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GEOLOGY OF POSSIBLE RUNWAY SITES IN THE DAVIS REGION, VESTFOLD HILLS, EAST ANTARCTICA

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ABSTRACT

Five possible runway sites have been proposed within 4 km of Davis on the northwestern part of Broad Peninsula, Vestfold Hills. Most are on thin, young, sedimentary sequences on low level flat areas, although two are dominantly on Precambrian basement, one of which is at low elevation.

This report reviews the geology of each site as a background summary for use by engineers in the event of a decision to build.

Permafrost level in the area is normally within 100 +/- 20–30 cm of the surface and appears to vary depending on location and proximity to water masses.

The report uses as much information as can be assembled from earlier dispersed reports and adds detailed grain size data from eight sites cored during the 1993–94 summer.

Stratigraphy of the sediment sections is not well understood and is best documented in the Heidemann Valley. Maximum sediment thickness known is about 4 m. All sediments appear to be younger than one million years and probably are much younger.

Speculation is given about the origin and significance of some of the features of the area.

1. INTRODUCTION

Reconsideration was given, in the 1993–94 Federal budget context, to developing a runway in the Davis region (Figures 1, 2) in support of fixed wing aircraft operations to complement a single ship transport option for the Australian National Antarctic Research Expeditions (ANARE). In the early 1980s and earlier, similar consideration had been given, but then in relation to intercontinental aircraft. The more recent focus has been on smaller aircraft equivalent to a de Havilland Twin Otter. Klokov (1996) has reviewed the potential for snow/ice runways as part of the larger alternative system.

Consistent with the requirements of the Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol), a Comprehensive Environmental Evaluation (CEE) of the air system proposal commenced but has been deferred until specifically required. It will need basic geological information on the likely conditions to be encountered in building any runway in the Davis region. This project was initiated to summarise existing information scattered through many unpublished reports, and to provide a geological overview taking advantage of the presence of appropriate geological expertise and equipment that would be in the vicinity during the 1993–94 field season. The 1993–94 studies involved field mapping, aerial photograph interpretation and coring.

The opportunity was taken to investigate the geology of the sediments underlying the surface of the flat floored potential runway sites and to gain information that will be of value in engineering aspects of runway development and environmental evaluation. In particular, information was sought on sediment type, thickness, depth to permafrost, and possible influences of sediment/water features on permafrost or *vice versa*. Other, more purely scientific, papers could emerge as a sideline. Other more detailed studies of part of the region are included in Gore (1997), Gore *et al.* (1994, 1996) and will come from those of Franklin (in prep.). The broader context is set by Barker (1995) and Quilty (1992). Lundqvist (1989) discussed some of the landform controlling factors in the area.

The significance of the study lies in the fact that any building on the runway sites in the Davis region would represent the first deliberate venture of Australian building activities into the realms of permafrost. Until now, even Antarctic building activities have been restricted almost entirely to basement sites where permafrost influence is negligible, except in some foundation preparation activities such as blasting and, in one case at least, where foundations thought to be on solid rock were, in fact, on permafrosted fill. It is essential that a firm knowledge base is developed before any deliberate permafrost building is initiated. The difficulties of engineering in permafrost are explored in Eyles (1983) and Williams and Smith (1991).

The area is covered in detail by helicopter colour aerial photography Run 6, photographs 14-17, and Run 7, photographs 4-7, of January 26, 1979, by ANTC 1011, Run 2, photographs 44-46, photographs on ANTC 1011 Run 3, and ANTC 1012 Run 1 of January 2, 1994, and by Australian Antarctic Territory, Princess Elizabeth Land, Vestfold Hills, 1:50 000, second edition, September 1982. There also are special maps produced by the Australian Construction Services (ACS and its predecessors) for activity in the area and in scientific publications, such as Pickard (1986) and Hirvas *et al.* (1993).

Initially, coring in 1993–94 was attempted using a JACRO rig on loan from the Australian Defence Force Academy, Canberra but this was not successful, and drilling continued with a portable percussion rig taken to the Vestfold Hills as part of another program. Unfortunately, because the percussion drilling unit was employed elsewhere initially, it reduced the amount of time that could be devoted to runway site drilling and only six new sites (three in Heidemann Valley *sensu stricto* and another three on the area north-north-west of Lake Dingle) were drilled. Table 1 summarises the location information for the cored sites. Earlier studies were based on a variety of techniques including hand augering, excavations using bulldozers or excavators, or hand dug pits. Samples taken during earlier studies are no longer available. Those taken in 1993–94 will be preserved.

Site	Latitude (°S)	Longitude (°E)	Core length (m)
HVDH-1	68°34.554'	78°0.062'	0.35
HVDH-2	68°34.554'	78°0.062'	2.00
HVDH-3	68°33.752'	78°2.931'	2.10
HVDH-4	68°33.694'	78°2.421'	2.00
HVDH-5	68°33.452'	78°01.964'	2.10
HVDH-6	68°34.462'	78°01.15'	0.80
HVDH-7	68°34.462'	78°01.15'	0.80
HVDH-8	68°34.776'	77°59.488'	1.20

Table 1. Sites cored in the Vestfold Hills runway sites region, 1993–94.

1.1 EARLIER STUDIES

Earlier investigations on engineering and geological aspects (very dominantly the former) are listed in Bailey (1977?) and include 1959, 1961, 1974 and 1975. No early geological reports specific to the area, other than published papers referred to herein, are available, although Bailey (1977?) refers to an earlier geologist's report which has not been located.

Wilson (1959) prepared a report, with abundant photographs, and identified three possible sites for use by aircraft from small multiengined to Super Constellation. He introduced the term Valley site for the modern concept. Other sites he considered were 'Local site' (less than 1 km northeast of Davis and including the beach), and Beach site (about 2 km northeast of Davis, probably partly equivalent to the modern Coastal site). The Valley site was considered suitable for Super Constellation aircraft. The report contains an appendix by I.R. McLeod on the geology which addresses only the Precambrian which it describes as charnockitic gneisses with basalt dykes.

Australian Construction Services (1984) was a more comprehensive study but did not refer to earlier studies even though prepared for the same organisation. DHC (1983A) and Australian Construction Services (1984) seem each to have conducted independent sampling in the area and on Figure 2, we have tried to compile the total program of coring, augering, and pit digging that has been done in the area as part of reports we have been able to find. A difficulty in presenting this information is the lack of coordinates for each site. The only reference is a location on a map. Details are contained in the above reports.

Australian Construction Services (ACS) prepared a summary of the site options for possible runways in the Davis region. Three (Valley, Coastal and Heidemann Bay sites) were identified in 1983 surveys as suitable, and a fourth (earlier termed the STOL site) was added at the request of the Director of the Antarctic Division. Two (Valley and Heidemann Valley) were the preferred sites following the analysis by Bailey (1977?). The locations of all options are shown on Figure 2, and three in more detail in Figures 2–4 in Airfield Construction Team (ACS 1984). As indicated by ACS (1993), centreline positions for each of the Valley, Coastal and Heidemann Valley sites were surveyed and pegged in 1983. Those pegged sites are still clearly identifiable through the presence of survey stakes. The STOL site has been neither surveyed nor staked.

ACS and its predecessors had conducted a significant amount of foundation drilling and analysis in the early 1980s for the three options it examined, but this was without formal coring (other than by hand augering) and the samples were not kept. Several unpublished reports on the investigations were prepared (see references). Test sites for vertical ground temperature profiles and runway foundation and surface materials have been established and preliminary results included in ACS (1984), but the interest in test results has not been maintained except by individuals.

While titles of many reports are mentioned in those included in the reference list, many have not been located, even after considerable search.

Five runway sites (Figure 2) have been recognised in various reports that have investigated the concept. They are:

- Heidemann Valley,
- Valley site, running due west from Lake Dingle,
- Coastal site, beginning 2 km northeast of Davis and running northeast,
- North West Alignment of Bailey (1977?) running northwest from Lake Dingle to the coast (also termed in part the 'Borrow Area' of DHC (1983A), and
- STOL site, running northeast beginning about 0.5 km NE of Davis.

1.2 FOUNDATION MATERIAL

This report addresses mainly the sediment section but construction of a runway will require foundation material calling for a significant volume of aggregate which will have to be either imported or crushed locally. Economics suggests that the latter would be the more obvious solution and the source will be the local Precambrian rocks, described by Collerson and Sheraton (1986). The distribution of these rocks in the northern part of the area is shown in Figure 3. These consist of gneisses and dolerite, which will behave very differently in engineering terms. Both are abundant and it is a simple matter to calculate required volumes and sources of either of these rocks. Some test beds for this material as runway aggregate already exist in Heidemann Valley (but whether or not the rock types are differentiated there is not obvious). These should be reexamined to investigate the suitability of the local rocks. At first glance it could be assumed that the gneisses are more readily weathered and that the dolerite is more resistant to chemical weathering. This is consistent with some test results (Spate *et al.* 1994) based on measuring weathering rates. It is an engineering question to examine the type of product needed for the runway base but the geologist can help. Bailey (1977?) reviewed approximate volumes required for the options he examined.

Another potential source is the coarse boulder till which overlies much of the area and which would have to be cleared from any potential site.

1.3 GENERAL GEOLOGY OF THE AREA

The region can be divided into higher standing Precambrian basement and lower level, approximately flat, valleys, some of which are boggy or contain shallow lakes and ponds. The areas are differentiated on Figure 2 and Figure 3. The Precambrian is not the subject of this study and will be discussed no further except where specifically relevant (eg Figure 3). The geology of the Precambrian rocks was reviewed by Collerson and Sheraton (1986) and in Tingey (1991). Hoek (1994) and Lanyon *et al.* (1993) are examples of papers that documented specific aspects of some of the rocks in great detail. Gore *et al.* (1994) has provided a convenient summary of studies on the younger sections.

The lower level areas are generally below 10 m a.s.l. and in places are below sea level. Four of the five sites identified as possible runways are on the lower level valleys and are indicated on Figure 2.

The lower level areas are underlain by sedimentary sequences discussed in part by Hirvas *et al.* (1993) and by Gore *et al.* (1994). Sediment type, distribution, age, thickness variation, and environment of deposition are all very poorly understood. It is not known whether all the sediments are part of the same depositional event(s) but it is unlikely.

Lake Dingle has no role in the siting of a runway but acts as a boundary between the main contending areas and has been cited as a feature under threat of pollution from exhaust emissions should a runway be installed. Its surface lies at 8.9 m below sea level.

Lake Dingle lies at the intersection of two marked linear features (Figure 1). One trends east-northeast from Heidemann Bay as Heidemann Valley and its extension to the northeast of Lake Dingle—the Death Valley System (Korotkevich 1958, Adamson & Pickard 1986B). The other trends northwest and southeast of the lake. To the northwest it marks the southwestern side of the hills north of the Lake and to the southeast is marked by a small 'river' valley which drains into Lake Dingle, and its extension, even across Ellis Fjord where it may mark the northeastern side of Poseidon Basin. Although not discussed in detail anywhere, this lineament appears to mark the boundary between two fundamentally different geomorphic aspects of the Vestfold Hills.

To the northeast, the Hills are higher, more rugged and with a stronger north-south orientation suggesting more recent emergence from under a glacial load. The difference also is evident at times of the year when the area to the southwest is snow free and that to the northeast still with a significant snow cover. The nature of this linear feature is not obvious but it may mark the position of a significant shear zone parallel to several others in the area, occasionally coinciding with the position of early, wide dolerite dykes.

Although not directly relevant to this study, another such northwest-southeast trend extends from the southwestern ends of Partizan and Soldat Islands, through a valley to Deep Lake, and continues through a line of small lakes and valleys, almost to the southwestern end of Crooked Lake. Again, the land to the northeast seems higher, more rugged and even more recently emergent from under the icecap.

2. HEIDEMANN VALLEY AND THE HEIDEMANN VALLEY SITE

Heidemann Valley is one of the sites being considered for a runway/hangar facility in support of fixed wing aircraft operations, originally discussed in the context of commencing in 1995–96. The area examined is shown on Figure 2 and in some detail in Figures 4 and 5. It extends from the shore of Heidemann Bay immediately southeast of Davis 2.9 km on a bearing of 69°57'22" (True) to Lake Dingle. While the area being considered for runway development constitutes only a small part of the area covered by the figures, the opportunity was taken to gather information on the broader setting and history of the valley. The potential runway is 1200 m according to Bailey (1977?).

Hirvas *et al.* (1993) used variations in the position and scale of the Sørsdal Glacier to explain some of the features of the glacial sediment. Because of the scale of activity and the distance from the present Sørsdal Glacier, we prefer not to refer to the Sørsdal Glacier as operating in Heidemann Valley but to regard any glacial activity as being related to a separate glacier that operated in the valley. If the scale of glacial activity is larger, we prefer to regard that as part of the icesheet, not any individual glacier, similar to the views of Gore (1997).

2.1 LANDFORMS

Heidemann Valley is a narrow, straight feature parallel to the foliation of the Precambrian gneisses. West of Lake Dingle (Heidemann Valley *sensu stricto*), it is covered by a layer of evenly distributed, very coarse boulders ('boulder till' of Adamson and Pickard 1986A), usually up to about 1 m in diameter but rarely much larger, formed into a series of ridges that cross the valley. Some boulders are facetted and striated and attest to a glacial source. The Precambrian rocks bounding the Valley are rounded and some, especially the dolerite dykes, have preserved glacial striations indicating ice flow to the northwest consistent with the directions of the Vestfold Glaciation of Adamson and Pickard (1986A). The eastern end of this part of the valley is marked by a ridge up to 13 m a.s.l. which is concave to Lake Dingle and clearly part of the 'modern' history of Lake Dingle.

Where the extension of Heidemann Valley lies east of Lake Dingle, it is very different. Here the Precambrian rocks are very fresh, clearly 'recently' glaciated and retain their fresh glacial landforms. Snow accumulations remain east of Lake Dingle long after they have been removed from the area to its west. The contrast is very marked.

Transversely Heidemann Valley is a flat floored valley but along azimuth it consists of series of steps separated by transverse basement ridges or old beach positions with both beach deposits and beach ridges preserved (Figure 4). Ridges are steeper and appear to be less altered towards Heidemann Bay. The surface altitude rises gently but irregularly towards Lake Dingle from the beach in Heidemann Bay to about 13 m a.s.l. near Sentinel Knoll. The valley length between Heidemann Bay and Lake Dingle is 2.9 km. The valley can be divided along length into three shallow flat floored basins (usually with shallow lakes or ponds in them) separated by basement ridges or old beach ridges. The profile along the valley is shown on Figure 6 and the three basins are indicated thereon. A normal valley width is about 400 m. The contact between the sediments that fill the valley and the Precambrian basement is straight and parallel on both sides of the valley with a trend identical to that of the valley itself, indicating the valley originated by glacial action. The age of the origin is not known and it is likely that it has been subject to several episodes of glaciation.

The profile along the valley (Figure 6) is consistent with land rising steadily at a rate of 1-1.5 mm/ year (with sea retreating relatively), corresponding to the figure identified in Adamson and Pickard (1986A) over an interval of about 8000 years.

Much of the eastern extension of Heidemann Valley is occupied by Lake Stinear which is separated from Lake Dingle by basement and a moraine ridge. The surface of Lake Dingle is at -8.9 m and that of Lake Stinear at -13 m. Lakes Dingle, Stinear and others to the east constitute part of the Death Valley System of Korotkevich (1958) and Adamson and Pickard (1986B).

It seems that Heidemann Valley and its eastern extension have had very different 'recent' histories, even though they may have a common earlier origin.

2.2 SEDIMENTS

Heidemann Valley was studied in early 1989 by two Finnish scientists and resulted in Hirvas *et al.* (1993) which summarises what is known of the geology of the area to this time.

That paper was based on study of sediments excavated in one exposed section about 1 m thick, and three test pits dug by excavator to a maximum of 4.5 m, the maximum to which the machine would work, but also, probably, to basement. All sections were on the northern side of the valley or near Heidemann Bay and thus did not provide an adequate coverage of the information available in the entire valley. All excavations were confined to one of the three flat floored areas, in this case the one nearest Heidemann Bay. Nonetheless, the information gained allowed Hirvas *et al.* to recognise two sedimentary sequences and to define an upper and a lower till unit separated by waterlain sediments. Each unit contains diverse fossil evidence indicating deposition in a marine environment deep enough to allow ingress of planktonic organisms such as diatoms, foraminifera, silicoflagellates and radiolaria.

The lower till was named the Heidemann Till and the upper till the Vestfold Till. Neither name was formally defined and must be taken at this stage as informal. If considered worthwhile, these will be defined formally following this project and the required information passed to the Australian Geological Survey Organisation (AGSO) which is the formal repository for stratigraphic units defined under the Australian Code of Stratigraphic Nomenclature.

The upper till is some 2 m thick and the lower till about 1.5 m. The upper till includes the surface of Heidemann Valley but it is highly modified by surface activity in the zone to about 1 m depth which is the zone above permafrost where the ground is frozen in winter but unfrozen in summer.

Figure 7 is a stratigraphic section along the valley, incorporating data from the Heidemann Valley drill holes of 1993–94 in addition to those from DHC (1983A) where those holes were close to the site of the runway. A few holes near the valley edge have been ignored on that section. That section indicates that the lithological and facies variation is greater than suggested by Hirvas *et al.* (1993). Perhaps three relatively continuous units can be recognised and a few others that are less continuous, perhaps lenticular. The lowest unit, only seen in the bottom of HVDH 8 and HVDH 1,2, is of sandy gravel with cobbles and boulders. Above this, about 1 m thick, is a finer unit of silty sand and clay. This occurs in all holes except HVDH 8. Above this is a unit of gravelly sand with varying amounts of clay and silt. In places there is a thin unit of sand above this.

The age of the marine sediments in Heidemann Valley was stated by Hirvas *et al.* (1993) to be 300 000 to 1 million years old but there is scope for reconsidering this estimate should new, better information become available. Reworking of shell material from these sediments is likely to be the source of such material, reported as >33 000 years BP and thus beyond the range of radiocarbon dating (about 40 000 years), found in moraine on the southeastern side of the valley and reported by Pickard (1985) and Adamson and Pickard (1986A). Samples of shell material have been selected for further dating using U/Th and Sr techniques at University of Queensland and results will be published elsewhere.

Although the sediments underlying Heidemann Valley *sensu stricto* are marine (Hirvas *et al.* 1993), the coarse surface glacial sediments are devoid of any specific evidence of a marine influence such as the bivalve *Laternula elliptica.* Similarities in rock type, distribution and elevation all suggest that it is the same age as material widespread in the Vestfold Hills below 15 m a.s.l. that has been reliably dated, for example immediately northwest of Lake Dingle, as 8–5000 years BP (Adamson and Pickard 1986A) and deposited in marine conditions, probably from icebergs in fjord conditions, and later modified by beach processes as the land rose isostatically.

One site was drilled in each of the three basins of the valley to a maximum depth of 2.55 m. All three 1993–94 Heidemann Valley holes (HVDH) were drilled and cored along the centreline of the 1983 survey. The location of each cored drillsite is shown on Figure 2 and the stratigraphic section for each hole drilled, and that derived from other references, is shown in Figure 7. Further sample details are given in Appendix 1. It is difficult to correlate the sections identified with those recorded by Hirvas *et al.* (1993) but it is possible to distinguish an upper, less variable section, from a lower more variable one.

The area was the site of hand auger sampling to a maximum depth of 1.39 m at sites H42–H46 (Department of Housing and Construction 1983A). Basic analyses are also contained in that paper and the sites shown on Figure 2.

A summary of the history of Heidemann Valley and its eastern extension seems to be:

—erosion of Heidemann Valley and perhaps the Death Valley System
—filling of Heidemann Valley with marine sediment in one or two intervals of deposition
—glaciation in the Death Valley System during the Vestfold Glaciation, but probably not west of Lake Dingle
—retreat of the ice (approximately 8–5000 years ago) allowing shallow marine conditions to enter an elongate Heidemann Bay which then extended beyond Lake Dingle in the Death Valley System
—retreat of marine conditions, isolation of Lake Dingle and development of concave-to-the-sea beach ridges and interridge 'flats' along Heidemann Valley as land rose and the beach line migrated to the southwest
—desiccation of the isolated water bodies to produce the present lake surfaces well below sea level.

Orientation studies of pebbles in the till show that the dominant iceflow direction recorded in the till clast fabric (Hirvas *et al.* 1993) was from the east-northeast.

2.3 PERMAFROST

Two investigation have provided data relevant to this topic. Sampling was performed in December–February and thus the depth probably represents a figure close to the maximum for the year. Local controls on depth to permafrost include the thermal inertia of adjacent lakes. Major lakes will depress the permafrost near them.

DHC (1983A) bored and hand augered sites H42–46 (Figures 2, 7) in the centre of Heidemann Valley and H51, 52 on the northwestern margin close to the coast. H46 entered basement at about

47 cm. Permafrost was recorded at variable depths from 33–118 cm, most nearer the deeper level, suggesting that the permafrost level in Heidemann Valley is at about 100 cm or a little deeper. Data are too few to allow any trend to be identified.

ACS (1984) also conducted excavations specifically looking for permafrost. The report also refers to the results of a series of test pad temperature profiles. These studies are more specific than those of DHC (1983A) and suggest a deeper permafrost, averaging 130 cm with a range from 105 to over 300 cm.

3. LAKE DINGLE NORTHWEST TO THE COAST

This area is much larger than that of Heidemann Valley and has been identified as the location of three possible long runway sites—one (North West Alignment site of Bailey 1977?) from Lake Dingle northwest parallel to the edge of the Precambrian hills; the second (Valley site) due west to the coast from Lake Dingle; the third (Coastal site) along the coast from Airport Beach near Davis to near Law Cairn, parallel to the direction of the prevailing wind. The locations of these possible sites are indicated on Figure 2. The possibility has been raised of a shorter runway crossing the area at its widest. Figures 8–11, also included in ACS (1984), give detailed survey information for the Valley Site and Figures 14–18, from the same source, equivalent data for the Coastal Site.

3.1 LANDFORMS

From Lake Dingle, two low, flat areas extend to the coast and form a rough Y with the base immediately west of Lake Dingle. One arm of the Y is west-north-west (marking the Valley site) to Airport Beach and the other is north-north-west (the North West Alignment site) in the direction of Plough Island. Each is about 2.25 km long, sharing the same 0.75 km wide base immediately west of Lake Dingle, tapering to the coast where each is about 0.3 km wide. The upper arms of the Y are separated towards the coast by an area of outcrop of Precambrian rocks to an elevation of a little over 30 m. At its southeastern extremity, this outcrop of Precambrian has a right angled margin, one side of which provides an approximately straight western margin to the North West Alignment site, and the other provides an approximately straight northern margin to the Valley site.

The area is crossed by a series of low ridges but these are very different from those that characterise Heidemann Valley. The Heidemann Valley ridges have a core of Precambrian rock or are old beach ridges becoming progressively much higher inland and are concave towards Heidemann Bay (the coast). The area to the northwest of Lake Dingle is marked by straight, very low, subtle ridges a little oblique to the valley sides and parallel to the prevailing northeast wind direction and probably owe their origin to the wind. There is no evidence of a Precambrian core to the ridges of the North West Alignment site but there may be Precambrian at very shallow depth under the western half of the Valley site.

Each site has an altitude of about 5 m near Lake Dingle. The North West Alignment site slopes rather uniformly to the beach with a common altitude of about 2.5 m a.s.l. The Valley site is markedly different, sloping initially away from Lake Dingle to an altitude of 2.5 m halfway along its length. It then rises for about 300 m over a shallow ridge at 5–5.5 m before dipping again to the beach.

4. VALLEY SITE

The Valley site (azimuth 90°10'25") was not examined in detail because of time and equipment constraints but it seems to differ from the North West Alignment site in having a higher elevation, better drainage and probably thinner sediment cover over Precambrian rocks. A good description of the site is contained in ACS (1983A). It is a low level, low relief, very gently undulating area of poor drainage. At its eastern extremity it slopes steeply to Lake Dingle. There are lakes or swampy areas north and south of the runway in the centre but these do not impinge on the runway site itself. They indicate that in summer, water may be a problem and that special account may have to be taken of this feature.

The western end overlaps with the southern end of the Coastal site and slopes gently to Airport Beach. Thus its western half is probably similar to the Coastal site in engineering terms. Bailey (1977?) indicates it could be the site of a 1800 m runway. DHC (1983A) provided a great deal of hand auger information on sediment thickness and type, permafrost etc, and ACS (1984) gave very detailed locations of excavation sites, contour data and more auger/excavation data. The relevant figures from ACS (1984) are reproduced as Figures 8–11 (Figure 8 is in common with discussion of the Coastal site). A profile along the Valley site is shown in Figure 12.

The centre of the site seems to have basement close to the surface, but sediment thickness appears to be greater at each end. More drilling is required where sediments are thicker.

DHC (1983A) and ACS (1984) contain the logs of hand auger and excavated pits along the site (Figure 2), usually only to about 1.2–1.5 m. There is a stratigraphy that emerges. Generally the upper 30–40 cm consists of brown and grey gravelly sand, with or without 'fines' and occasionally with shells (probably *Laternula elliptica* representing the uncorrected 5600–6600 years BP date recorded in Adamson and Pickard (1986A)). This upper unit has very few cobbles, contains shells from the coast to approximately 1100 m along section, and again near Lake Dingle. It seems to be similar along section and is dominantly marine. Below the upper unit lies a thicker unit, usually about 80 cm thick but actually to the bottom of the sampling. It is described as dark grey silty sand with varying plasticity, perhaps reflecting a variable clay content. Shelly fossils are recorded in one site only and then near the top of this unit. Gravel is common and there are scattered pebbles and cobbles and sporadic lenses or pockets of sand. The cobble concentration seems higher in the centre of the section and nearer the coast. Near Lake Dingle they are rare to absent. It is less well sorted than the upper unit but may be better sorted towards Lake Dingle. It contains evidence of marine deposition in one locality only. In addition to the more continuous units, there are places along section where distinctive lenses can be correlated between a few auger holes. They do not extend more than a few hundred metres. Figure 13 is a compilation of the sections recorded in the reports.

4.1 PERMAFROST

According to the results contained in DHC (1983A), depth to permafrost varies systematically along the site. At each end, the depth is about 80–95 cm, but in the middle, in the vicinity of H15, it is deeper, about 115 cm. To the north of the site in holes H22–25, it is even deeper, perhaps 130 cm. This is an area of meltwater lakes and swamp and the deeper permafrost may represent the influence of thermal inertia of such water bodies.

The ACS (1984) report refers again to deeper permafrost but it is difficult to relate the depth to specific areas. Generally the estimate therein is about 50 cm deeper than in DHC (1983A).

5. NORTH WEST ALIGNMENT SITE

The North West Alignment site could support a 1700 m runway (Bailey 1977?) with an azimuth of about 137°. It is 1–1.5 m higher on the western than on the eastern side and the eastern side is marked by a series of five small shallow ponds or swampy areas of internal drainage. The pond/swamp surfaces are progressively lower towards the coast. Each is flat floored, about 200 m across, and where elongate, that is parallel to the prevailing wind. They appear black on aerial photographs. These ponds/swamps lie very close to major snow drifts and to the ends of valleys in the Precambrian rocks immediately to their east. Much of the water for these swamps appears to come from these valleys and snow drifts. This area is very wet in summer and in the central drill hole (HVDH4) which recovered a grey clay section, the permafrost was not encountered until about 2.5 m indicating that the amount of water provides a thermal inertia which prevents the permafrost from reaching to shallower depths.

5.1 SEDIMENTS

Three sites (HVDH3–5) were drilled near the centreline of the North West Alignment site, one near Lake Dingle, one about halfway along it and one near its coastal end. Locations of the drillsites are shown in Table 1 and on Figure 2, and the lithology of the sections, including DHC data, is depicted on Figure 14.

Very little is known about sediment lithology or thickness distribution in this area. Sites HVDH3 and 5 drilled until drilling encountered substrate that prevented further penetration. Whether this was a large boulder or basement is not known. The central site was drilled to 2.1 m. Details of the samples from each site are contained in Appendix 1. DHC (1983A) gave data for hand auger sites H26-32 for maximum depths to 1.4 m (Figure 2). This depth may not be basement but the depth at which further hand augering became impossible. Sediment thickness to several metres should be anticipated in future work. Figure 14 illustrates what is known of stratigraphy. Unfortunately, not enough coring has been done to allow meaningful comment on the stratigraphy.

The surface sediments of the North West Alignment site contain abundant *Laternula elliptica* in living position, and in the Lake Dingle and Death Valley System area these have been dated using radiocarbon techniques, at 4700–6600 years BP, subject to a reservoir correction which could reduce these ages by about 1300 years (Adamson and Pickard 1986A). 'Sea shells' were also encountered in hand augering noted by DHC (1983A) but not by others investigating the area. *Laternula elliptica* was living in sandy seafloor while or shortly before the surface layer of coarse boulders was deposited. This judgement is based on the presence of large dropstones sitting on *in situ Laternula*. Other algal/serpulid crusts seem to have grown on, and have been disrupted by, such dropstones indicating that icebergs, sea-ice or fjord ice were present over the area during and after the deposition of the sandy sediments and were responsible for dropping the stones as it melted. These sediments accumulated in a normal marine evironment. *L. elliptica* can tolerate hypersaline conditions, but in this area it is accompanied by echinoids, gastropods (limpets and quite large coiled forms), indicating that there is no evidence of hypersaline conditions at the time, in marked contrast to the situation that prevails in Lake Dingle and other lakes of the Death Valley System today (Deep Lake is approximately 10 times normal marine salinity—*L. elliptica* does not live there!).

5.2 PERMAFROST

DHC (1983A) presented the results of hand augering at sites H25–32, and pits P1 and P2, concentrated about halfway along the site. Permafrost was encountered in a narrow range of depths, 55–85 cm, usually towards the lower part of the range. This is in conflict with the comments above about the 1993–94 drilling results which suggested a deeper permafrost in places.

6. COASTAL SITE

The Coastal site (azimuth 34°18'18") was examined by walking along its length. It is dominantly on basement with a thin sediment cover in places. It was not drilled because of time constraints. Bailey (1977?) and ACS (1984) have slightly different concepts of the location of the centreline of the proposed runway, but the difference is irrelevant to discussion of the geology. The Bailey model is completely on what is presently land, except for a small fill in a bay for support facilities. The southern end of his model lies on the small knoll of Precambrian basement immediately north of Airport Bay Beach and the azimuth is 45°. The ACS (1984) version has its southern end offshore, south of the end of Airport Bay Beach. Details of survey information are shown in Figures 8, 15–19.

In either version, it has been chosen carefully to avoid involving high ground and excavation. Thus, while low in elevation (0.5–6.5 m), much is on basement. A profile along the Bailey version of the site is shown on Figure 20 and another is contained in Bailey (1977?). Bailey (1977?) indicates that it is potentially the site of a 2900 m runway.

DHC (1983A) presented the results of analyses of material obtained by hand augering at sites H53–55. These encountered Precambrian bedrock at depths of 50–75 cm with a thin veneer of sediment or broken or weathered rock. No evidence of marine influence was found in the sediments. These sites, unfortunately, were located where a brief examination of aerial photographs would indicate that sediment would be very thin, that is, they are all situated where Precambrian outcrops or is very close to the surface.

ACS (1984) conducted a much more comprehensive investigation including digging of many test pits along the length of the proposed runway. Under the Airport Beach end of the site, sediment thickness is about 2.5 m. Elsewhere, where basement is not exposed and sediments could be expected, the maximum pit depth was 3.2 m, usually about 1.5–2.0 m, but it is not clear whether or not basement always was reached. This needs to be examined further.

Like the STOL site, the Coastal site could be expected to provide much of the fill required for construction, by removing the tops of hills adjacent to the proposed runway.

6.1 PERMAFROST

In the DHC (1983A) report, permafrost in the basement was encountered at 75–80 cm in two of the three holes. No record was made for the third.

The more comprehensive report of ACS (1984) again suggested a generally deeper permafrost, from 80–320 cm. It also commented on the impact of water mass thermal inertia in depressing the surface of permafrost, so that areas where significant sediment exists could be expected to have a deeper permafrost. For much of the runway length, permafrost would not be the problem for this runway site that it would for others, but in the areas underlain by sediment, it needs careful study before any building commences.

7. STOL SITE

The STOL site, suggested because of its potential use by STOL aircraft, lies on Precambrian basement running northwest from the station limits for 1.2 km (Figure 2) at an azimuth of about 40°. Most lies at 10 m or more above sea level but, at the northeastern end it is lower and may include some sediments over bedrock.

The southwestern part of the site is on Precambrian rock and was not examined as part of the 1993–94 exercise. DHC (1983A) listed results of hand augering to depths usually less than 1 m at sites H33–41. H36 penetrated to 1.2 m, perhaps including a genuine sediment section. Although not examined, it would appear that most of the section augered was of weathered and broken bedrock and not part of a sedimentary sequence. The exception is at the northeastern end.

Permafrost was recorded at 74–110 cm but, like the Coastal site, permafrost is not likely to be a serious problem.

If this site is to be developed for STOL aircraft, it could be designed in such a way as to be self contained for foundation rock.

7.1 PERMAFROST SUMMARY

As indicated elsewhere, permafrost is a feature of the region and is likely to be an engineering problem, more so in sediments. When building on basement, care should be taken to ensure that the building is on basement rather than on large boulders in sediment. On the STOL site, sediment cover is thin or nonexistent and the basement readily accessible. Permafrost under these conditions seems to be shallow, usually at about 70–80 cm.

The Coastal site is complex as it is a mixed basement/sediment site and care would be needed to avoid problems in areas where sediment cover is up to 3.2 m or more and the depth to permafrost very variable, partly controlled by water mass thermal inertia. Permafrost here seems to vary from about 80 cm on basement to as much as 320 cm on sediment.

In the sediment covered sites the situation is more complex. The permafrost surface usually lies at about 70–85 cm but there are two areas, one on the eastern end of the Valley site, and another immediately north of the Valley site and a little west of centre, where the permafrost surface lies at deeper than 1 m, even to 1.3 m or so.

Sediment thickness is generally greater than depth to permafrost and the permafrost surface will move both seasonally and as a result of engineering works altering the thermal regime. Engineering work will then have an impact on a thickness greater than the depth to permafrost.

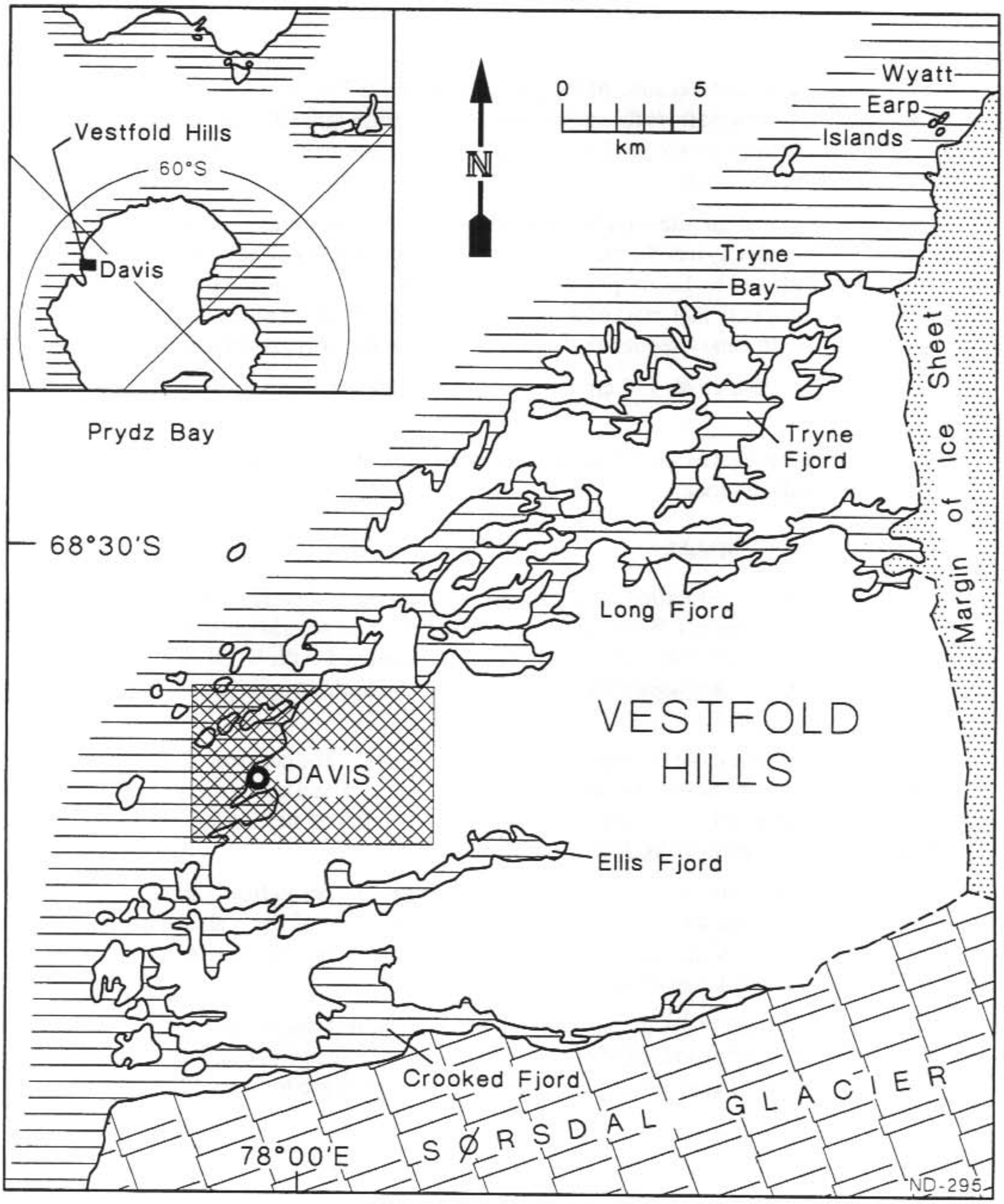


Figure 1. Locality map of the Davis area, the study area crosshatched.

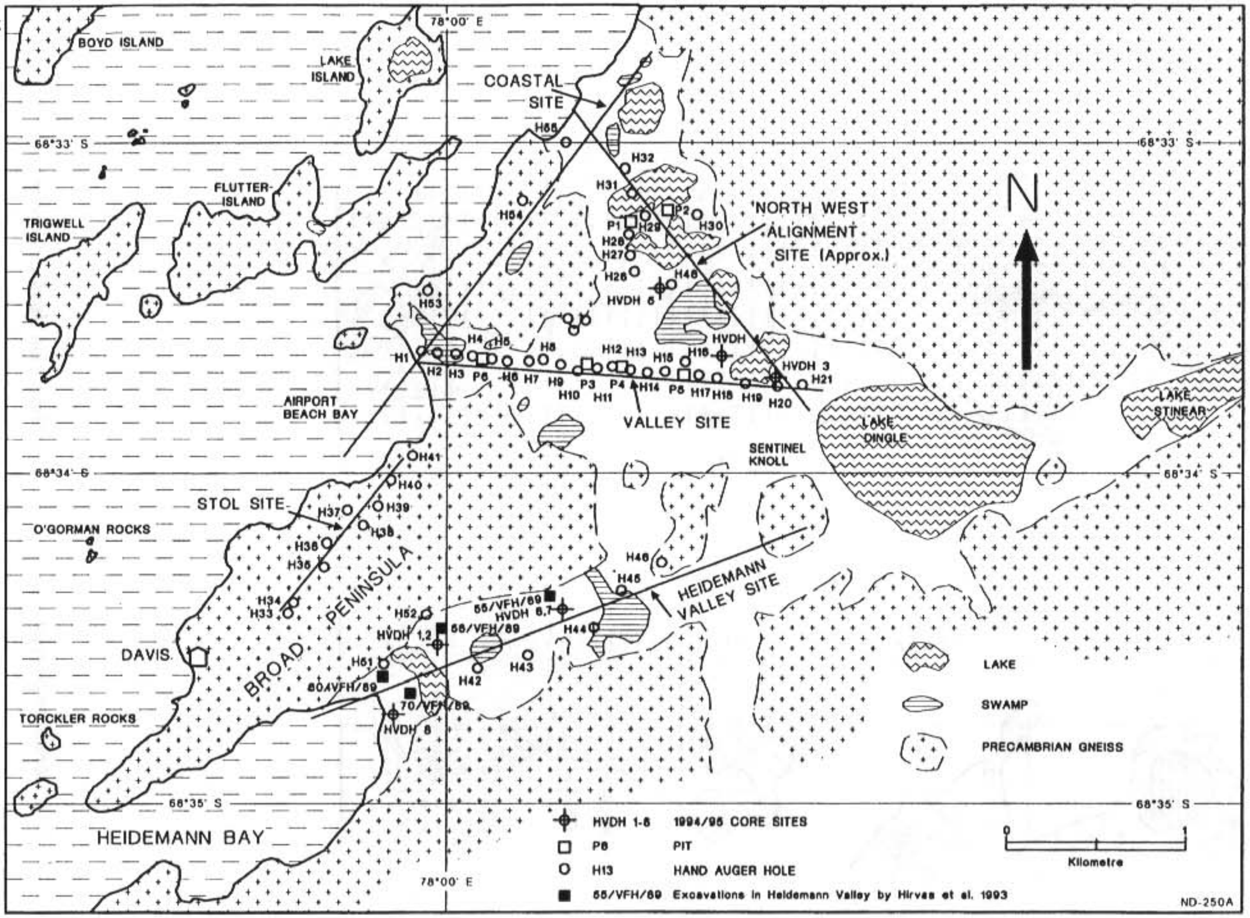


Figure 2. General geology, potential runway sites, sample localities DHC (1983A) (H and P), 1989 sites of Hirvas et al. (55/VFH/89 etc) and 1993–94 drillsites (HVDH 1–8).

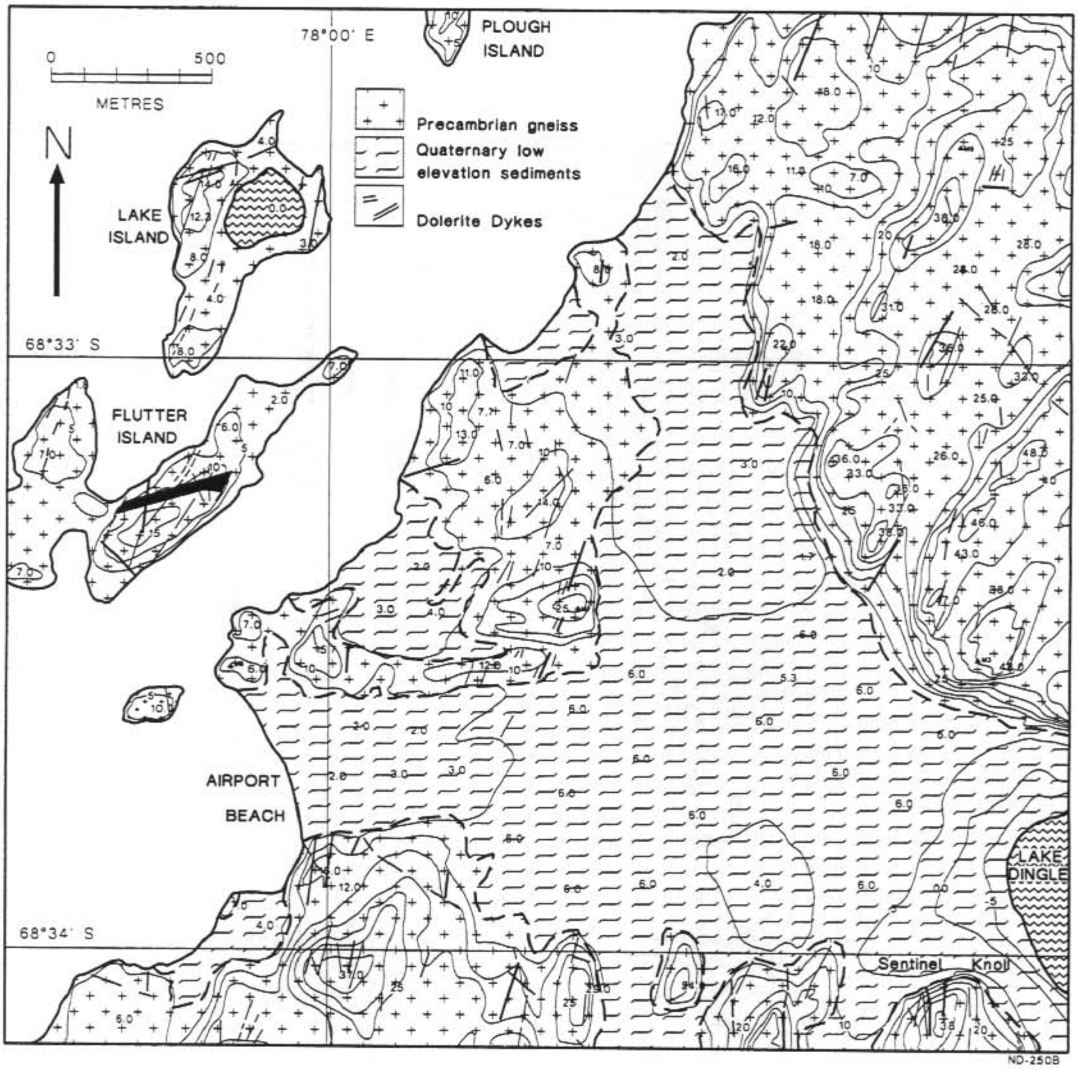
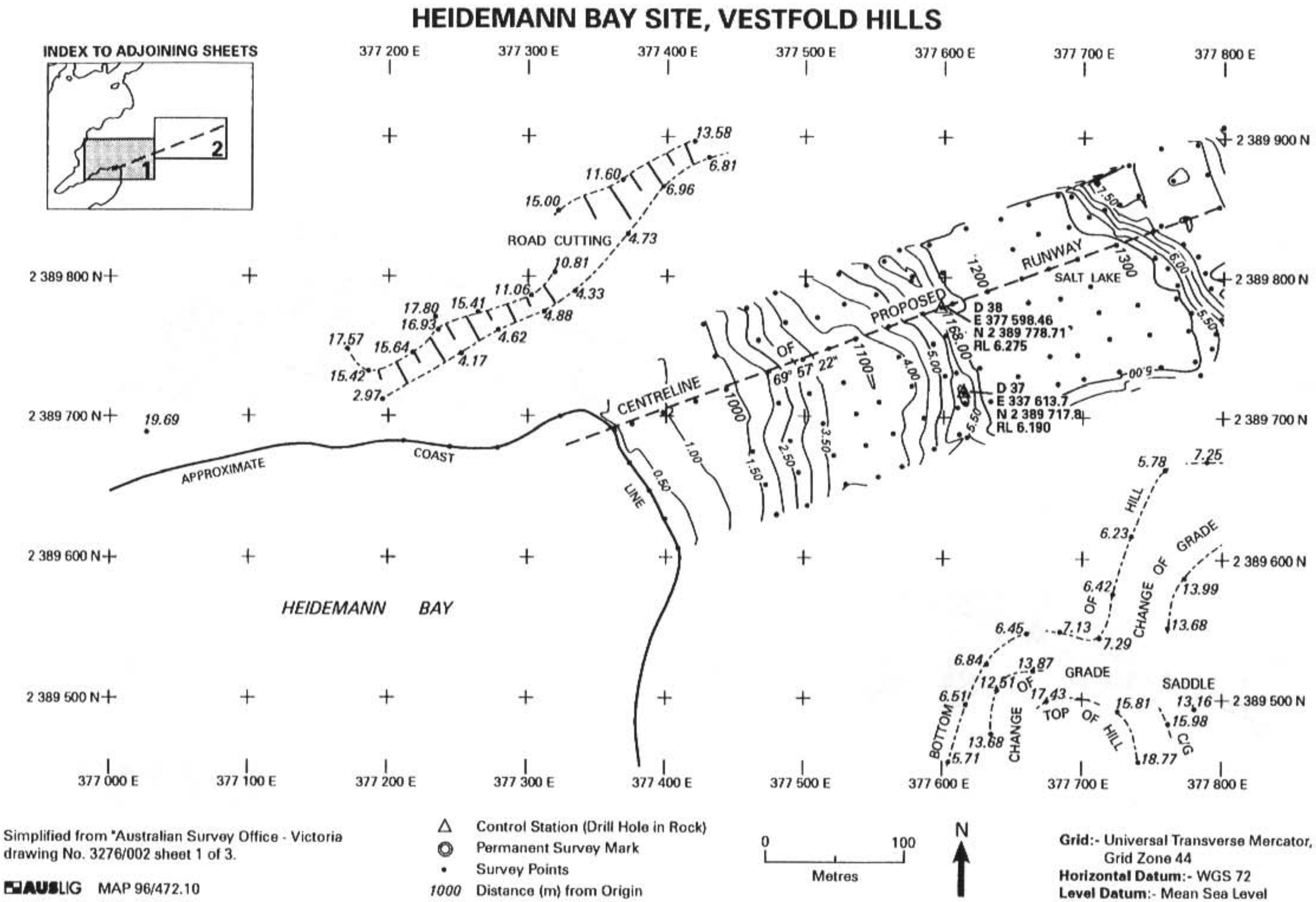
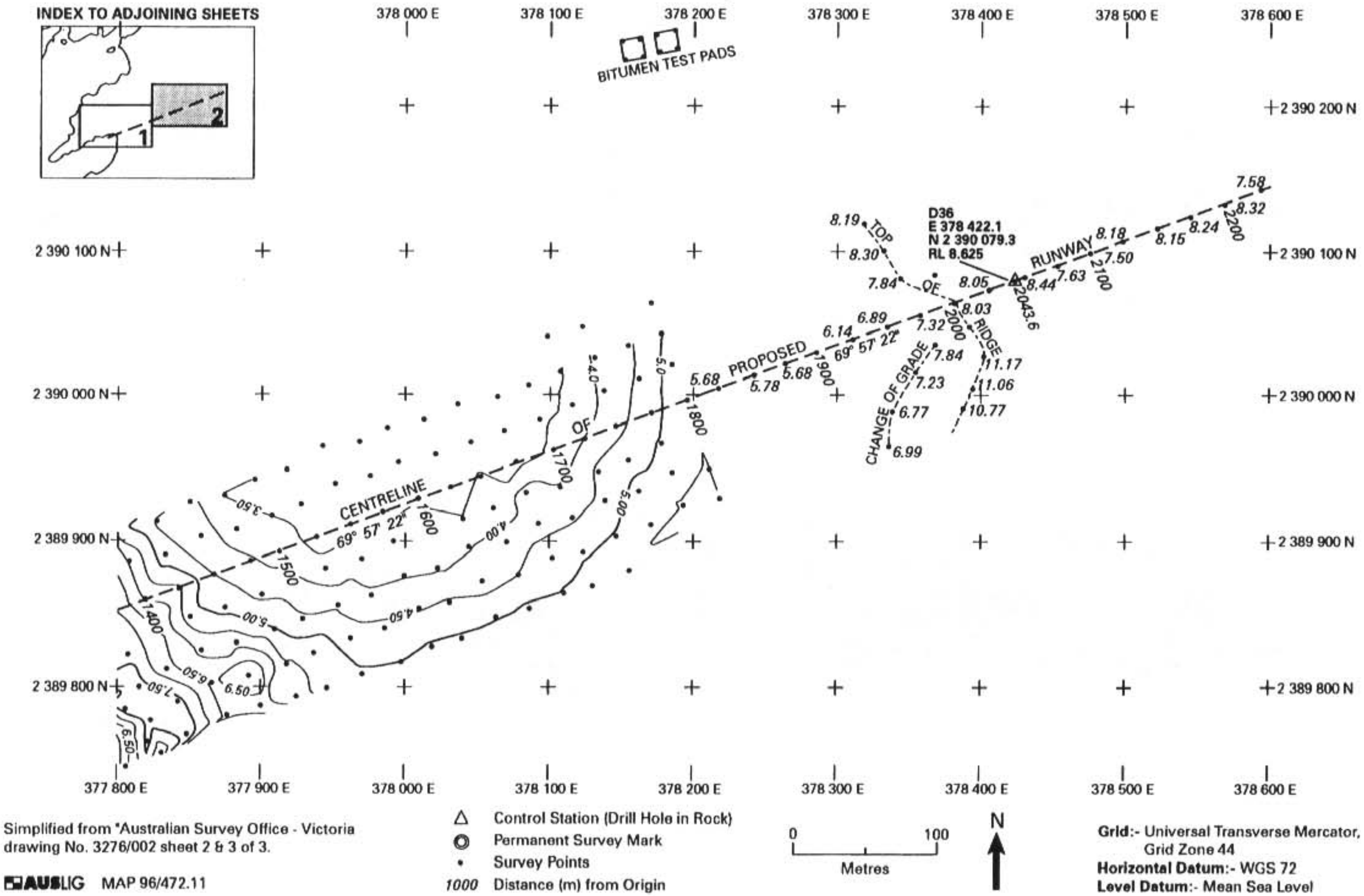


Figure 3. Geology of the northern part of the area, with emphasis on the features of the Precambrian basement.



Figures 4, 5. Survey locations, contours, position of centreline of proposed runway, Heidemann Valley. Simplified from Australian Survey Office - Victoria drawing numbers 3276/002 sheet 1 of 3 (fig. 4), and 2 & 3 of 3 (fig. 5).

HEIDEMANN BAY SITE, VESTFOLD HILLS



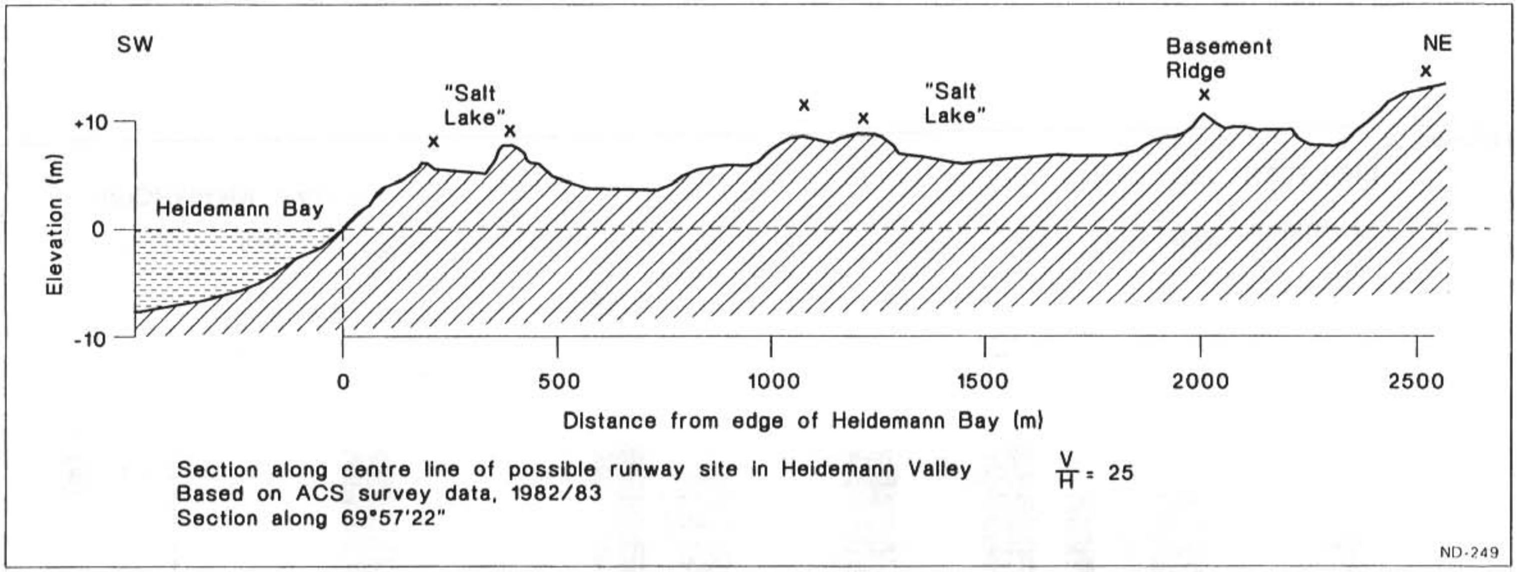


Figure 6. Profile along Heidemann Valley. Heidemann Bay to left.

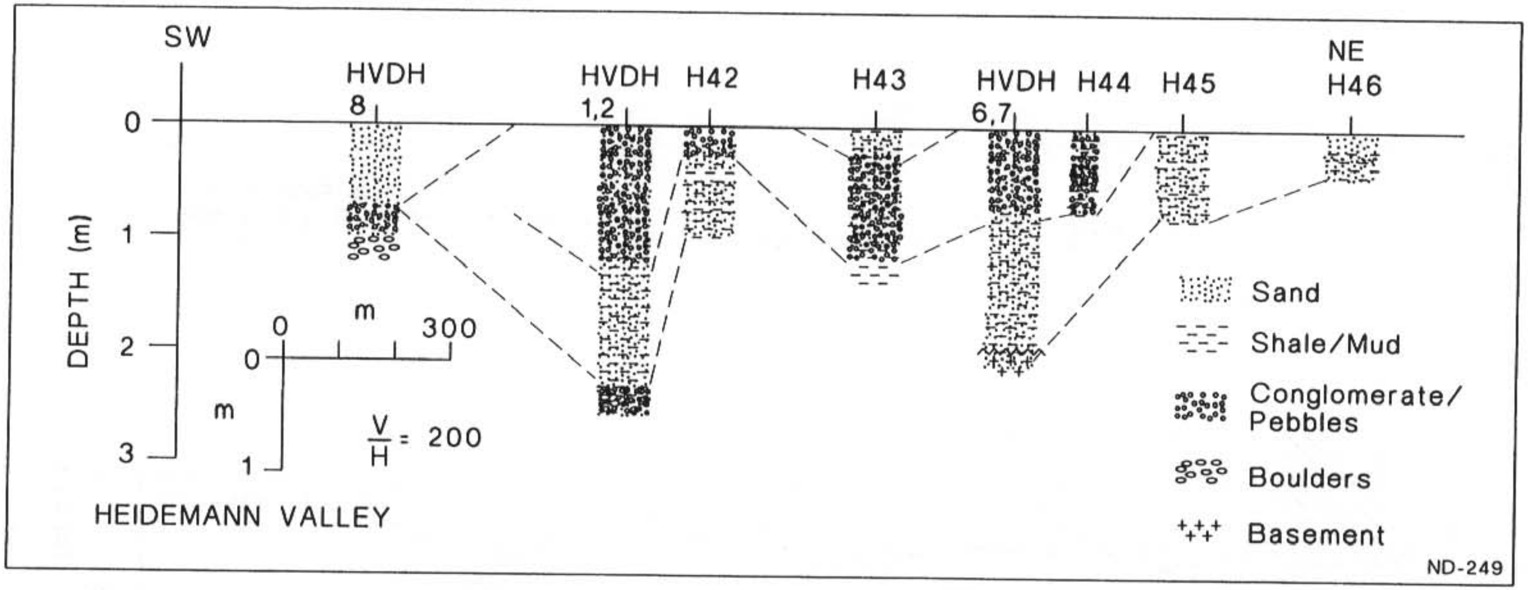
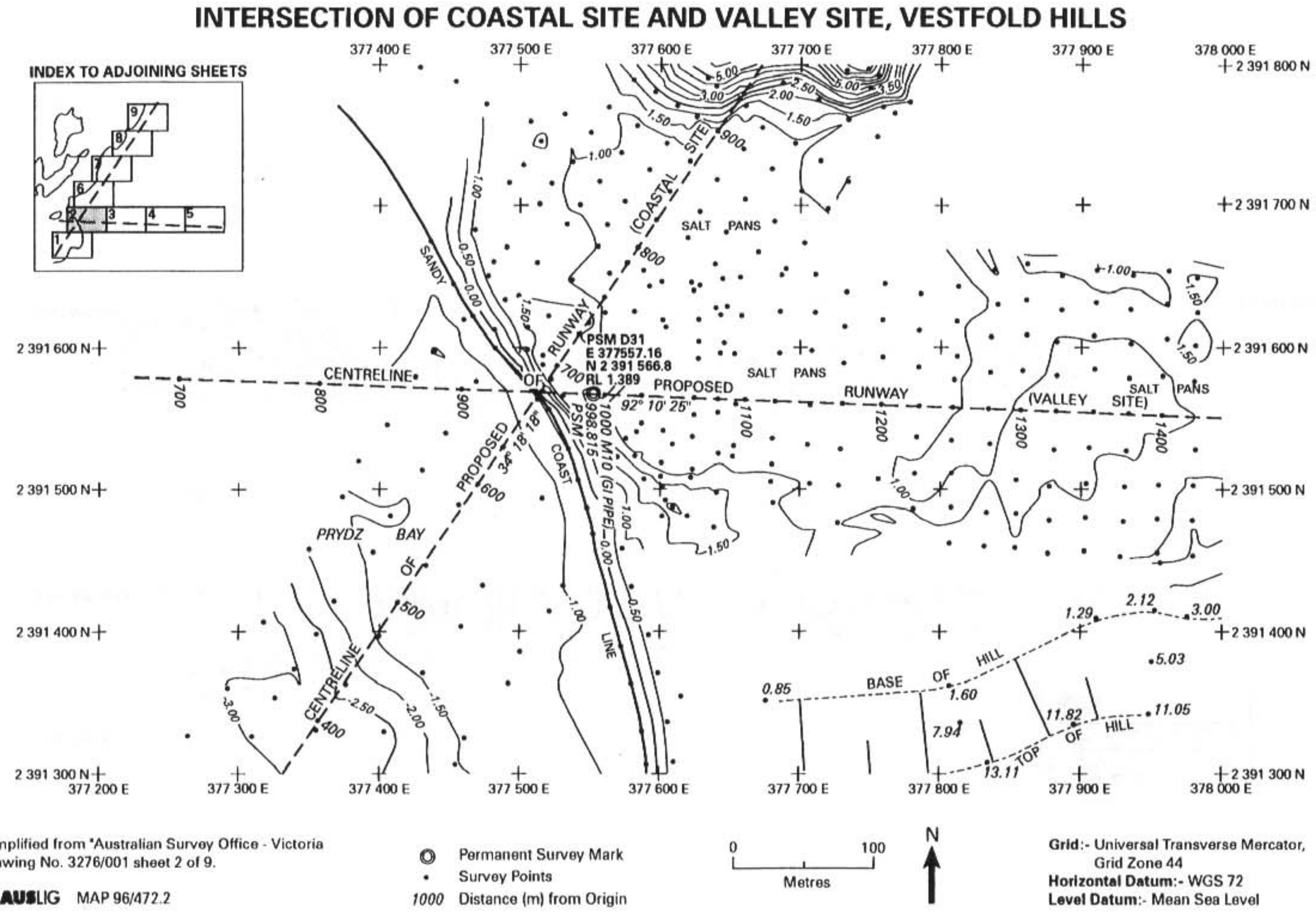
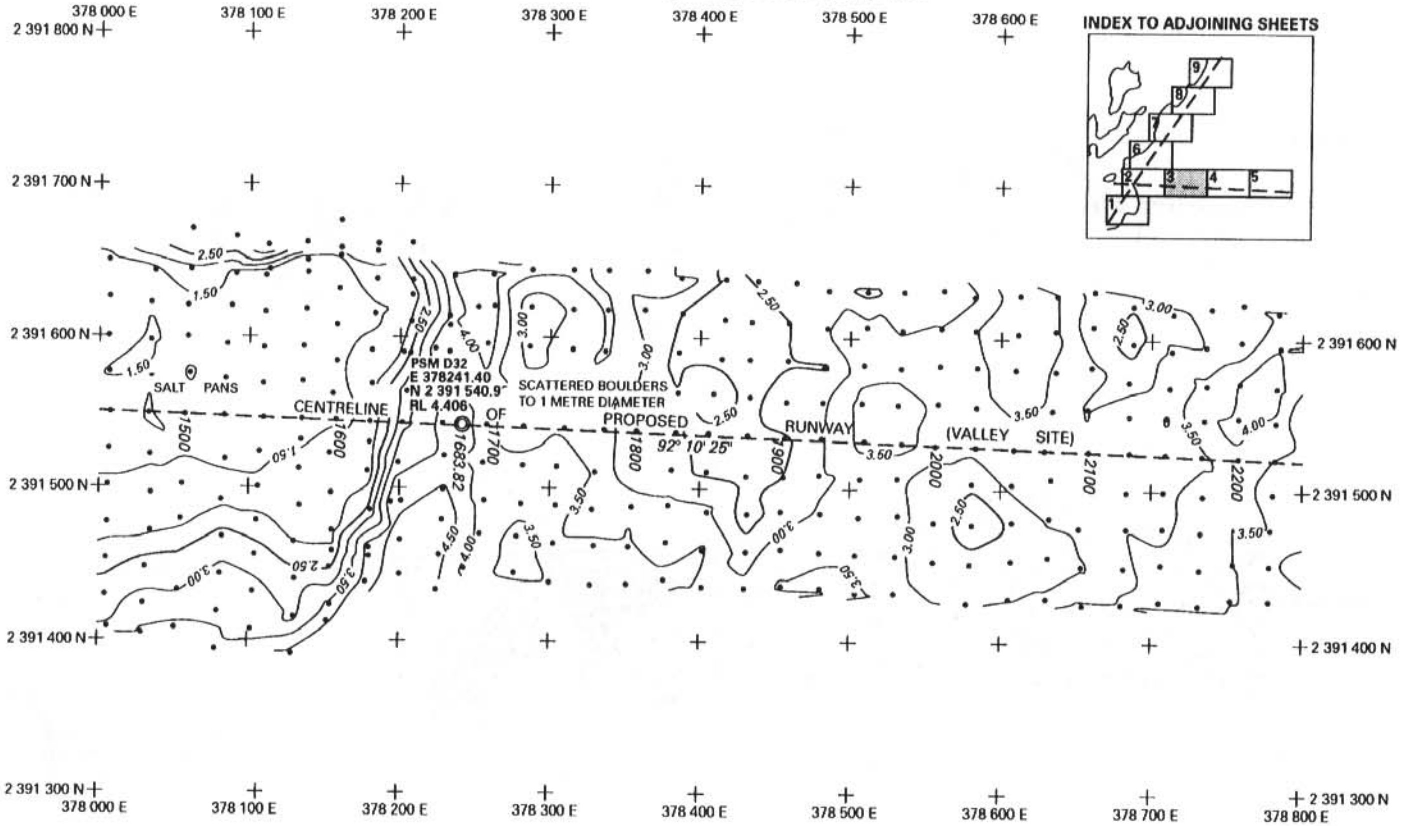


Figure 7. Stratigraphic sections including data from DHC (1983A) and Heidemann Valley drillsites drilled in 1993–94.



Figures 8–11. From ACS (1984) giving details of sample sites, survey data for the Valley site. Reproduced with permission. Simplified from Australian Survey Office - Victoria drawing numbers 3276/001 sheet 2 of 9 (fig. 8), 3 of 9 (fig. 9), 4 of 9 (fig. 10), 5 of 9 (fig. 11).

VALLEY SITE, VESTFOLD HILLS



Simplified from 'Australian Survey Office - Victoria drawing No. 3276/001 sheet 3 of 9.

AUSLIG MAP 96/472.3

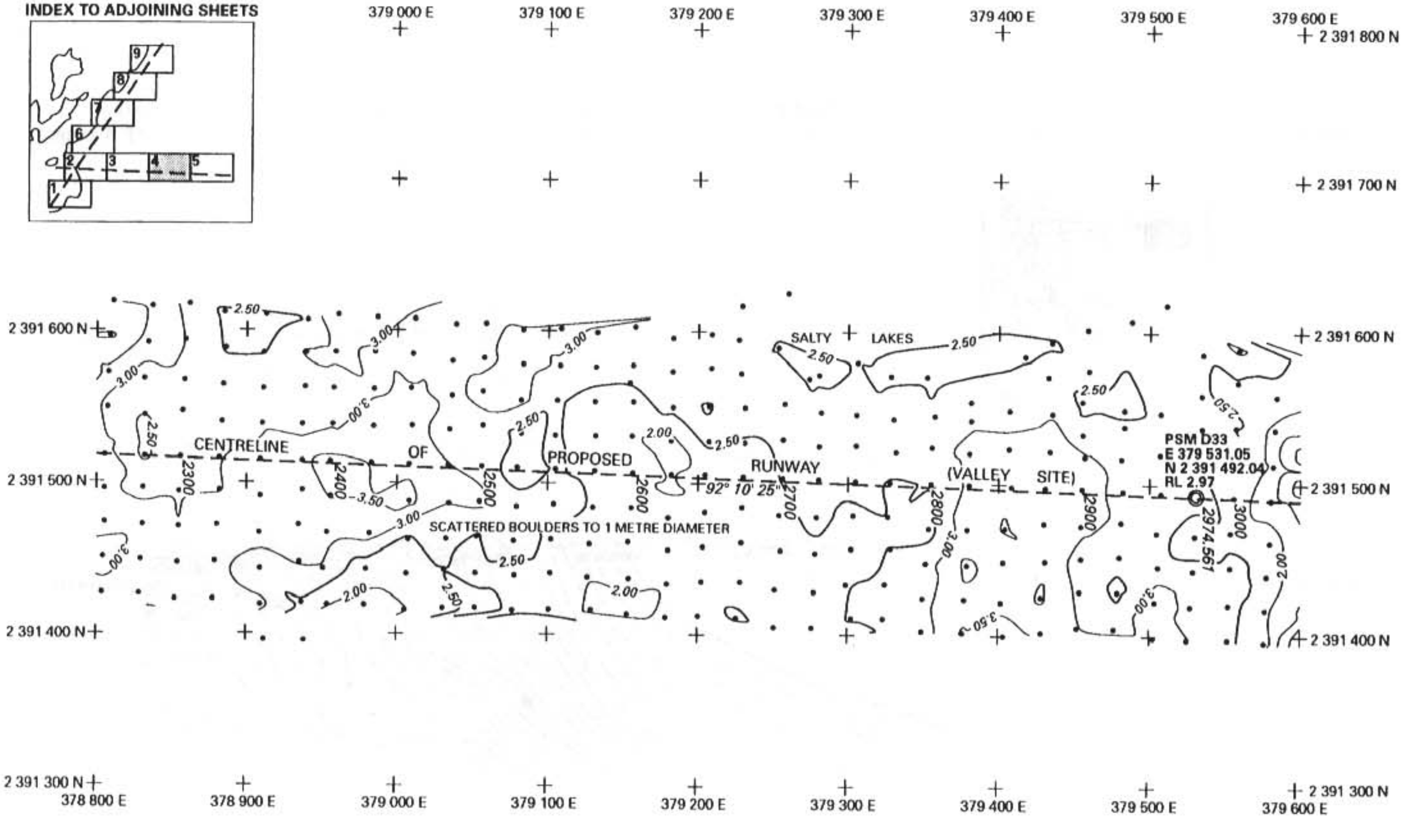
◎ Permanent Survey Mark
• Survey Points
1000 Distance (m) from Origin

0 100
Metres

N

Grid:- Universal Transverse Mercator, Grid Zone 44
Horizontal Datum:- WGS 72
Level Datum:- Mean Sea Level

VALLEY SITE, VESTFOLD HILLS



Simplified from "Australian Survey Office - Victoria drawing No. 3276/001 sheet 4 of 9.

AUSLIG MAP 96/472.4

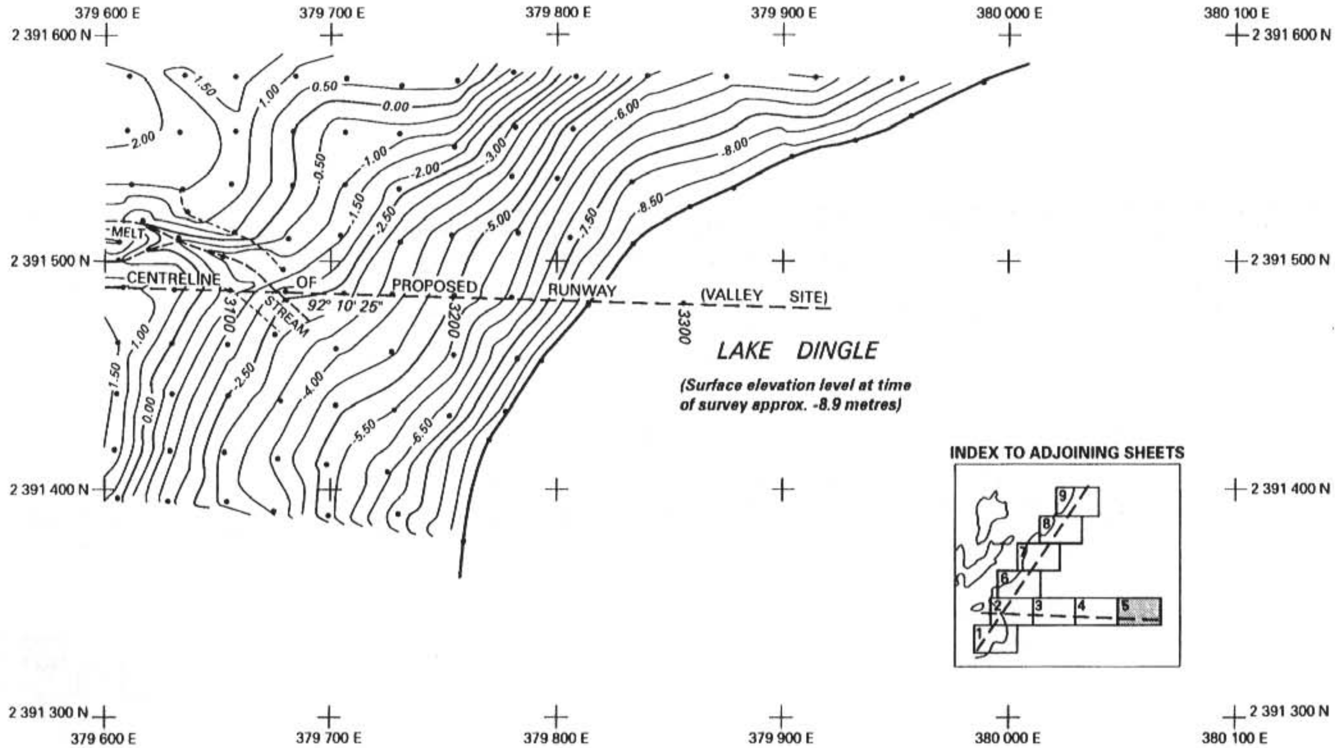
- ◎ Permanent Survey Mark
- • Survey Points
- *1000* Distance (m) from Origin

0 — 100 Metres

N

Grid:- Universal Transverse Mercator, Grid Zone 44
Horizontal Datum:- WGS 72
Level Datum:- Mean Sea Level

VALLEY SITE, VESTFOLD HILLS



Simplified from 'Australian Survey Office - Victoria drawing No. 3276/001 sheet 5 of 9.

AUSLIG MAP 96/472.5

◎ Permanent Survey Mark
• Survey Points
1000 Distance (m) from Origin

0 — 100 Metres

N

Grid:- Universal Transverse Mercator, Grid Zone 44
Horizontal Datum:- WGS 72
Level Datum:- Mean Sea Level

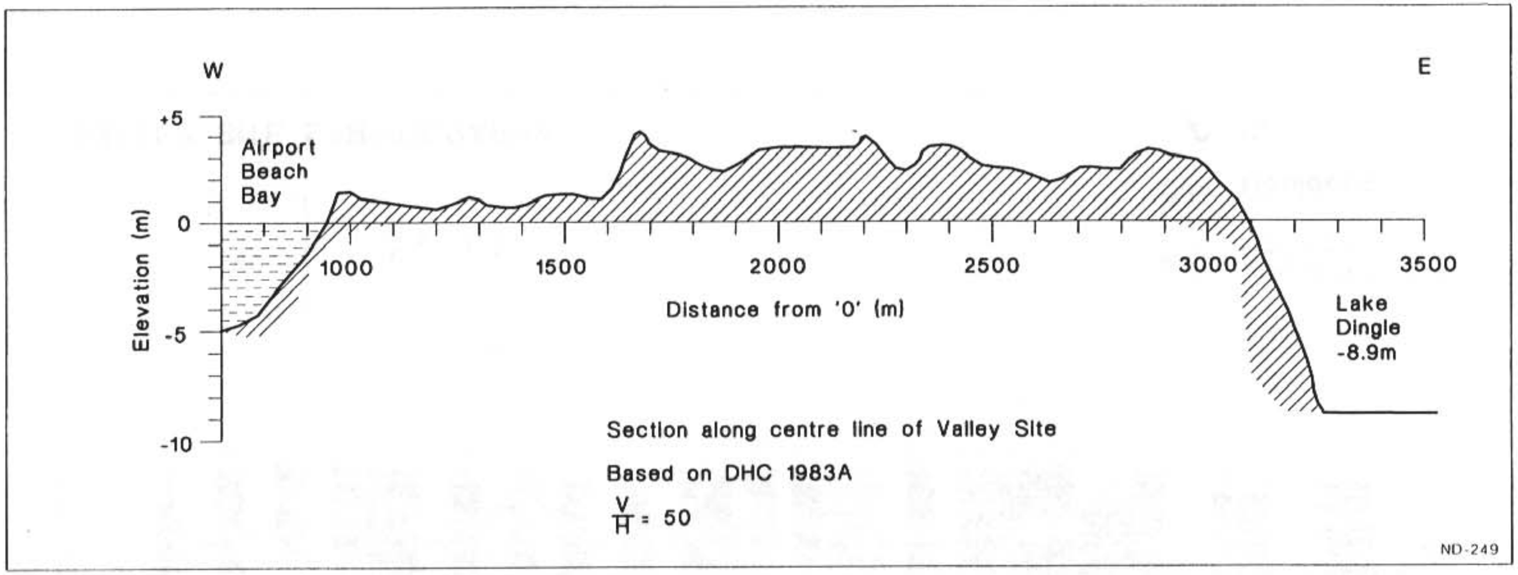


Figure 12. Profile along Valley site using data from Figures 8–11.

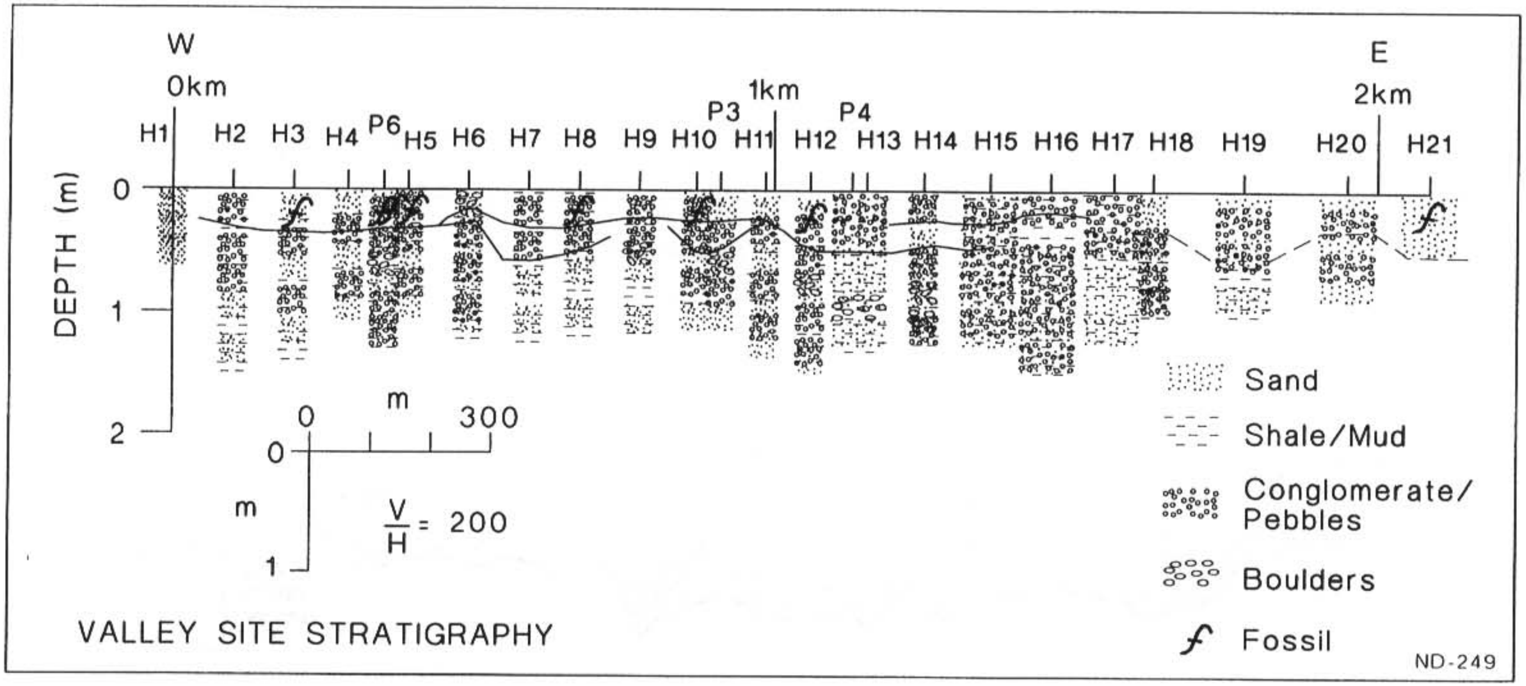


Figure 13. Stratigraphic section along Valley site, including data from DHC (1983A).

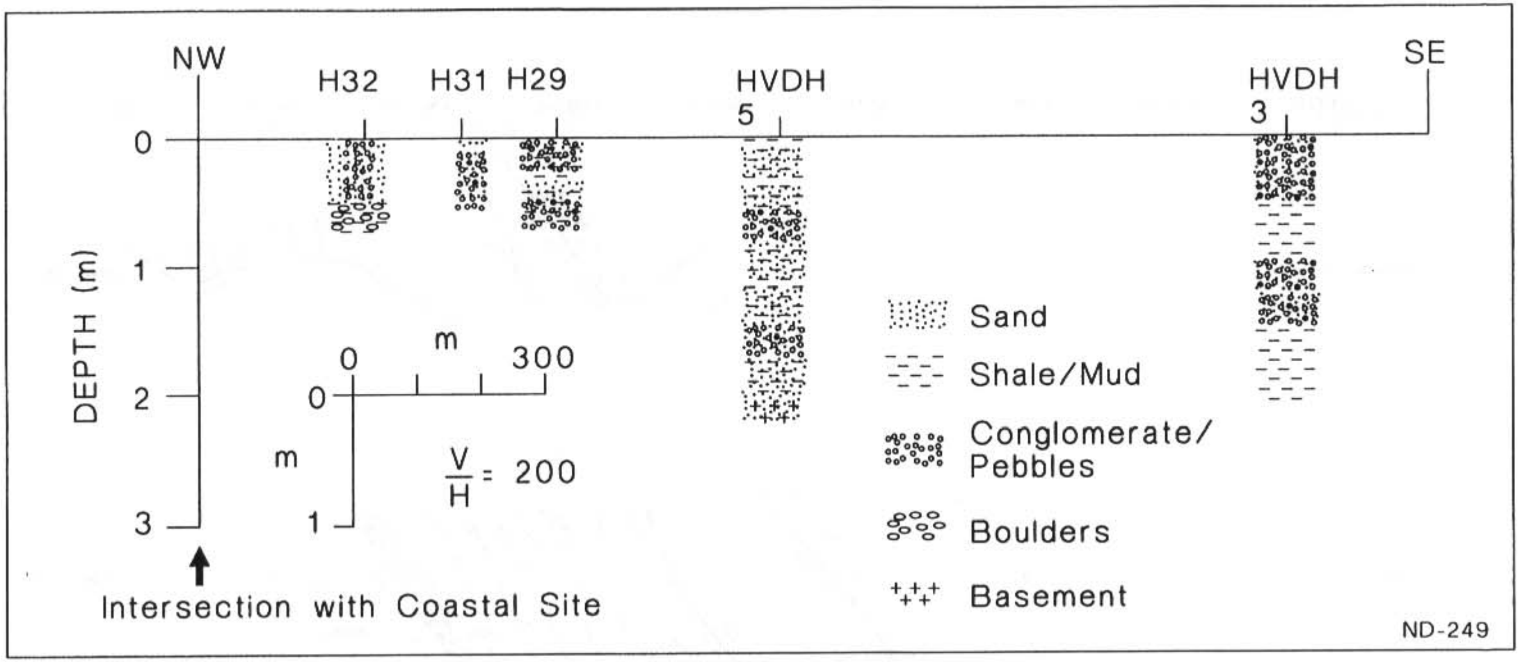
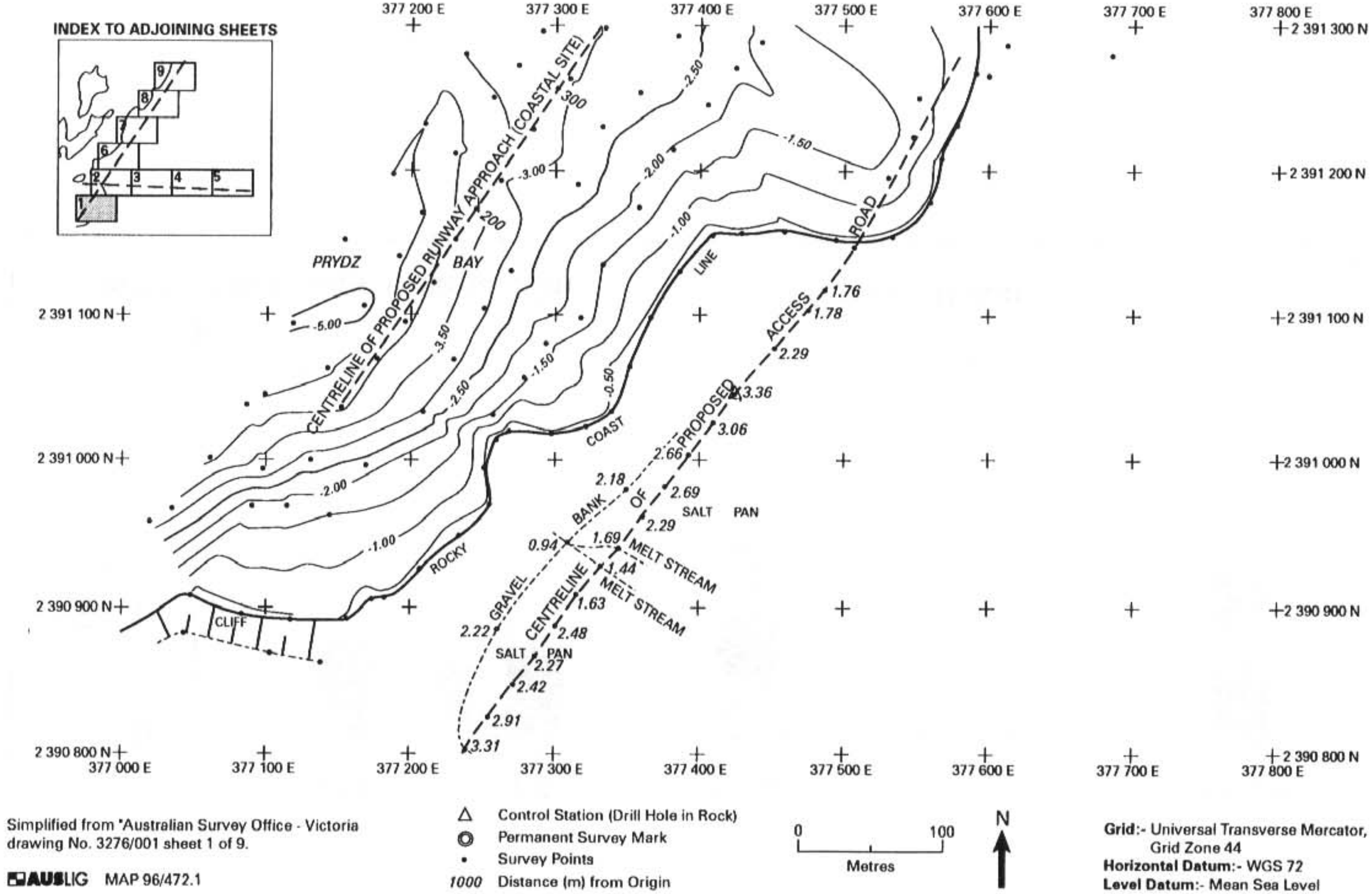


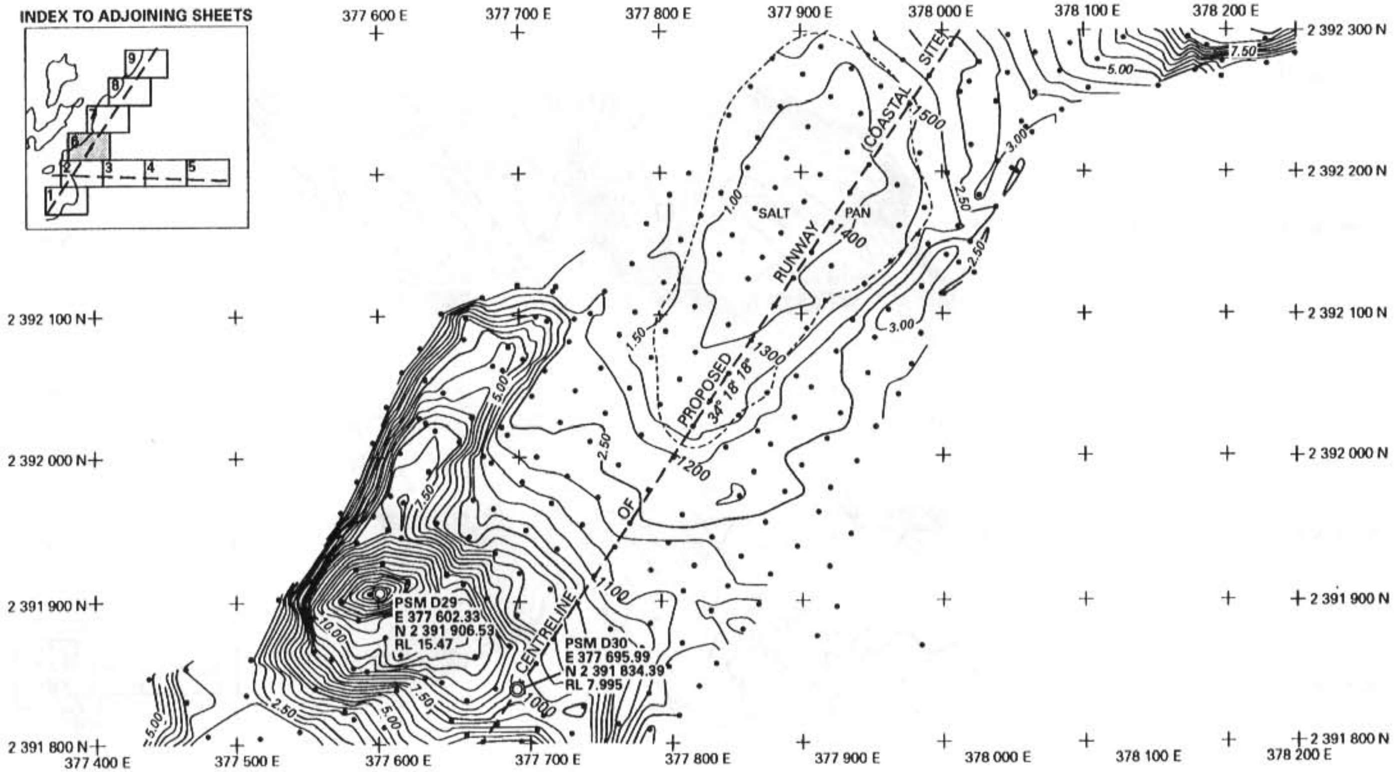
Figure 14. Stratigraphic section, North West Alignment site drillsites drilled in 1993–94.

COASTAL SITE, VESTFOLD HILLS



Figures 15–19. From ACS (1984) giving details of sample sites, survey data for the Coastal site. Reproduced with permission. Simplified from Australian Survey Office - Victoria drawing numbers 3276/001 sheet 1 of 9 (fig.15), 6 of 9 (fig.16), 7 of 9 (fig. 17), 8 of 9 (fig. 18), 9 of 9 (fig.19).

COASTAL SITE, VESTFOLD HILLS



Simplified from "Australian Survey Office - Victoria drawing No. 3276/001 sheet 6 of 9.

AUSLIG MAP 96/472.6

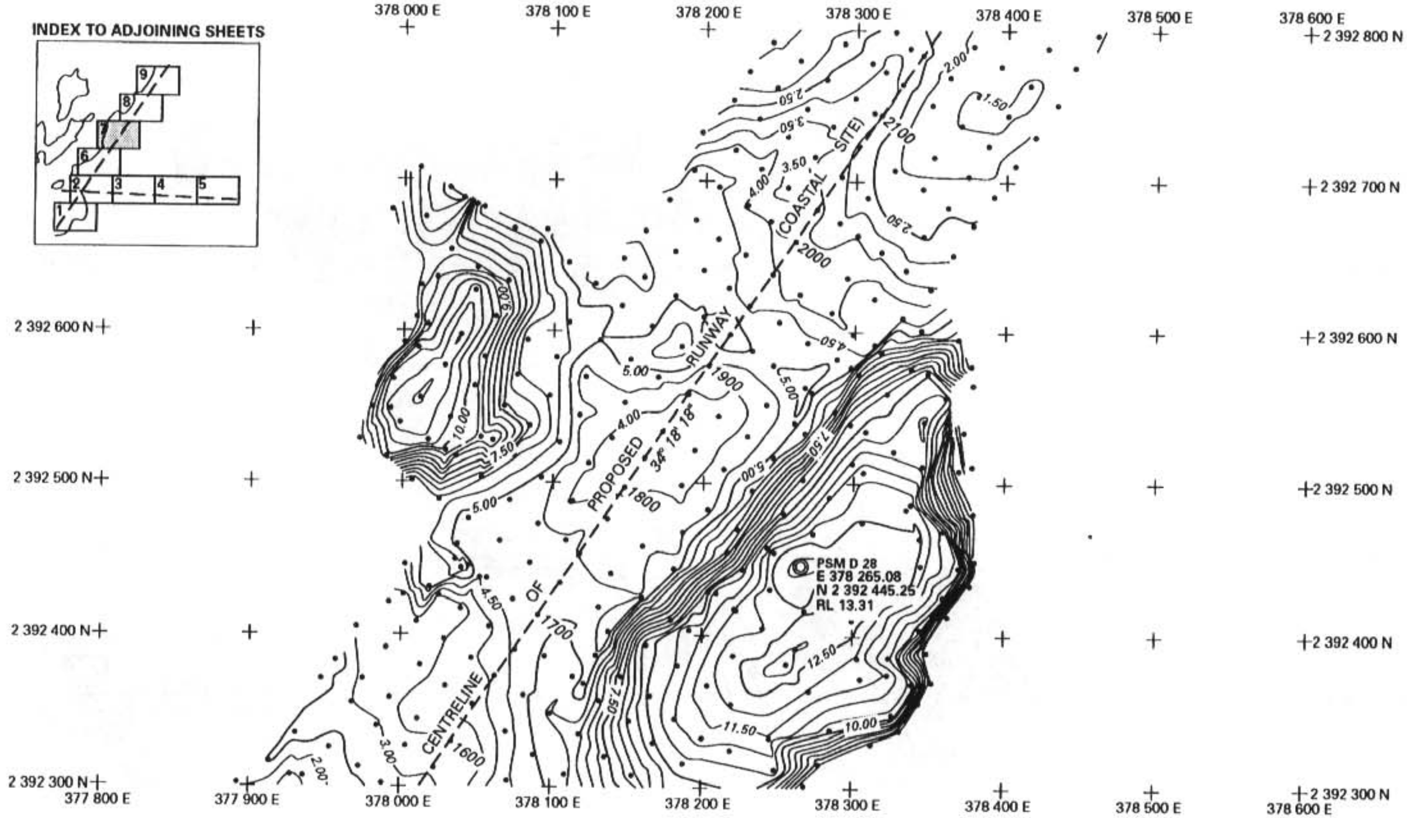
◎ Permanent Survey Mark
• Survey Points
1000 Distance (m) from Origin

0 — 100 Metres

N

Grid:- Universal Transverse Mercator, Grid Zone 44
Horizontal Datum:- WGS 72
Level Datum:- Mean Sea Level

COASTAL SITE, VESTFOLD HILLS



Simplified from "Australian Survey Office - Victoria drawing No. 3276/001 sheet 7 of 9.

AUSLIG MAP 96/472.7

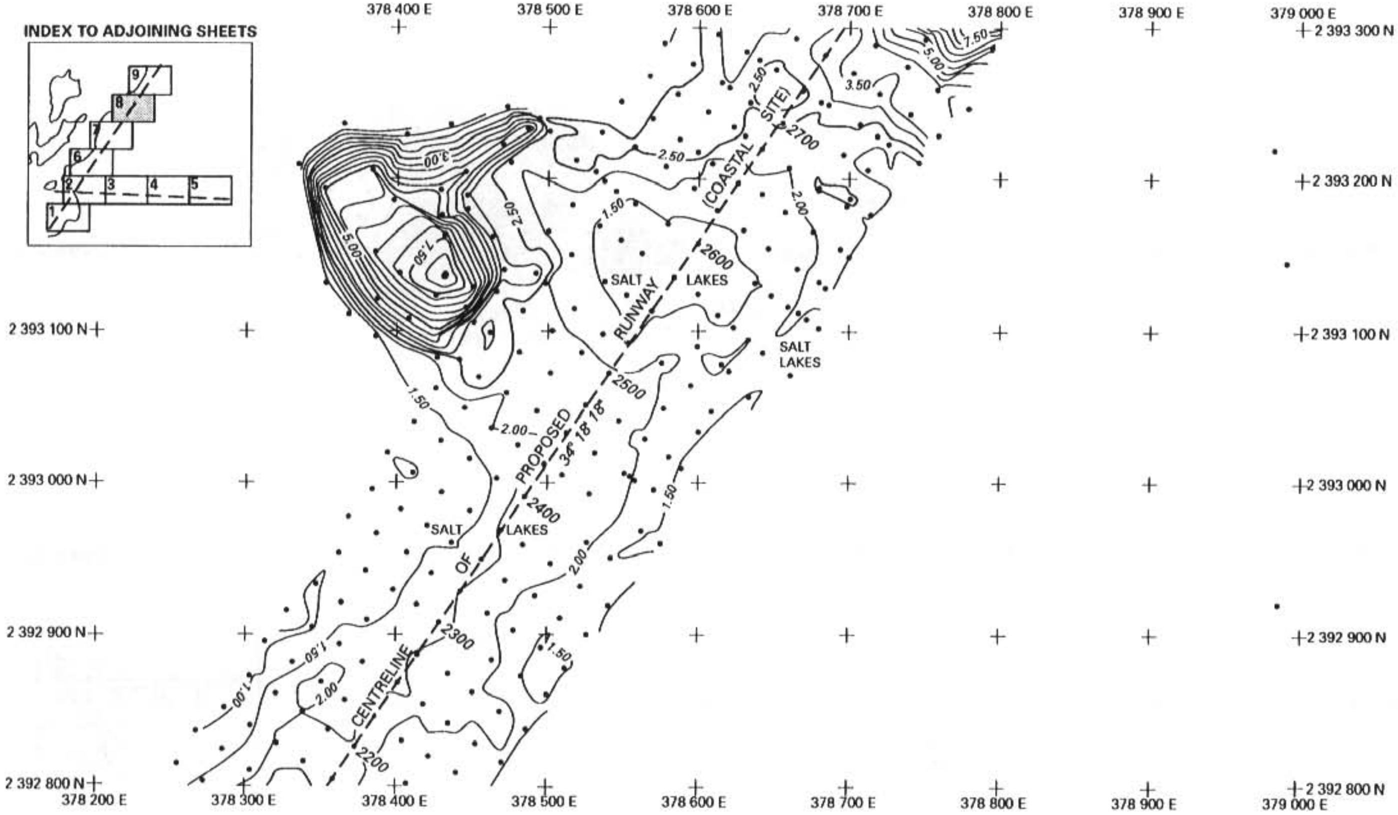
- ◎ Permanent Survey Mark
- • Survey Points
- *1000* Distance (m) from Origin

0 — 100 Metres

N

Grid:- Universal Transverse Mercator, Grid Zone 44
Horizontal Datum:- WGS 72
Level Datum:- Mean Sea Level

COASTAL SITE, VESTFOLD HILLS



Simplified from 'Australian Survey Office - Victoria drawing No. 3276/001 sheet 8 of 9.

AUSLIG MAP 96/472.8

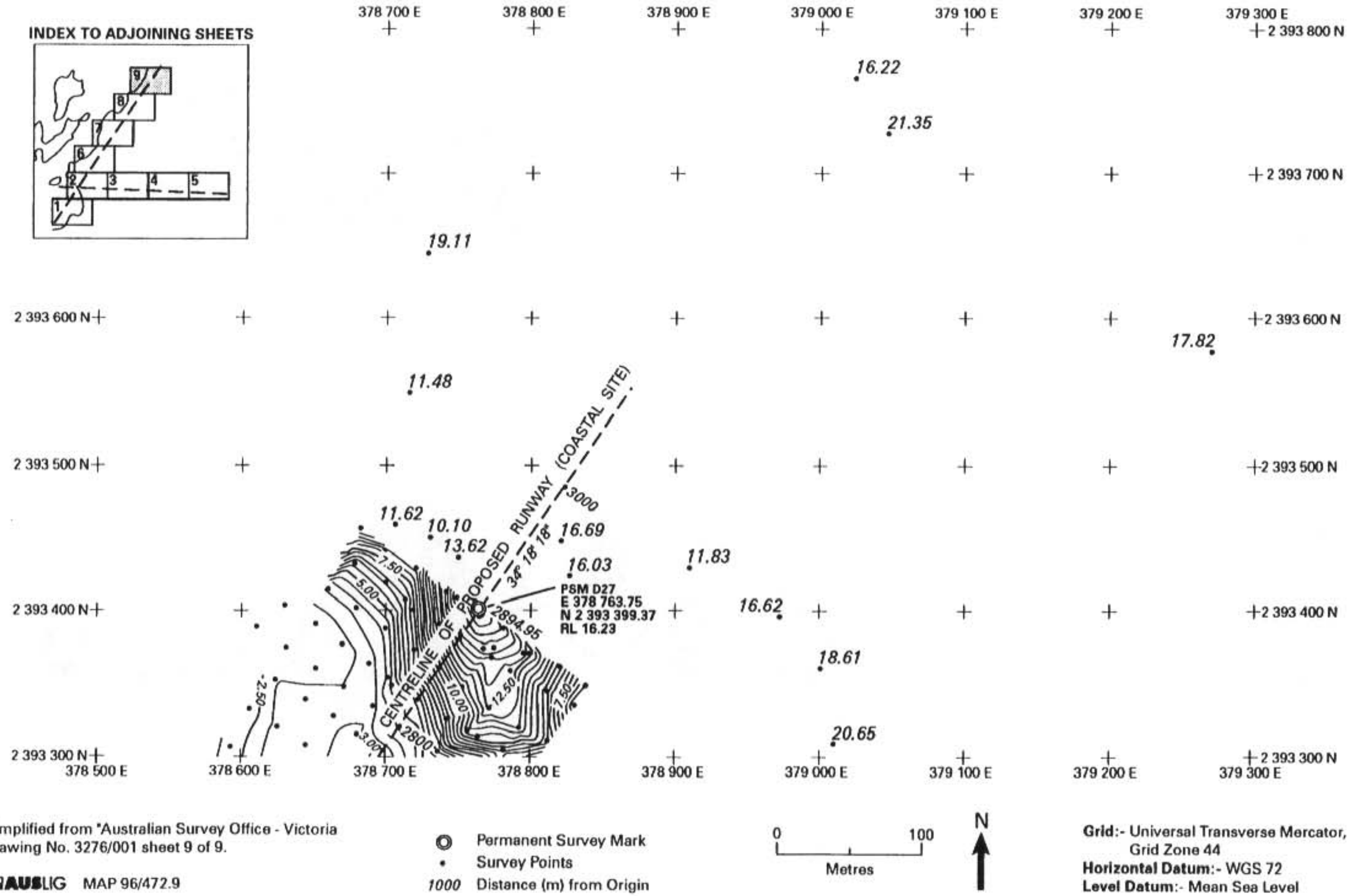
◎ Permanent Survey Mark
• Survey Points
1000 Distance (m) from Origin

0 100 Metres

N

Grid:- Universal Transverse Mercator, Grid Zone 44
Horizontal Datum:- WGS 72
Level Datum:- Mean Sea Level

COASTAL SITE, VESTFOLD HILLS



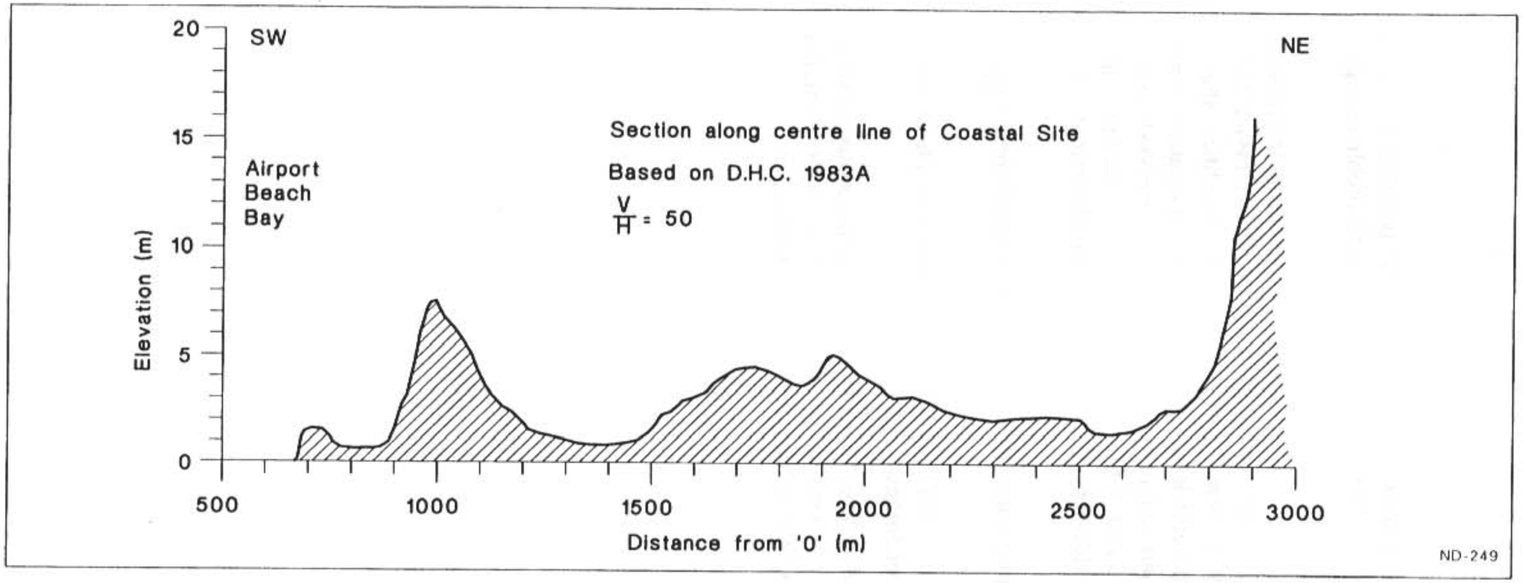


Figure 20. Profile along Coastal site using data from Figures 8, 15–19.

8. CONCLUSIONS

A summary is given of what is known of the geology of five potential runway sites in the Vestfold Hills within 4 km of Davis station. The report draws out several problems that need to be overcome before the definitive report on the region can be compiled.

In particular there is the need for much more dating of sediments to improve our understanding of the stratigraphy. At present, correlation is based on very rough lithological basis. There needs to be a dedicated C^{14} program on shells from many, well controlled localities. Shell material is common but the number of ages from the area is small and the control on location of samples dated so far is not as good as it could be. Where sediments are too old for radiocarbon techniques to be successful (for example the *in situ* equivalents of the old shell material reworked into the moraines lateral to, and on the southern side of, Heidemann Valley), diatoms, possible strontium, and other techniques should be used.

In all sites, there is need for more controlled coring with more geological logging techniques. Some samples should be retained.

There needs to be study of the clays in the sediments on all runway sites to identify the engineering impact of varying water/ice conditions on the clays.

Studies of valley forms and subsediment geomorphology are necessary to refine the understanding of the origin of valleys and the relation to the glacial history of the region. This could employ ground penetrating radar, simple 'thumper' seismic or equivalent techniques.

ACKNOWLEDGMENTS

We thank particularly Mr Greg Hoffmann, Australian Construction Services for his help in locating earlier reports. We are grateful to those who worked with us in the Davis region, especially the Station Leader and members of ANARE at Davis over the 1993–94 summer.

We are indebted to Nick Poltock for the use of his portable percussion drilling unit which he developed for work in remote localities. It worked well.

Ruth Dodd, John Manning and Jane Lawton of the Australian Surveying and Land Information Group (AUSLIG), Canberra, were of very great assistance in helping the production of the figures based on Australian Survey Group compilations. John Manning was also helpful in identifying literature from the early days of the runway discussion.

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APPENDIX 1. HEIDEMANN VALLEY DRILL HOLES—Preliminary Results

INTRODUCTION

This appendix presents preliminary results of eight drill holes drilled over the 1993–94 summer season near Davis station. In the first instance, these holes were drilled to examine the nature and extent of sedimentary facies in support of engineering reports on the feasibility of building an airport runway at one of three possible sites in the vicinity of Davis station. As a consequence of the drilling program, however, further scientific study of the sediments in the study area can now be undertaken.

METHODS AND MATERIALS

Coring was conducted using a portable percussion coring system that provides continuously cored sections with a core diameter of 35 mm. It consists of a Wacker motor driven vibrating unit atop a series of 1 m long core barrels and a core cutting device. It was built for and designed and owned by Nick Poltock of Devonport, Tasmania. Coring proceeded in 50 cm stages until progress was stopped by either a large boulder or basement rock. Fifty centimetre lengths of core were removed from the core barrel and were logged and sampled immediately. The core was cut into 10 cm lengths and the outer 0.5 to 1 cm which was presumed to have been contaminated by the core barrel during the coring process was peeled off and discarded. The remaining material was packaged, labelled (Fig 1), and returned to Australia for further analysis.

Selected samples were analysed for gravel, sand, and mud proportions, in a few instances ice, and biogenic silica content. The separated mud and sand fractions have been analysed for grain size statistics. Gravel, sand, and mud (GSM) was determined by the wet sieving of whole sediment to separate the >2 mm (gravel), 2 mm–63 μm (sand), and <63 μm (mud) fractions. The gravel fraction was dried and weighed, the sand fraction was weighed by the settling tube instrument (see below) during grain size determination, and the weight of the mud fraction was determined by subtracting the gravel and sand weights from the weight of the whole sediment.

The statistical grain size analyses of the sand (2 mm–63 μm) were conducted in a rapid sediment analyser at the Australian Geological Survey Organisation (AGSO) in Canberra. A Sedigraph 5100 (V3.03), also at AGSO, was used for the mud analyses. Biogenic silica was determined by the method described in Mortlock and Froelich (1989).

Hole #		Lat	S	Long	E	Core Length in cm.
HVDH	1	68	34.554	78	0.062	35
HVDH	2	68	34.554	78	0.062	255
HVDH	3	68	33.752	78	2.931	210
HVDH	4	68	33.694	78	2.421	290
HVDH	5	68	33.452	78	1.964	210
HVDH	6	68	34.462	78	1.15	80
HVDH	7	68	34.462	78	1.15	80
HVDH	8	68	34.776	77	59.488	120

Sediment	Descriptor	%G	% S	%M
Boulder Till	Tb	Very large clasts		
Gravel	G	>75%		
Diamict, coarse	Dc	>35%		
Diamict med	Dm	>10,<35	More sand than mud	
Diamict, Fine	Df	>10,<35		More mud than sand
Sandy mud	Ms	<10%		More mud than sand
Muddy sand	Sm	<10%	More sand than mud	
Mud	M			>90%

DISCUSSION

Five general types of sediment were encountered; boulder till, diamict, gravel, sand, and mud.

Boulder Till

This very coarse sediment overlies all other sediment types in the study area. It covers the surface of more than 80% of the study area but is locally absent. These places, which can be easily identified from the aerial photographs, tend to be areas where meltwater from snow drifts accumulates in the summer.

The boulder till is composed of a variety of clast sizes from very large, up to 2 m, to 10 cm cobbles, the average size being between 20 and 30 cm. These large clasts are set in a sandy to fine silty matrix. This sediment is only found on the surface and is little more than one clast thick. Local concentrations of these large clasts form transverse ridges across the valleys parallel or sub-parallel to the current shoreline and probably represent ancient beach ridges concentrated by the action of grounded sea ice. In these ridges the till may be reasonably thick (up to 2 m, that being the height of the ridges above the surrounding surface level); however this suggestion could not tested during this drilling program as the drilling equipment was not able to penetrate the clasts. The boulder till is clast supported within the transverse ridges and matrix supported between the ridges.

Diamict

Diamict is a mixture of gravel, sand, and mud fractions in varying proportions. Diamict can be further broken down into three grades; fine, medium, and coarse, according to the relative percentages of the size fractions. These categories are arbitrary and relate to depositional environment in only a general sense. The relative coarseness is due to a number of factors including the distance from the sediment source and the amount of reworking by water currents subsequent to deposition. In reality the variation in grain size within the diamict sediments is gradational, suggesting that the differences are due to a complex interplay of all of these factors.

Gravel

This coarse grained sediment is >75% gravel and is found in HVDH 8 where it overlies the basement and underlies the beach sands currently being deposited.

Sand

All sand encountered in the drilling program contained some mud. Consequently, all sands identified here are referred to as muddy sand. Texturally, Heidemann Valley sands do not vary greatly except that the black sand body in HVDH 3 contained significant amounts of ice and some gas which was liberated when the core barrel was opened. This sand overlies a coarser sand body which was reddish brown in colour and resembled the beach sands at the middle and top of HVDH 8. While there is no significant variation in grain size statistics between the beach sands at HVDH 8 and the downcore sands from other cores, similarity of depositional environment cannot be inferred. The most likely reason for this uniformity is that the sand size fraction in all samples has been affected by a single process before being subjected to the later, depositional, event.

Mud

Muds in Heidemann Valley have been separated into sandy muds (Ms) and muds (M). Again this distinction is purely arbitrary and based on relative proportions of the size fractions mentioned. This sediment type compresses very easily. At HVDH 4 the core barrel was pushed by hand for the first metre. This metre of sediment was compressed to less than 30 cm. This compressibility was a characteristic of all of the very fine grained material and is probably related to the proportion of mud in the sediment.

Sample No.	Ice wt.	%G	% S	%M	Mean	Std D	Skew	Kurt	Sediment
HVDH1-0		9.94	55.87	34.18	1.87	0.98	-0.14	-0.15	Sm
HVDH1-10		2.98	61.84	35.19	1.75	1.01	-0.03	-0.47	Sm
HVDH1-20		8.06	52.10	39.84	1.95	1.06	-0.11	-0.55	Sm
HVDH1-30		21.04	43.21	35.75	2.04	1.04	-0.12	-0.47	Dm
HVDH2-15		11.19	37.20	51.61	2.05	1.09	-0.19	0.52	Df
HVDH2-60		11.90	40.90	47.19	1.90	1.10	-0.12	-0.62	Df
HVDH2-110		15.19	30.97	53.84	2.09	1.11	-0.28	-0.39	Df
HVDH2-130		0.00	29.59	70.41	2.02	1.02	-0.14	-0.40	Ms
HVDH2-150					1.99	0.99	-0.16	-0.38	
HVDH2-170		9.25	43.01	47.74	1.84	1.01	-0.10	-0.38	Ms
HVDH2-180		0.00	33.13	66.87	1.99	0.99	-0.16	-0.38	Ms
HVDH2-210		0.00	19.81	80.19	2.38	1.20	-0.51	0.11	Ms
HVDH2-230		2.17	15.06	82.77	2.62	1.00	-0.60	1.26	Ms
HVDH2-250		44.34	22.22	33.44	2.03	1.11	-0.19	-0.57	Dc
HVDH3-0		16.60	68.37	15.02	1.47	0.88	-0.02	-0.10	Dm
HVDH3-50		0.00	7.71	92.29	1.89	0.99	0.00	-0.30	M
HVDH3-70	34.00	0.00	6.31	29.27	2.07	0.99	-0.14	-0.16	M
HVDH3-90		0.00	24.20	75.80	2.10	0.98	-0.16	-0.23	Ms
HVDH3-110		12.84	21.55	65.61	2.08	1.01	-0.16	-0.28	Df
HVDH3-130		11.62	67.52	20.86	1.85	0.83	-0.05	0.26	Dm
HVDH3-145		0.60	5.70	93.71	2.23	1.16	-0.33	-0.51	M
HVDH3-160	2.00	0.93	22.39	67.44	2.45	0.79	-0.48	1.47	Ms
HVDH3-180	9.26	0.00	0.48	62.48	2.12	1.37	-0.28	-1.03	M
HVDH3-200		0.00	6.09	93.91	2.56	0.98	-0.57	1.31	M
HVDH4-0		4.81	33.56	61.62	2.09	1.08	-0.22	-0.46	Ms
HVDH4-80		18.44	23.64	57.91	1.82	1.09	-0.09	-0.63	Df
HVDH4-100		6.02	28.36	65.62	1.80	1.11	-0.04	-0.70	Ms
HVDH4-120		4.34	24.39	71.27	1.84	1.14	-0.10	-0.65	Ms
HVDH4-140		26.96	34.12	38.92	1.88	1.16	-0.11	-0.85	Df
HVDH4-160		25.13	32.67	42.20					Df
HVDH4-180		12.95	42.32	44.73	1.66	1.17	0.00	0.90	Df
HVDH4-200		21.69	32.76	45.56	1.58	1.07	-0.01	0.69	Df
HVDH4-220		35.68	27.42	36.90	1.81	1.07	-0.04	-0.58	Dc
HVDH4-240		39.05	12.90	48.05	2.07	1.14	-0.24	-0.61	Dc
HVDH4-250		68.93	14.06	17.01	1.67	1.21	-0.03	-1.01	Dc
HVDH4-270		0.58	16.20	83.22	2.50	0.99	-0.53	1.00	Ms
HVDH4-290		0.00	38.97	61.03	2.07	1.05	-0.20	-0.49	Ms
HVDH5-0		0.00	43.63	56.37	1.85	1.08	-0.04	-0.70	Ms
HVDH5-20		7.96	44.25	47.80	1.83	1.03	-0.16	-0.44	Ms
HVDH5-60		13.04	43.52	43.44	2.18	1.07	-0.25	-0.34	Dm
HVDH5-80		9.24	31.78	58.98					Ms
HVDH5-100		6.97	36.84	56.20	2.12	1.09	-0.22	-0.49	Ms
HVDH5-120		8.34	38.95	52.71	1.97	1.07	-0.12	-0.58	Ms
HVDH5-140		6.42	35.55	58.03	2.12	0.97	-0.20	-0.29	Ms
HVDH5-160		10.57	18.61	70.82	2.17	1.07	-0.27	-0.39	Df
HVDH5-180		6.44	22.79	70.77	2.11	1.02	-0.19	-0.35	Ms
HVDH5-200		6.65	41.42	51.93	1.97	1.10	-0.14	-0.67	Ms
HVDH6-0		26.53	33.91	39.56	2.00	1.09	-0.15	-0.60	Df
HVDH6-20		19.48	42.94	37.59	1.95	1.06	-0.17	-0.55	Dm

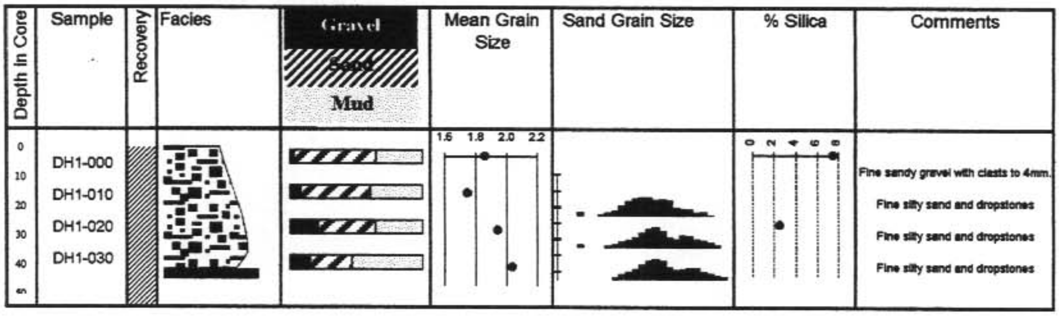
Sample No.	Ice wt.	%G	% S	%M	Mean	Std D	Skew	Kurt	Sediment
HVDH6-60		17.18	44.53	38.29	1.87	1.05	-0.11	-0.60	Dm
HVDH7-80		20.04	42.32	37.65	1.87	1.04	-0.15	-0.53	Dm
HVDH7-100		8.48	20.15	71.38	1.98	1.10	-0.19	-0.61	Ms
HVDH7-120		7.49	49.00	43.51	2.18	0.98	-0.23	-0.07	Sm
HVDH7-140		6.40	29.13	64.47	1.65	1.06	0.00	-0.58	Ms
HVDH8-0		0.29	81.27	18.44	2.26	0.80	-0.46	1.73	Sm
HVDH8-20		5.28	77.03	17.70	2.05	0.82	-0.02	-0.33	Sm
HVDH8-60		2.21	80.24	17.55	1.80	0.92	-0.12	-0.22	Sm
HVDH8-80		27.25	57.61	15.14	1.66	0.93	-0.07	-0.25	Dm
HVDH8-100		78.74	21.43	-0.17	1.75	1.05	-0.08	-0.49	Gravel

DRILLING RESULTS

HVDH 1

This hole was drilled to 40 cm before the corer encountered a large rock. The sediments in the core are fine silty sands with frequent dropstones at the bottom, fining upwards into fine sands with occasional dropstones at the top. Only two samples were tested for biogenic silica, with the coretop sample having approximately 8% by mass biogenic silica as compared to less than 3% by mass at 20 cm depth. The mean sand grain size is not independent of the proportion of gravel. The increase in mean grain size between 10 and 40 cm depth is probably related to an increase in current action winnowing out finer sands as can be seen from the decreasing importance of the fine sand peak of the bimodal distributions at 20 and 30 cm depth. The smaller mean grain size of the sands at the core top probably relates to a drape of aeolian material on the surface.

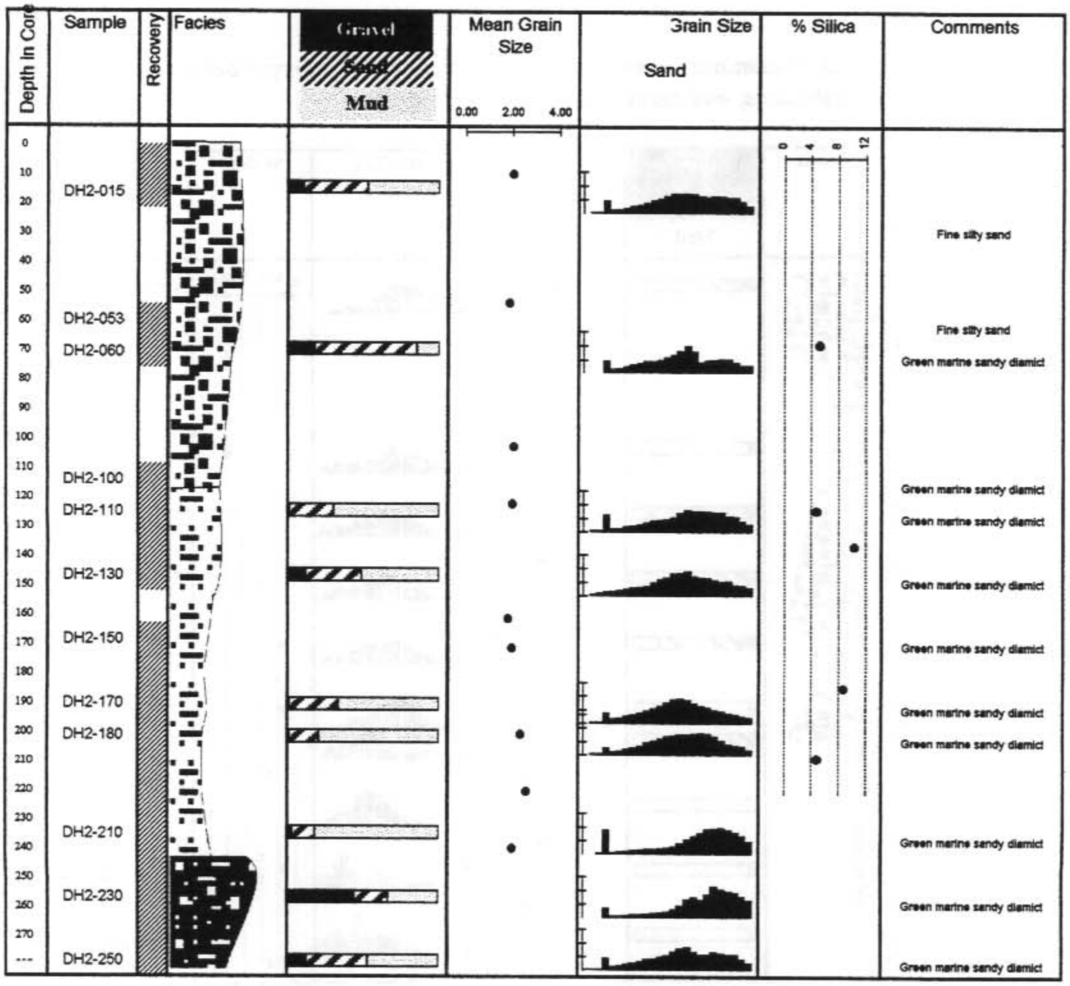
Figure A–1. HVDH 1. Preliminary core log, Gravel, Sand and Mud proportions, mean grain size, sand grain size distributions, and percentage of biogenic silica.



HVDH 2

This hole was drilled approximately 5 m from HVDH 1. The surface at HVDH 2 was some 40 cm lower than at HVDH 1. The sediments at this site commence with a coarse grained diamict below the 237 cm level. This is unconformably overlain by green marine muddy sand grading upwards into fine to medium diamict at the surface. Biogenic silica contents vary between 4 and 10% by mass with the higher values represented in the green marine muddy sand. The mean grain size of the sand component is fairly constant throughout the unit above 237 cm depth. Grain size distributions of the sand fraction show typical unsorted patterns except for those at the top of the lowermost unit below 237 cm. In this horizon, the sands are generally fine but display good sorting. This distribution is problematic but as such well sorted material probably represents aeolian deposition, this distribution may represent a subaerial or coast proximal (and shallow water) drape of aeolian transported material.

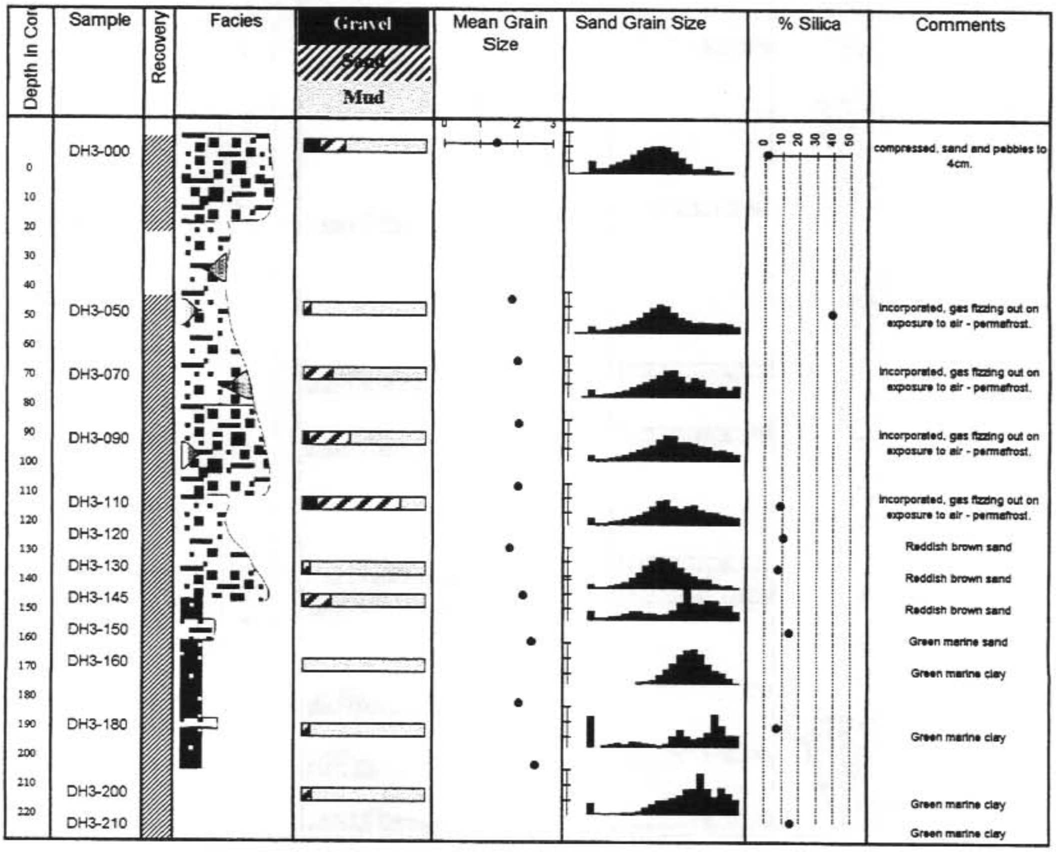
Figure A–1. HVDH 2. Preliminary core log, Gravel, Sand and Mud proportions, mean grain size, sand grain size distributions, and percentage of biogenic silica.



HVDH 3

This site has a green marine sandy mud, with minor muddy sand layers, unconformably underlying two fining upward sequences which are more marked and more complex than that seen in HVDH 2. Of particular interest is the presence of blocks of ice below the 50 cm level and the presence of a gas which was liberated from the surface of the core when it was removed from the barrel. Biogenic silica is around 10% by mass but rises, in one sample, to 40%, indicating a significant marine influence in this core. The mean grain size of the sand component increased slightly from top to bottom and the grain size distributions of the sand fraction show generally unsorted sands with the exception of one sample at 150 cm depth which is well sorted and a second sample at 160 cm depth which is very well sorted. There is a suggestion of bimodality in the sample from 110 cm depth and the sands of the surface sample are coarse skewed suggesting winnowing of the fine tail. This core seems to represent a deep marine environment, abruptly overlain at a probable erosional boundary with sedimentation of proximal glaciomarine sediments, as evidenced by the increased dropstone frequency. The topmost material probably represents an armoured surface formed by the removal of fines by aeolian processes.

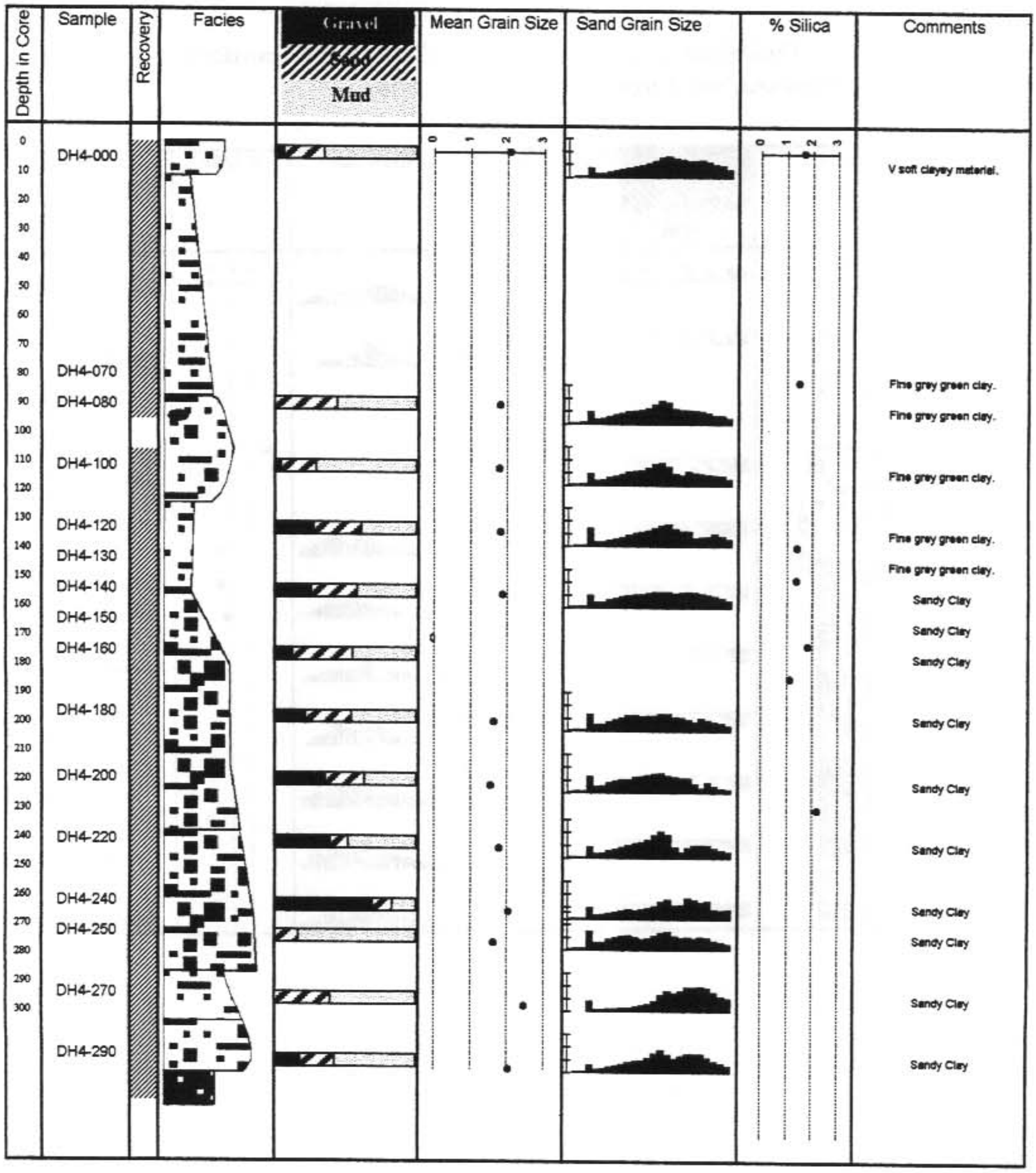
Figure A–1. HVDH 3. Preliminary core log, Gravel, Sand and Mud proportions, mean grain size, sand grain size distributions, and percentage of biogenic silica.



HVDH 4

HVDH 4 in Airport Valley shows three fining upwards sequences, and generally low values for biogenic silica. Bottommost in the core is a sandy mud with an unconformable upward transition into very coarse gravelly diamict. From there, there is a generally fining upward gradation to the top of the core except for a thin interval between 70 and 100 cm. Sand grain size varies little and appears to be independent of gravel content. Sand grain size distributions are generally unsorted with some evidence of bimodality, especially in the coarser sediments at 200 and 240 cm.

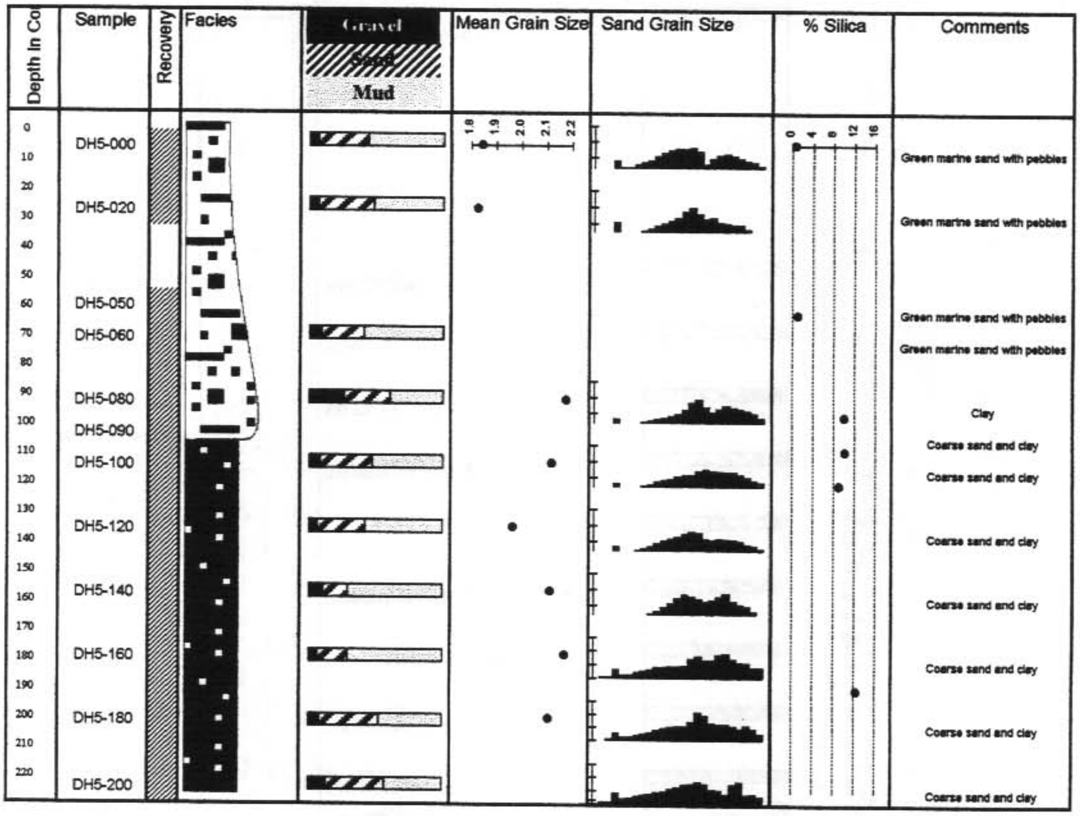
Figure A–1. HVDH 4. Preliminary core log, Gravel, Sand and Mud proportions, mean grain size, sand grain size distributions, and percentage of biogenic silica.



HVDH 5

This core from Airport Valley is fairly homogenous, with sandy mud throughout, punctuated with sediments containing slightly more than 10% gravel. The lowest unit is a muddy marine sand with relatively high amounts of biogenic silica (10% by mass and greater), which is interpreted as a marine sandy mud. The upper unit overlies and unconformity at ~100 cm depth, above which biogenic silica drops to close to 0, and is interpreted as a proximal glaciomarine deposit or a waterlain till. The mean grain size of the sand fraction is variable in the marine unit, but to the fine to medium end of the scale, while the upper glaciomarine unit has a coarse sand fraction. Sand grain size distributions are unsorted and some bimodality is seen in the upper unit.

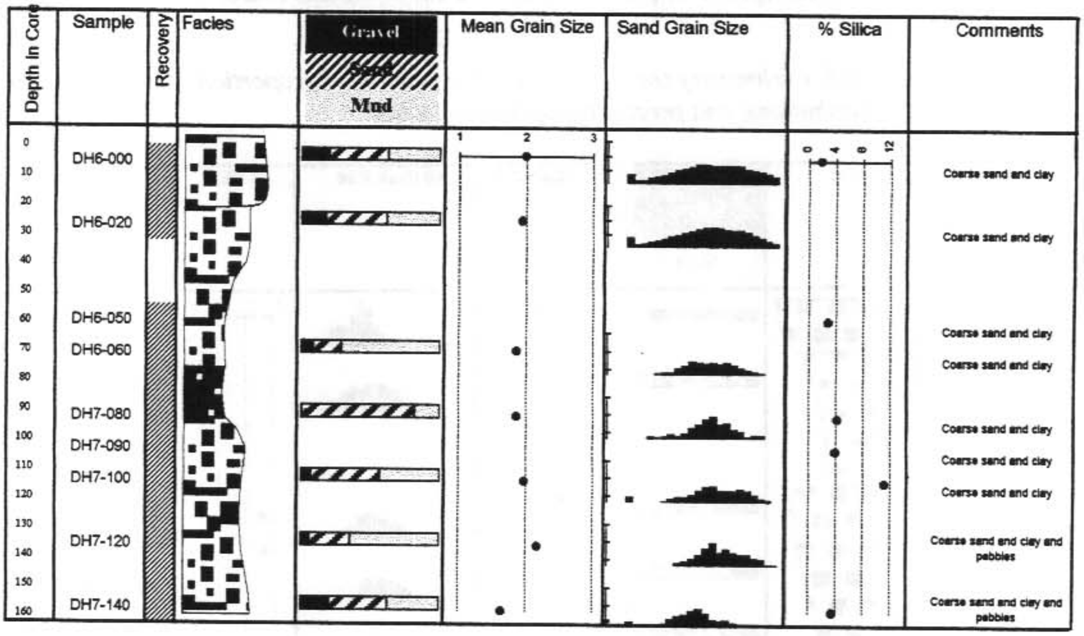
Figure A–1. HVDH 5. Preliminary core log, Gravel, Sand and Mud proportions, mean grain size, sand grain size distributions, and percentage of biogenic silica.



HVDH 6 AND HVDH 7

These sites were drilled within 2 m of each other and show a diamict in two horizons, separated by a sandy mud at about 80 cm depth. While the sediments appear to be coarsening upwards above the mud and fining upwards below the mud, the coarse horizon at the surface is probably due to surface armouring and ice heave processes concentrating larger clasts on the surface. Taking this into consideration the more generally seen situation of fining upwards sequences is repeated here. Biogenic silica is generally low with one high value of 12%, indicating an interval of marine influence. As seen in the other areas, grain size distributions are poorly sorted in the diamict and a little better sorted in the marine horizon. This sequence is interpreted as proximal glaciomarine sedimentation with occasional marine influence.

Figure A–1. HVDH 6 & 7. Preliminary core log, Gravel, Sand and Mud proportions, mean grain size, sand grain size distributions, and percentage of biogenic silica.



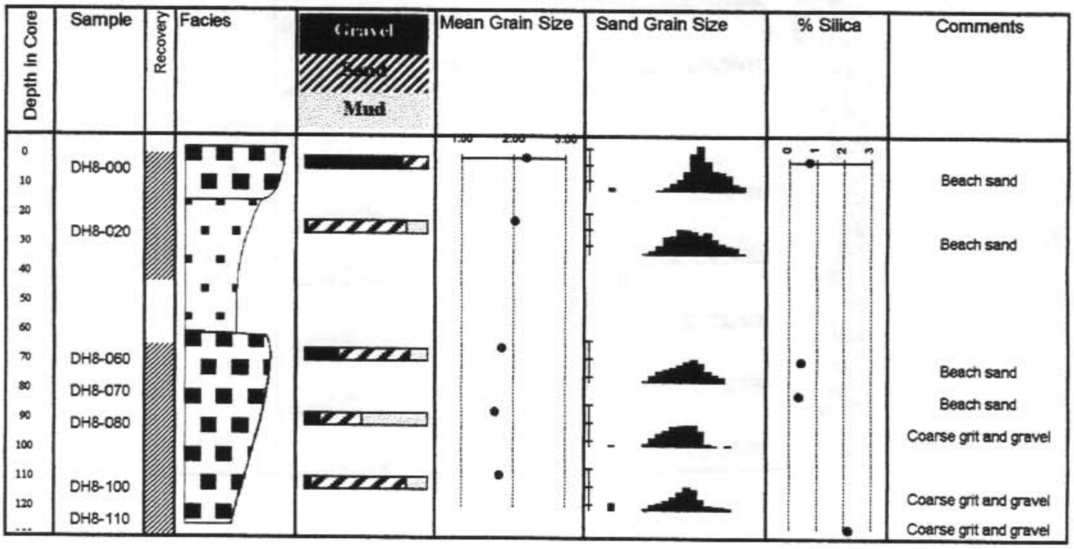
HVDH 8

This site was drilled on the beach at Heidemann Bay and shows beach sand with some mud grading downwards into coarse diamict then into coarse grits and gravels. Surprisingly, there is very little biogenic silica, which is perhaps due to the winnowing out of fine material by wave action.

The eight cores from six sites on coastal Broad Peninsula show very different sedimentary histories for Heidemann Valley and Airport Valley. In Airport Valley, the sediments form three units, generally high in biogenic silica. These units are unconformable and each displays a fining upwards sequence. This pattern probably represents the waxing and waning of a proximal glacier, resulting in glaciomarine sedimentation interspersed with marine influences.

In Heidemann Valley the lack of marine influence is marked. However, there is a peak in biogenic silica at about the 100 cm level in HVDH 2 which probably represents a single event of marine influence. The Heidemann Valley cores show two distinct fining upwards diamict units, interlayered with sediments displaying a definite marine influence. Even so, the diamict units, because of the lack of biogenic silica, are interpreted as proximal glaciomarine sediments and/or waterlain tills.

Figure A–1. HVDH 8. Preliminary core log, Gravel, Sand and Mud proportions, mean grain size, sand grain size distributions, and percentage of biogenic silica.



ENVIRONMENTAL INTERPRETATION

Glacial deposition of boulder field

The deposition of the boulder fields in Heidemann Valley and Airport Valley occurred in two different regimes and a number of phases. In Heidemann Valley, the deposition of subglacial or waterlain tills interlayered with glaciomarine sediments over at least two glacial events is difficult to date accurately (Hirvas *et al.* 1993). Dating of a shelly gravel between the two subglacial tills, not found during this study, has given two ages; one of 50 ka by a ^{14}C date, which is therefore suspect due to the unreliability of the method at ages over about 40 ka, and the second of >300 ka (Hirvas *et al.* 1993) using a thermoluminescence date which is also suspect (A. McMinn, pers comm). Thus the dating of the deposition of till unit overlying the shelly gravel is equivocal and can not even be said to be younger than 300 ka. Further work is currently underway on this issue with more dates expected.

If the uppermost till unit, named the Vestfold Till by Hirvas *et al.* (1993), is older than 50 ka then it must have been deposited at a previous glacial maximum and must therefore have survived the late Pleistocene glaciation intact. This could occur if the last glacial maximum did not result in ice cover in the coastal part of the Vestfold Hills, or if the landforms survived the overrun by glacial ice. The question of the survival of small scale landforms under glacial ice was investigated by Kleman (1992), who hypothesised that if landforms that predate ice-sheet burial can survive subglacial conditions and if the possibility is not recognised, then erroneous conclusions about ice-sheet dynamics and landscape development may be drawn. Kleman (1992) concludes that, because basal sliding cannot occur under cold-based conditions and because of the evidence for preservation from a variety of regions, settings, environments, and scales, that such preservation is possible.

Alternatively, the possibility that glacial ice did not extend as far as the current coastline was raised by Adamson and Pickard (1986b), suggesting that the boulder fields and depositional forms would have remained completely undisturbed during the last glacial maximum. Were this the case, isostatic depression would have seen this area submerged and undergoing glaciomarine sedimentation. Indirect evidence that this was the case is seen in the much more recently glaciated surface in the landwards extension of Heidemann Valley to the east of Lake Dingle. If there was an active glacier in Death Valley during the last glacial maximum, it is possible that the ridge surrounding Lake Dingle on its seaward side is a grounding line moraine.

The results of this study can assist in choosing between these two possibilities: subglacial deposition of Heidemann Valley tills (Hirvas *et al.* 1993) as opposed to glaciomarine deposition (Adamson and Pickard 1986b). The very low, yet measurable amounts of biogenic silica, visible forams, radiolaria, molluscs, and glass sponges (Hirvas *et al.* 1993) in all of the sediments in Heidemann Valley suggest at least some marine influence in their deposition. In addition, a spike of high silica content at about the 100 cm level at the base of Hirvas *et al.*'s (1993) Upper or Vestfold Till unit probably indicates a significant marine influence. Such would not be expected if the till was sub-glacial. Thus, Adamson and Pickard's (1986b) theory that the glaciation did not extend to the current coast but only as far as Lake Dingle is supported by this evidence. The overwhelming glacial as opposed to marine influence may be explained by waterlain deposition beneath a floating ice tongue in Heidemann Valley and the periodic failure of that ice tongue could explain intervals of high marine influence.

Regardless of the depositional situation in Heidemann Valley, the sediments in Airport Valley are very different. These sediments are high in biogenic silica when compared to Heidemann Valley.

The sediments are clearly influenced by both marine biogenic and glaciomarine sedimentary processes.

This evidence is interpreted as indicating a depositional environment with a minor glacier occupying Death Valley, decoupling from the sea floor around the seaward side of Lake Dingle and terminating in a floating ice tongue or minor ice shelf occupying Heidemann Valley during deposition of the Heidemann Valley sequence. There was little or no extension of a permanent floating ice mass over Airport Valley. Whether the two sequences, Heidemann Valley and Airport Valley, were deposited at the same time is not known and accurate dating is required.

Formation of boulder armour

The surface of all of the sediments in coastal Broad Peninsula is armoured by a layer of boulders which is mostly one clast thick but up to 2 m thick in the vicinity of the beach ridges. This armour is formed by freeze thaw processes in the active layer above the permafrost. The abundance of fines in this layer assists the frost action (Hirvas *et al.* 1993) in the upward migration of large clasts. This is supported by the presence of large clasts in and below the active frost layer in excavations in Heidemann Valley (Hirvas *et al.* 1993)

Bench and beach ridge construction

Bench and beach ridges are formed by the action of sea ice. As the land surface emerges from the sea, new sections are exposed in the intertidal area. Sea ice freeze-in incorporates smaller clasts and fines which are removed during the summer and deposited elsewhere when the ice melts. During the winters, the sea ice is moved up and down by the tides and tamps down the bottom sediments with which it is in contact. During this study, the sea ice was consistently measured at 2.1 m thick in the vicinity of the Vestfold Hills and so the depth to which this process occurs is 2.1 m plus the tidal range which is about 60 cm in the study area.

Similar laterally extensive landforms, identified as intertidal boulder pavements, are formed by the tamping action of glacial ice and winnowing by marine processes (Eyles 1994). They appear much more mature than the benches in Heidemann Valley; however there is a variety from poorly developed to very well developed (Eyles 1994). Pavement formation occurs as marine lag surfaces which are abraded by the grounding of icebergs and seasonal pack ice. Although the mechanisms here are different, the concept that ice and marine processes in concert may cause the boulder benches in Heidemann Valley is supported. Critical differences are that the Heidemann Valley structures are probably built by sea-ice action as opposed to glacial ice.

In addition, the lateral expansion of the sea ice during its formation in early winter, pushes against the sediments and forms the ridges which cut across the valley. These processes result in a characteristic landform with an arcuate rounded ridge cutting across the valley sediments and an adjacent wide flat area to seawards.

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