a result of collision probably during wave action, rather than by saltation, under which process as velocity increases, particles move short distances with a jerky movement. Broken particles found within the unroofed 'stores hut' had probably been broken by high energy wave activity. Only one pebble appeared to have been recently broken and two had some polishing, perhaps indicative of having been embedded for

Table 3. Pebbles embedded between boards in the 1911 hut.

| Sample No. | B-axis mm | Weight gms | Height above ground cms | Depth |
|---|---|---|---|---|
| **1** | 21.83 | 12.133 | 110 | 7 |
| **2** | 17.64 | 11.178 | " | 5 |
| **3** | 15.06 | 3.856 | " | 10 |
| **4** | 14.08 | 2.425 | 190 | 7 |
| **5** | 17.68 | 7.217 | 90 | 1 |
| **6** | 17.64 | 1.744 | " | " |
| **7** | 16.62 | 3.331 | 83 | 5 |
| **8** | 16.63 | 3.062 | 62 | 1.5 |
| **9** | 30.18 | 22.893 | 200 | 5 |
| **10** | 24.92 | 14.353 | " | " |
| **11** | 19.72 | 8.252 | " | " |
| **12** | 16.61 | 7.183 | 213 | 3 |
| **13** | 11.43 | 2.035 | " | " |
| **14** | 21.83 | 4.872 | 184 | 5 |
| **15** | 15.59 | 4.058 | 196 | 5 |
| **16** | 12.50 | 2.099 | " | " |
| **17** | 16.62 | 7.968 | 88 | 8 |
| **18** | 18.72 | 5.633 | 70 | 7 |
| **19** | 14.56 | 3.922 | 213 | 6 |
| **20** | 20.82 | 11.616 | 230 | 10 |
| **21** | 14.58 | 3.504 | 220 | 8 |
| **22** | 12.50 | 1.848 | 220 | 8 |
| **23** | 10.04 | 0.897 | 22 | 6 |
| **24** | 14.56 | 2.753 | 47 | 3 |
| **25** | 12.48 | 2.168 | " | " |
| **26** | 13.54 | 1.723 | " | " |
| **27** | 27.00 | 21.894 | 120 | ? |
| **28** | 20.08 | 12.987 | 123 | ? |
| **29** | 20.00 | 8.887 | 127 | ? |
| **30** | 18.71 | 6.975 | 127 | ? |
| **31** | 16.68 | 6.708 | 125 | ? |
| **32** | 15.58 | 6.601 | 130 | ? |

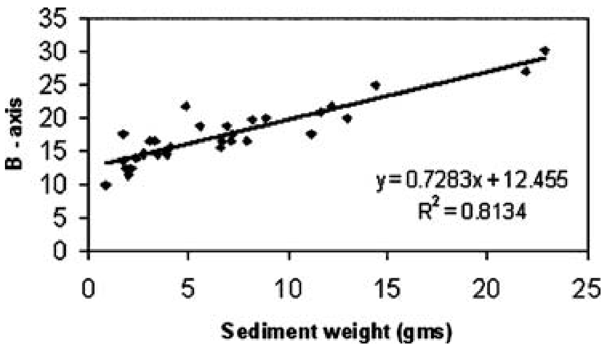


Fig. 9. Relationship particle weight to pebble B-axis 1911 hut.

some time. This is a common feature of some ventifacts, shaped over time by sand-blasting. The embedding of the pebbles suggested that the two boards may have become separated in the last 25 years.

There was a strong correlation, with an 81% level of confidence, in the relationship between particle weight and the B-axis, with a reduction in the B-axis as weight increased (Fig. 9), but only a slight correlation between pebble weight and depth of penetration between the boards with many pebbles within 100 cm of the ground surface. The depth of penetration ranged from 0.5–10 cms with the largest particle 23 gms and a B-axis of 28.11 mm, driven in 3 cms at 2 m above ground level. When pebble weight was compared to height, 'populations' of indentations corresponded to the surface area of indentations on the 'stores hut' and related directly to the velocity at which pebbles were picked up and transported within the air stream.

## Field recordings of wind gusts

To confirm observations made previously (Harrowfield 1984, 1996) and to relate airflow to the pattern of weathering and damage being sustained, a series of field recordings was made during a low intensity storm in 1990. Records were similar for both the west and east sides of Borchgrevink's huts, although there was a reduction in airflow beside the 'living hut' which may be attributed to variation in the height of the ground surface. Similarly for the 'stores hut' there was an increase in airflow at the northeast corner where the wind was then funnelled through the alleyway and as expected and observed in 1982 (Harrowfield 1984), a decrease of about 50% was noted for 'stagnant air' in the lee of both huts.

Readings obtained to the top of the 2.23 m 'stores hut' wall, were taken with a Munro hand-held anemometer with braking device and were in agreement with the Cassella anemometer erected at 250 cm on a mast in a swale 8 m from the south-east corner of the hut. Despite the quality of the instrument that was used, because it was hand-held, and given conditions at the time of recording (02:30 and 03:30), the record (Tables 4a, 4b) must be considered as an approximation.

Table 4a. Wind velocities with two sets of readings each over 60 secs; 'stores hut', 1990.

| | Wall centre | | North-east corner | | Alley centre | |
|---|---|---|---|---|---|---|
| Ground | 5–7 m/sec<br>(18–25.2 km/hr$^{-1}$) | 8–11<br>(28.8–39.6) | 5–7<br>(18–25.2) | 10–15<br>(36–54) | 13–15<br>(46.8–54) | 18<br>(64.8) |
| 100 cm | 10–14<br>(36–50.4) | 10–15<br>(36–54) | 9–10<br>(32.4–36) | 19–24<br>(68.4–86.4) | 20–23<br>(72–82.8) | 24<br>(86.4) |
| 200 cm | 8–11<br>(28.8–39.6) | 8–11<br>(28.8–39.6) | 9–14<br>(32.4–50.4) | 15–18<br>(54–61.2) | 24–26<br>(86.4–93.6) | 20–27<br>(72–97.2) |
| Top of wall | 9–10<br>(32.4–36) | 10–15<br>(36–54) | 9–22<br>(32.4–79.2) | 20–24<br>(72–86.4) | - | 20–25<br>(72–90) |

Table 4b. Wind velocities each over 60 secs; 1911 hut porch, 1990.

| | Wall south-east corner | East wall centre | |
|---|---|---|---|
| Ground | 15–17 (54–61.2 km/hr) | 9–12 (32.4–43.2) | 15–17 (54–61.2) |
| 100 cm | 14–20 (50.4–72) | 5–10 (18–36) | 15–20 cladding damaged (54–72) |
| 200 | 15–20 (54–72) | 7–12 (25.2–43.2) | 15–18 (54–64.8) |
| 250 | 5–10 (18–36) | 5–10 (18–36) | 15–20 (54–72) |

Approaching storms from the southeast or east-southeast are usually indicated by the occurrence of slight variable winds and a rapid fall in barometric pressure. William Colbeck, magnetic observer and cartographer on Borchgrevink's expedition, described a typical storm on Friday, 24 March 1899: 'By 1pm bar[ometer] had fallen to 28.518 [inches of mercury] and wind had increased to a moderate gale, 3 pm strong gale SE and terrific squalls. Bar[ometer] 28.447. Finn's tent blew away about this time' (Colbeck 1899).

An indication of the short-lived nature of east-south-east storm conditions can be gained from the meteorological record for 8–9 January 1990. At 0900 on 8 January, barometric pressure was 1002.4 mb and a south-west wind $<1$ m sec was blowing. By the evening pressure had begun falling and the wind was from the east-southeast and steadily increasing. At 02:00 on 9 January the pressure was 992.2 mb with the wind now gusting to 15 m/sec and an hour later, the pressure had further decreased to 988.8 mb and the wind was gusting at 22 m/sec. However, by 09:00 the wind velocity was decreasing rapidly and within 24 hours, the pressure had risen to 992.2 mb and continued to rise (Harrowfield 1990).

## Analysis of wind velocities

In 1941 R.A. Bagnold's important work *The physics of blown sand and desert dunes* was published (Bagnold 1941). It is from this pioneering research that included the use of wind tunnels to confirm theories, and from the subsequent studies by Gardiner and Dackombe (1987), that wind velocities attributed to weathering of timber and embedding of particles may be calculated. The critical erosion velocity required to dislodge a particle until it enters the air stream at a height of 2 m has been calculated (Table 5).

Because the forward pressure of the wind is able to counteract the downward force of gravity, at height (d) the kinetic energy (E) of a particle with a mass (M), is relative to the roughness of the ground surface (KL) over which the particle travels. Since, $E = 1/2\,mv^2$, where $v =$ velocity. The mechanical energy is subjected to the force of gravity. Once the particle is suspended in the airflow, it will continue to increase its forward velocity until it approaches that of the wind, with the velocity proportional to the logarithm of the height.

The extent of the force (pressure) exerted by the particle on striking the hut wall, is the most important primary parameter and relates to the compression of the wood parallel to the grain. For Norway spruce compression can amount to 36.5 N/mm$^2$ (Dinwoodie 1981). This is largely determined by the age of the late wood that is likely to have high lignin content. Parameters of importance are the extent of surface area, volume and depth of the indentation and the mass and B-axis of the particle. For large indentations, $V = KE$, where E is the kinetic energy determined by the mass and B-axis of the particle and K, a coefficient of proportionality, is derived from the velocity (Kloot 1952).

Saltation, while well established as a process for sand grains, requires entry into higher velocity zones with a velocity of at least 4–5 m/sec$^{-1}$ to continue the process until the grains eventually reach the same velocity as the wind at that height (Pethick 1986). Given the violent nature of gusts experienced at Cape Adare, and the process of rolling, or possibly saltation, under which large particles with a B-axis of at least 25 mm are moved

Table 5. Calculated wind velocities.

| Particle size | $V_{*t}$ | | $V_z$ at 2 m | | |
|---|---|---|---|---|---|
| 1 mm – B axis | 46.1 cm/sec | .46 m/sec | 795.30 cm/sec | 7.953 m/sec | 28.62 km/hr |
| 5 | 103.0 | 1.03 | 1779.86 | 17.79 | 64.00 |
| 10 | 145.90 | 1.459 | 2517.12 | 25.17 | 90.60 |
| 15 | 178.70 | 1.787 | 3082.12 | 30.82 | 110.97 |
| 20 | 206.36 | 2.063 | 3559.71 | 35.50 | 128.15 |
| 25 | 230.72 | 2.307 | 3979.92 | 39.79 | 143.27 |
| 30 | 252.74 | 2.527 | 4359.76 | 43.59 | 156.95 |
| 35 | 272.99 | 2.72 | 4707.52 | 47.07 | 169.47 |
| 40 | 291.83 | 2.91 | 5034.06 | 50.34 | 181.22 |
| 45 | 309.54 | 30.95 | 5339.56 | 53.39 | 192.22 |
| 50 | 326.86 | 32.68 | 5638.33 | 56.38 | 202.97 |

over Ridley Beach, and also bearing in mind the mass of large particles, it is unlikely that such particles would be within the air stream for any great duration or distance. Furthermore, in comparison with the frictional influence of the modern beach surface, large particles if saltating over areas of particle-free dry guano, are likely to be moved at a far greater rate. However, as Bagnold observed, the factors to consider which would influence rate of movement, include shape and mass of the particles, resistance to gravity and the frictional effects of the wind itself.

Since the critical erosion velocity occurs at the ground surface, this can be calculated by the method adopted by Bagnold (cited in Gardiner and Dacombe 1987), in which,

$$V_{*t} = A\{(\sigma - p)gd/p\}^{1/2}$$

where $V_{*t}$ is the threshold velocity; $\sigma$ = specific gravity or density of the particles ($2.65\,g \cdot cm^{-3}$); p = specific gravity of a fluid (air) = $1.22 \times 10\,gm \cdot cm^{-3}$; g = the gravitational constant ($980\,gm \cdot cms^{-2}$); d = the mean particle diameter (cms) and Bagnold's A; is a coefficient which for grains above 1.0 mm in diameter = 0.1; the wind speed is calculated for the height of 2 m above the ground from the formula,

$$V_z = 5.75\, V_* \log(z/k)$$

where k is taken as the surface roughness height of 2 mm, the elevation at which the wind speed is zero; and Z is the elevation above the bed (mm), the threshold velocity for particles of very course sand (1–2 mm), granules (2.38–3.36 mm) to pebbles (4–64 mm) (Folk 1965).

In 1990 the unroofed 'stores hut' was subject to archaeological excavation. The stratigraphy of a frozen deposit, revealed up to three layers of organic material and particles identified as beach sediment (Harrowfield 1992). With the exception of artefacts, including the bow of a whaleboat wrecked in 1899 and placed there later that summer with a survival box, the floor area was left clear. However, in 2003, there was considerable disarray with wind-deposited particles from coarse sand to well-rounded large pebbles having been moved at least 15 m from the nearest source and blown over the 2.23 m high wall.

The sediment was presumed to have been deposited during violent gusts from the east-southeast and the largest particle with a B-axis of 46 mm and weight of 100 gms, would have required a $V_{*t}$ of 31.29 m/sec (112.64 km/hr) and at 2 m height, a $V_z$ of 53.98 m/sec (194.34 km/hr). Other large beach pebbles had B-axes of 41 mm (62 gms), 35 mm (42 gms), 34 mm (26 gms), 33 mm (44 gms) and 32 mm (26 gms).

Sediment collected from the badly eroded windward ridge line (5.79 m) of the 'living hut' roof included one pebble with a B-axis 13 mm (2 gms).

When a comparison is made of calculated wind velocities against particle weight (Table 6), there is a good relationship in regression curves expressed exponentially and with over 95% confidence in the data. Particles moved at threshold velocity suggest, with an increase in velocity, there is a greater chance for a given particle to be suspended in the airflow (Fig. 10). However, as height above substrate increases, sediment transport is likely to diminish and this is especially so when particle weight increases (Fig. 11).

Table 6. Comparison of Bagnold predicted velocities and particle weights from a random beach sample.

| Bagnold $V_{*t}$ | Particle weight (gms) | Bagnold $V_z$ @ 2 m | Particle weight (gms) |
|---|---|---|---|
| 1.459 m/sec | 1.87 | 25.17 m/sec | 1.87 |
| 1.459 | 1.84 | 25.17 | 1.84 |
| 1.787 | 4.69 | 30.82 | 4.69 |
| 1.787 | 4.44 | 30.82 | 4.44 |
| 2.063 | 19.69 | 35.50 | 19.69 |
| 2.063 | 15.44 | 35.50 | 15.44 |
| 2.307 | 31.45 | 39.79 | 31.45 |
| 2.307 | 20.29 | 39.79 | 20.29 |
| 2.527 | 53.51 | 43.59 | 53.51 |
| 2.527 | 35.69 | 43.59 | 35.69 |
| 2.72 | 68.55 | 47.07 | 68.55 |
| 2.72 | 53.05 | 47.07 | 53.05 |
| 32.68 | 48.98 | 56.38 | 48.98 |

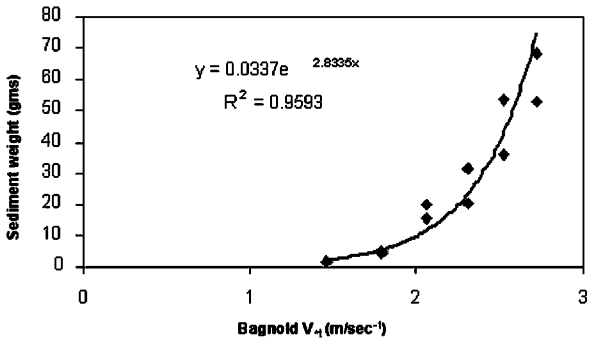


Fig. 10. Predicted velocities for particles at threshold velocity with weight 0–80 gms.

Although the shape and mass of the particles are unknown, by using specimens from a representative beach sample, the radius of curvature for well rounded specimens, can be determined from the A, B and C axes, as can an indication of mass. From these measurements and the density of the wood and the other variables, it

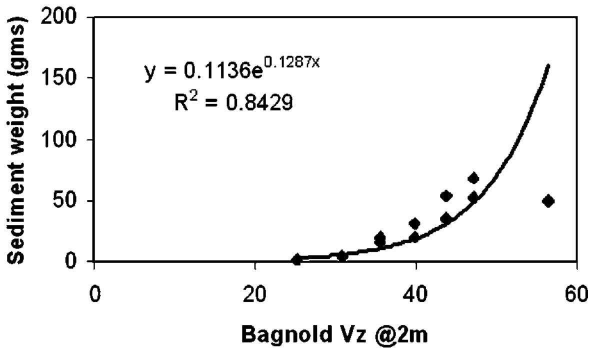


Fig. 11. Predicted velocities for particles above threshold velocity with weight 0–200 gms.

should then be possible to obtain a general approximation of velocity. Impact hardness tests could also be applied to obtain an indication of surface area for indentations. In the Janka Test for example, the indentation varies directly as the square of the ball diameter and both the square root of the ball density and height of drop (Kloot 1952).

Since the strength of the wind varies within the boundary layer, in comparison to Bagnold's formulae this approach could only provide an approximation of wind velocity at a given point and any result is subject to conjecture.

### Other factors

Although minimum temperatures reaching −39°F (−39.4°C) have been recorded in July (Colbeck 1899) which could influence the density of the air and assist the lifting of particles, because of the location, maritime environment and site elevation, this is not considered a factor in timber weathering. In contrast to winter conditions, ambient air temperatures in January can reach 12°C and relative humidity is often 70–90% or higher (Harrowfield 1982, 1990). Detailed data from sensors installed by the Antarctic Heritage Trust in February 2003 are expected to provide an important hourly record of temperature and relative humidity for this site.

In summer and early autumn, it is not unusual for hut timbers to become wet from melting snow and sudden storm events, which can lash the huts with ice-laden sea spray or from water blown from nearby lagoons. Under such conditions, the surface density of the wood may be affected and readings obtained using a moisture meter, indicated saturation up to 5 mm below the surface (Harrowfield field notes). Furthermore, according to Kloot, the relationship between strength and moisture content for timber is more complex for impact resistance than for static strength of wood (Kloot 1954).

Defibration, due to high concentrations of salts such as sodium chloride, under which melt water with salts in solution gently flows over the exterior and is present on historic huts such as at that at Cape Evans on Ross Island, has not been observed at Cape Adare. In addition to destroying the surface of the wood, the process also results in degradation of hemi cellulose and lignin thereby seriously compromising wood structure and integrity (Blanchette and others 2002). It is not known to what extent freeze-thaw may have a role in timber degradation in such a marine environment.

A further factor relates to the potential biological deterioration of cell wall components by soft rot fungi, thereby reducing the strength of the wood. *Cadophora* sp the cause of soft-rot fungi, has already been isolated from timber at Cape Royds and Cape Evans historic huts on Ross Island, and may be present at Cape Adare (Blanchette and others 2004).

### Experimentation

Ridley Beach can, at times, be an inhospitable place and in order to obtain a better understanding of the conditions and what is happening to Borchgrevink's huts, a series of experiments were undertaken.

#### Predicted compared to actual wind velocities

To obtain an indication of the threshold velocity at which particles begin to move, experiments were undertaken using a Low Noise boundary layer wind tunnel with a 0.75 m nozzle, in the Department of Mechanical Engineering, University of Canterbury (Tables 7a; 7b).

Individual particles with a B-axis 10–40 mm were selected from a random surface sample, collected in 2003 under an Antarctica New Zealand Permit on the beach at Cape Adare and 80 m south-east of Borchgrevink's stores hut. The pebbles pre-weighed in the physical laboratory of the Department of Geography, were placed on a flat wood surface at the wind tunnel exit, this approximating the hard dry surface of guano on parts of Ridley Beach and also having a minimal friction.

Before starting the tests, calibration was undertaken with a micro manometer AXD-530 with reading directly in metres per second, to check velocity in the centre of the wind tunnel compared with that at the top, sides and base. For each test, the velocity was steadily increased from

Table 7a. Pebbles from random beach sample used in wind tunnel.

| Sample number/total sample | Mean weight total sample | Particle weight | Description | B-axis | Creep | Steady movement |
|---|---|---|---|---|---|---|
| 3a/10 | 1.97 gms | 1.87 gms | Angular blade | 10 mm | Nil | 16.3 m/sec |
| 3b | – | 1.84 | Well rounded equant | 11 | Nil | 11.9 |
| 4a/10 | 3.70 | 4.69 | Well rounded blade | 15 | 11.4 m/sec | 12.7 |
| 4b | – | 4.44 | Sub rounded blade | 14.5 | 14.5 | 14.98 |
| 5a/10 | 15.37 | 19.69 | Well rounded roller | 20 | 10.4 | 14.8 |
| 5b | – | 15.44 | 50% well rounded prolate | 20 | 11.4 | 17.9 |
| 6a/10 | 20.45 | 31.45 | Rounded prolate | 25 | 15.6 | 23.8 |
| 6b | – | 20.29 | 50% sub rounded blade | 26 | 12 | 18.39 |
| 7a/5 | 44.31 | 53.51 | Rounded blade | 30 | Nil | 24.6 |
| 7b | – | 35.69 | Rounded equant | 30.5 | Nil | 15.88 |
| 8a/5 | 44.88 | 68.55 | Sub rounded blade | 35 | 11.0 | 15.4 |
| 8b | – | 53.05 | Sub rounded equant | 36 | 16.5 | 18.66 |
| 9/1 | 48.98 | 48.98 | Well rounded oblate (disc) | 40 | Nil | 26.5 |

Table 7b. Pebbles from random sample, floor of stores hut.

| Sample number/total sample | Mean weight total sample | Particle weight | Description | B-axis | Creep | Steady movement |
|---|---|---|---|---|---|---|
| 1/10 | 41.34 gms | 102.64 gms | Well rounded equant | 41 mm | 14.1 m/sec | 16.3 m/sec |
| 3 | – | 47.74 | Sub rounded equant | 29 | 17.5 | 18.56 |
| 5 | – | 56.88 | Sub rounded blade | 33 | 18.2 | 19.7 |
| 7 | – | 32.13 | Part sub rounded equant | 32 | 19.4 | 20.16 |
| 9 | – | 10.18 | Rounded disc | 21 | Nil | 19.0 |
| 10 | – | 15.69 | Sub rounded prolate (roller) | 21 | 12.2 | 14.42 |

Particle descriptions after Powers (1953) and Ziing (1935).

2 m/sec and was measured with a pitostatic tube linked to a Magelis control unit. The degree of variation amounted to ±.2 m/sec.

Most particles when subjected to increased velocity were, depending on their shape, observed to orientate, vibrate slightly and then creep forward until such time as the critical threshold was reached and steady movement under direct pressure of the wind occurred.

Particle shape and, to a lesser extent, degree of roundness, was important and Blatt and others (1980) note that the mode of sediment motion depends strongly on grain size as was evident in the experiments. For example, a large well-rounded pebble (equant) with greater surface area did not necessarily attain threshold velocity later than a particle that was both smaller and lighter, the mass of the particle therefore being of lesser significance.

The time when first movement was observed also varied in well-rounded fractured pebbles. The lack of early movement was attributed to the presence of a micro low-pressure zone and associated vortex created in the lee of the particle.

The threshold velocities required to move particles with the same B-axis as those in Table 4, are considerably higher than the predicted velocities derived from Bagnold's formulae (Table 8). This is perhaps explained by Bagnold's hypothesis under which particles prior to reaching threshold velocity, have much greater resistance to airflow and the force of gravity, whereas in the wind tunnel experiment, because velocity at the time of movement for a particle was generally constant, there was considerably less frictional drag (Fig. 12).

In contrast, Hjulstrom's diagram suggests that a particle 20–50 mm in a fluid at 1 m depth, will attain a velocity of 5–50 m/sec$^{-1}$ (Blatt and others 1980: 105).

From the wind tunnel observations, it is suggested that large particles in particular have originated from beach deposits, and nearby penguin nests with the nearest concentration 7 m from the southeast 'stores hut' corner. They then tend to creep or are blown over the ground surface until they reach a point 4 m from the east wall of the hut where the 10° slope of the surface includes two steps of 45° and 65°. The particles are then picked up during strong short-lived wind gusts and are blown against the hut or deposited within the hut. It is suggested that the lack of pebbles immediately below the east-facing wall can be attributed to removal by penguins for nest sites.

Table 8. Comparison of Bagnold 'predicted' threshold velocity $V_{*t}$ values and the wind tunnel.

| Sample No. | Particle B-axis | Bagnold "predicted" Threshold velocities | Wind tunnel threshold velocities |
|---|---|---|---|
| 3a | 10 mm | 1.459 m/sec | 16.3 m/sec |
| 3b | 11 | " | 11.9 |
| 4a | 15 | 1.787 | 12.7 |
| 4b | 14.5 | " | 14.98 |
| 5a | 20 | 2.063 | 14.8 |
| 5b | 20 | " | 17.9 |
| 6a | 25 | 2.307 | 23.8 |
| 6b | 26 | " | 18.39 |
| 7a | 30 | 2.527 | 24.6 |
| 7b | 30.5 | " | 15.88 |
| 8a | 35 | 2.72 | 15.4 |
| 8b | 36 | " | 18.66 |
| 9 | 40 | 2.91 | 26.5 |
| 1 | 41 | " | 16.3 |
| 3 | 29 | 2.307 | 18.56 |
| 5 | 33 | 2.527 | 19.7 |
| 7 | 32 | " | 20.16 |
| 9 | 21 | 2.063 | 19.0 |
| 10 | 21 | " | 14.42 |

Particles with a B-axis of 20 mm are more likely to move by saltation and in strong gusts, and remain longer

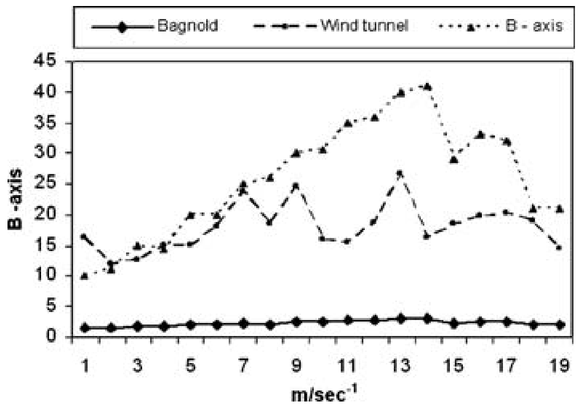


Fig. 12. Comparison of Bagnold predicted velocities with wind tunnel and B-axis of particles tested.

Table 9. Predicted velocities for falling particles.

| t | y | v | v |
|---|---|---|---|
| 0.1 seconds | 1 m | 4.8 m/sec | 17.3 km/hr |
| 0.2 | 2.0 | 9.6 | 34.6 |
| 0.4 | 3.9 | 19.2 | 69.3 |
| 0.8 | 7.8 | 38.5 | 138.6 |
| 1.6 | 15.7 | 77.0 | 277.2 |

(I.F. Owens, personal communication, 2005).

in suspension. As noted by Bagnold, the highest point attained by any particle, is dependant on the initial upward velocity attained when the particle leaves the ground surface. The nature of the surface is therefore important to sediment transport.

### Relationship of velocity to indentations

An alternative method in estimating velocity can be achieved from the equation:

$V_y = gt$ and $y = 1/2\,gt^2$

in which,

$V_y$ = velocity from height y (m/sec), g = gravity (m/sec), y = height of drop (m), t = time (s).

Using a 2 m stepladder, beach pebbles of varying shapes and mass, were dropped to a maximum of four metres. However, a 105 gm particle, the largest present among the beach samples when released from this height, failed to make an impression on a sample of *Picea abies* with zero moisture content. Table 9 based on the above equation, provides an indication of velocities possible for varying heights.

An additional experiment was undertaken to attempt to ascertain the shape and mass of particles considered responsible for the indentations. With a 560 gm hammer, fifty well-rounded particles from the Ridley Beach sample and having a B-axis of 20–25 mm were impacted on a dry sample of *P. abies* from Cape Adare collected in 1982. The particles when struck with the hammer resulted in similar indentations and dimensions to those observed on the hut wall (Table 2) and could be related to the shape of particles on the present beach rather than the indentations observed on the wall boards.

### Physical characteristics of *Picea abies*

To examine further the physical characteristics of the wood, experiments were undertaken using a Schmidt rebound hammer. This instrument, designed by Ernst Schmidt in 1948 as a means of enabling non-destructive testing of hardness for *in situ* concrete and rock, is generally used for concrete testing but is also employed by geologists and geomorphologists. The rebound test is based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the fixed amount of energy imparted to it by extending the spring to a fixed position impacts. This is achieved by pressing the plunger against the surface of the sample under test. Upon release, the mass rebounds from the plunger, still in contact with the concrete (or rock) surface, and the distance travelled by the mass, expressed as a percentage of the initial extension of the spring, is called the rebound number. This number is indicated by an indicator moving along a graduated scale (Neville 1963). It is believed that the present paper records the first occasion on which the Schmidt test has been applied to wood associated with historic buildings.

Two samples tested were a modern sample of *Pinus sylvestris* from the Larsemann Hills East Antarctica (Progress 1 Station, Russia) examined in 2001 and a sample of historic wood *P. abies* from Cape Adare collected in 1982. The Larsemann Hills sample of *P. sylvestris* was used for comparative purposes. The samples which had similar appearance, showed no evidence of surface deterioration and were milled from trees estimated at 110 and 70 years of age respectively.

Rebound (R) values obtained for 50 readings on each sample were converted following the manufacturers guidelines, to MPa this being the impact force on a unit area. The difference between the two was a reflection of the difference in structure and hardness of the two species and represents the resistance of the soft wood to impact, although generally measurements for the two species had little variation. This was confirmed statistically with a poor correlation and only a 24% level of confidence in the relationship between the two timber species.

The range of values for *P. sylvestris* was 3.773818–7.374935 MPa with Mz 5.36 and SD 1.097; and for *P. abies* was 5.641145–8.432448 MPa with Mz 6.65 and SD 0.694.

### Some comparisons with other Ross Sea region historic sites

#### *Discovery* hut, Hut Point

At R.F. Scott's *Discovery* hut erected in 1902 on a promontory of the Hut Point Peninsula, Ross Island, and exposed to the south (Cochran 2004), extensive weathering of early wood by scoria particles and probably ice crystals, is evident on such components as the south facing 150 mm$^2$ veranda support posts of Douglas Fir (*Pseudotsuga menziessii*). However, from observations including random measurements made in 2001–02 and 2002–03, of the post at the south-west corner near the hut entrance, no significant change was recorded over 12 months, this probably reflecting the extent of accuracy of the vernier calliper, and profiling gauge, used.

Movement of scoria was observed by H.J. Harrington during a blizzard experienced at the U.S. McMurdo Station in the summer of 1958–59 when 'large particles of frothy basaltic debris were blowing a long way over the sea ice and some were quite large' (H.J. Harrington, personal communication, 2006). This is not unusual for the area and, in 1962–63, H.W. Wellman observed that pebbles of basalt up to 15 mm in diameter and perhaps originating from further west, had recently blown up a snow-free slope, until being stopped by snow cover 60 m higher than the foot of the slope (Wellman 1963).

### Scott's hut, Cape Evans

A study was made over three summers in January 2001–02, 2002–03 and 2003–04, of timber weathering on the south-east corner of R.F. Scott's hut erected in 1911 and of the meteorological instrument housing on Wind Vane Hill. At Cape Evans, extensive weathering is primarily from particles of hard wind-blown scoria, during southerly blizzards and presumably also from ice crystals, although with the exception of Mawson's Huts in particular, it is not clear to what extent ice contributes. Timber is badly weathered on cedar components of the meteorological screen and the 'hardwood' support, on other artefacts such as cases with drums of fuel, and in other areas of Scott's hut. Stencilled lettering on the side of a 1910 tractor case, clearly readable in 1960, was barely visible in 1977 (Harrowfield 1981).

### Scott's hut, Cape Evans. South-east wall

The 17 feather-edged weather boards of Baltic pine (*P. sylvestris*) attached to the southeast wall, are tapered from 8 mm at the top edge to 24 mm at the bottom and were originally 185 mm wide. The boards were fixed horizontally over the 'Gibson Quilting' insulation and lapped between 30–40 mm (Cochran 2004). Measurements with a vernier calliper for each centimetre were obtained for the upper 11 south-facing board ends from below the Skellerup Butylclad roof covering lapped over the eave, although heavy snow in 2003 prevented measurements below board nine.

Many of the boards have split, often from corroding nails and cupping, while weathering can be attributed in part to the 'air scoop' often 1.5 m out from this end of the building, in late summer by abrasion from scoria ranging from coarse sand to large granules and in winter also from ice crystals. The window glass of the biology laboratory area is badly abraded (Fig. 13) with the extent of abrasion on the upper panes coinciding with the slope of scoria mounded up against the reconstructed outer wall of Bowers' 1911 stores annex and the end of the box wall. An observation made by A.K. Jack, a physicist with the Ross Sea Party, 1914–17, on 14 September 1916 was recorded in his diary: 'Tonight it is again howling with veloc[ity]. Over 50 mph [80.46 km/hr] . . . tremendous amount of grit and gravel blown onto sea ice by last gale. At [tide] crack many pieces of rock 1/4″ [5 mm] diameter. Close in shore patches up to 1″ [25 mm] diameter' (Jack 1914–17).

Fig. 13. Abraded glass of window on southeast wall, Scott's hut Cape Evans. January 1998.

In late summer, scoria windward of the reconstructed remnant of Bowers' 1911 stores annex, rise towards the hut then slopes down to the base of the southeast wall. At the end of the building four zones of weathering by coarse sand to larger particles of scoria with a B-axis of 20 mm, on the exposed board ends was recognised. From board 1 to the top of board 3 the timber has been abraded over three years from 1–1.3 mm; for boards 5–6 from 1–2 mm; for boards 7–9 from 1–4.2 mm and for boards 10–11, from 1–3.2 mm. Board 8 approximately 140 cm above ground level, was the most severely weathered with an average loss of 1.6 mm down the edge of the board.

### Instrument housing Wind Vane Hill

As with the southeast wall, weathering of the 47 cm high support post originally $6.5 \times 7.5$ cm high for the south-facing instrument housing can be related to abrasion from scoria and ice crystals. The artefact is on the top of a slope ranging from 3° at the exposed base of the support, to a 25° slope beginning at 1.63 m.

Changes in thickness for one side of the support were measured with a vernier calliper each centimetre from the top in the 2001–02, 2002–03, and 2003–04 summer seasons. The most significant loss of timber is 20 cm above ground level, this coinciding with the steeper down-slope angle. Severe weathering of 34 mm, 13 cm below the top has occurred over three years with a total loss of 39 mm since 1911 when the instrument housing was installed. This suggests that weathering has increased dramatically in recent years and is confirmed with the condition of the hut corner and meteorological screen photographed in 1977.

On the rear of the box, copper alloy tacks once held in place Malthoid which covered the six rear boards and other outer surfaces. Measurements of those firmly embedded in the wood, suggested an average loss of wood since removal of the Malthoid, of 1 mm over the rear surface (Fig. 14). However although the tacks appeared firm, there is no certainty that they have not moved in time.

## A possible solution

Following experiments with coatings by Hughes (1992) on samples at Cape Denison, Farrell and others (2004) have installed panels with blocks of pine and spruce and a range of coatings to try and control all forms of weathering (UV, salt, wind), near the three historic huts on Ross Island. Some have lasted and some have not. However, the field trials have not only provided valuable data on the materials used, and an indication of weathering rates

Fig. 14. Weathered instrument housing and support instrument stand, Wind Vane Hill, Cape Evans. January 2004.

with significant change evident after two years, but most importantly the results can be compared to those from the huts (Held and others 2003). These field experiments and other concepts yet to be developed and tried, will enable a better understanding of the timber weathering problem confronting conservators and those with an interest in preserving timber buildings and other structures, in polar and temperate environments.

## Conclusions

There were four primary objectives in the preparation of this paper:

1. to present for the first time, an important record of timber weathering on the first buildings erected in Antarctica, over 100 years ago;
2. to examine the processes to which the weathering can be attributed;
3. to identify sources of sediment believed responsible for the weathering including 'sand-blasting', splitting and bruising;
4. to relate observed damage to the unusual wind regime. The only comprehensive meteorological records for wind available for Cape Adare, are those collected by the two expeditions that spent the winter at that location in 1899 and 1911.

While a useful scientific record, it was not possible to link the historic meteorological data to sediment transport. To overcome this anomaly, formulae developed by R.A. Bagnold (1941) were applied and have provided a prediction of velocities that perhaps lift particles with a B-axis of at least 40 mm and of 100 gms, from threshold velocity into the boundary layer of the air stream. It is concluded that such events take place during violent gusts that can exceed 200 km/hr$^{-1}$. At Cape Adare, the undulating terrain of beach ridges with swales, some with lagoons east of the huts, is not regarded as a significant factor in enhancing or confining wind velocity.

Bagnold's predicted values were also tested experimentally in a wind tunnel, in which velocities required to move a range of particle size, shape and weight, were considerably higher than those derived from the formulae. This was attributed to the constant and confined velocity of the airflow, compared to the gusting observed in the field. An alternative method for predicting velocities was also tried and, although of limited value, this did confirm the hypothesis that damage to the huts is caused by violent, short-lived gusts of high velocity and that these are strong enough, to pick up and blow large particles over a 2.23 m high wall and into the unroofed 'stores hut', or embed particles in and between wall boards.

Since density and compressive strength are important parameters in timber and can vary according to age and moisture content of the wood, an indication of resistance to impact by larger windblown particles, was obtained through use of a Schmidt rebound instrument. The experiment was useful although little variation was found between two species of pine and a better approximation although not measured, was obtained using standard carpentry and engineering ball peen hammers, with examples of beach particles.

The research has shown that most weathering on the huts in the Ross Sea region is confined to specific areas. At Cape Adare, severe degradation is evident on the support of the carpenter's bench; at the northeast corner of the 'stores hut'; from sand blasting of alleyway wallboards and, to a lesser extent, from bruising by windblown pebbles. The weathering on the 'living hut' is not considered to be a serious problem. On Ross Island, the loss of 39 mm from wood on the instrument housing support at Wind Vane Hill; at the ends of some weather boards at the southeast corner of Scott's hut and the large losses observed on the veranda posts of the *Discovery* hut are significant. From some of the results presented, it therefore appears that wind can be considered to cause very serious problems in some areas.

In conclusion, all objectives were confirmed and the weathering process common to all huts in the Ross Sea region, is considered to be mostly associated with wind transported rock particles. This is in contrast to Mawson's huts at Commonwealth Bay, where ice particles are likely to be the main weathering agent. While further research with a wind tunnel could focus on the dynamics of airflow within the boundary layer and about the huts, it is concluded that with specialised conservation such as reversible coatings or by attaching durable protective cappings, the huts will be in good condition for many decades to come.


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## References


Australian Antarctic Programme. 2001. Mawson's Huts Foundation expedition report 2000–01.

Bagnold, R.A. 1941. *The physics of blown sand and desert dunes*. London: Methuen & Co Ltd.

Bernacchi, L.C. 1899. Diary of the *Southern Cross* expedition. Cambridge: Scott Polar Research Institute MS 253.

Blanchette, R.A., B.W. Held, and R.L. Farrell. 2002. Difibration of wood in the expedition huts of Antarctica: an unusual deterioration process occurring in the polar environment. *Polar Record* 38 (207): 313–322.

Blanchette, R.A., B.W. Held, J.A. Jurgens, D.L. McNew, T.C. Harrington, S.M. Duncan, and R.L. Farrell. 2004. Wood destroying soft rot fungi in the historic expedition huts of Antarctica. *Applied and Environmental Microbiology* 70:1328–1335.

Blatt, H., G. Middleton, and R. Murray. 1980. *Origin of Sedimentary Rocks*. Englewood Cliffs: Prentice-Hall Inc. (2nd edition).

Blunt, W. 1991. Mawson's huts Antarctica. A conservation proposal. Volume 2, constraints, condition, policy and implementation. Sydney: Project Blizzard.

Cochran, C.C. (editor). 2003. Conservation plan Shackleton's hut. Christchurch: Antarctic Heritage Trust.

Cochran, C.C. (editor). 2004. Conservation plan: Scott's hut, Cape Evans. Christchurch: Antarctic Heritage Trust.

Cochran, C.C. (editor). 2004. Conservation plan: *Discovery* hut, Hut Point. Christchurch: Antarctic Heritage Trust.

Colbeck, W. 1899. Diary of the *Southern Cross* Expedition 1898–1900. Christchurch: Canterbury Museum MS 212.

Colman, B.R., and C.F. Dierking. 1992. The Taku Wind of southeast Alaska: its identification and prediction. *Weather and Forecasting* 7: 49–64.

Crawford, J. (editor). 1998. *That first Antarctic winter: the diaries of Louis Bernacchi*. Christchurch: South Latitude Research Ltd.

Dinwoodie, J.M. 1981. *Timber: its nature and behaviour.* London: Van Nostrand Reinhold Co. Ltd.

Farrell, R.L., R.A. Blanchette, M. Auger, S.M. Duncan, B.W. Held, J.A. Jurgens, and R. Minasaki. 2004. Scientific evaluation of deterioration in historic huts of Ross Island, Antarctica. In: Barr, S., and P. Chaplin (editors). *Cultural heritage in the Arctic and Antarctic regions*. International Council on Monuments and sites: International Polar Heritage Committee (Monuments and Sites VII).

Folk, R.L. 1965. *Petrology of the Sedimentary Rocks*. Austin: Hemphill's.

Gardiner, V., and R. Dackombe. 1987. *Geomorphological Field Manual*. London: Allen & Unwin.

Godden Mackay Logan. 2001. Mawson's huts historic site Cape Denison Commonwealth Bay Antarctica. Australian Antarctic Programme: Mawson Huts Foundation (Conservation Management Plan).

Goldberg, F., L. Wiklander, and R. Capdevila, 2001. *The Swedish hut in Antarctica*. Stockholm: Ulrika Francke.

Harrowfield, D.L., 1981. *Sledging into history*. Auckland: Macmillan New Zealand.

Harrowfield, D.L. 1982. Historic sites in the Robertson Bay Region, northern Victoria Land Antarctica. Christchurch: Canterbury Museum (Report to Canterbury Museum Trust Board).

Harrowfield, D.L. 1984. The effects of wind on some historic Antarctic huts. *Fram: the Journal of Polar Studies* 1 (2): 471–486.

Harrowfield, D.L. 1990. General conservation report Cape Adare Historic Site, northern Victoria Land Antarctica. Antarctic Heritage Trust and Department of Scientific and Industrial Research Antarctic. Christchurch: Antarctic Heritage Trust.

Harrowfield, D.L. 1992. Archaeology of Borchgrevink's stores hut, Cape Adare Antarctica. *New Zealand Journal of Archaeology* 13: 177–197.

Harrowfield, D.L. 1996. The role of the wind in the destruction of an historic hut at Cape Adare in Antarctica. *Polar Record* 32 (180): 3–18.

Harrowfield, D.L. 2003. Field note books and photographs. Oamaru: Archives of the author.

Held, B.W., R.A. Blanchette, J.A. Jurgens, S.M. Duncan, and R.L. Farrell. 2003. Deterioration and conservation issues associated with Antarctica's historic huts. In: Koestler, R.J., V.R. Koestler, A.E. Charola, and F.E. Nieto-Fernandez (editors). *Art, biology and conservation: biodeterioration of works of art*. New York: The Metropolitan Museum of Art: 370–389.

Hughes, J.1986. Mawson's huts interim conservation report to Project Blizzard. Sydney: Project Blizzard.

Hughes, J. 1988. The problems of preservation in a polar climate: the conservation of Sir Douglas Mawson's huts at Commonwealth Bay Antarctica. *Bulletin of the Institute for the Conservation of Cultural Materials* 14 (3 and 4): 1–32.

Hughes, J. 1992. Mawson's Antarctic huts and tourism: a case for on-site preservation. *Polar Record* 28 (164): 37–42.

Hughes, J. 1992. Evaluation of protective coatings for the *in situ* preservation of historic timber buildings in a harsh Antarctic environment. Materials Research Society, (US) Spring Symposium, San Francisco.

Hughes, J. 2004. Deterioration of Antarctic historic sites—effects of Antarctic climates on materials and implications for preservation. In: Barr, S., and P. Chaplin (editors). *Cultural heritage in the Arctic and Antarctic regions*. International Council on Monuments and sites: International Polar Heritage Committee (Monuments and Sites V11).

Jack, A.K. 1914–1917. Imperial Trans-Antarctic Expedition diary. 14 September 1916. Cambridge: Scott Polar Research Institute MS 801/2.

King, H.G.R. 1988. *The wicked mate: the Antarctic diary of Victor Campbell*. Aldburgh: Bluntisham Books and the Erskine Press.

Kloot, N.H. 1953. Impact hardness tests on wood. *Australian Journal of Applied Science* 4 (1): 65–76.

Kloot, N.H. 1954. The effect of moisture content on the impact strength of wood. *Australian Journal of Applied Science* 5 (2): 183–186.

Lambert, D., P. Metcalf, and J. Macdonald. 2001. Logistics report to Antarctica New Zealand. Christchurch: Antarctica New Zealand Archives.

Mabin, M.C.G. 1982. Report to Ross Dependency Research Committee, Geomorphological Investigations at Ridley Beach. Christchurch: Antarctica New Zealand Archives.

Madigan, C.T. 1929. *Meteorology: tabulated and reduced records of the Cape Denison Station, Adélie Land*. Sydney: Government Printer Australia.

Marslander, L. 2000. Cultural heritage management on Svalbard: Problems and Challenges. In: Sigurdsson, I., and J. Skaptason (editors). *Aspects of Arctic and sub-Arctic history*. Reykjavik: University of Iceland Press (Proceedings of the International Congress on the History of the Arctic and Sub-Arctic Region, Reykjavik. 18–21 June 1998): 345–355.

Mawson, D. 1915. *The home of the blizzard: the story of the Australasian Antarctic Expedition 1911–14*. London: Heinemann.

Morrison, M. (editor). 2004. Conservation plan: the historic huts at Cape Adare. Christchurch: Antarctic Heritage Trust.

Neville, A.M. 1963. *Properties of concrete*. London: Longman.

Nordenskjöld, N.O.G. 1905. *Antarctica*. London: Hurst and Blackett.

Pethick, J. 1984. *An introduction to coastal geomorphology*. London: Edward Arnold.

Powers, M.C. 1953. A new roundness scale for sedimentary particles. *Journal of Sedimentary Petrology* 23: 117–119.

Priestley, R. E. 1914. *Antarctic adventure; Scott's northern party*. London: T.Fisher Unwin.

Turner, G.A. 1990. Field note books with survey data and plans. Auckland: Department of Survey and Land Information: Archives.

Wellman, H.W. 1963. Transport of pebbles over smooth ice in Antarctica. *Nature* 4866 (16 February 1963): 681.

Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments. *Journal of Geology* 30: 377–392.

Ziing, T. 1935. Beiträge zur Schrotteranalyse [Pioneer work on shape analysis]. *Schwiezerische Mineralogiche und Petrologische Mittheilungen* 15: 39–140.