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The onset of deglaciation in the Larsemann Hills, Eastern Antarctica

J.S. BURGESS[1], A.P. SPATE[2] and J. SHEVLIN[3]

[1]Department of Geography and Oceanography, University College, University of New South Wales, Northcott Drive, A.C.T. 2600, Australia
[2]N.S.W. National Parks and Wildlife Service, 6 Rutledge Street, Queanbeyan, 2620 N.S.W., Australia
[3]Australian Antarctic Division, Channel Highway, Kingston, 7050 Tasmania, Australia

Abstract: The Larsemann Hills is an ice-free area of over 150 lakes that are not ice covered in summer. Despite being located at 69°30'S the area is not characterized to any extent by expected glacial indicators such as till, moraine or striations. Although the lakes show signs of evaporative lowering of water levels evolution to a saline state has not advanced to any great degree. While some evidence has been advanced to suggest only recent deglaciation (less than 10000yr BP) and large accumulations of ice (200–500 m) it is now suggested that the area has not been glaciated during the Wisconsin to the extent previously claimed. The paper reports moss deposits aged 24950 yrBP that are significantly older than those previously reported for the area.

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Introduction

The Larsemann Hills, an ice-free area of approximately 50 km^2, is located on the Ingrid Christensen Coast of Princess Elizabeth Land in Eastern Antarctica (69°30'S, 76°20'E). To the north-east of the hills are the Rauer Islands and the Vestfold Hills (Davis Station) and to the west-south-west are the Bolingen Islands and the Amery ice shelf (Fig. 1).

The area was not discovered until 1935 when Captain Klarius Mikkelsen in the *Thorshan* led an expedition for the Norwegian whaling magnate, Lars Christensen. Despite the early Norwegian interest in the area and a subsequent Australian National Antarctic Research Expedition (ANARE) led by Dr. Phillip G. Law in March 1954, few scientists visited the area until the recent establishment of an Australian summer base (Law Base) and the USSR (Progress) and People's Republic of China (Zhong Shan) Stations. The Australian base was begun during 1986 and coincided with the commencement of the building of Progress Station and, more recently, (January 1989) by Zhong Shan Station. The authors, jointly or severally, have worked in the area in all the austral summers since 1986–87 with the exception of the 1987–88 season.

While there is debate on the origin and definition of Antarctic oases, one characteristic common to all is the existence of lakes that are ice-free, or partially ice-free, during summer months. Such lakes in the coldest continent on earth have attracted considerable attention in recent years. Much of the literature is summarized by Heywood (1972, 1977, 1984), Burton (1981), Wright & Burton (1981) and Priddle (1985). It has been suggested that many Antarctic lakes follow an evolutionary sequence as deglaciation occurs (Priddle & Heywood 1980). Priddle (1985) has suggested that since deglaciation such lakes have evolved with age and frequently have become more saline. It has been suggested that climatic and the lake evolution changes are reflected in the stratigraphic record of the sediments and consequently considerable interest has been shown in such lakes particularly in a global warming context.

The purpose of this paper is to report observations made of some of the large number of lakes (> 150) that are major features of the Larsemann Hills Oasis, and to reconsider Pleistocene history of the area in the light of a new ^{14}C date on moss recovered from the shore of Lake Nella 2km from the ice plateau.

Physiography of the Larsemann Hills

The Larsemann Hills are a series of rocky peninsulas and islands in Prydz Bay. The broad regional geology has been described by Sheraton & Collerson (1983), Collerson &Sheraton (1986) and Stuwe *et al.* (1989). The area is a band of Proterozoic aged rock (by inference) suggested by Stuwe *et al.* (1989) to be predominantly meta pelitic cordierite and gneisses rich in Fe and Ti oxides. The basement rocks have been subjected to a complex metamorphic history with a number of deformation episodes (Harley 1987, Stuwe *et al.* 1989).

The Hills are dissected by steep sided valleys which are structurally controlled and reflect past glaciations. Patterned ground is relatively common and erratic boulders are scattered throughout the Hills. Glacial till, moraine deposits and glacial striations are uncommon. Scattered throughout the Hills are more than 150 freshwater lakes that vary in size from Lake Progress (10 ha and 38 m deep) to small ponds less than a few square metres in area and a metre deep. The lakes and ponds can be classified as supraglacial ponds, lakes and ponds in large rock basins and colluvium dammed ponds. Most are fed by meltwater from snow banks and some have well developed entrance and exit streams that flow persistently for about 12 weeks during summer months. A common feature of many of

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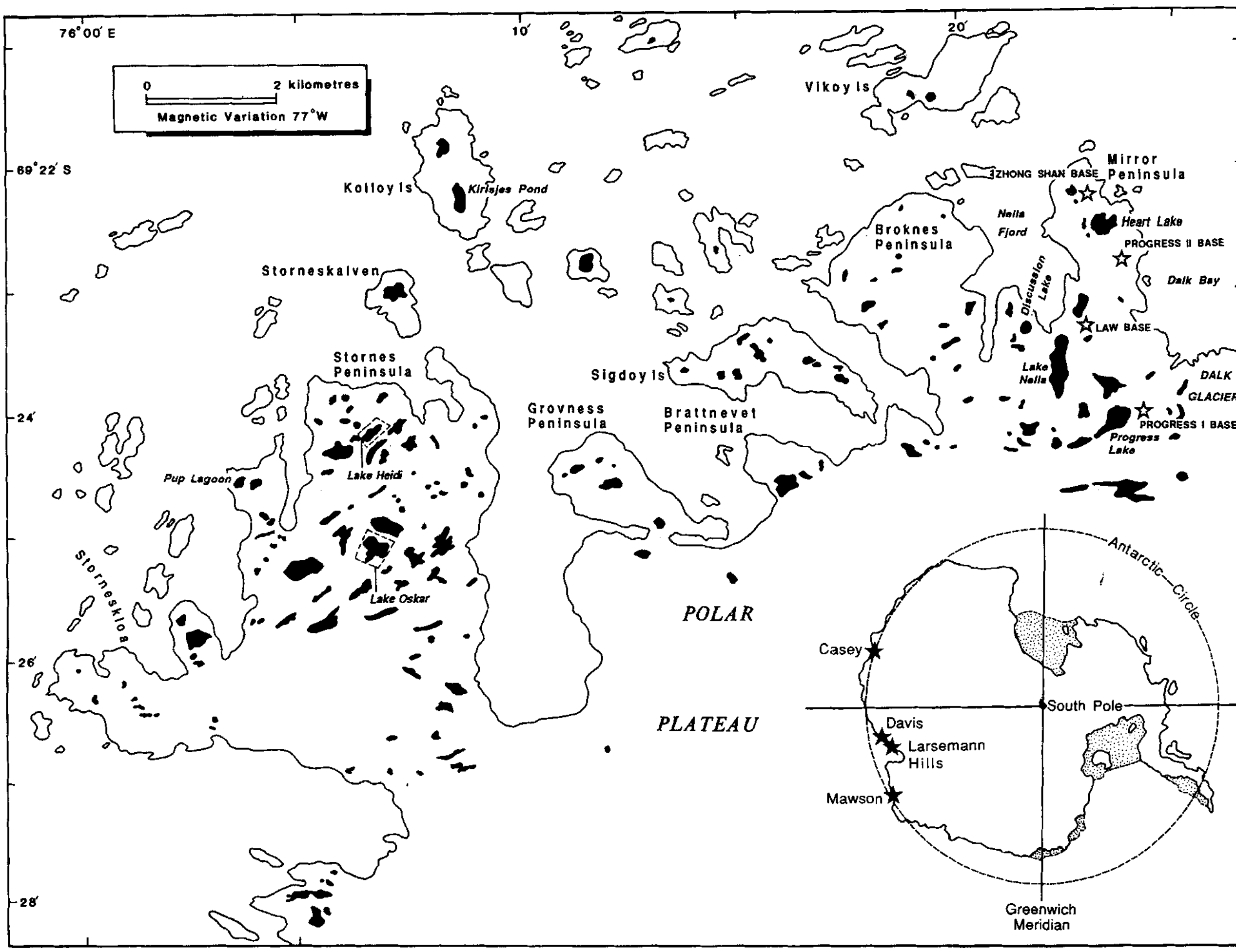

Fig. 1. Location map showing the Larsemann Hills.

the lakes is evidence of past shorelines up to two metres above present lake levels.

Drainage systems in the area are well developed with a number of streams that flow continuously during summer months. Second order drainage networks exist as do numerous outwash fan features. Present stream flows are generally low (usually less than 1 $m^3 sec^{-1}$) except in the case of ice dam collapse (in excess of 2 x 10^4 m^3 of water drained from Discussion Lake on 31/12/90) a process occurring in the Vestfold Hills (Gore 1992). Stream flows are, however, sufficient to rework sediments even at low flow and alterations to waterways resulting from station development and road construction are particularly apparent. An unusual feature of the landscape are large V-shaped valleys that generally connect lake systems to the coast. Normally they are 50–100 m deep and 500–600 m long and exhibit evidence of being substantially affected by freeze-thaw processes. At present their genesis is uncertain.The landscape is also characterized by landforms that have been modified by wind and salt weathering. Tafoni are widespread and can exceed of 100 cm in diameter and 60 cm in depth. Wind blown sand accumulates in snow banks and presumably in lake beds.

Methods

Initial observations of the Larsemann Hills Lakes were made in January 1987 and 74 lakes were sampled by helicopter for basic physical and chemical characteristics. Some of those results have been presented in Burgess *et al.* (1988) and Gillieson *et al.* (1990). Further water samples were collected in 1989, 1990, 1991 and 1992.Lake sediment cores were obtained for a number of lakes using a percussion corer deployed from an inflatable boat or, if ice cover permitted, from that surface. However, there is no certainty that the bottom of the sediment profile was reached using this method. Further lake sediments were collected from the edges of Lake Nella using a 'Jacro' drill rig and a lightweight post hole corer with thin walled diamond tipped core tubes that allowed penetration of the permafrost.

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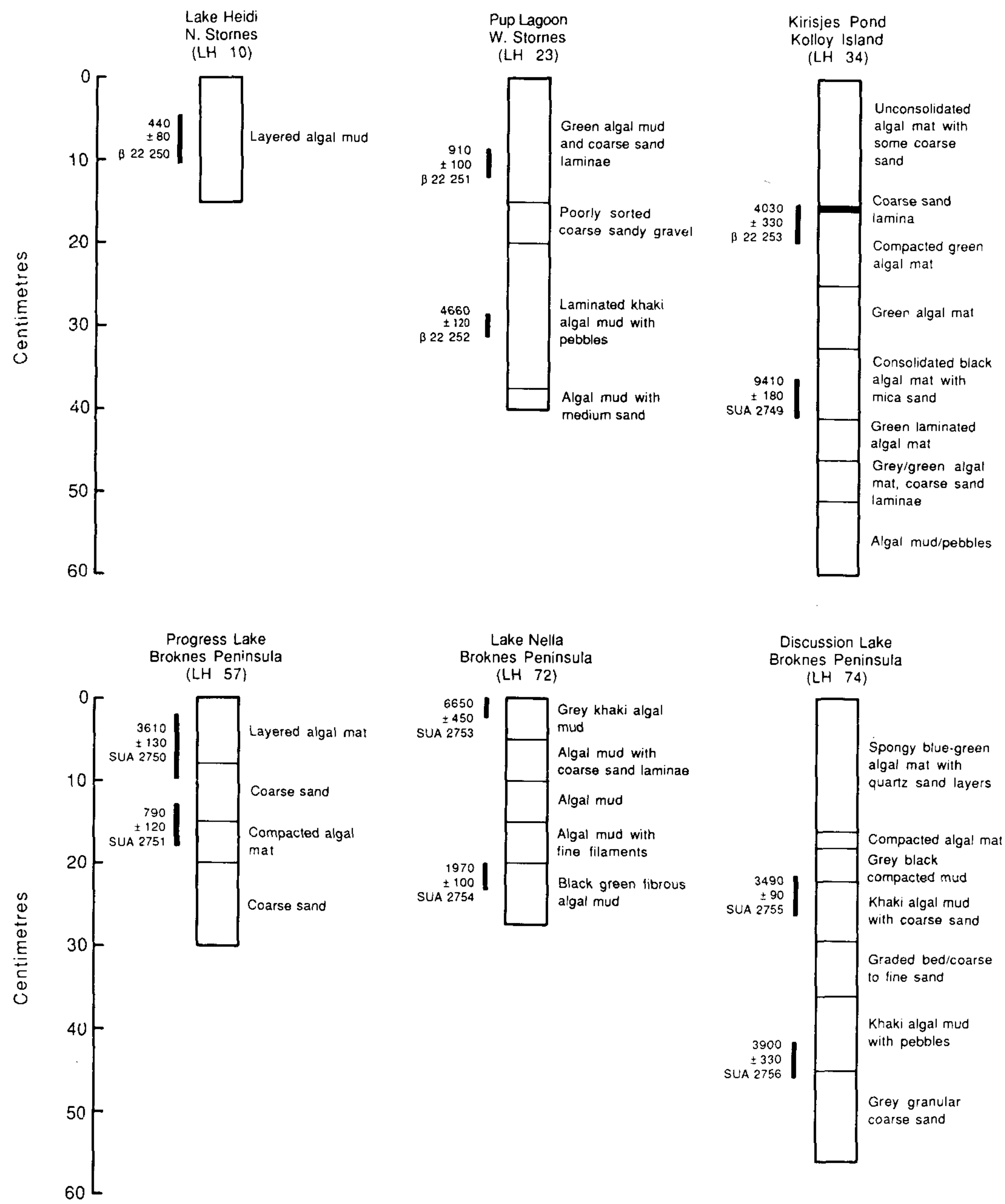

Fig. 2. Stratigraphy of Larsemann Hills lake sediments (Source: adapted from Gillieson *et al.* 1990).

Lake chemistry

Lake chemistry data (Gillieson *et al.* 1990) show that the lakes have low conductivities ranging from 14 mS cm^{-1} in an unnamed lake near the ice sheet on the western side of Stornes Peninsula to 3340 mS cm^{-1} in Sarah Tarn near Law Base on Broknes Peninsula. The mean conductivity values for the two major peninsulas varied substantially with that for Broknes Peninsula being 585 mS cm^{-1} while Storness Peninsula was less than half at 288 mS cm^{-1} although greater variation occurred within the peninsulas. A second feature of the water is the dominance of Na^{+}. Invariably in the Larsemann Hills the standard ionic order took the form of:

$$Na^{+} > Mg^{2+} \geq Ca^{2+} > K^{+}.$$

Conductivity variations occurring across the Larsemann Hills are considered to reflect the amount of freshwater input and/or the time elapsed since deglaciation. Generally the lakes on Stornes Peninsula have lower conductivities than those on Broknes Peninsula and those closest to the ice edge have lower values than those most distant. In the lakes pH generally mirrors conductivity with lower pH being associated with low conductivity.

During the 1986–87 summer season samples for stable isotope analysis were collected and analysed for the stable isotopes deuterium and oxygen 18 by Dr C. Barnes of the Division of Water Resources Research, Canberra. Results of that analysis are reported in Gillieson *et al.* (1990). It is suggested that since deglaciation little isotopic depletion has occurred which probably indicates large additions of melt water.

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Lake sediments

Sediment characteristics for samples collected as part of the 1986/87 season, when a light weight percussion corer was used, are shown in Fig. 2. Considerable variation within the sediments occurs from core to core, however, the sediments are generally mixtures of algal muds with sand laminae. The maximum accumulation of sediment was *c.* 60 cm found at Kirisjes Pond and Discussion Lake although there was no certainty that the basement of sediments had been reached. In other lakes sedimentary accumulations were either absent or less than 40 cm. Gillieson (1991) has described the sedimentary assemblages of Kirisjes Pond and Pup Lagoon, and suggests that they have evolved from, oligotrophic, proglacial lagoons to fresh or brackish lakes affected by periodic influxes of salt water from sea spray and surges produced by glacial calving. It is further suggested that the major changes have been due to the postglacial recovery of sea level. That evidence suggested that the nearshore islands in the Larsemann Hills were ice-free by 9500 yr BP with the present coastline exposed by 4500 yr BP. Lakes closer to the ice plateau were assumed to be younger.

The stratigraphic record in other lakes is more complex. In Progress Lake sediments dated at 3610 yr BP overlie sediments dated at 760 yr BP. In Lake Nella a date of 6650 yr BP was obtained for the upper 4cm of one core overlying sediment dated at 1970 BP located at *c.* 25 cm. Another core obtained from Lake Nella returned a date of 2800 yr BP for the top 8 cm of the core. Clearly no simple explanation of lake evolution can be deduced from the sediment cores. It seems likely that sediments have been subjected to reworking since deposition. Three mechanisms for that reworking seem possible. First, the lakes could have been subjected to glacial surges following the initial retreat. Secondly, ice dam collapse has the potential to release large volumes of water into lakes and could have the capability to rework the largely unconsolidated sediments. Thirdly, it has been observed that during winter and spring the algal mats break away from the lake bottoms aided by ice bodies that have been frozen to the bottom and are then moved about in spring by wind, leaving clearly defined tracks in the sediments. The detached mats float some distance, frequently being deposited on shore or are re-assimilated into the algal mats. Of the three hypotheses the second and the third are the most likely. Gore (1992) has documented ice dam failure in the Vestfold Hills in 1987 where 1.1×10^6 m^3 of water was released. In the Larsemann Hills Discussion Lake drained in 1990 and lake drainage has been seen by Russian observers. Similarly in the Larsemann Hills there is also ample evidence for higher lake levels in the form of raised beaches and the existence of lacustrine sediments above present lake level.

Sediments recovered from lake deposits on the northern shore of Lake Nella during the 1992–93 season add a new dimension to the sedimentary picture. At a site close to the edge of the present lake the permafrost was penetrated to a depth of 2.5 metres where drilling ceased. The upper 60–80 cm of the deposit was coarse sand mainly derived from Yellow Gneiss. The sediments were not frozen and were saturated with melt water. Sediments below 80cm were frozen (permafrost) and composed of sand and some organic matter. At the base of the core, which was beneath the surface of the present lake intact *in situ* moss was recovered, frozen, in the growth position. This material has been dated at 24950 yr BP ± 710 (ANU 8826). Sediment collected above the sample contained moss and other organic material and it is possible that older material is below, as bedrock was not reached.

Discussion

Gillieson (1990, 1991) has concluded from evidence from lake sediment cores recovered from Kirisjes Pond and Pup Lagoon that the outer islands and coast of the Larsemann Hills became ice free about 12000 yr BP with a progressive retreat of the ice sheet since that time. Complications to the sediment record as a result of reworking mean that many of the lake basins do not provide a simple sequential sedimentary record. The small sheltered nature of Kirisjes Pond and Pup Lagoon has meant that sediments deposited there have remained relatively undisturbed except that the nature of the biological processes could well mean that algae accumulations are continually being re-worked. If so simple stratigraphic interpretations of lake sediments would be almost impossible. The morphologies of the catchments of lakes like Nella, Progress, Oskar and Discussion are such that sediments could be reworked by glacial incursions or by high magnitude flows related to ice dam collapse. Numerous V-shaped valley features indicate either that subsequent to ice retreat fluvial processes of high magnitude have been an important landform process or alternatively that these features are relic and predate the most recent glacial phase. Some preliminary evidence does suggest that from time to time large flows do occur. Gore (1992) has demonstrated that in the Vestfold Hills significant flows have resulted from ice dam collapse. Similarly high flows have been observed in the Larsemann Hills and anecdotal evidence from members of the USSR expedition that wintered in the area in 1988 reported a 'wall of water' subsequent to such a collapse. A more definite interpretation of these features will, however, await a detailed examination of the sedimentary deposits associated with them.

The existence of moss at the edge of Lake Nella dated at 24950 yr BP casts very serious doubts on Gillieson's interpretation of deglaciation. While only one date is as yet available, the material submitted for analysis was well preserved moss recovered in the growth position, was of adequate size and free from contamination allowing confident dating leading to the suggestion that the area has been icefree for much longer periods than previously thought. This poses many more questions than it answers, however. Colhoun (1985) has suggested a maximum glacial advance of the Margaret glaciation in Tasmania to have occurred at 18 800BP in the King River that would be similar in age to maximum temperature lowering in other parts of the world. Colhoun has suggested that a substantial temperature reduction occurred soon after 30 000BP in Tasmania.

It seems likely that the estimated depths of ice suggested by Gillieson (1991) (200–500 m during the Wisconson glaciation) are overestimates. That there is no evidence of isostatic rebound is consistent with this. The suggestion by Colhoun(1991) and Colhoun *et al.* (1992) that the ice-sheet margin during the last glacial maximum was thinner and less extensive than previously thought would appear to be confirmed by the existence of moss of the age found in the Larsemann Hills at a time where previously it was thought that the area was covered with a substantial ice cover. Circumstantial evidence, such as the relative lack of raised beaches, till, glacial moraine and glacial straie support the contention that perhaps ice accumulation during the Wisconsin was small.

Lake chemistry data suggest that since deglaciation some lakes have been subjected to greater net evaporation than others although little major lake salinisation has occurred. The lakes on the eastern peninsula (Broknes and Mirror) generally having higher conductivity and sodium ion concentrations. This is supported by stable isotope analyses reported in Gillieson *et al.* (1990).

Gillieson (1990,1991) postulated that the Larsemann Hills started to become ice free about 10000 – 12 000 yr BP with the ice edge retreating to its present position in the last 200 years. This now seems simplistic in that there is little morphologic evidence for substantial ice accumulation and the existence of moss beds in the area *c.* 25000 yr BP, covered with sediments containing organic material, casts doubts on any suggestion that the area was covered with a thick and stable ice sheet. While it is possible to suggest that moss growth at *c.* 25000 yr BP may reflect an interstadial period in the Larsemann Hills it is also probable that during the Wisconsin glacial period the Larsemann Hills merely saw variations in snow and ice cover without expansion of the the major ice sheet. The existence of more substantial snow cover on Stornes Peninsula coupled with variation in conductivity of waters and the existence of evidence for higher lake levels suggests that the peninsulas on the eastern extremity have been ice free for longer than those in the west. The general overall low conductivities, however, suggest that the entire area is moist by Antarctic standards and that the process suggested by Priddle (1985) whereby lakes become progressively more saline with age, has not occurred to any significant degree.

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