Brown Hills and Darwin Glacier Region Site Description and Literature Review

This document is provided to give a description of the physical characteristics of the Brown Hills area in the Darwin Glacier region, especially for those unfamiliar with the location, as well as a review of the research that has been undertaken in the area that pertains to the LGP. The review is by no means comprehensive, but should present the most prominent work that has been carried out in this region.

Air photos, regular photos and a topographic map of the area can be viewed and downloaded from the LGP website (www.lgp.aq)

1. Location

For the purposes of this document the *Brown Hills region* is defined by the ice free area to the north of the Darwin Glacier which comprises the Brown Hills and other features such as Diamond Hill, Erewhon Basin and Blanks Peaks (see Figure 1). Collectively these constitute approximately 600km^2 of ice-free terrain. This region is located around 79°46'S 158°33'E and lies approximately 270km south west of Scott Base.

2. Geology

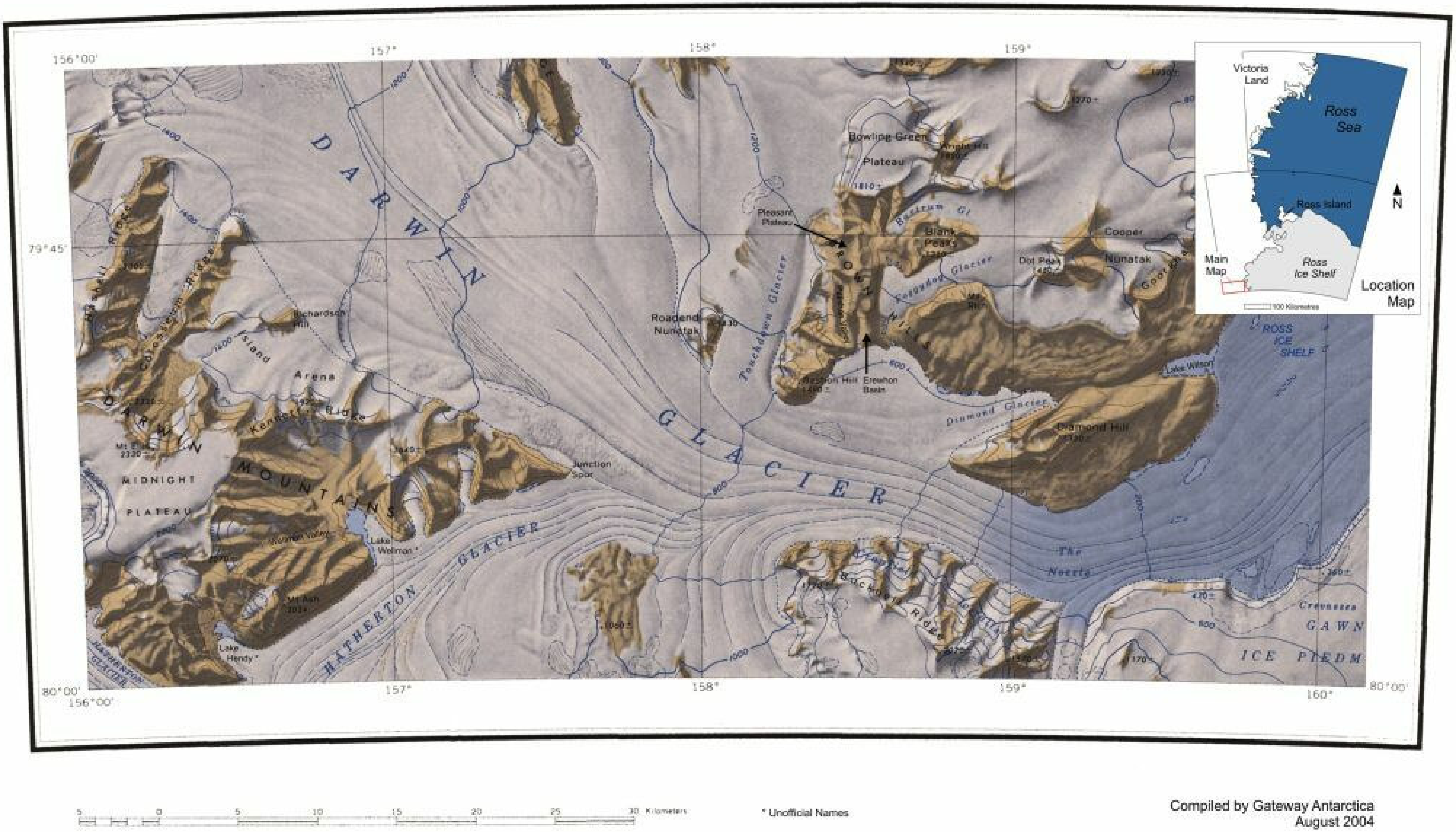
In 1962-63 the Victoria University of Wellington (VUW) Antarctic Expedition No. 6 was the first group to map the geology of the Brown Hills area. They found that the geology was similar to that of the rest of Victoria Land; the terrain consisting of Paleozoic and older crystalline basement granites, metasediments and dikes overlain by Mesozoic Beacon Group sediments (Haskell et al. 1965).

Most of the basement rocks are granitic with several different granite types from coarse to fine grained, the fine grained rocks being younger than the coarse grained. Metasediments were rare with the main outcrop east of Diamond Hill with about 100 feet of black and white bands of quartz mica schists with interbedded metaquartzite.

1800ft of low dipping Beacon sediment lies unconformably on the basement rocks. At Bastion Hill, this contact is well exposed. Granite is weathered to a depth of 6-15 ft below the unconformity. 60 ft of quartz pebble sandstone is exposed as the basal formation of Bastion Hill.

Sills and dikes of Ferrar Dolerite formation intrude the basement complex and the Beacon Sandstone.

Figure 1: Map of the Brown Hills Region, Darwin Mountains and Darwin Glacier



* Unofficial Names

Lambert Conformal Conic Projection—Standard Parallels 76°40' and 79°20'
CONTOUR INTERVAL 200 METERS—DATUM IS MEAN SEA LEVEL
Elevations and ice thickness in meters

Compiled by Gateway Antarctica
August 2004

Source: USGS Map - Carlyon Glacier
Antarctica 1:250,000
Reconnanisance Series

3. Glaciology

The Brown Hills region is most notably bound to the south by the Darwin Glacier. This glacier is about 15km wide and flows roughly eastwards from the Antarctic Plateau between the Darwin Mountains on the south side and the Brown Hills on the north, to reach the sea at the Ross Ice Shelf.

On a smaller scale, the Brown Hills region is punctuated by several small glaciers. These include the Bartrum and Foggydog Glaciers which flow from a highland névé and the Diamond Glacier which is an off shoot of the Darwin Glacier (see Figure 1). As a matter of interest, the Foggydog Glacier was so named by the 1962-63 VUW Antarctic Expedition as from plan view it looks like a dog's head with the two lakes being its ears and tongue, and a morainal band being its collar. It was also often covered by low-lying fog. Its original name however was Fogdog Glacier (pers. comm. Graeme Claridge).

The 1962-63 VUW Antarctic Expedition recognised three distinct phases of glaciation in the Brown Hills and Darwin Mountains region. In the initial phase, ice covered the entire area except for a few nunataks. In the second Phase, glaciation was confined to valleys, cirques and glacier margins. The Darwin Glacier was approximately 30m higher than present. This is shown by the presence of lateral and terminal moraines in the cirques of the Darwin Mountains to the south of the Darwin Glacier. The third phase was identified by limited areas of lateral moraines along the Darwin and Hatherton Glaciers (Haskell et al. 1965).

Both Hendy (1974/75) and Denton (1979) noted that the exposed erosional terrain of the Transantarctic Mountains exhibits morraines, erratics, and striations that attest to former fluctuations of outlet glaciers and ice streams.

In studying the late Quaternary history of the Antarctic Ice Sheet, Denton (1979) concluded that the exposed morphologic features in the Transantarctic Mountains that he observed in the Byrd-Darwin Glacier region could be explained by the uplift of the mountains through a pre-existing ice sheet. These features include the deep transverse valleys which are now filled by the Darwin, Byrd, and Hatherton Glaciers for example, short cirque-like valleys that fringe isolated plateaus, and high-level horn-like peaks that resemble present-day nunataks.

Bockheim et al (1989) studied the drift sequences around lower Darwin Glacier and the Hatherton Glacier, and concluded that these areas thickened up to 1100 m more than what they are now, but that at higher elevations the glaciers did not exceeded 100-150 m more than now over the last two global glaciations. The reason was thought to be the effect of the ice shelf grounding as a control.

4. Geomorphology

Campbell and Claridge (1964/65) undertook to describe the soils and geomorphology of the Brown Hills region. They observed that the area has been extensively glaciated and now has rugged relief with the basins separating the hills being filled with moraines of various ages. The Bartrum and Fogdog (now Foggydog) Glacier tongues being fed from the plateau, have retreated leaving remnant moraines exposed.

The soils of this area have many of the features seen elsewhere along the Victoria Land coast. A crust was found in many places which appeared to be formed by wetting and drying of the soil surface. Soils were distinguished in age by the differences in physical weathering and staining as well as topographic position. Salts didn't form obvious horizons in the soil although some salts were found under stones, sometimes showing a carbonate reaction. However, most of the salts found were later found to be thenardite on later examination.

In general most of the soils were coarse in texture and showed little evidence of soil horizons. They appeared to show only a small amount of chemical weathering and physical weathering was limited to the breakdown of the coarse textured rocks into their component minerals. Cavernous weathering was present on some of the steeper granite cliffs, which hadn't been exposed to ice action for a very long period of time. Elsewhere cavernously weathered rocks found in the moraines appeared to be being broken up by later physical weathering processes.

This study of theirs was part of a wider expedition visiting sites along the Victoria Land coast. When comparing the sites visited on this trip: in general, the expected variation in weathering from north to south didn't appear, the effect on increasing altitude from east to west having a much more noticeable effect. Coastal regions were more humid even in the far south. Lower coastal areas received quite frequent snowfalls, which thawed rapidly and allowed the soil to become moist. Air temperatures didn't seem to be so important. Big temperature differences between inland and coastal areas were recorded, but soil temperatures seem to remain constant. Temperatures of 4°C and greater were consistently measured in soils subjected to strong sunlight in the north and south and at low and high and high altitudes.

In a paper resulting from this 1964/65 expedition, Campbell and Claridge (1967) described three soils typical of those formed in small, enclosed, glacially scoured basins in the Brown Hills region. The soil-forming factors, parent material, regional climate, and age were considered to be the same for each of the soils; slope and aspect were the principal site variants, and these gave rise to considerable moisture variations. The soils were arranged in a sequence, from a dry soil that contained only a little salt and showed little weathering of clay minerals, to a wet, very salty soil that contained clay minerals, which by Antarctic standards, are considerably weathered and hydrated. A detailed description of each of these soils is given.

Table 1 shows the information given regarding soil temperature versus air temperature at the three sites (values converted to metric).

Slope	Depth to Permafrost	Soil Surface Temp.	Temp. at Permafrost
17°	56 cm	3.3°C (air of 1.8°C)	-0.6°C
5°	30 cm	2.2°C (air 0.7°C)	-0.6°C
Flat	41 cm to water table	6.7°C	-2.8°C

In addition they generally found surface soil temperatures of 6.7°C with air temperatures of 1.8°C on sunny days. During overcast days with low air temperatures, soil temperatures were rarely above 0.7°C on sun facing slopes, and 4 degrees less on slopes not facing the sun.

They concluded that warmer temperatures in flats may account for more weathering that is observed in these soils. Also that the effect of differences in aspect is to give rise to soil moisture differences and these are expressed chiefly as differences in depth to frozen ground or water table. Overall, although there were varying salt contents in the soils and differences in soil development, Campbell and Claridge described all the soils as frigic soils.

Bockheim et al (1979) later described the soils in the area, worked out the relative ages of these soils and took samples for chemical analysis. Their data suggested that Ross Ice Shelf became grounded at the Darwin Glacier area around 1myrs BP and was last grounded about 18,000yrs BP.

5. Limnology

In the eastern part of the Brown Hills region lies Lake Wilson (see Figure 1), a pro-glacial lake at the base of a secondary valley formed when the Darwin Glacier merged with the Ross Ice Shelf and blocked the valley exit. The main tributary draining in to the lake is a very turbid stream flowing northwards along the west side of the Darwin Glacier entering the lake at the south east corner. There is no surface outlet from the lake and in mid-summer the ice cover (~4.1m thick) remains practically complete with only minor moat development at a few sites at the margin (Webster et al. 1996).

In the 1974/75 season, Chris Hendy and his team from Waikato University were the first to study Lake Wilson. They observed that the major meltwater streams flowing from the North and South along the margins of the Darwin Glacier had flows of several m^3/sec and were vigorously eroding into the Darwin Glacier and its lateral moraines resulting in several large ice caves. Ice marginal channels carried considerable fine silt into the lake. The ice thickness was measured as 4m (which was the same as Lake Bonney despite Lake Wilson being 300km further South).

Hendy drilled 36 holes into the lake ice to measure its bathymetry. This revealed a regular lobate depression 95m deep, with the deepest portion being ~0.5km east of the centre of the lake (Figure 2). He thus concluded that this lake was the deepest known lake in Antarctica. From these measurements, the lake's volume was estimated to be 234×10^6 m^3 which made it the largest known volume of any known lake in Antarctica (Vanda being $196 \times 10^6 m^3$).

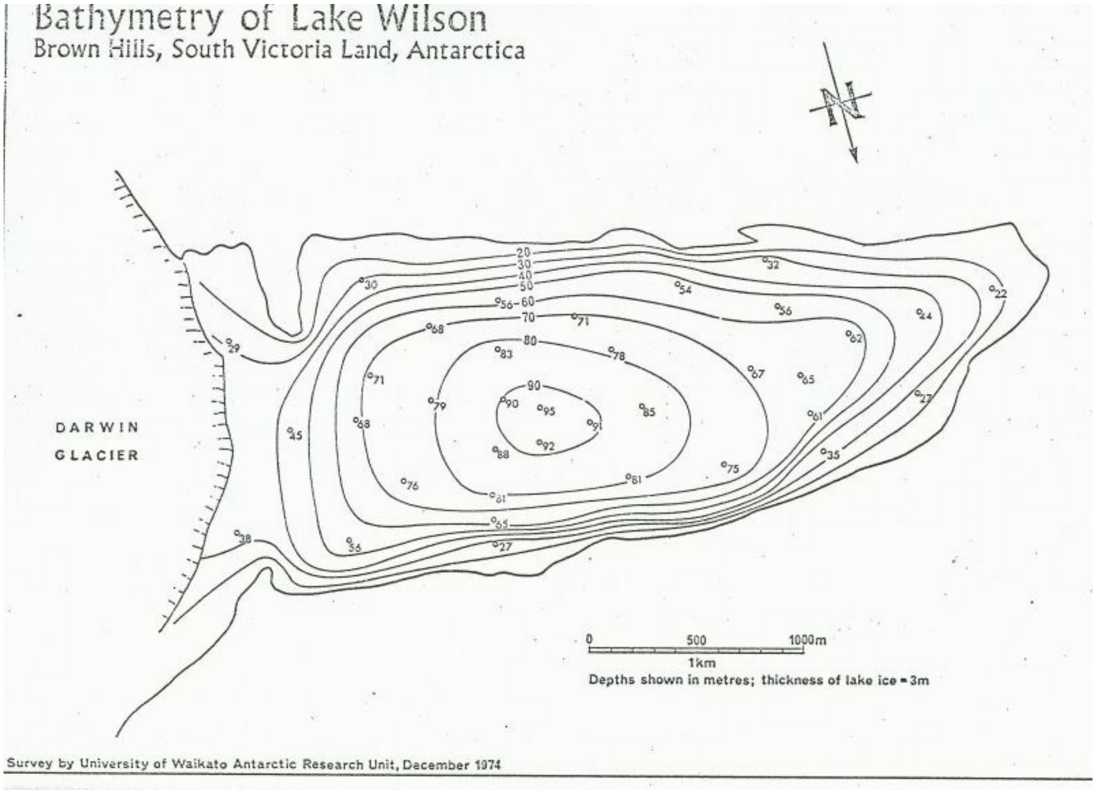


Figure 2: Bathymetry of Lake Wilson as measured by Hendy (1974/75)

Surface sediment samples revealed a ubiquitous fine yellow grey silt with little variation in texture or colour throughout the lake. Below 90m water depth traces of black organic matter were observed. All coring ended at about 60cm sediment depth when a hard surface was encountered. It was therefore concluded that the sediment was only 60cm thick, and that as there was a rapid supply of sediment to the lake at the time, the lake was very young.

Conductivities were taken to 70m depth and water samples to 52m were taken by pumping the water to the surface. Deeper sampling could not be undertaken as the depth of the lake was not anticipated and the team didn't have adequate equipment. Figure 3 shows that the Lake is strongly stratified with several diffusion and convection cells. They conclude that it is probable that the water in the lake to a depth of 34m is cooled by contact with the Darwin Glacier, the upper 15m probably fluctuating markedly in temperature with seasonal changes in solar radiation and meltwater fluxes. Application of a diffusion equation for the salt concentrations in the diffusion cell between 15 and 28m indicated that this cell was a very recent event, resulting from the raising of the lake level by about 12m between 10-20 years ago.

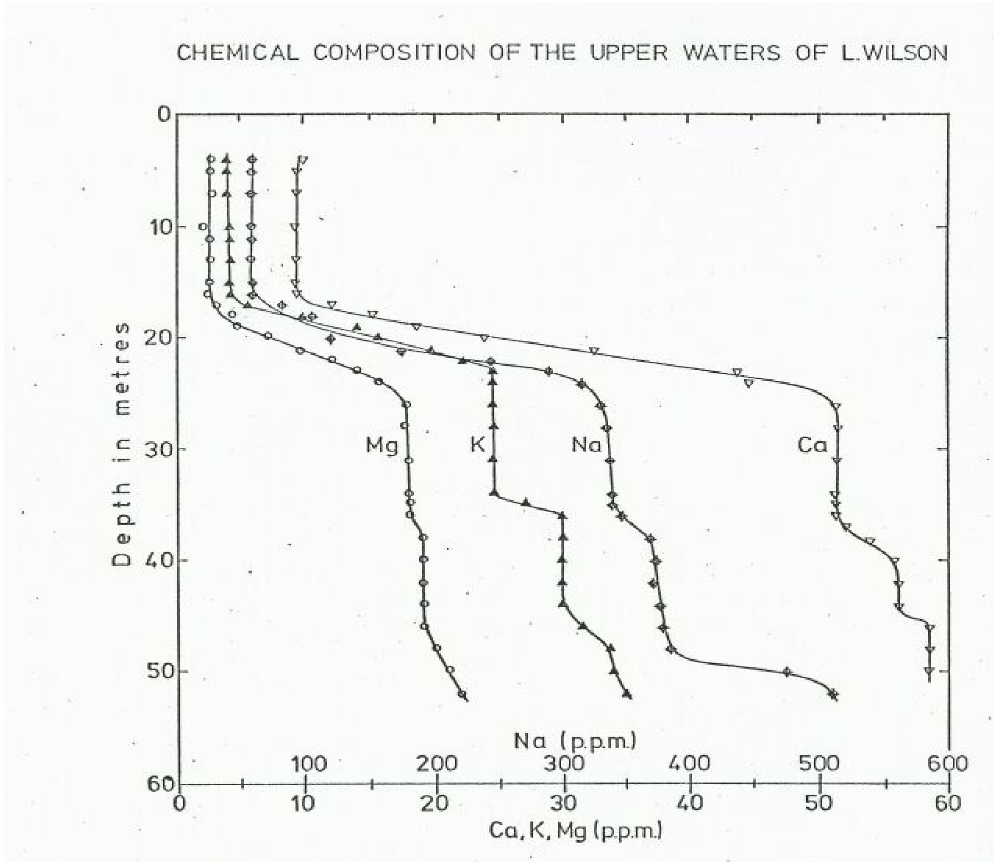


Figure 3: Chemical composition of the upper waters of Lake Wilson. (Hendy, 1974/74)

The chemical composition of the lake shows that the dissolved salts cannot have been derived from trapped sea water without extensive modification. Compared to seawater it is enriched in potassium and calcium and appreciably depleted in magnesium. So the salts are more likely to have been derived from accumulation of atmospherically precipitated salts. Lake Wilson was shown to have a low total salt content compared to other Antarctic Lakes with $1x10^5$ tonnes of Cl^-. This also indicated that this lake was very young.

Hendy and his team also visited two lakes on the northern side of the Hatherton Glacier just east of Midnight Plateau in the Darwin Mountains (see Figure 1). These are known as Lake Hendy and Lake Wellman (unofficial names). Both lakes flood shallow depressions in ice-cored moraine, and both had smooth surfaces indicating that were are frozen to the bottom.

In 1990/91 and 1992/93 a team led by Clive Howard-Williams spent some time studying the limnology of the area around Diamond Hill, including Lake Wilson where they measured an ice depth of 4.2m and a water depth of 105m. They also measured temperature, dissolved oxygen, pH and conductivity with depth and retrieved water samples for major ion and trace metal and nutrient analysis. They collected samples for dissolved gasses and measured light profiles and planktonik primary production at various light intensities and retrieved 30cm of core from the lake bed. Samples were also collected from ponds on the moraine of the Darwin Glacier to the north of Lake Wilson, ponds and the melt stream flowing into Lake Wilson from the Darwin Glacier to the South, and ponds on the east side of Diamond Hill. A photographic record of the study area was also taken.

Vincent et al (1994) describe sites around Diamond Hill which has many small valleys each containing small ponds and interconnecting streams, and a site at a valley South of mount Ash in Wellman Valley which was morraine-filled and occupied by several hundreds of ponds of variable size, but typically 40x40m or less at about 100m altitude. Pools of clear water up to 500m long and 100m wide covered mostly by a thin (<0.5m) layer of ice and several streams of up to 1m wide of greenish coloured water were flowing over the glacier surface were observed.

In sharp contrast to northern sites that had been studied, all waters in the Darwin Glacier region contained concentrations of NO_3^- above 100mg Nm $^{-3}$. As these sites are ~300km from open sea, local marine input wasn't seen as the dominant input of these waters. A positive relationship between nitrate concentration and conductivity suggested that concentration mechanisms such as freezing and evaporation were the primary cause of nitrate enrichment.

Vincent et al (1994) also looked at the biological characteristic of the meltwater environments. Results demonstrate that nitrate was largely derived from snowmelt and concentrated by physical enrichment rather than biotic processes. Waters from the Darwin Glacier region had a low microbial biomass, but high dissolved organic nitrogen, which was hard to explain.

No N_2 fixing genera were found in the Darwin area at all. This was thought not to be due to the harsh environment because these genera can withstand prolongued periods of desiccation and freezing, but probably more due to high nitrate concentrations along with low phosphate levels neither of which favour nitrogen-fixing cyanobacteria. There was also an almost complete absence of diatoms from the Darwin region in spite of the relatively high abundance of cyanobacteria.

So, this study showed that remote polar sites can be highly enriched in inorganic nutrients, specifically nitrate (Vincent, 1994).

Although no nitrogen-fixing genera were reported by Vincent (1994), analyses derived from later work, have confirmed the presence of nitrogen-fixing genera in ponds of the area, particularly *Nostoc.* (pers. coms. Clive Howard-Williams).

The meltwater ponds around Lake Wilson, which exist in depressions in either frozen groundwater or in glacier ice demonstrated widely different water chemistries. Total Dissolved Solids ranged from 15 gm^{-3} to 5500gm^{-3} (Timperley, 1997). Results from the ionic concentrations of the ponds showed that the pond water compositions are mostly mixtures of 2 groups of ions. This division was consistent with Na, Mg and Cl originating from sea salts in which they are dominant ions, and Ca and HCO_3 originating from chemical weathering of minerals in the pond catchments. The 2 groups may also reflect their mobility in the catchement soils as some of these are more mobile than others.

Some NO_3 and SO_4. were also present, and although the origin of these is obscure, there is general agreement that atmospheric deposition is the most logical pathway for these species to arrive in Antarctic snow, meltwaters and snow (Timperley, 1997).

Webster et al. (1997) found Lake Wilson to be stratified with respect to salinity with an upper/oxic layer of low salinity extending to 45m depth, a moderately saline middle/oxic layer from 50-70m depth and a more saline lower/oxic layer which extends from 80m to the redox boundary. All major ion profiles reflected the salinity stratification to some degree. The temperature and pH profiles were more subdued than the saline profile. Temperature ranged from 0-3.6°C and pH from 6.62 to 8.02.

Basal waters of the lake exhibited a Na-Cl brine composition and also had moderately high concentrations of SO_4. Two diffusion cells existed at 45-50m and 70-85m which suggests some mixing has gone on. A deep brackish layer with conductivity around 4000µS cm^{-1} with anoxic conditions was observed in the lower 5m (Webster et al. 1997).

Trace metals in the inflow to Lake Wilson were predominantly bound to suspended sediment. Trace metal speciation appears to be mainly controlled by adsorption/desorption at oxide surfaces in suspended sediment. High trace metal levels were found in the lower lake waters. Upward diffusion from here was suggested to possibly be an important factor influencing metal distribution in the water column (Webster et al. 1997).

Looking for evidence for regional climate change, Webster at al. (1996) compared Hendy's 1974/75 work with that undertaken in 1992/93. They suggest a 54% increase in lake volume and argue that this is from an increase in meltwater inflow rather than the glacier displacing the water as the same physical features seen were seen in 1993 that were described by Hendy. The lake appeared to have risen by about 25m since measured in 1975.

An observed supersaturation of oxygen could not be explained by the photosynthesis measured and could indicate a relict layer from a previous lower lake level. Primary productivity was limited to a turbid upper mixed layer and three distinct chemical layers separated by diffusion cells were observed.

Webster et al. (1996) conclude that the lake appears to have undergone a 'dry down' phase during a cooler climate about 1000yrs BP which matches that of several McMurdo Dry Valley Lakes 320km to the north. This suggests that climate change was regional rather than just in the dry valleys.

6. Terrestrial Biology

Very little about the terrestrial biology of the area is mentioned in the literature. The 1962/63 VUW expedition report mentions that samples of lichen and algae were collected from the Darwin region. Campbell and Claridge (1964/65) also make mention that samples of mosses and lichens were collected for the Dominion Museum. They also comment that lichens were quite abundant in their study area and that several different species were observed and collected. Some were growing on the soil rather than on rocks, and some yellow and black lichen were found on the underside of some surface stones (Campbell and Claridge, 1967).

7. Meteorology

There are no long-term meteorological records for the Brown Hills region. However, some insight can be gained from the reports of groups that have visited the area.

Haskell and Prebble's (1965) field observations of the weather during the VUW expedition indicated that the climatic pattern of the area was like Scott Base, with winds from N NE for over 200 days each year and snow falls on 90 days each year. Records from mid-November to mid-December 1962 show average temperatures of –10°C and snow fell on 15 days with a total water equivalent of 5-10mm. At the beginning of January 1963, temperatures were about 0°C with several light falls of snow which melted soon after.

Campbell and Claridge in late December 1964/early January 1965 report of 'warm' temperatures between –7 to -1°C and light, variable winds. Most days were clear, but snow fell three times, although it was never enough to stop fieldwork.

K062 camped at Erewhon Basin (by Foggydog Glacier) in December 2000 for five days and reported good and settled weather (Cooper 2000/01).

The group that camped at Lake Wilson for 7 days in early January 1993, report of mainly fine though overcast weather with only two days of snowfall followed by subsequent melting. Strong winds of 40-50kn were recorded on one day. Temperatures ranged from–5°C to +1°C (Howard-Williams 1992/93).

Bockheim (1989) observed that in summer, the Darwin Mountains receive relatively moist Easterly air flow, so get quite mild summer mean temperatures. Mean monthly temperatures at the US Darwin Camp by Roadend Nunatak in 1978-79 were –11°C, -3°C and –2.8°C for November, December and January. However, these are likely to be less representative of the Brown Hills region as this area is ice covered and at higher altitude, being on the plateau.

8. General Logistics Notes

The VUW Antarctic Expedition undertook a reconnaissance flight in 1962 and a found ski landing site on Western side of Brown Hills [at Touchdown Glacier?]. They then went and camped in valley NE of Bastion Hill [by Foggydog Glacier?] on Nov 22nd.

In 1964 a reconnaissance flight was undertaken for the Campbell/Claridge work. The pilot decided that landing site that VUW used in 1962 was not suitable and they landed 30 kms further up the Darwin Glacier as the glacier appeared badly crevassed. Campbell and Claridge ended up taking a helicopter from Scott Base to the Darwin Glacier. They camped at Foggydog Glacier and studied the eastern and western parts of Brown Hills. They took a day to travel along Diamond Glacier to get to a lake 3kms from Lake Wilson where they set up a fly camp for a few days.

From November 1978 to February 1979 the US staged a major deep field camp on the Darwin Glacier 240km south of McMurdo for geologic and glaciological investigations, called the Darwin Glacier Project. This camp housed up to 58 people. Three helicopters were based at the camp to take people around the area. This enabled the establishment of satellite camps for a few days up to 180km from the main camp (Unnamed, 1979)

In January 1991 an overnight reconnaissance occurred at Diamond Hill for K081 (Howard-Williams, 1990/1991) with close helicopter support. Fuel dumps were deposited at Diamond Hill and Teal Island.

The same event was flown into Lake Wilson from Scott Base on December 1992 by 2 VXE-6 helicopters. This trip took 2.5 hours with fuel dump on Teal Island for return flight. It was a difficult landing near north side of Lake Wilson due to the bouldery terrain. Although the camp was in a protected basin, the large boulders made it hard for tent pitching. A note was made that it was hard to spot people and dome tents on this kind of terrain. The southern side of Lake Wilson is flanked by steep slopes, making access to the lake from this side difficult. However, the lake itself has a very smooth surface and does not develop much of a moat through the season (pers. comm. Clive Howard-Williams).

This group had problems with melting snow on their tents and poor HF radio communications with Scott Base (not sure if this was due to mechanical fault or not). Greywater was collected in containers and disposed of out of the Lake Wilson catchment (took 2 hours), and solid waste was returned to Scott Base (Howard-Williams, 1992/1993).

LC-130's and Bresslers have landed mostly close to Roadend Nunatak (e.g. K221 1988/89 and K062 2000/001).

K062 camped by Foggydog glacier (158° 35 E; 79° 48 S) at Erewhon Basin in December 2000. They had close Helicopter support for some hours to study the geology of the area, and were then left for 5 days before being flown back to Scott Base by helicopter. For radio contact, they used a repeater station installed south of the Darwin Glacier.

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