Proceedings of the Seventh Symposium on Antarctic Logistics and Operations

Cambridge, United Kingdom
6 to 7 August 1996

conducted by the

Standing Committee on Antarctic Logistics and Operations (SCALOP)

of the

Council of Managers of National Antarctic Programmes (COMNAP)

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XXIV Meeting of the

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Cover Picture : British Antarctic Survey DHC-7 (Dash7) and DHC-6 (Twin Otter) in flight over Rothera Station.

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Foreword

This publication provides a summary of the proceedings of the Seventh Symposium on Antarctic Logistics and Operations which was held at the Moller Centre, Cambridge, England during 6-7 August 1996. The Symposium was conducted by the Standing Committee on Antarctic Logistics and Operations (SCALOP) of the Council of Managers of National Antarctic Programmes (COMNAP). The Symposium was held in conjunction with the XXIV meeting of the Scientific Committee on antarctic Research (SCAR).

Up until 1988 and the establishment of COMNAP (and associated formation of SCALOP) the Logistics Symposia were held under the auspices of SCAR and the Antarctic Treaty Parties. Since 1988 the Logistic Symposia have been organised through COMNAP/SCALOP and it has become the practice to hold them biennially in conjunction with the meeting of SCAR.
Summary of Logistic Symposia :-

1962	Boulder - USA
1968	Tokyo - Japan
1982	Leningrad - Russia
1990	Sao Paulo - Brazil
1992	Bariloche - Argentina
1994	Rome - Italy
1996	Cambridge - United Kingdom

Efficient and effective logistics is vital to the success of any Antarctic activity and support to Antarctic science. National programmes are under continuing pressure to sharpen their operations and become more cost effective. There are also new requirements on national operators introduced as a result of the Environmental Protocol. This Seventh Symposium successfully served to provide a forum for exchanges of information, discussion and the presentation of new ideas, best available techniques (BATs) and achievements in a wide range of Antarctic activities.

Thirty (30) good quality papers were presented that had been selected by the Symposium Selection Committee from over sixty (60) submitted abstracts.
The six topic themes were as follows :-

* Remote Sensing and the Use of Satellites for Science Support.
* Deep Drilling Technologies.
* Significant and Proven Developments in Operations, Logistics and Science Support.
* Energy conservation.
* Best Available Technologies for Waste Management and the Protection of the Antarctic Environment.
* Science Operation Planning and Resource Allocation.

The Symposium attracted record size audiences ranging from 55 - 98 persons, indeed on one morning it was standing room only. It was also gratifying to see many SCAR participants.

There was a four-day commercial trade exhibition running in association with the SCALOP Seventh Symposium which reflected the distinct and growing industry related to Antarctic (polar) operations and logistics. The trade exhibits included more than thirty (30) international companies representing :

Shipyards, marine support and shipping agents.
Aviation engineering and operations.
Vehicle and sledge manufacturers.
Special mechanical and electronic engineering designers and fabricators.
Book publishers.
Clothing manufacturers.
Buildings and temporary shelter manufacturers.
Logistic support providers and contractors.
Rope manufacturers.
Manufacturers of waste management equipment and machinery.
Medical consultants.
Telecommunication manufacturers and providers.
Satellite remote sensing equipment and services.

On behalf of the SCALOP Symposium Steering Committee I wish to thank the authors and presenters for their time and effort in providing the wide selection of superb quality papers.
I also wish to thank all who found time from a busy meeting schedule to attend presentations and generate stimulating questions and discussion. Likewise my thanks to the trade exhibitors for professional trade stands & participation throughout their four day exhibit.

Finally I would personally like to thank the members of the 1996 SCALOP Symposium Steering Committee who assisted in the selection of papers and in keeping the various sub-sections of the Symposium on track and on time.
Membership of the 1996 SCALOP Symposium Working Group comprised Erick Chiang (USA), Luis Fontana (Argentina), Pietro Giuliani (Italy), John Hall (UK), Olle Melander (Sweden), Jack Sayers (Australia) and Raymond Schorno (Netherlands).

John Hall
Chairman of the Seventh SCALOP Symposium Steering Committee.

Acknowledgments

This work was sponsored by the Operations Section, Office of Polar Programs, National Science Foundation. Vernon Tejas, Oriol Sole-Costa, Quinton Rhoton, and Mike Darrah assisted greatly in performing the field work for this study.

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Table 1. Ranking of glaciers in Transantarctic Mountains based on their suitability for heavy tractor train travel (Bindschadler, 1995, personal communication).

Rating	Glacier
Good	Leverett
Fair	Skelton
	Darwin/Hatherton
	Beardmore (margin)
	Beardmore/Mill Stream
	Shackleton
Poor	Nursery
	Starshot
	Beardmore (USGS)
	Liv
Not practicable	Mullock
	Darwin
	Darwin/Touchdown
	Nimrod
	Lowery
	Robb
	Lennox-King
	Ramsey
	Amundsen
	Scott

Table 2. Synopses of two potential heavy haul traverse routes from McMurdo to South Pole. (Location of route waypoints can be obtained from the authors.)

Skelton Route	Segment Distance (km)	Max. Grade (%)	Speed Limiter	Elevation (m)
Williams Field to Shear Zone	38	0	minor sastrugi	35
Shear Zone	22	0	minor sast. & crevasses	50
Z11 to S0 (Skelton base)	205	<2	big sastrugi	150
S0 to S3	40	2	big sast. & blue ice [2]	200
S3 to S5	12	-2 to 3	deep soft snow [2]	500
S5 to SB	33	7-8, 10	deep soft snow & short steep slopes [2]	1600
SB to Plateau	85	<4	unknown	2500
Plateau to South Pole	1473	<1	unknown	3000

Leverett Route	Segment Distance (km)	Max. Grade (%)	Speed Limiter	Elevation (m)
Williams Field to Shear Zone	38	0	minor sastrugi	35
Shear Zone	22	0	minor sast. & crevasses	50
Z11 to L00	990	<2	unknown	150
L00 to L4	57	4	large sastrugi [2]	1100
L4 to L7	21	5	hard snow & large sastrugi	1500
L7 to L8	6	-3 to 5	bumps	1600
L8 to L9	6	6	none	1850
L9 to L12	7	2-6	slopes	2100
L12 to L18	4	2, 10, 15	two 0.5 km steep slopes [2]	2400
L18 to South Pole	443	<2	moderate sastrugi	3000

[1] Elevation is the maximum elevation within route segment.
[2] Crevasses shown in radar records.

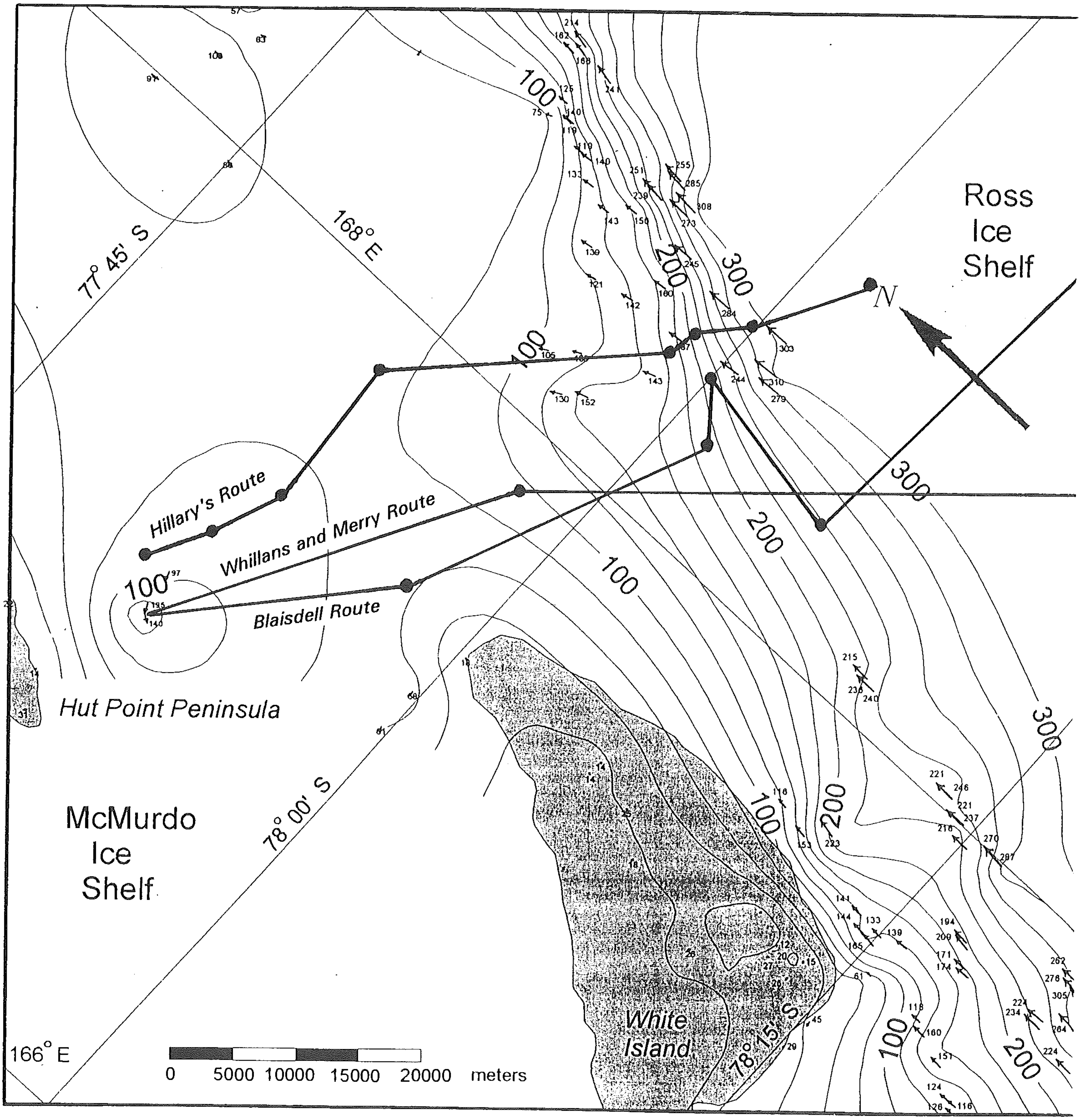

Figure 1. Velocity contours for the McMurdo and Ross Ice Shelves interpreted from satellite imagery; interval is m·a^{-1} (Whillans and Merry, 1996). Bold lines show GPR survey lines.

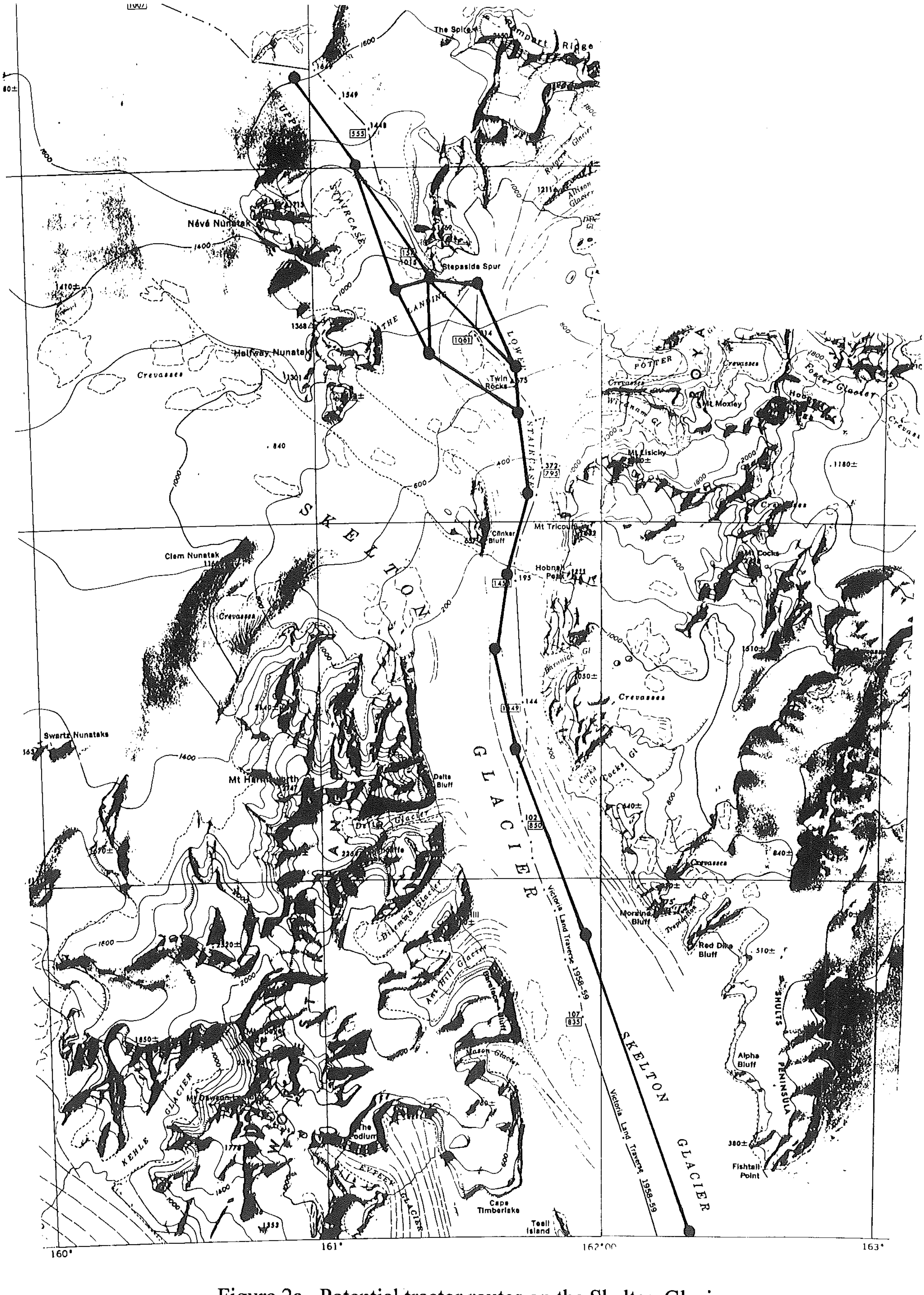

Figure 2a. Potential tractor routes on the Skelton Glacier.

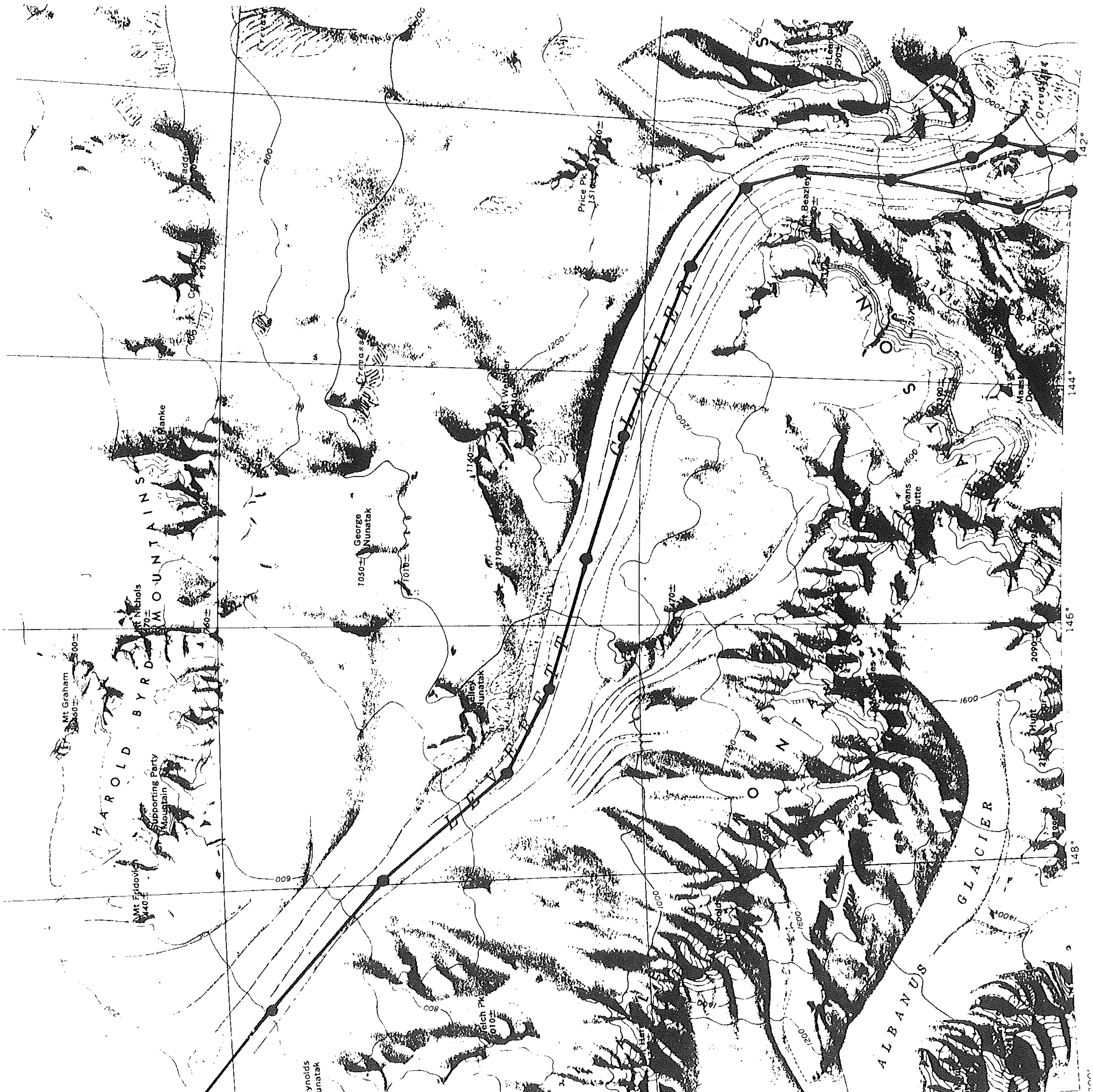

Figure 2b. Potential tractor routes on the Leverett Glacier.

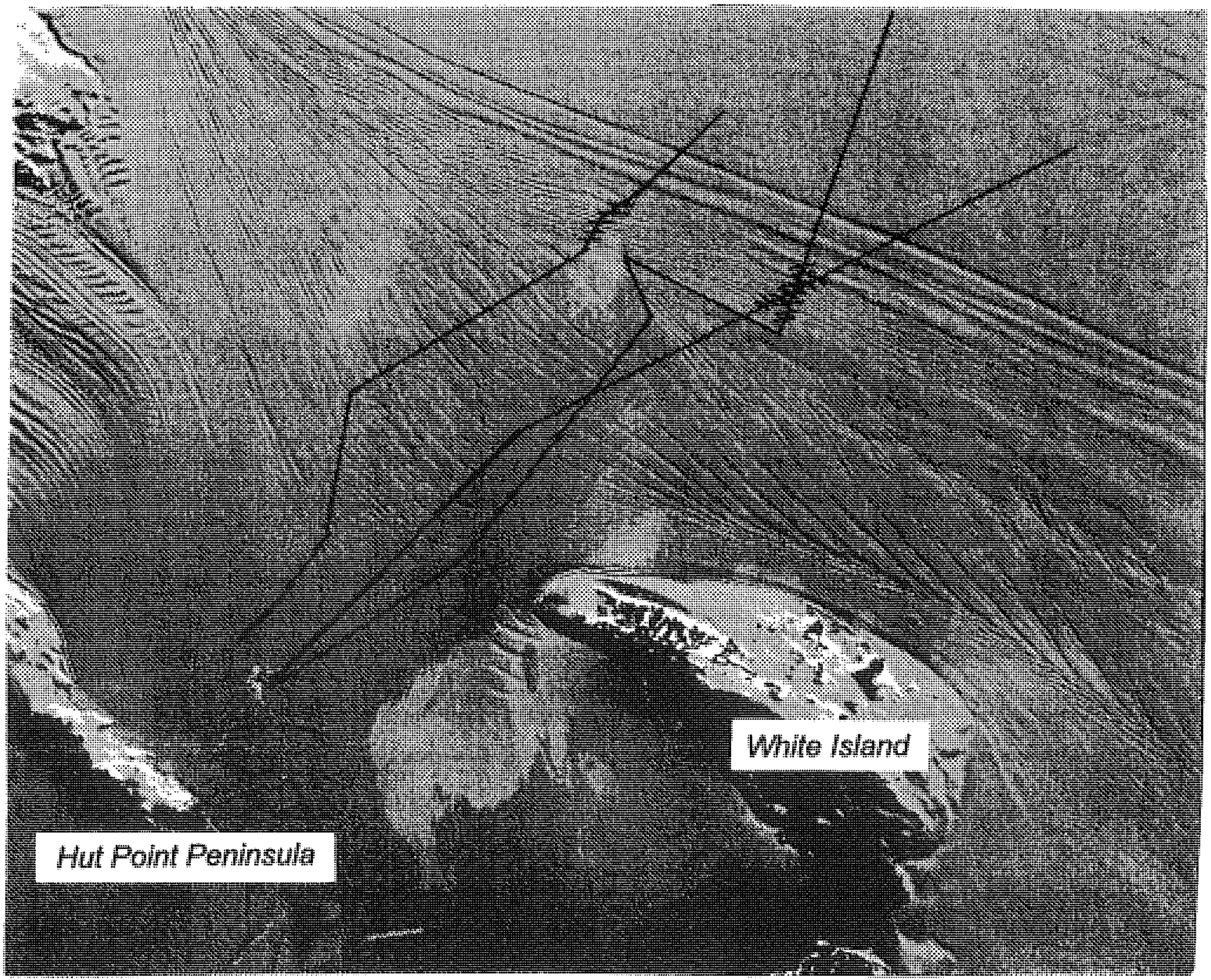

Figure 3. Crevassing (hatched areas) detected in GPR survey lines overlayed on satellite image (Whillans and Merry, 1996) of McMurdo and Ross Ice Shelves.

Airborne and Surface Radar Crevasse Detection Along The Proposed Overland Traverse Route: McMurdo to South Pole Stations

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ABSTRACT

Airborne and surface-based ground-penetrating radar was used to profile hidden crevasses along selected transects on the McMurdo Ice Shelf, and Skelton and Leverett Glaciers. The transects lie within areas being considered for the overland traverse route from McMurdo to South Pole Stations. The radar utilized a low-power transmitter and radiated a 2-cycle wavelet with a local frequency of 500 MHz. The antennas were mounted to a helicopter and flown at approximately 30 knots. Surface traverses oved at approximately 5 knots. Radar penetration varied from about 10 to 20 m, depending on aircraft altitude above the ice surface. Snow bridge dimensions and crevasse walls are interpreted from the placement of strong diffractions; weaker diffractions are interpreted as being associated with stratigraphic folding. The hidden crevasses are interpreted as both steep-walled chasms and large cavities, some of which appear to be connected. Snow characteristics profiled besides folding include wind slabbing and sagging associated with the snow bridges. Crevasses in the McMurdo Ice Shelf were confined to a 4-km-wide corridor, within which snow was intensely folded due to the compression within this area. The shallow snow bridge thickness of some crevasses imply that they are actively forming. At least 22 crevasses with snow bridges less than 5 m thick were found along a 2.6-km section of the surface traverse; their widths may generally range from about 1.4 to 17 m. Severe hidden crevassing occurs along the Skelton Glacier in the vicinity of Twin Rocks and no route was found that could avoid it. Crevassing along the Leverett Glacier appears far less severe. A route was found along the Leverett in which most crevasses occurred beneath snow bridges greater than 8 m thick. A comparison between the airborne and ground profiles recorded on the ice shelf reveals that less detail of the snow-bridge dimensions was available from the air due to the faster speed. Advance ground surveys are recommended for any ground excursions. Longer time ranges and higher frequencies can be used to improve detail and increase information, including cavity depth. This is feasible for surface profiles with present technology, but airborne work will require faster scan rates.

INTRODUCTION

Detection of hidden crevasses is a necessary safety measure for selection of an overland traverse route from McMurdo to South Pole Stations. This traverse is being considered for a supply route for South Pole Station. At present, the planned traverse must pass over the transition between the McMurdo and Ross Ice Shelves where a shear zone exists. The traverse then accesses the polar plateau along either the Skelton or Leverett Glacier. These three regions all have particular areas of crevassing that must be avoided or remediated. We surveyed for crevasses within these areas late in 1995 by using both air- and ground-based ground-penetrating radar (GPR). Our objectives were to delineate the crevassed zones, and estimate both the frequency of crevasse occurrence within them and the crevasse snow bridge dimensions. This paper reports on the results of both the ground and the airborne surveys and also discusses individual crevasse responses. Companion papers in these proceedings discuss the logistics and operation of the radar system (Delaney et al.), and field investigations of the crevasses and snow conditions (Blaisdell et al.).

The ability of surface-based high-resolution GPR radiating at bandwidths centered at 80--120 MHz to detect crevasses is well documented (Kovacs and Abele 1974; Jezek et al. 1980; Glover and Rees 1992; Bentley et al. 1992; Clarke and Bentley 1994). Finding crevasses with radar requires detection and imaging of diffractions produced by crevasses. The formation of a diffraction image requires a complete crevasse traverse with the GPR antenna, and therefore, the embarrassing risk of falling into the crevasse while it is being imaged. Consequently, safe imaging requires either an extremely long and unwieldy boom, or a well controlled aircraft radar platform.

The research done by Glover and Rees in Greenland at 500 MHz and by Clarke and Bentley on antarctic Ice Stream B with an 80-MHz antenna, is particularly relevant to this work because the responses to folding and crevassing that they observed are similar to our results. In particular, Clarke and Bentley reported that steep-walled crevasses have weak surface and strong bottom returns, that crevasse walls are often defined by half-images of diffraction hyperbolas with stronger responses for rougher walls, and that sagging snow bridges or faults can cause weak diffractions that can be mistaken for crevasse diffractions. In this study we used a 500-MHz center frequency and performed our ground surveys with higher data acquisition rates than did Glover and Rees or Clark and Bentley. These survey parameters enabled us to estimate better snow bridge width and depth. We show that crevasse images recorded when the radar is aboard a low and slow-moving helicopter are similar to those recorded on the ice surface, despite the added layer of (refracting) air and different antenna directivity patterns. We find that we are able to distinguish hyperbolas generated by sagging snow bridges from those due to buried ice-air interfaces by signal amplitude, and by the steepness of the diffraction asymptotes. We also find strong evidence for the presence of large buried cavities in some of the areas surveyed.

EQUIPMENT AND PROCEDURES

The following discussion briefly summarizes the operation and deployment of our radar system. A more detailed discussion is given by Delaney et al. in these proceedings.

Radar System

The GPR system consisted of a GSSI, model 10a+ control unit and model 3102 antenna transducer. The control system set the frequency filters, gain functions and data acquistion parameters and also operated a separate video monitor that gave a real-time profile display. The transducer contained the transmitter and receiver electronics and close-coupled, bistatic and dual shielded, resistively loaded, bow tie dipoles that produced a 2-2.5 cycle pulse (Fig. 1) with a local frequency of about 500 MHz. Peak power delivered to the transmitter antenna terminals is specified by the manufacturer at 8 W. The received radar radio frequency signals were converted by sequential sampling to audio frequencies for amplification and digitization. Time-range gain was then applied to the audio scans to suppress the higher-amplitude early returns, especially from the transducer direct coupling, and enhance the lower-amplitude, later returns. Data were recorded directly to computer hard drive in 8-bit, 512- or 1024-word scans and displayed over a selected calibrated time range window.

Transmit-receive antenna radiation patterns for the model 3102 are shown in Figure 2 (after Arcone et al, 1986). The half-power (3-dB) beamwidths in the principal radiation planes (the plane parallel with the antenna axis and with the radiated electric field, and the plane perpendicular to the antenna axis, but parallel with the radiated magnetic field) are each about 70 degrees for the airborne patterns. After accounting for refraction within snow of density about 0.5 gm/cm^3, these widths narrow to about 45 degrees and continue to narrow slightly with depth. The 10-dB beamwidths are 120 to 130 degrees in air and about 70 to 74 degrees in snow. The wide beamwidth is critical to diffraction detection; a high-gain antenna would give greater penetration, but little off-axis response. These patterns are to be compared with theoretical subsurface patterns for a ground-based antenna (Fig. 2). The surface patterns are far more irregular. In the plane of the profiling transects (H-plane) they are far wider and increase to a peak value at an angle of 110 degrees from vertical. Therefore, they are more sensitive to subsurface diffractions.

Data acquisition and processing

All data were recorded using high- and low-pass filters to remove dc gain offsets ("tilt") within individual scans and electronic noise, respectively. Scan density was sometimes maximized for helicopter speeds of 10-15 m/sec by recording at 8 bits and at 512 samples/scan to allow 78 scans per second to be recorded. This necessitated undersampling of the waveform when recording at scan durations longer than about 120 ns. We found that as few as four samples for each cycle within the pulse were sufficient to reproduce an interpretable, quality record.

Post-processing began with a horizontal (scan-to-scan) high-pass "background removal" filter that eliminated direct aircraft reflections, which occurred at a constant time delay. Normal inability of the aircraft to hold a constant altitude prevented ice data from being sensitive to this filter. The ice surface reflection was then normalized (made horizontal by eliminating aircraft altitude changes). This process allowed responses to stratigraphy within the firn to be distinguished from multiple aircraft-to-surface reflections.

Transformation of echo time delay *t*, measured in nanoseconds (ns) into depth *d* in meters is generally based on the simple echo delay formula for flat interfaces or point reflectors

$$d = ct/2\sqrt{\varepsilon} \qquad (1)$$

where c is the speed of electromagnetic waves in a vacuum (0.3 m/ns) and ε is the dielectric permittivity of the propagation medium. The factor of two accounts for the round-trip propagation path. A value of $\varepsilon = 2.2$ (snow density about 0.6 gm/cc) was used to translate echo time delay into snow and firn depths to about 20-m depth.

Data are displayed as echo-time-of-return versus profile distance using a grey-scale, line intensity format. Both a linear and nonlinear scheme are used for the intensity format. The linear scheme shows mainly the stronger crevasse diffractions. The nonlinear scheme gives more tone to weaker events so that responses to the firn layering and faint diffraction hyperbolas, such as from apices within folding, can be viewed.

Aircraft and Ice-Surface Procedures

The transducer, GPS antenna and their supports were attached to helicopter fuselage port-side hard-points (Delaney et al., these proceedings). The control unit and power supply were situated in the rear passenger area. The survey altitude was 3-15 m and air speed was generally about 15 m/s. Speed was read from aircraft instrumentation and the GPS receiver. Ground traverses across the McMurdo Ice Shelf were performed by pushing the antenna transducer ahead of a snow machine at about 2-3 m/s. All surface traverses had first been walked and probed to establish some measure of safety for these traverses.

Survey position control was provided by a Magnavox MX300 using an external antenna mounted atop the radar transducer for airborne surveys, and on a sled for the surface surveys. The GPS acquires an initial position within several minutes and then updates position once every second. Position way points were manually recorded at the ends of all survey lines, and incrementally on long survey lines coincidentally with event markers entered onto the radar data file.

LOCATION OF SITES

The surveys discussed are all located along the western margin of the Ross Ice Shelf (Fig. 3). The currently proposed route to Amundsen-Scott South Pole Station leaves McMurdo Station, passes to the north of White Island, and then either winds south around Minna Bluff and east up the Skelton Glacier, or continues southwest across the Ross Ice Shelf and accesses the polar plateau along the Leverett Glacier. The route must traverse a 5-km-wide corridor near White Island known as the McMurdo shear zone, an area where shearing results from the faster moving ice of the Ross Ice Shelf shifting past the more constrained and slower moving ice of the McMurdo Ice Shelf. This entire area has a somewhat wrinkled, or turbulent, appearance in satellite images (Fig. 4), and was suspected of being heavily crevassed. Although the satellite imagery reveals surface streamlines and undulations, locally the surface appears smooth and there is no evidence of crevassing.

Parts of the McMurdo Ice Shelf have been well investigated with high-resolution GPR. Ground-based studies (Kovacs and Gow 1975; Kovacs et al. 1982; Arcone et al. 1994; Arcone 1996) were confined to areas containing a horizontal brine zone where seawater has infiltrated the more permeable firn near the surface. It lies between the shelf front and a line running approximately from the north end of White Island to a point on Ross Island about 10 km from McMurdo Station. The brine generally blocks any deeper radar penetration. Although the shear zone lies well to the east of the brine zone, the detailed density profiles obtained by Kovacs and Gow, the diffraction velocity analysis of Arcone (1996) and Arcone et al. (1994), and the dielectric permittivity versus snow density calibrations of Cumming (1952) provided us with enough information to estimate the relative ε of firn in order to calibrate depth from the GPR time delays to better than 10%. Airborne GPR studies have been performed within the shear zone in the past (Delaney and Arcone 1995) to determine the influence of speed and altitude on airborne data quality and to define the extent of crevassing. A grid survey was also recorded near the reported location of a lost bulldozer. At the time of those surveys (January 1994) the satellite image of Figure 4 was not available. The surveys discussed here were close to, but south of, the tractor site.

The Skelton Glacier was chosen as a possible tractor route because of its proximity to McMurdo Station and its past history of supporting traverses to the polar plateau. Expeditions in 1957 and 1959 encountered severe crevassing near an area known as Twin Rocks, but successfully reached the South Pole. The Leverett Glacier was chosen for its generally gentle slope, hard-packed snow surface and its general lack of visible crevassing. Its far distance from McMurdo Station will require a long traverse across the Ross Ice Shelf. Both glaciers have been investigated by airborne visual reconnaissance, but neither has ever been investigated with GPR for crevasse detection. Minimal surface reconnaisance on the Leverett was performed in January 1994 (G. Hamilton,Ohio St. Univ., pers. comm.) and initial flightlines for the GPR survey were based on that work. Flightlines along the Skelton were established by inspection of USGS topographic maps and air photos upon which severely crevassed areas are obvious.

RESULTS AND DISCUSSION

Shear Zone

The shear zone airborne and ground transects discussed are located on Figure 4. The ground profile consisted of three parallel profiles that spanned a swath about 13 m wide. Within the shear zone crevasses were encountered continuously over an area approximately 2.7 km wide. A few of these crevasses were opened and one is discussed here. The airborne profile was one of several that traversed the shear zone, all of which were used originally to define the extent of the crevassed area. Several other profiles continued 10 to 20 km beyond both sides of the shear zone and showed only relatively undistorted layers of firn. The surface was dry and cold during all surveys. The airborne profiles were performed on 8 November 1995 and the ground profiles on 1 December 1995. Blaisdell et al. (these proceedings) discuss the exploration of some of the crevasses surveyed on the ground.

Surface-based radar responses from two (north-side and south-side) parallel transects that crossed a steep-walled crevasse are shown in Figure 5. The transect orientation was about 45 degrees to the axis (or strike) of the crevasse. A linear intensity scale is used so that weak signals are not visible. The horizontal compression factor in the profiles is approximately 2.5. The blank areas are reflectionless zones that image the crevasse at the transect crossing angle. The radar time range was not long enough to see any response that we could interpret as the bottom of the crevasses in the shear zone. The bottom appeared to pinch closed and the exact radar response to such a feature is unknown. The imaged representations of the walls are made possible primarily by the firn stratification that allows reflections to be monitored continuously with depth, but also by the edges of the hyperbolically shaped half-diffractions that emanate from the crevasse walls and are recorded as the crevasse is approached. These diffractions end abruptly as the wall is crossed; the open crack prevents detection of the wall just passed.

On the north-side survey line of Figure 5, the crevasse had a measured 2.75-m thick snow bridge, was 3.7 m wide at an unspecified point near the top, and the bottom was 25 m deep. According to the radar image, the north-side snow bridge is about 3.0 m thick as measured from the onset of the surface reflection to the onset of the last snow bridge diffraction. Accounting for the transect orientation, the north side widens in the radar image from about 2.5 m near the top to about 4.6 m at the 6-m depth. Along the south-side survey line the internal inspection showed the snow bridge was 2.5 m thick, the width near the top was 4.6-7.6 m and the bottom depth was 28 m. The crevasse appeared to become more cavernous with depth on the south side and the walls were not straight; i.e., the crevasse curved with depth. According to the radar image, the south-side snow bridge is about 2.5 m thick, and the crevasse width is about 2 m near the top and widens to about 2.5 m at 6-m depth. The south-side crevasse is very close to a second, more deeply buried crevasse at about 6- or 7-m below the surface, which is consistent with the observations. On the north side, however, these two crevasses are more separated.

The reason for the larger discrepancies (lesser widths) in the radar interpretations of the south side of the crevasse is not totally clear at the time of this writing, but it appears to be related to the dip of the stratigraphy near the walls, which in turn, may be caused by the distortion of the crevasse itself. If the stratigraphic horizons dip across the crevasse, as occurs on the south side profile in Figure 5, then the horizons near the crevasse walls will continue to be detected while the radar moves over the crevasse because the dipping strata are then perpendicular to the direction of the antenna. The opposite case, that of too great a width being imaged by radar, has also been observed in other crevasses where strata are pushed up on either side of a crevasse (e.g., the deeper cavity in the north-side profile). In this case, reflections are not received when the antennas are very near the crevasse walls because the near-wall strata deflect the signals away from the receiver antenna, thus making the crevasse appear wider than it is. Other possible reasons precluding exact interpretation of crevasse width are scattering of energy by the complex snow and ice structure of the snow bridge, complex propagation paths along the crevasse walls, and scattering from the numerous small fins of ice that have been observed along the otherwise smooth crevasse walls.

There is much evidence of active dynamics in this area. Many crevasses are beneath snow bridges less than about 200 cm deep, which implies recent formation. Yearly snow accumulation rates may be as high as 50 cm, which implies that a crevasse beneath a 2.5-m-thick snow bridge has been opening for only the past five years. In a shear zone, crevasses can form "en echelon," producing regions where their ends may be closely spaced, as is apparently happening in the south survey line in Figure 5. Figure 6a shows a different example where a narrow wall exists between two crevasses that begin at the same depth and appear to widen with depth. In Figure 6b we see several examples of crevasses, which appear as rectangular cavities with ledges. These crevasses all occur in a 100-m span and the widths of two of them appear to increase to greater than 20 m toward the bottom of the record.

In general, we detected 22 crevasses beneath snow bridges of 5 m or less thickness along a 2.6 km distance on the north survey line. Their widths, accounting for an assumed average orientation of about 45 degrees to the survey line, ranged from about 1.4 m to 17 m. The average snow bridge thickness was 3 m and the average width was 7 m. The bottoms of all these crevasses were greater than 10 m deep and probably extended to over 25 m depth. There were many more crevasses with bridge thickness in excess of 5 m.

A section of the airborne profile across the shear zone is shown in Figure 7. The responses to crevasses are obvious as they have the same characteristic open zones of reduced reflections as do the ground-based surveys. This is understandable in that the wave impedance of the additional "layer" of air between the antenna and snow surface is still fairly well matched to that of the snow. The main differences are that they show less definition of the crevasse walls, and pronounced diffraction responses to the snow bridges are less intense or absent. This is a consequence of a slower scan acquisition rate (used to obtain a sufficent sampling density for the scans of 1024 samples/scan) because of the greater profiling speed (note the difference in length scales between Figures 5 or 6, and 7). The airborne profile obtained over the Leverett Glacier (discussed below) was obtained at a higher scan rate in deference to a decreased scan sample density.

Skelton Glacier

Transects on Skelton Glacier along which bridged crevasses were detected are shown superimposed on a USGS topographic map in Figure 8. The left side of Figure 8 shows the region around Twin Rocks. During our visits the area was covered with fresh loose snow, and topographic relief here is severe. The profiles were obtained on 28 and 29 November 1995, at which time the surface appeared dry. The figure shows areas of conspicuous, open crevassing, as depicted on the USGS map and as reported from recent reconnaissance, and sections of hidden crevassing marked in our radar transects. Although the transects were flown in an effort to locate routes that could avoid the hidden crevassing, it is apparent that none were successful. In addition, some lines, such as transect 8, could not avoid open crevassing. High winds were encountered along all flight lines and aircraft speed varied from about 30 to 60 knots, so that it is difficult to estimate the crevasse frequency from the radar records.

A typical segment of a radar profile (transect 8, located at the center of the Twin Rocks map near the letters "LO" in the word "LOWER") that shows crevassing on the east side of Twin Rocks is shown in Figure 9. This is a particularly treacherous area with thin snow bridges, a few of which have collapsed (open areas indicated in figure). The record is dominated by diffractions from within snow bridges and from collapsed snow at the bottom of crevasses. Between 0 and 200 m horizontal distance on the profile the snow stratigraphy appears intensely folded. Many of the crevasses on this transect appear to be very large, and the radar could not detect any discernible crevasse bottom within the time range used (approximately 15-m penetration into the firn).

Leverett Glacier

The Leverett Glacier transects are shown superimposed on a USGS topographic map of almost the entire glacier in Figure 10. The transects are indicated as LVG1, LVG2, etc. The map marks areas of open crevassing mapped by the USGS and by a pevious survey of January 1994 (G. Hamilton, Ohio St. Univ., pers. comm.). The transects flown were chosen to avoid these areas. The entire glacier profile encountered little local relief (sastrugi), but some was seen in the vicinity of Mt. Beasley. At the time of the survey (24 November 1995), twenty-knot downglacier winds and fine blowing snow along the surface were encountered on the upper trunk.

Hidden but apparently deeply buried crevassing was found within LVG1 (Fig. 11), and at the start of LVG4 (Fig. 12, top). The lower reach of the glacier appears to be part of the Ross Ice Shelf, and the orientations of nearby open crevasses to the northeast are transverse to the glacier flow lines. The folding (top, Fig. 11) implies compressional stresses in the snow and ice and the crevasses appear to be forming at synclinal hinges in the stratigraphy. The snow bridges range in thickness from 8-15 m and the estimated crevasse widths may be as large as 10 m. More dangerous crevassing nearer the surface occurred along transect LVG4 (Fig. 12, top). Alternate transects LVG17, LVG18, and LVG19, approximately 1/3 of the way from the lower reach, were successful in finding a route to avoid near-surface crevassing.

Routing through the upper trunk avoided an area known as the heart-shaped crevasse region (Fig. 13). This crevassing appears to be within an ice fall and is in the only area with any significant topographic relief. Only a few hidden crevasses were detected along transect LVG13 (Fig. 12, bottom). transects LVG11 and LVG12 are also along this western bypass and both appeared to be crevasse-free. This is surprising in view of the open crevassing that also existed west of LVG13. An alternate route past the heart-shaped area to the east was flown as well and also found to have only a few crevasses. In Figure 12, the crevasses along LVG13 appear to be buried over 8 m deep and are possibly as wide as 10 m. An interesting feature is the disposition of the snow stratigraphy from 40 to 160 m, as indicated by the distinct horizons. We interpret these horizons as possible yearly melting and refreezing events. The depositional horizons appear to increase downglacier (towards zero m). Therefore, the ice about the crevasses (and over a steeper slope?) may be moving faster than it is beyond the crevasses. We cannot estimate the slope of this transect, but it is the most severe within the glacier.

CONCLUSIONS

Crevasses within the McMurdo shear zone appear to be both cracks that reach near the surface, and cavities at depth, some of which appear to be connected. This is consistent with crevassing in a zone of ice shear. At least 22 crevasses were detected along one 2.6-km traverse. They may range up to about 17 m in width, and up to 5 m in snow bridge thickness. Our surface radar survey was safely performed here so that it appears possible to continue an investigation of any planned route by snowmobile. Any route established in the shear zone will require periodic monitoring with radar.

Crevasses near Twin Rocks on the Skelton Glacier appear to be mostly large cavities within folded snow and ice. These areas appear particularly dangerous and we have photographed holes in the snow cover that appear to contain enormous openings. Several flight lines failed to find any route past the area that was not crevassed. In contrast, crevasses along the Leverett Glacier appear far less dangerous. This is surely due to the more gentle topography and less circuitous ice flow along this glacier. On the Leverett, although crevasse widths appear to range to about 10 m, a route was found along which depths were mostly greater than 8 m. We detected far fewer crevasses than expected along the upper trunk where slopes were steepest, but we think that more would be found if the survey could have extended several more kilometers south.

Airborne radar profiles appear capable of providing all the information that ground-based surveys do. However, our air speeds of 30 knots were still too fast for the data acquisition system we used and we recommend no greater than 20 knots in the future unless only a general reconnaissance-grade survey is required. In addition, if airborne GPS remains as inaccurate as it is at present then any ground traverses with heavy equipment will require an advance ground system for more precise crevasse detection and location.

Longer time ranges will be needed to see if clear responses at 500 MHz can be obtained from crevasse bottoms. This, too, will require faster data acquisition for airborne work at 30-knots speed; current radars are fast enough for ground work. The use of higher frequencies, 1-2 GHz, should be used to see if they can provide better detail on snow-bridge dimensions and on crevasse depth. Their narrow beamwidth may make them inapplicable for detecting diffractions from the air, but possibly make them much better for ground traverses where cavities could be well defined by reflections only.

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ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Figure 1. Radiated waveforms transmitted and received by the airborne 500-MHz antenna transducer. A single waveform (darkened) is seen at the ice surface reflection, and many others arrive later from beneath the surface. The waveform marked "direct coupling" is a transmission directly from the transmitter antenna to the receiver antenna and serves as a reference for altitude above the ice surface.

Figure 2. Transmit/receive beamwidths in the principal radiation planes for airborne (left) and ground-based (right), bistatic, shielded and closely spaced antennas. The snow density is 0.5 gm/cc for the surface pattern.

Figure 3. Location of the Shear Zone, Skelton and Leverett Glaciers, along the perimeter of the Ross Ice Shelf.

Figure 4. Satellite image (after Whillans and Merry, 1996) showing the Shear Zone (between dotted lines) in relation to White Island and Hut Point on Ross Island. Also located are the ground and airborne profiles discussed, and the approximate location of a tractor that is lost in a crevasse (marked "Linda"). The darker parallel bands east of the Shear Zone are flow patterns from the Skelton Glacier to the south.

Figure 5. 500-MHz profiles recorded across two locations (top: north; bottom: south) on the same crevasse and separated about 13.7 m. The horizontal scale is compressed by a factor of about 2.

Figure 6. Examples of crevasse images from the shear zone. Top: two closely spaced crevasses at their point of overlapping within an en echelon pattern. Bottom: large cavities that appear to widen with depth.

Figure 7. Two segments of an airborne crevasse profile across the shear zone.

Figure 8. Airborne profiles in the heavily crevassed, Twin Rocks area (left) of the Skelton Glacier. Shaded rectangles and short bars crossing profiles indicate hidden crevassing detected by radar. Cross-hatching indicates areas of open crevassing. The several flightlines were made in an effort to find an uncrevassed route. The right-hand map is of the lower Skelton trunk and shows a 15-km segment that showed possible crevasse diffractions throughout its length.

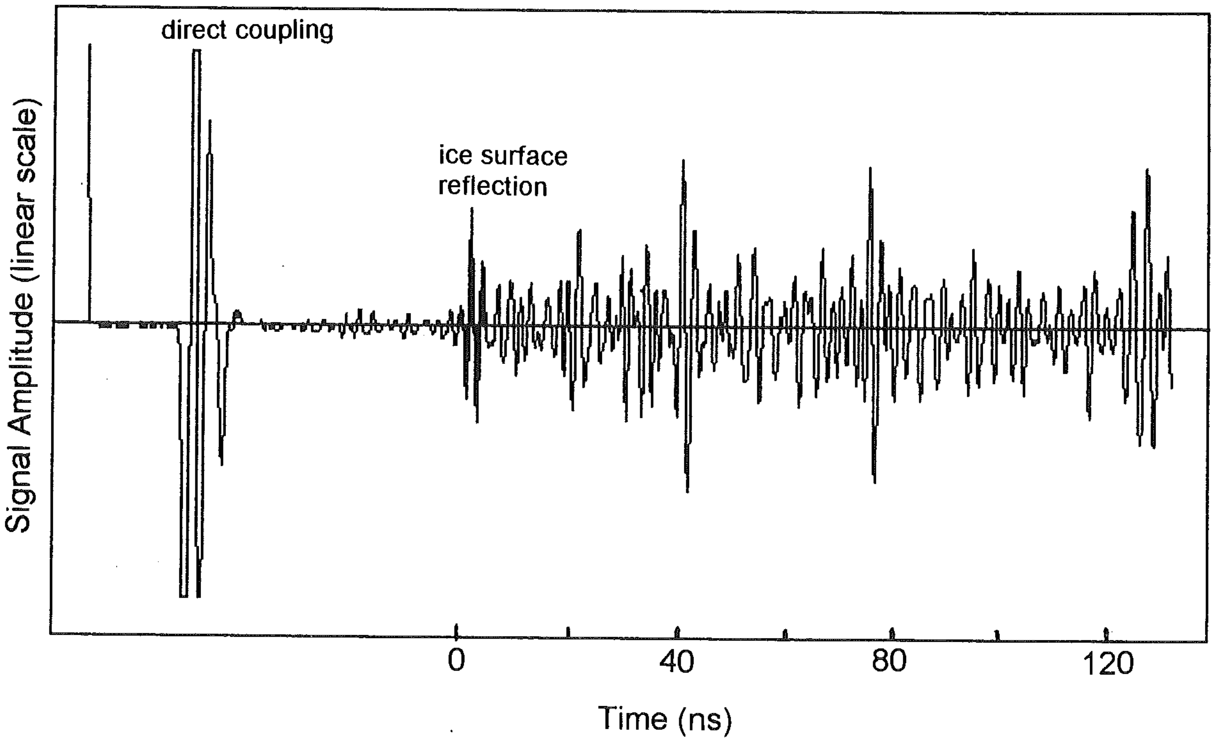
Figure 9. Crevasse profile along transect 8 in the Twin Rocks area of Skelton Glacier. Sections with discontinuities in the surface reflections contained visibly open crevasses and are so marked.

Figure 10. Airborne profile traverse along the Leverett Glacier. Hatchered areas indicate open crevasses. Segments 1, 4 and 13 (indicated as LVG1, LVG4 and LVG13 on map) contained hidden crevasses, most of which are several meters below the surface.

Figure 11. Crevassed segments of transect LVG1. The strong hyperbolas from the bottom of the snow bridges originate at least 8 m deep.

Figure 12. Profiles of crevasses at the start of segment LVG4 on the lower reach (top), and along segment LVG13 (bottom) near the heart-shaped crevasse area in the upper trunk of the Leverett Glacier. Figure 10 shows an alternate route (LVG17-LVG18-LVG19) that avoids the crevassing along LVG4.

Figure 13. The heart-shaped crevasse area on the upper Leverett trunk. The view is downglacier, to the north towards the Ross Ice Shelf.



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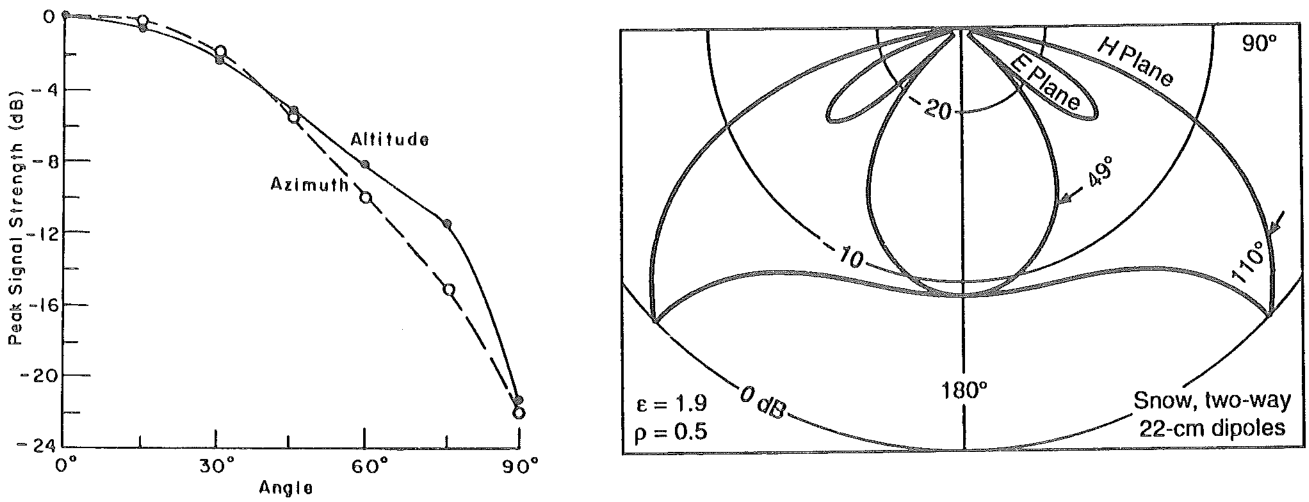

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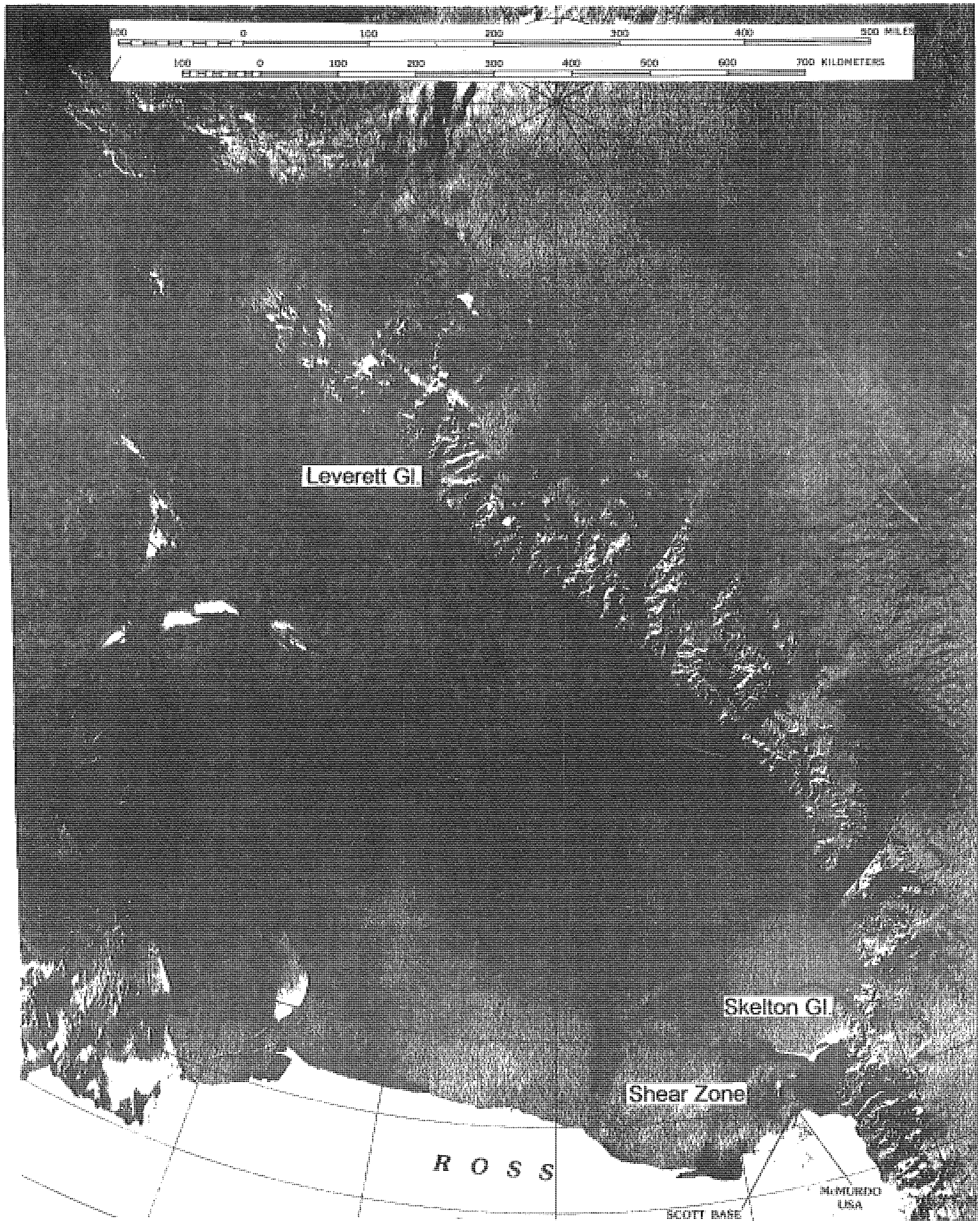

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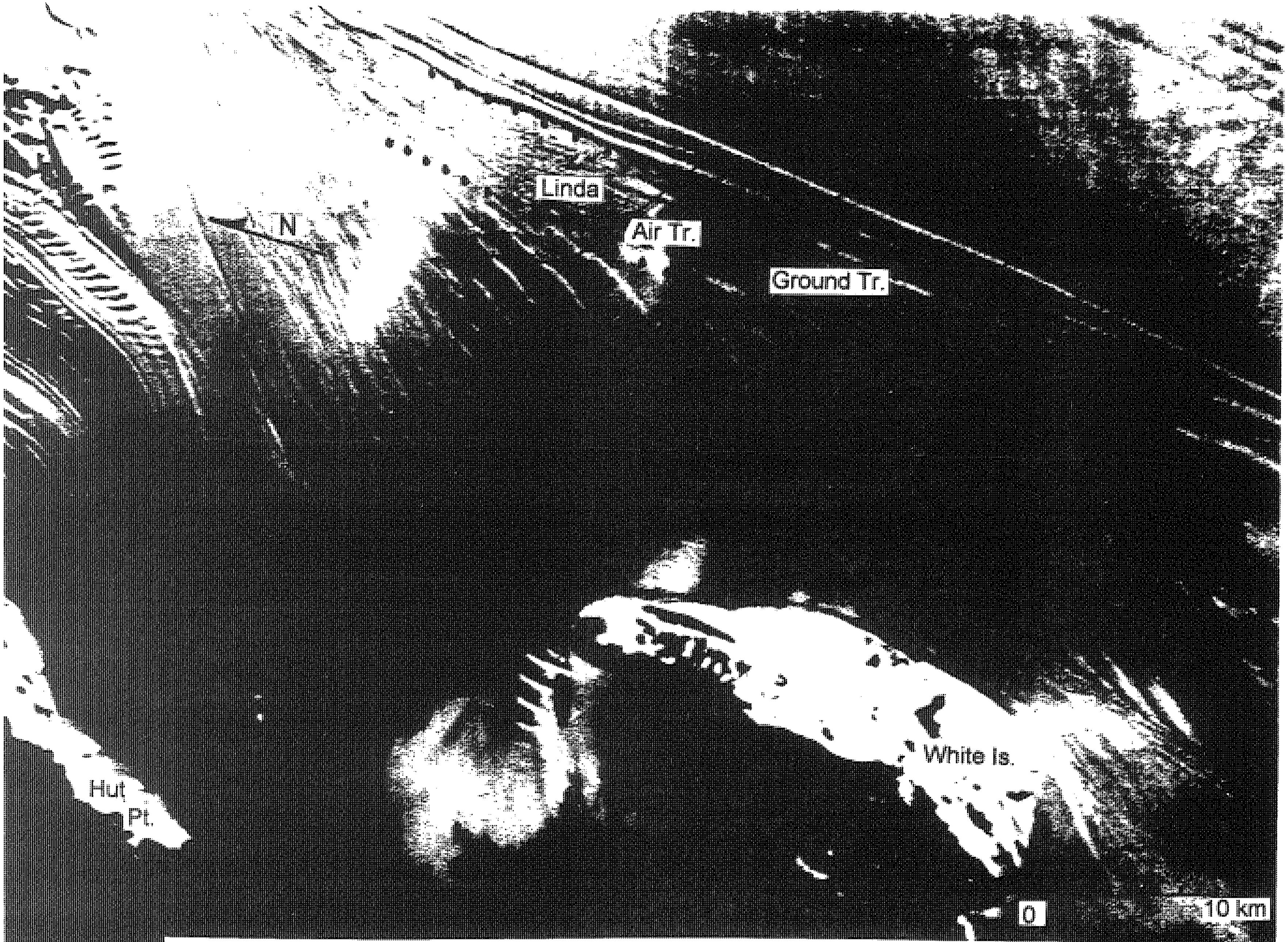

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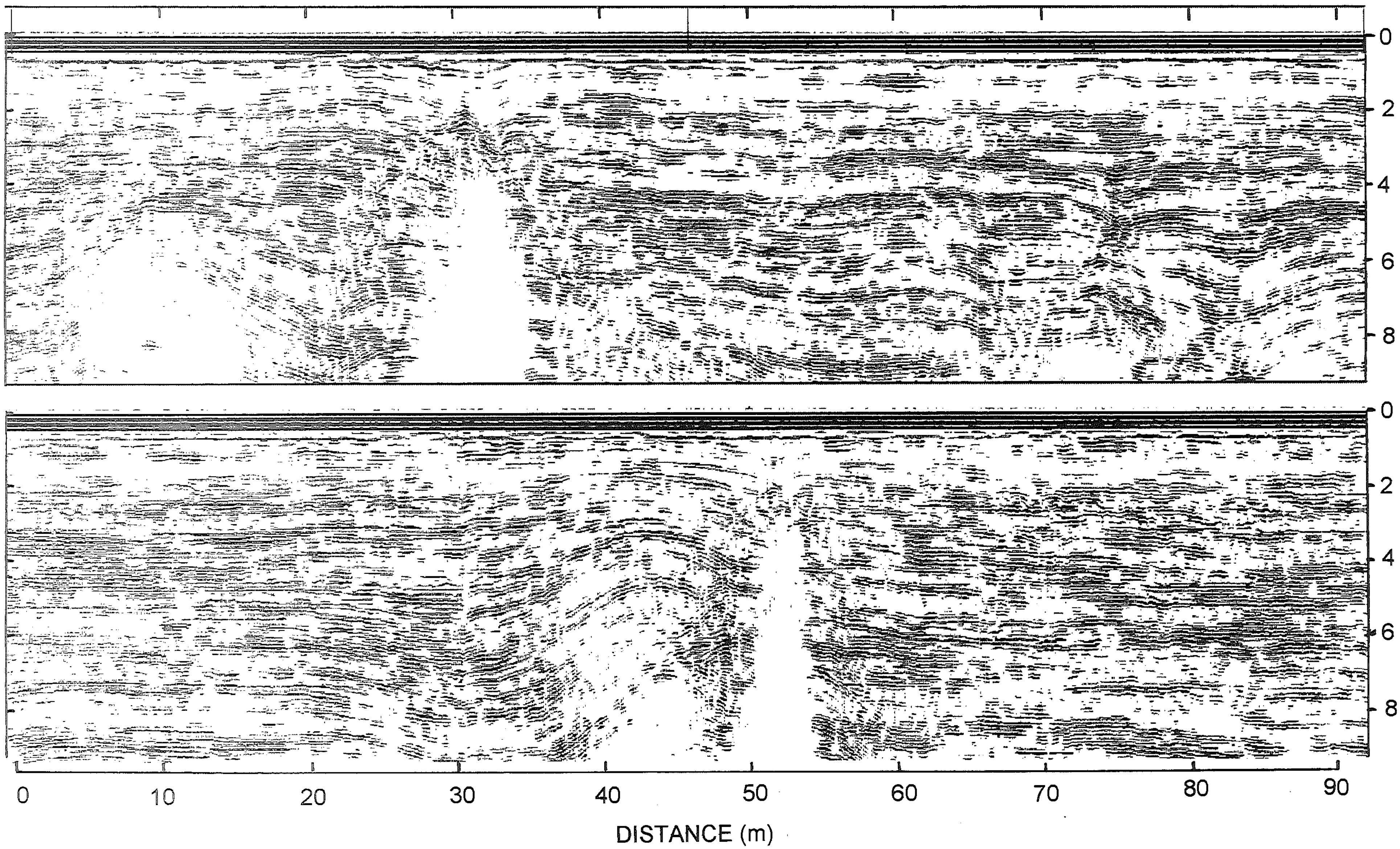

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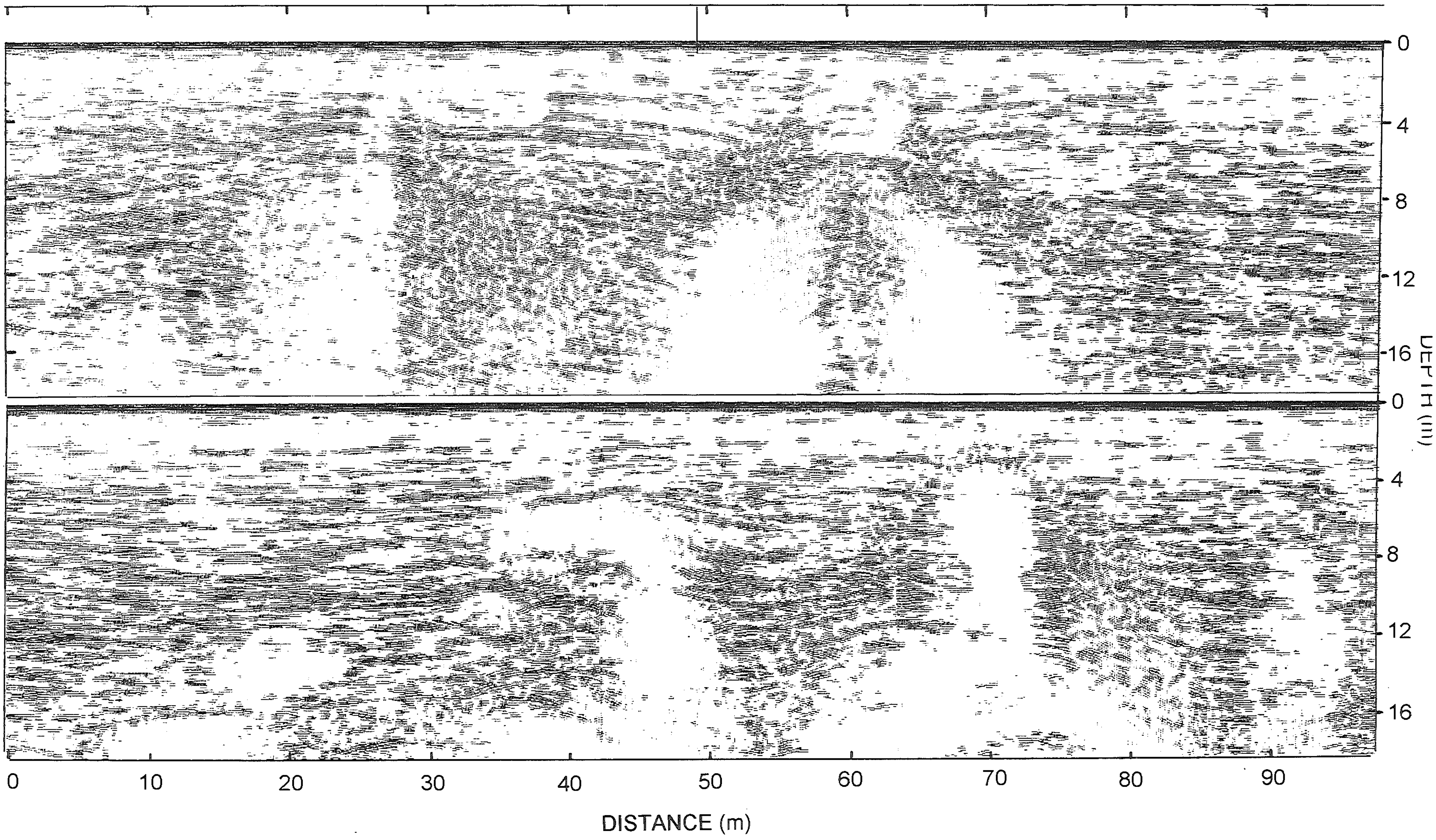

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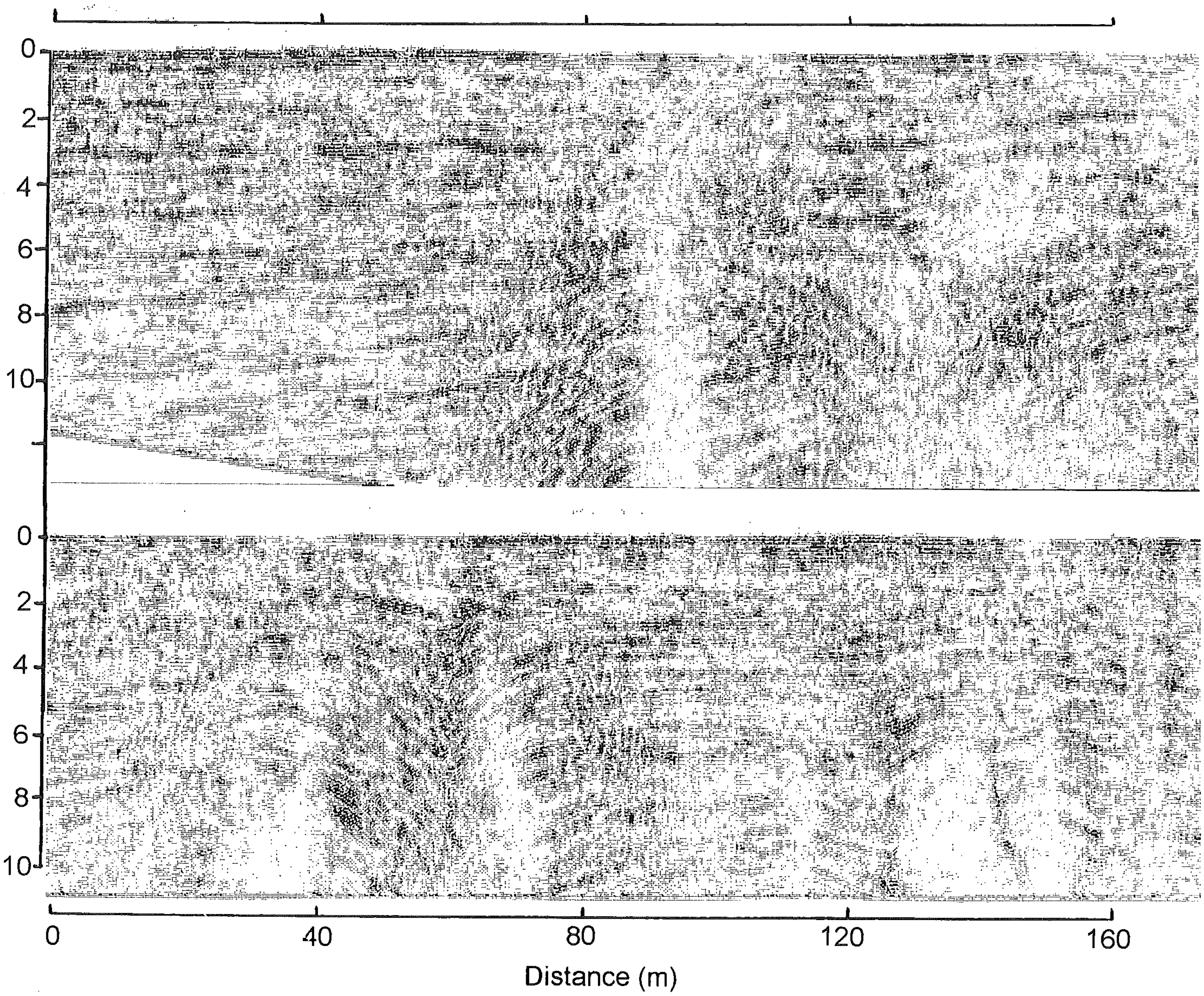

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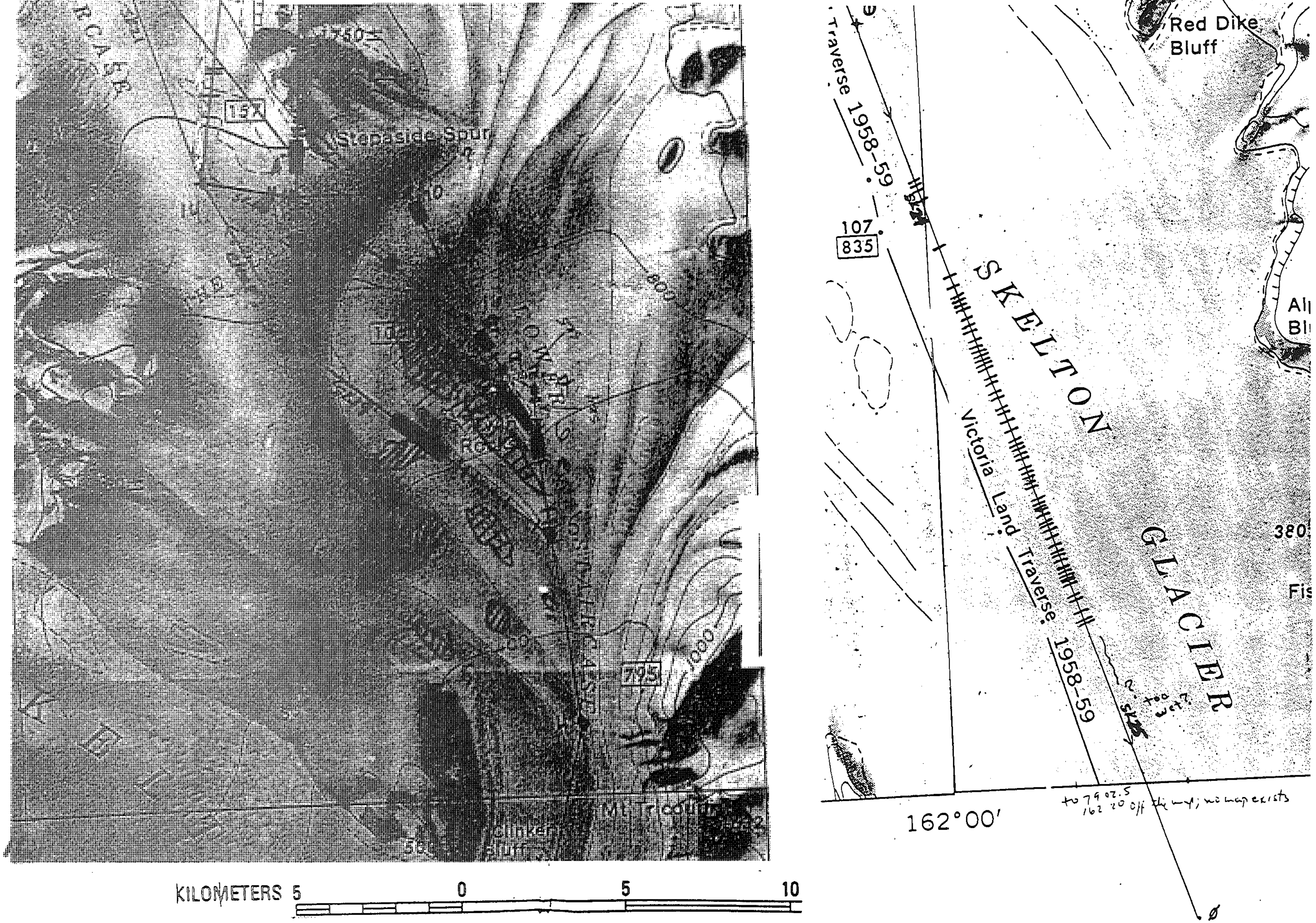

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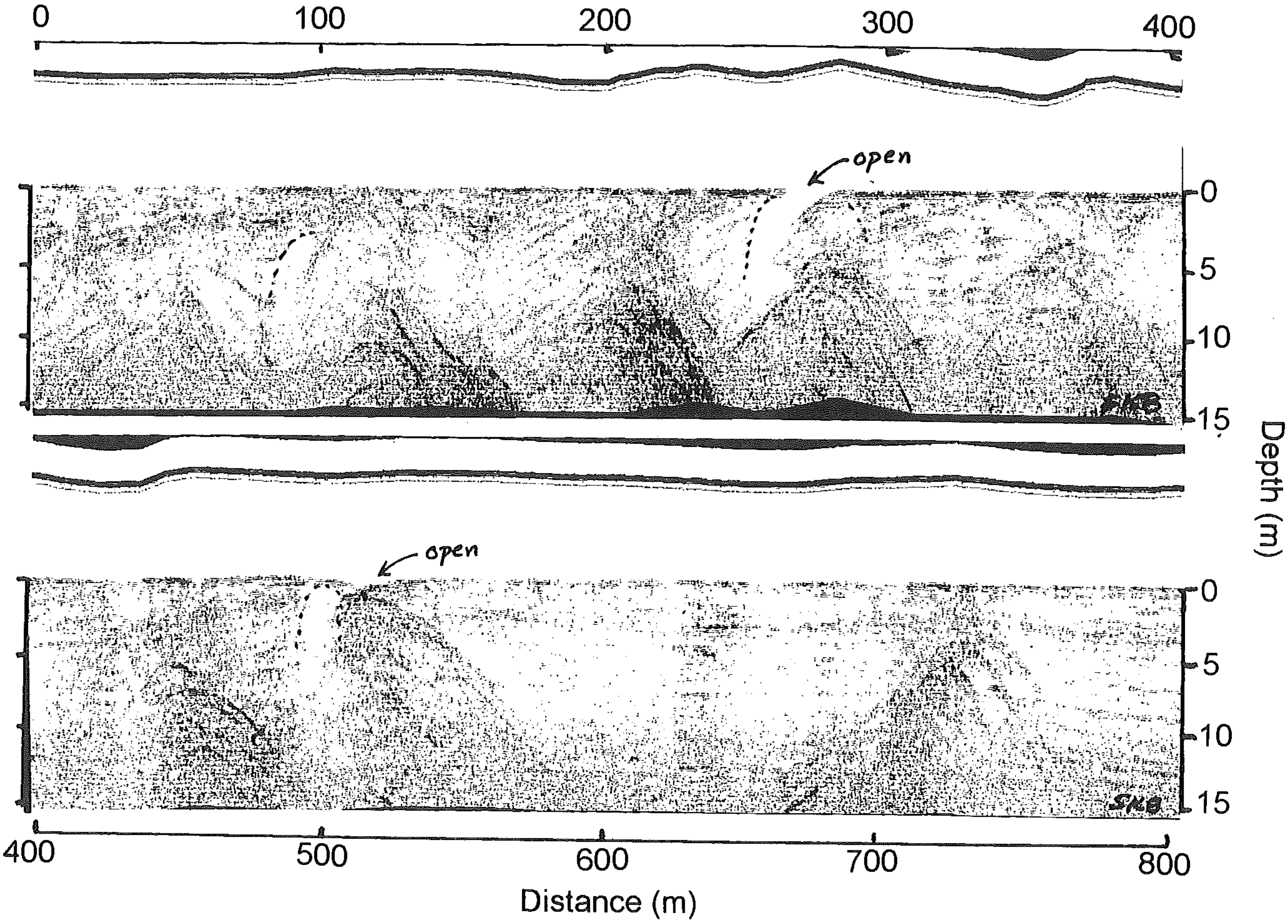

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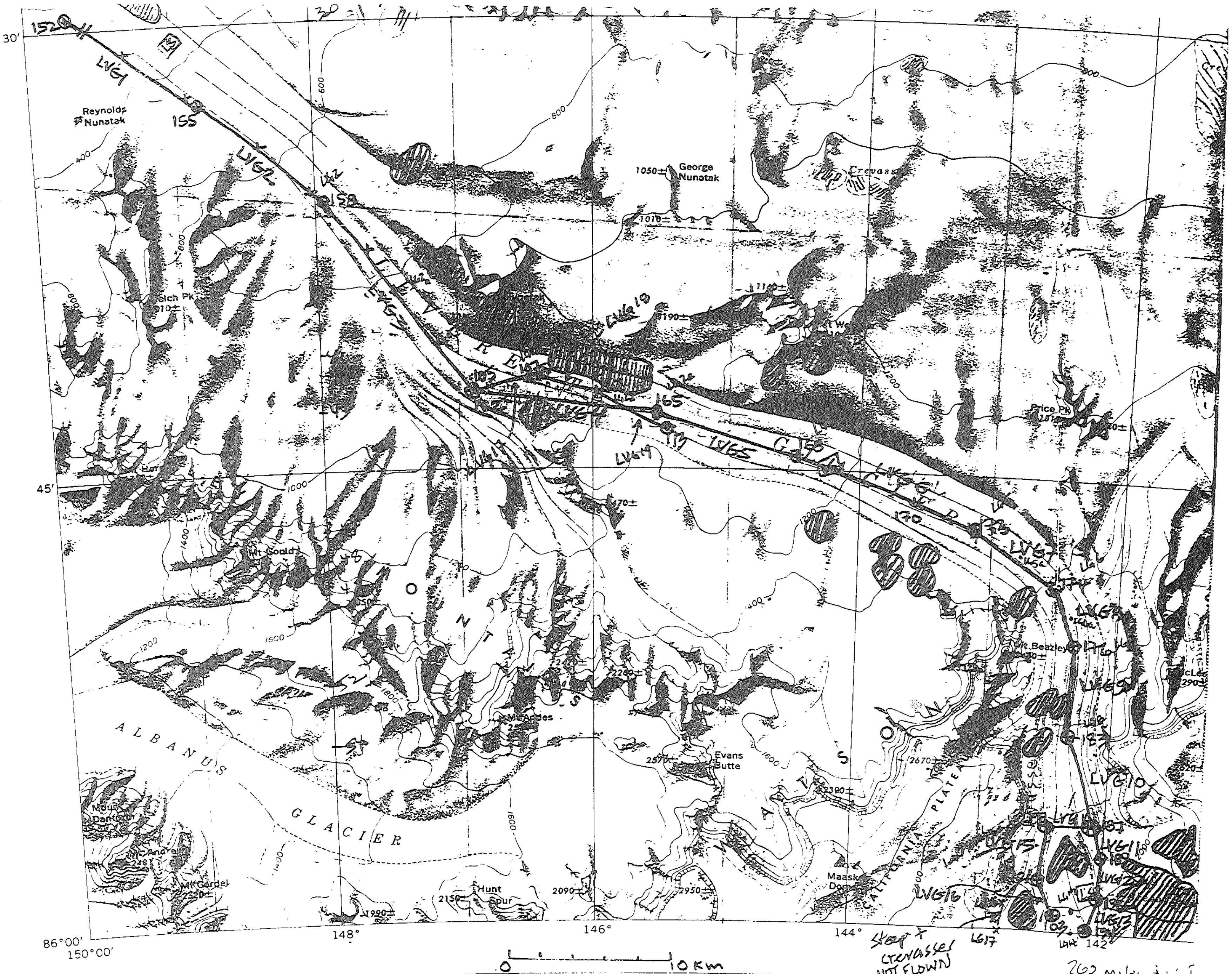

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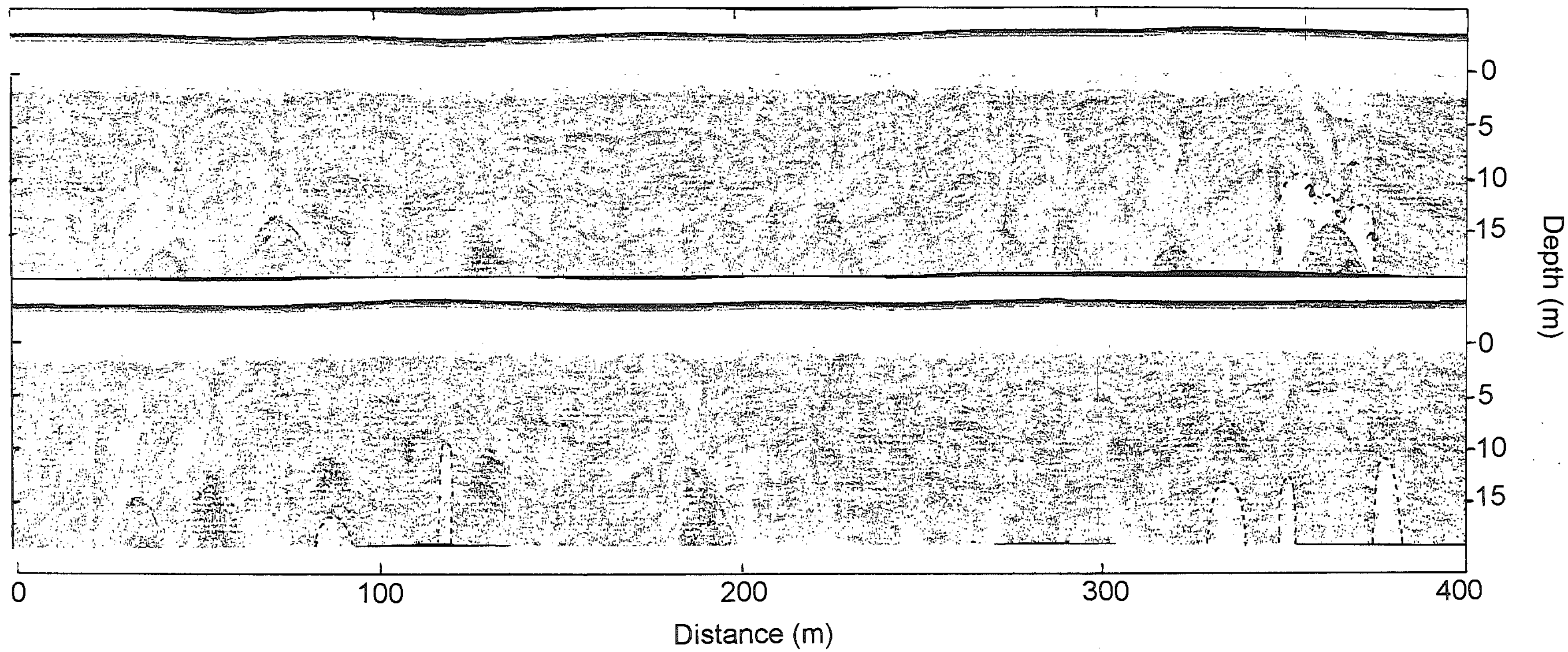

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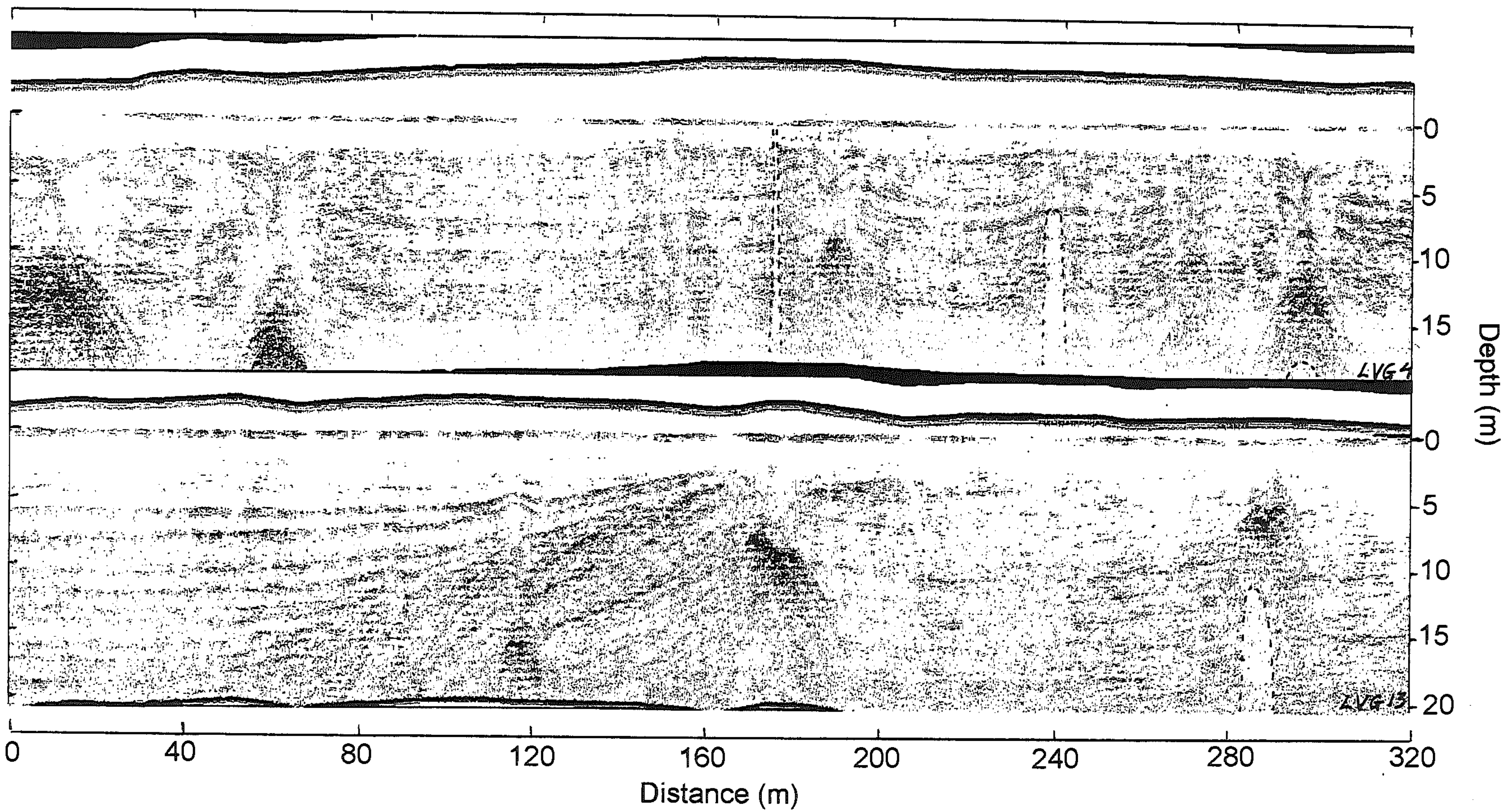

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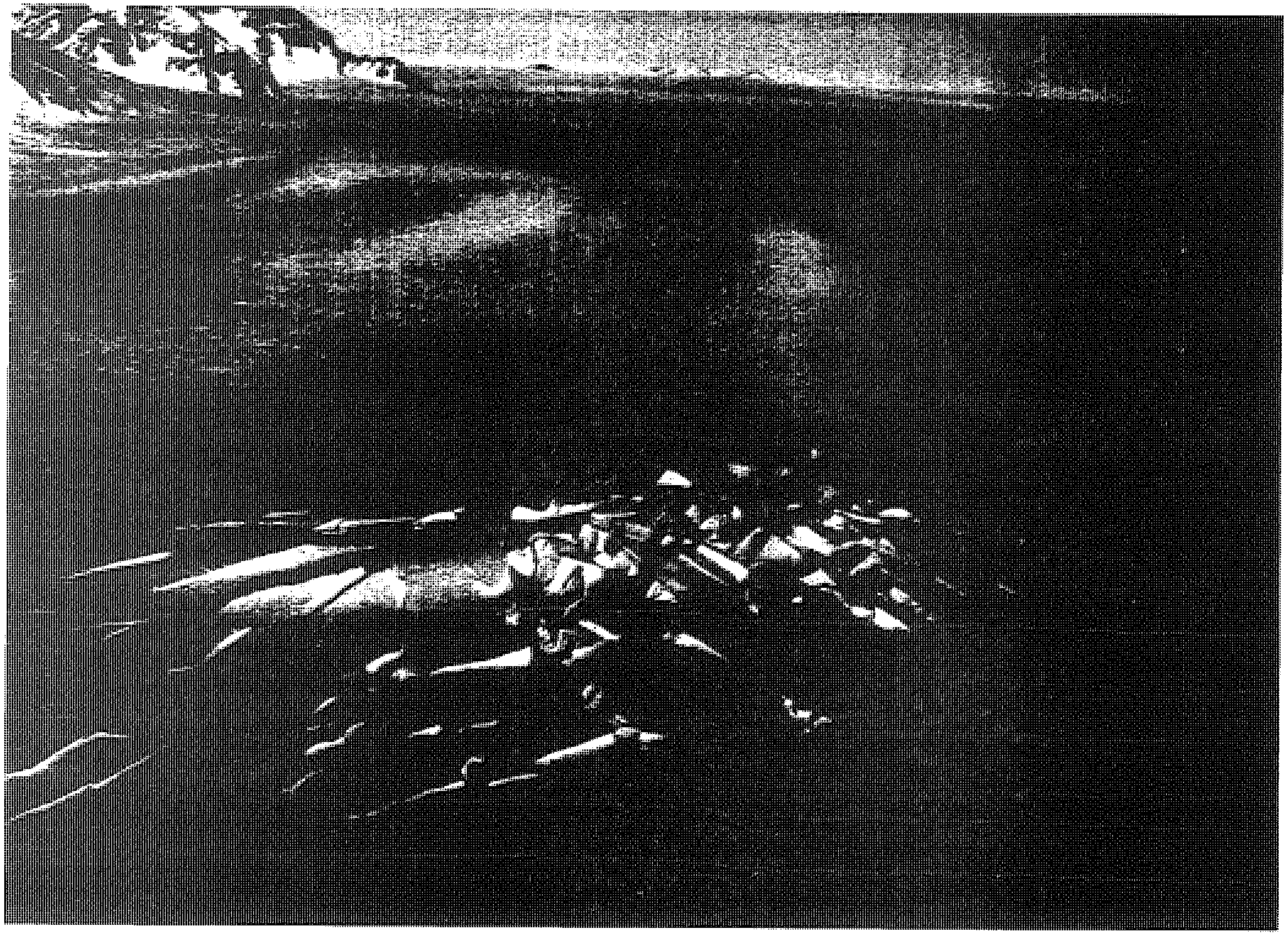

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Ground-Penetrating Radar Techniques for Crevasse Detection

Allan J. Delaney, Steven A. Arcone and George Blaisdell

ABSTRACT. This paper discusses radar techniques that we have used for crevasse detection in Antarctica. It is based on extensive GPR experience and our crevasse detection investigations during the 1993–94 and 1994–95 Antarctic summers. Tests were performed using equipment manufactured by Geophysical Survey Systems, Inc. (GSSI), North Salem, New Hampshire. Images of crevasses were collected when the transducers were pushed along the snow surface by snow machine or tracked vehicle, at speeds up to 10 mi/h, and attached to low-flying helicopters, at speeds of up to 40 mi/h. Confirmation of the surface and airborne radar results was obtained on the shear zone between the Ross and McMurdo Ice Shelves where no surface indication of crevasses could be seen. Detected crevasses were exposed to compare their actual size and depth with the radar data. We first discuss the general construction and operation of a digitally controlled ground-penetrating radar and the relevance of the operator-controlled variables. Finally, the methods we have used for both surface and airborne profiling of crevasses are discussed, and specific examples are drawn from our experiences on the McMurdo shear zone and the Skelton Glacier. We conclude that under the present limitations of GPR technology, surface work is far superior for locating crevasses and for determining crevasse width and snow bridge thickness. Airborne work is most effective as a reconnaissance tool that can aid the route selection process and for estimates of crevasse density for mitigation planning. Future airborne work will require radar systems with a faster scan capability to improve profile quality at higher air speeds.

INTRODUCTION

In the Antarctic, signal propagation conditions for GPR frequencies are nearly ideal. There are very few near-surface layers or objects to reflect a significant portion of the radar signals, and the relative absence of liquid water results in very little signal loss (attenuation). In this cold, low-attenuation environment, detection of layers and voids is made possible primarily by the contrast in the dielectric permittivities of air, dense snow (firn), and ice. There is also very little signal interference (electrical noise) in the Antarctic. These conditions allow use of a low-power, broad-band pulse transmitter and a very high gain receiver. This transmitter-receiver combination can detect closely spaced layers (high resolution) and distinguish between dense snow and air-filled voids (high sensitivity), making this system ideal for crevasse detection.

Consideration of a replacement structure at the South Pole and possible transportation of materials for that construction by surface vehicle, rather than airplane, has renewed interest in surface traverse techniques. The danger inherent in operating heavy equipment repeatedly along a narrow corridor of snow and ice that has variable subsurface conditions and unseen crevasses necessitates reliable crevasse detection. In 1993 the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) was funded by the National Science Foundation Office of Polar Programs to assess high-resolution ground-penetrating radar (GPR) as an expedient crevasse detector. That study successfully demonstrated GPR crevasse detection operating both on the surface and from helicopters (Delaney and Arcone, 1995). During the 1995 Antarctic summer a similar radar system, operated from a Nansen sled and Alpine snow machine, was used to pioneer a surface route through the McMurdo-Ross Ice Shelf shear zone and precisely locate crevasses for experimenting with techniques for explosive snow bridge demolition (Blaisdell et al., 1996). The same radar, later mounted on a helicopter, was also flown over both the Skelton and Leverette Glaciers to reconnoiter possible surface traverse routes.

Crevasse detection has always been a concern to polar exploration and safe traverse operation. An early attempt at crevasse detection, incorporating a resistivity technique and surface contact electrodes, was tested in Greenland (Cook, 1956). A similar system was tested in Antarctica (Fowler, 1963), operated in front of a Tucker Sno-Cat on an ascent of the Skelton Glacier.

More recently, crevasse detection has been implemented using GPR techniques, as suggested by Kovacs and Abele (1974). In Greenland, Glover and Rees (1992) used GPR to investigate firn structure and locate shallow crevasses. In Antarctica, the technique has been used to locate safe areas around field camps and buried utilities. Airborne profiling using short-pulse radar was suggested by Vickers et al. (1973), and airborne GPR technology was discussed by Butt and Gamberg (1979). The technique is now used routinely for many snow and ice investigations, including ice thickness (e.g., Arcone et al., 1992; Arcone and Delaney, 1987) and detection of water in the Arctic (Arcone et al., 1989; Kovacs, 1978). In Antarctica, CRREL proved the feasibility of crevasse detection from helicopters by determining the effects of airspeed, altitude, and radar scan rate on data quality (Delaney and Arcone, 1995). Also recorded were surface profiles directly over known and unknown crevasses where measurements of snow bridge thickness were made, providing a direct correlation between the voids and the radar signatures.

This paper discusses the installation, operation, and limitations of the GPR used for the 1995 crevasse detection investigations. It is intended primarily as a primer for potential radar operators. Detailed discussions of the GSSI equipment can be found in the radar operating manuals. Excellent discussions of signal propagation in snow and ice, data processing techniques, and radar technology can be found in the extensive GPR bibliography. The radar profiles recorded during these 1995 investigations are presented in companion papers at this meeting (Arcone et al., 1996; Blaisdell, 1996).

INSTRUMENTATION

The GPR equipment used for both the 1993 and 1995 investigations was manufactured by Geophysical Survey Systems, Inc. (GSSI) of North Salem, New Hampshire. The 1993 investigations used a GSSI System 4800 control unit that displayed individual radar scans. In 1995, we used a GSSI System 10A+, which provided higher data collection rates (the system could be flown faster and still detect crevasses), more sophisticated signal filtering, and the capability to display in real-time two-dimensional images representing the subsurface. Both systems consist of a radar control unit, power supply, transducer, and a cable connection between the control unit and the transducer (Figure 1). Data were recorded for post-survey processing, display, and printing. Power was provided by a 12-VDC source. A 500-MHz transducer containing a transmitter and receiver in one

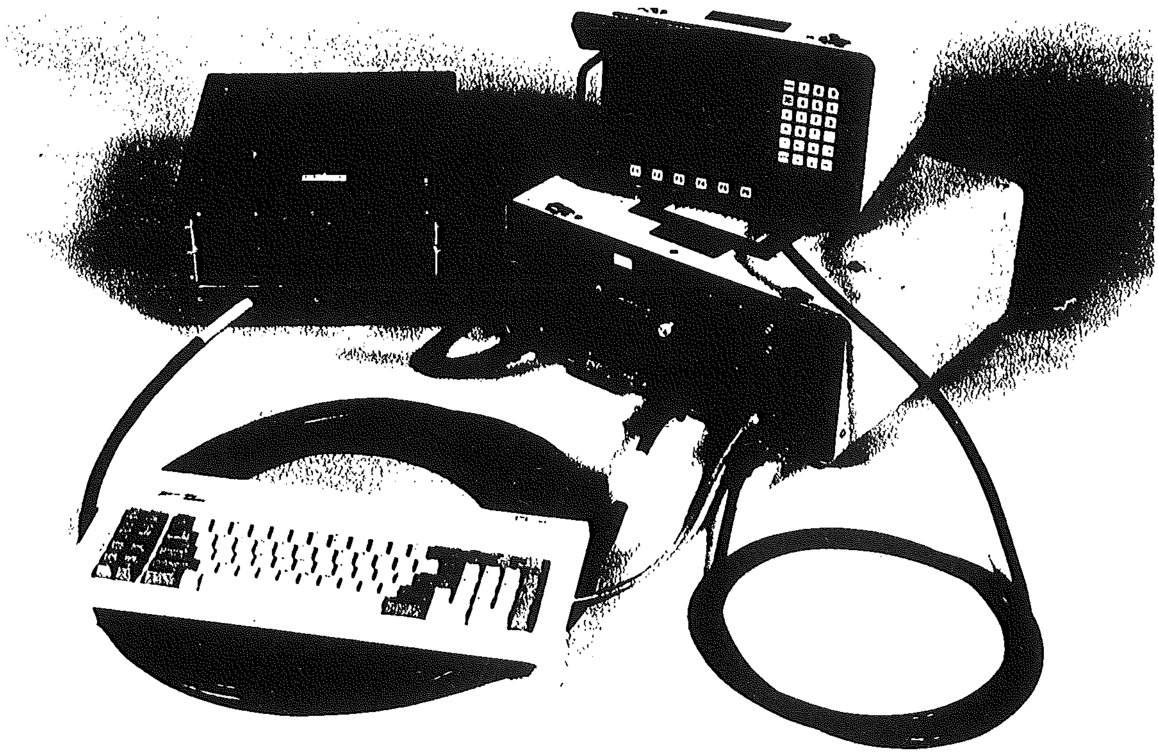


Figure 1. Photograph of the GSSI System 10A+, video display, 500-MHz transducer, and cables.

housing was used for both surface and airborne profiles. All of the timing pulses, system power, and received signals are transmitted via the multi-conductor control cable that extends from the control unit to the transducer.

The radar control unit (a radar signal processor and computer) provides all of the required timing signals and bias voltages to the transducer, displays the radar signal,and records scans for future processing or printing. Many of the controls, including time range, scan rate, signal amplification, and filter setting, are operator-selected, based on anticipated survey speed and required depth of penetration. A wide range of additional operating parameters is provided to accommodate the diverse applications anticipated by GSSI. The specific functions that affect crevasse detection surveys are discussed below. Detailed discussions are available in the GSSI System 10A+ operation manual.

A coarse acquisition global positioning system (GPS) receiver was operated simultaneously with the radar. Event markers superimposed on the radar profiles correspond with the stored GPS waypoint information. The GPS antenna was mounted on top of the radar transducer.

RADAR PARAMETERS

Scan rate

GPR data are recorded, processed, and displayed as individual scans. A scan is an operator-selected time interval, measured in nanoseconds (ns), during which echoes are received, displayed, and recorded. Radar file records, or profiles, may consist of hundreds or thousands of closely spaced scans displayed in an amplitude-sensitive format. In general, more scans per meter of glacier traversed give higher quality profiles. The maximum scan rate that can be selected with the GSSI System 10A+ is limited by operator-selected controls, including the number of sample points, data resolution, radar repetition rate (how frequently pulses are transmitted), and signal processing. These parameters determine whether data can be displayed real-time or have to be stored and post-processed.

The radar scan rate can be tailored to the vehicle speed to obtain a crevasse image with minimum horizontal exaggeration. The radar display is 640 scans across, and it scrolls continuously. For surface profiles, a rate of 24 scans/m provides a horizontal scale of approximately 25 m. This rate can be accomplished by estimating vehicle speed and adjusting the scan rate to achieve the desired horizontal scale. An alternative is to select a higher scan rate and use the scan stacking function to reduce the effective scan rate. Stacking offers the advantage of improved signal-to-noise performance and is fully discussed in the radar operation manual. For airborne surveys, a minimum of 4 to 8 scans for each meter of transducer travel can provide reliable crevasse detection and a satisfactory graphic representation of voids. While higher scan rates provide greater detail, collecting too many scans can greatly distort the scale by exaggerating the horizontal axis. The operator must determine the minimum data requirements to adequately display the feature of interest.

The number of sample points (data words) recorded to reconstruct each radar scan is selected by the operator (256, 512, 1024, or 2048). That number is chosen based upon knowledge of the radar time range (explained below) and the width of the transmitted pulse in nanoseconds. The goal is to record enough information to reconstruct the scan accurately, but not more sample points than are required. Increasing the number of sample points requires more signal processing time, slowing the speed at which the radar can operate.

Time range

The radar time range is displayed on the video monitor and on the printed record as the vertical axis. Travel time t is easily converted to depth d by estimating the speed v at which the radar waves travel in snow and ice. The simple formula is

$$d = vt/2$$

or

$$d = ct/2\sqrt{e}$$

where c is the speed of light in free space (3×10^8 m/s), t is the selected time range, and e is the estimated permittivity of the subsurface material. The factor of 2 accounts for the roundtrip travel time. For air, dense snow (firn), and ice, e is 1, 2.2, and 3.2, respectively. Table 1 gives estimated penetration for a 500-MHz radar signal operating in air, firn, and ice for several radar time ranges that might be selected for crevasse detection.

Transducer

The radar transducer contains separate transmitting and receiving antennas, the transmitter electronics, and the receiver/sampler electronics. The received radio-fre-

Table 1. The relationship between radar time range and estimated total depth of signal penetration in air, firn, and ice.

Time range (ns)	*Air*	*Firn*	*Ice*
50	7.5	5.1	4.2
100	15.0	10.1	8.4
150	22.5	15.2	12.6
200	30.0	20.2	16.8
250	37.5	25.3	20.9

quency signals are sampled (converted to audio frequencies) before transmission to the control unit. Commercial transducers are available in a wide range of operating frequencies and configurations (50 to 900 MHz), and transmitter power and receiver gain can be tailored to operating conditions and the depth of penetration required. The transducer that provides the best results for both surface and airborne detection of crevasses is a 500-MHz unit manufactured by GSSI (Model 3102). It is well shielded, compact, and easily mounted. The short pulse (2 ns) generated by this transducer provides high resolution (10–15 cm), and the low radiated power (8 watts) penetrates to 30 m depth in cold snow and ice.

When the radar transducer is operated on or within 5 m of the snow surface, it is possible to obtain high-quality radar profiles. The pulses, emitted by the radar transducer flying above, travel through the air, snow, and ice with little attenuation and are reflected back to the transducer from density interfaces. Most of the transmitted signal is coupled directly into the snow or ice, and reflected-signal amplitudes are significantly greater than the background noise. However, crevasse signatures can only be detected when the antenna is in motion. The reflections originating from the snow/air interface, anticipated in a void, can be distinguished from other subsurface horizons such as those originating from snow wind-slab layers, because the voids are sporadic features in an almost featureless material (snow with barely perceptible layering). The transducer is a broad-beam device, emitting pulses in a pattern approximately 90 degrees wide. Because of this wide beam and the changing transducer position, pulses arrive at and reflect from the void boundaries at slightly different times. This change in arrival time is displayed as a diffraction pattern that represents the crevasse. Range gain provides amplitude compensation for signal attenuation with distance. Since every interface encountered in the signal path (air-to-snow, snow-to-ice, or the reciprocal) can reduce the signal amplitude, maintaining optimum radar performance is a component critical to successful crevasse detection.

Data acquisition, display, and processing

Two types of signal processing, real-time and post-recording, can be applied to the data. Real-time vertical filters are used to improve the appearance of the display by removing DC bias and reducing the amplitude of out-of-band frequency components.

Real-time stacking can improve signal-to-noise performance and reduce file size. Real-time horizontal filters are seldom used because they can remove subsurface reflections. Post-processing can include surface normalization and filtering and background removal techniques that enhance crevasse reflections.

In our crevasse detection work, all profiles were recorded using high-pass and low-pass filters to remove DC gain offsets within individual scans and to reduce the amplitude of out-of-band frequencies. Post-processing began by passing the data through a horizontal (scan-to-scan) high-pass background removal filter that eliminated direct aircraft reflections, which can occur at a constant time delay. Normal variations in aircraft altitude ensure that the subsurface data are not sensitive to this filter. The surface reflections were then made horizontal by eliminating aircraft altitude variation, a process called normalization. This allows responses to stratigraphy within the firn to be distinguished from multiple aircraft-to-surface reflections. After normalization, a horizontal high-pass filter can then be applied again to retain only crevasse signatures (diffractions) in the record.

Recording 80 scans/s at an airspeed of 25 knots necessitates data storage and GPS positioning. High-speed data recording and transfer may best be accomplished by recording files directly on computer hard disk. As data are not permanently saved until the file is closed, it is best to limit file size to 50 Mb (80 scans/s at 512 samples/scan is 48 Mb of data in 20 minutes). This limitation facilitates post-processing and identification of event markers on the printed record. File copying and duplicating can be accomplished during convenient breaks in the survey (fueling, transit to a new site). If continuous resonance appears on the radar display, antenna installation is likely to be at fault (a connection between the antenna shield assembly and the airframe). If data storage capacity becomes a concern, stacking data (by 2 or 3) is preferable to lowering the scan rate.

SURVEY TECHNIQUES

Surface detection

Surface profiles were conducted with the transducer attached to a fiberglass boom extending from the front of an LMC tracked vehicle (Figure 2) and with the transducer mounted inside a large inflated inner tube that skimmed along the surface in front of an Alpine snow machine (Figure 3). To avoid unwanted reflections and resonance in the data, both mounts used a minimal amount of metal attached directly to the antenna or in the signal path. The installation on the tracked vehicle had the advantage of a transducer elevated about 2 m above the surface. This constant stand-off provided an excellent surface reference and allowed detection of near-surface features that might otherwise have been obscured by the signal direct coupling that occurs between the receiving and transmitting antennas. The rear seating area of the tracked vehicle provided a comfortable and convenient operating area for both radar equipment and the operator. In-vehicle operation also allowed us to attach a viewing hood to the monitor to make the display more visible and minimize the operator bumping his head on the equipment during a rough ride. DC power was provided by the vehicle electrical system. Profile speeds up to 10 mi/h were possible with the somewhat dubious prototype "ski" arrangement shown in Figure 2.

The Alpine snow-machine installation was more maneuverable, but an environmental box was required for mounting the radar system because of subzero air tempera-

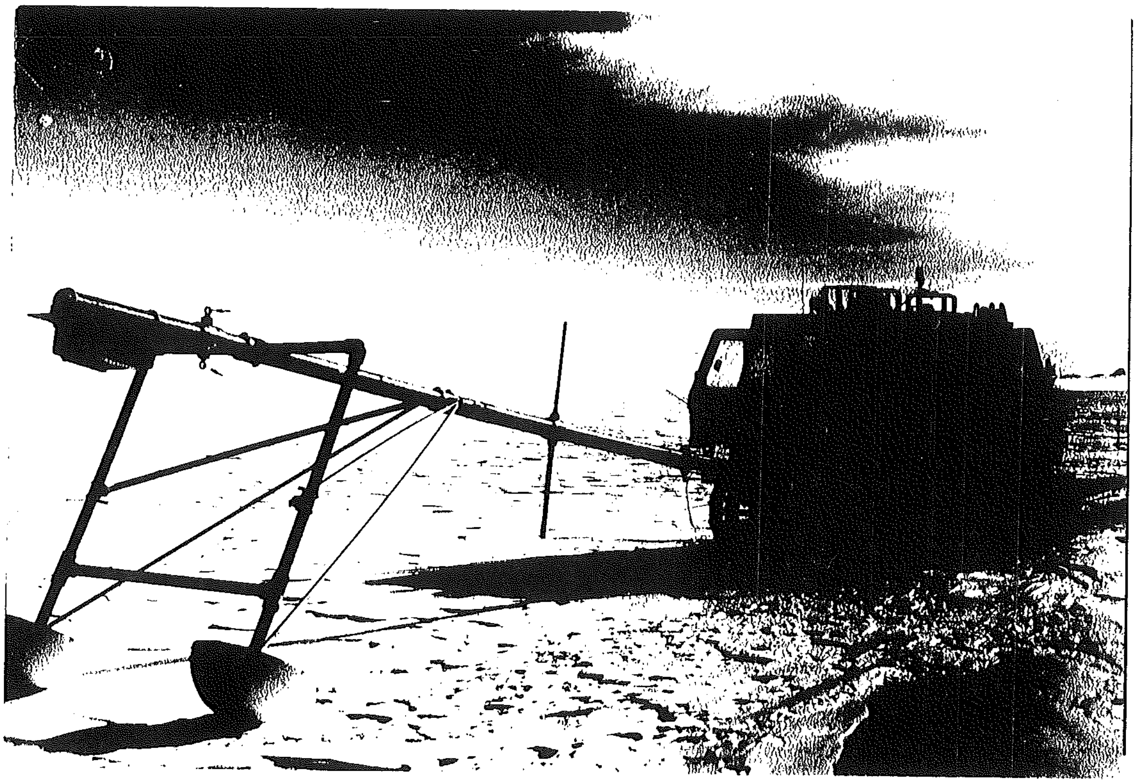


Figure 2. The 500-MHz transducer attached to a fiberglass boom assembly that was pushed and steered by the tracked vehicle. The cable was routed inside the boom, and the radar operated from the rear passenger seating area. Profile speeds up to 10 mi/h were achieved when operating on the route to Black Island.

tures and blowing snow exposure on the Nansen sled. Power was provided by an AC generator operating a regulated DC power supply. The intense light conditions and an awkward operating position made viewing the radar screen difficult at all but the lowest profile speeds. The environmental box was not sufficiently padded and resulted in a temporary equipment failure. However, the data quality was superb, and crevasse images were readily apparent. These operating difficulties could easily be remedied in future deployments.

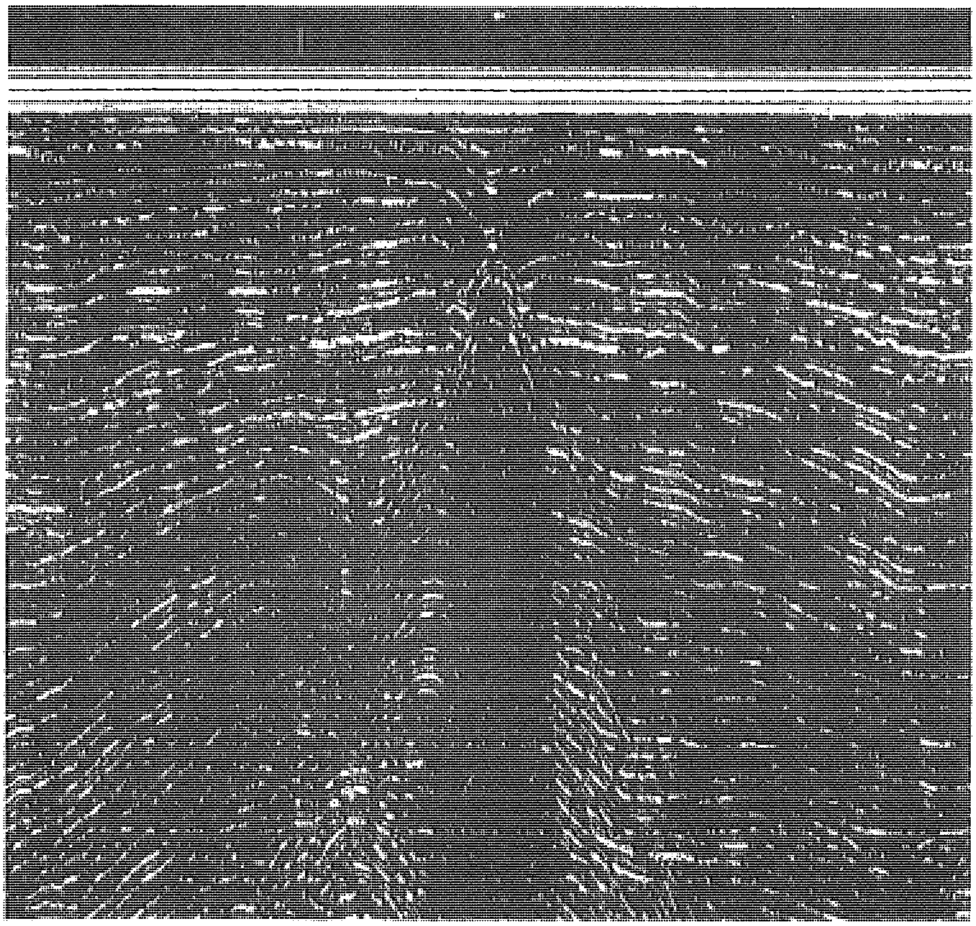
Suggested radar control unit settings for profiling from the surface include:

scan rate	48 scans/second
time range	100 ns
samples/scan	512 eight-bit samples/scan

A segment of data recorded directly over a large crevasse, using the settings recommended above, is shown in Figure 4. The radar profile was perpendicular to the ice shear direction, and the survey speed was approximately 4 mi/h. Since 48 scans per second were recorded, the data appear as a continuous record. The many reflections from

Figure 3. The 500-MHz transducer mounted inside an inflated inner tube and pushed by an Alpine snow machine. The radar was controlled from a Nansen sled towed behind. Profiles were recorded at speeds up to 5 mi/h on unprepared surfaces.

Figure 4. (a) A segment of 500-MHz radar data recorded directly over a large crevasse in the McMurdo-Ross shear zone using the antenna configuration shown in Figure 3. The horizontal and vertical scales are 30 and 10 m, respectively. The top of the crevasse was confirmed to be 2.0 m below the surface. The was no surface indication that a crevasse was present. The individual radar scans below, selected from this profile, show the types of reflections seen from snow wind-slab layers (b) and the absence of reflections directly above an air-filled crevasse (c).



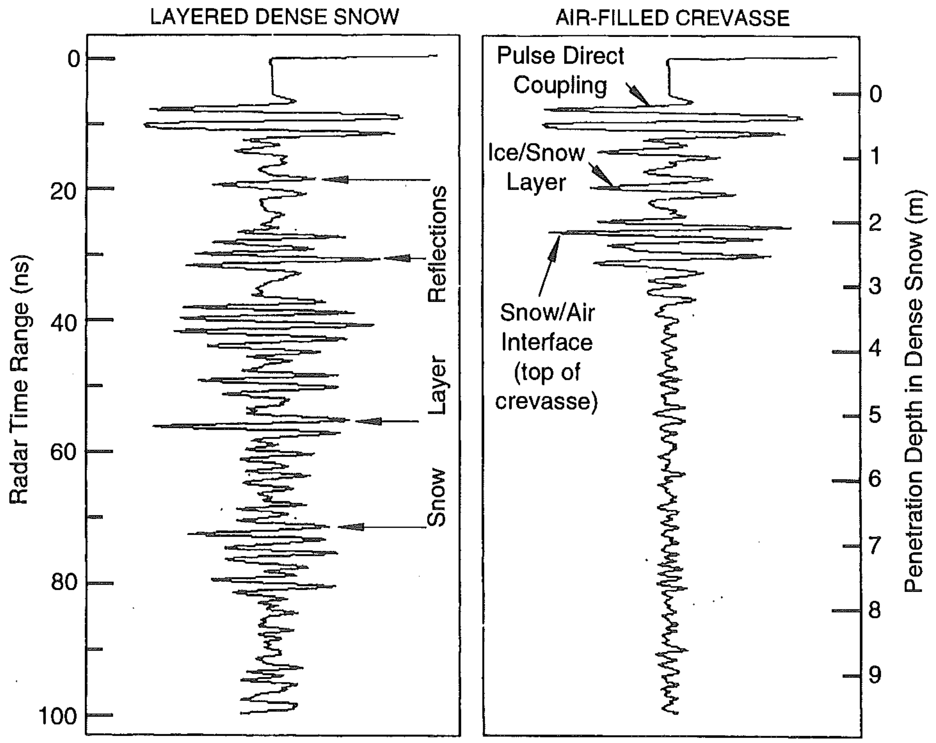


Figure 4. (b) and (c).

snow layers are represented by the light-colored near-horizontal bands. The crevasse is indicated by the diffraction pattern (downward curving reflections) and the absence of horizontal layering near the center of the profile. Shown directly below this profile are two individual radar scans from the profile. The scan on the left was recorded over multiple horizontal snow layers, and the scan on the right was recorded directly over the crevasse. The presence of this crevasse was confirmed by detonating an explosive charge (Blaisdell et al., 1996). The crevasse was 1.5 m wide at the top and more than 30 m in depth. A sketch of the excavated crevasse is shown in Figure 5.

Airborne detection

Profiles were recorded with the transducer attached to UH-1N helicopters operated by the Navy (VXE-6) and ASTAR B-1 aircraft operated by Helicopters New Zealand. On the UH-1N, the transducer was attached to port-side fuselage hard points with aluminum angle; the control cable was routed through the gasket at the base of the sliding door (Figure 6). For the B-1 aircraft, an expedient mount was fabricated from available materials and attached to skid-assembly bolts and one fuselage hard point (Figure 7); the control cable was routed through an existing bulkhead opening. On both aircraft, radar power was provided by deep-cycle 12-volt batteries. This was only a handling inconvenience on the UH-1N. However, the extra 150 lb. was a significant operational constraint on the smaller B-1 aircraft. Future airborne radar work should consider use of aircraft DC power with a 28 VDC to 12 VDC converter to eliminate the need for cumbersome batteries. Both installations used during the 1995 investigations positioned the transducer too close to the aircraft skid assembly, resulting in some un-

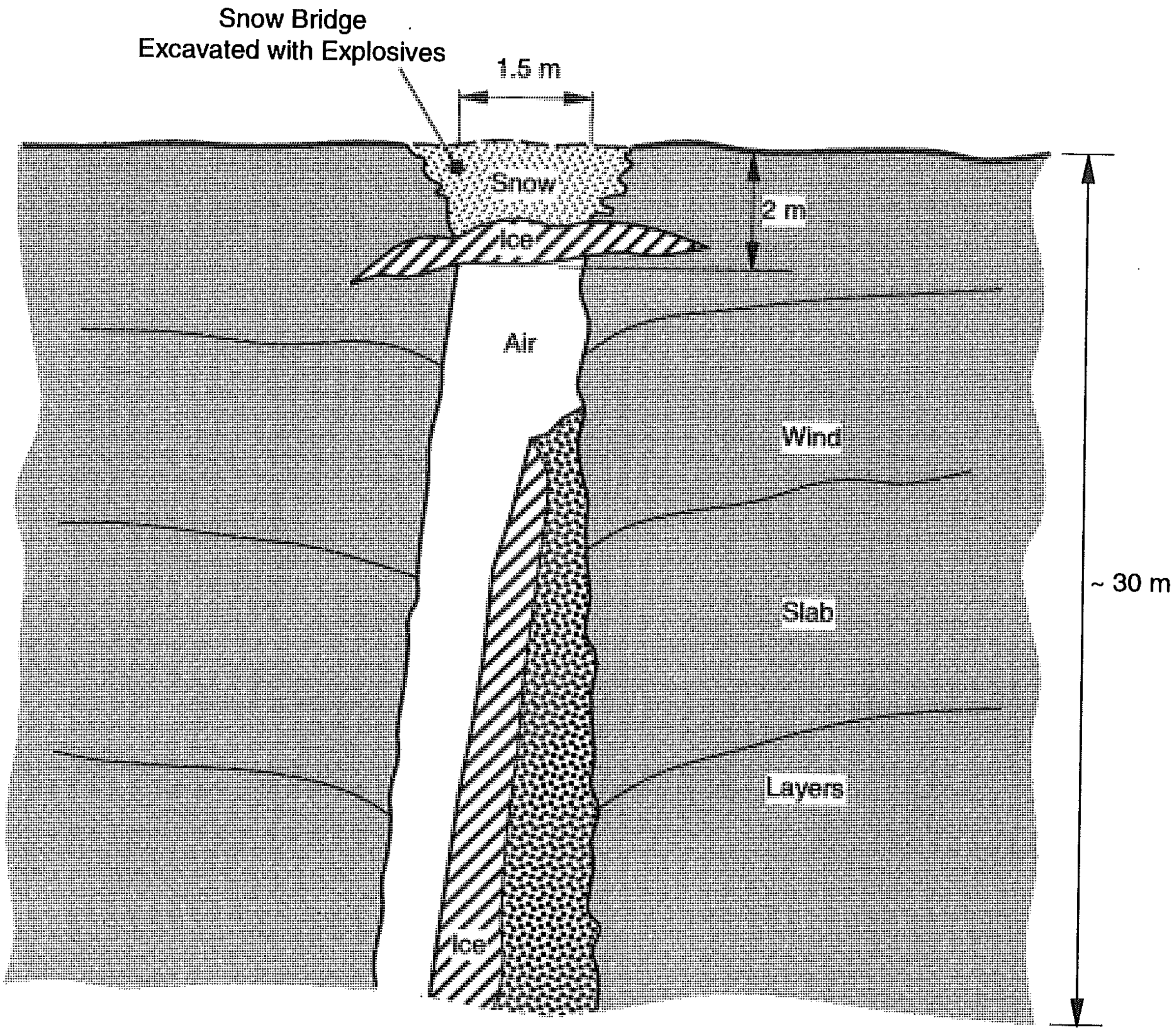


Figure 5. A sketch of the crevasse detected with the radar and excavated with explosives. This feature corresponds to and should be compared with the radar scans in Figure 4.

wanted reflections and resonance in the data. While some reflections can be adequately removed by signal processing, it is best to strive for the cleanest possible signal. Positioning the near edge of the transducer at least 40 in. from the skid and as low as possible usually results in a resonance-free installation. The 3102 transducer, mounted with the cable connection at the rear, positions the antennas' axes perpendicular to the airframe. This prevents direct aircraft reflections and offers a slight performance advantage.

Airborne radar profile work requires two people in addition to the flight crew. One operator monitors the radar system and records operating parameters, data file information, flight line information, and GPS waypoints and enters position markers on the radar record. The second person, familiar with the survey objectives and radar operational requirements, should coordinate the flight, by providing guidance to the pilots, and record additional flight-line notes. Comparison of the radar operator's and the flight coordinator's notes was usually needed to reconstruct the flight lines and coordinate data

Figure 6. The 500-MHz transducer attached to fuselage hard points on the port side of a VXE-6 UH-1N helicopter. A GPS antenna is mounted atop the radar transducer.

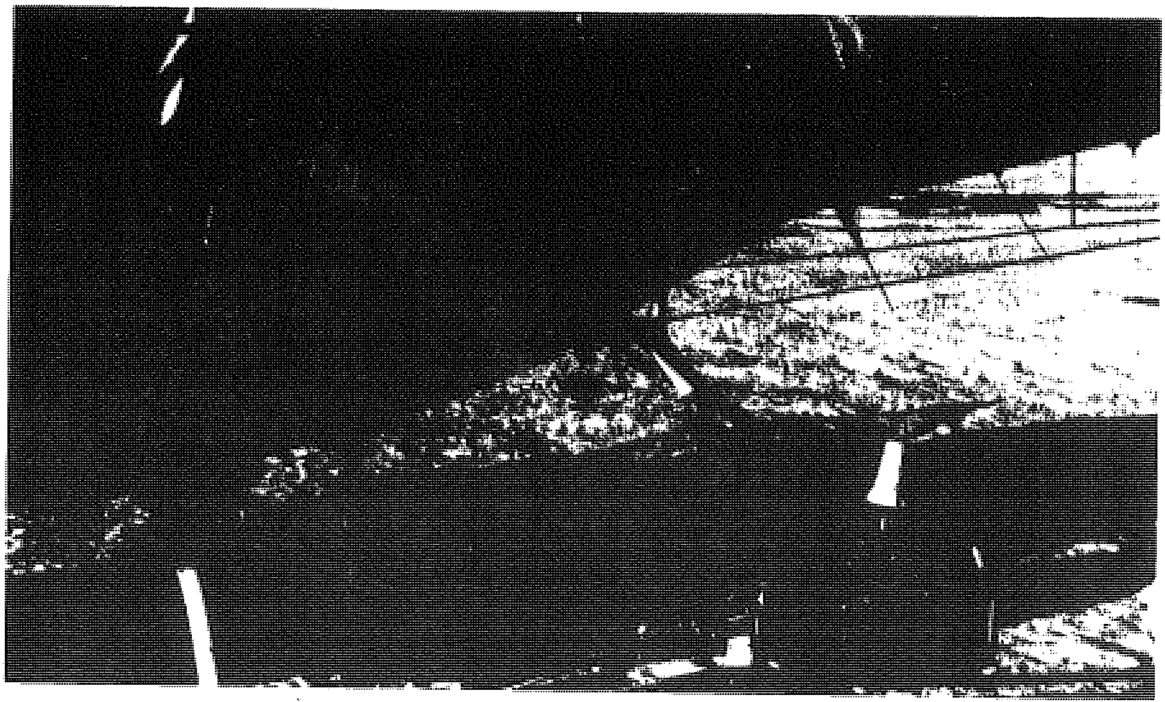


Figure 7. The 500-MHz transducer attached with aluminum angle and tie-down straps to the port side of a Helicopters New Zealand ASTAR B-1 helicopter.

files and GPS waypoints. This is a difficult environment for radar data collection. The data rate is very high, the system requires vigilant monitoring, and there is a great deal of flight-line information to record.

To best utilize aircraft time and to minimize tedium for the flight crews, the surveys are flown at the highest speed allowed by the radar scan collection rate. The relationship between airspeed and data collection rate is given in Table 2. A target airspeed of 25 to 30 knots usually provides satisfactory survey results. This speed range meets the minimum data requirement for crevasse detection (4 to 8 scans per meter) discussed earlier. The recommended target survey altitude is 6 m (20 ft) above the terrain. This flight altitude requirement is often more difficult to maintain and depends upon many factors, including surface definition, wind, and blowing snow. The altitude limitation is a product of both the antenna beamwidth and available radiated power (Delaney and Arcone, 1995). Requesting flight operations of 25 knots and 6 m usually results in airspeeds from 20 to 40 knots and altitudes from 3 to 12 m. It is helpful to both the flight crew and the radar survey to have routine verbal feedback to the radar flight coordinator regarding airspeed and altitude.

While crevasse features are easily distinguished on the scrolling radar display, the transducer may be tens of meters past the feature before the operator can react to provide feedback to the flight coordinator.

Typical radar settings chosen for airborne profile reconnaissance crevasse detection include:

scan rate	80 scans/second
time range	200 ns
samples/scan	512 eight-bit samples/scan

A segment of post-processed airborne data recorded on the Skelton Glacier is shown in Figure 8. The time range selected for this survey was 250 ns and aircraft speed and altitude were 25 knots and 5 m, respectively. Diffractions and reflections from multiple crevasse features and the undulating subsurface horizons are clearly seen beneath the smooth snow surface reflection. Reflections resulting from the aircraft reflections usually

Table 2. The relationship between profile speed and the number of scans per meter recorded at the maximum data rate of the GSSI System 10A+ control unit (80 scans/s).

Air speed *knots*	*m/s*	*Scans per meter*
10	5.2	15.4
20	10.3	7.8
30	15.4	5.2
40	20.6	3.9

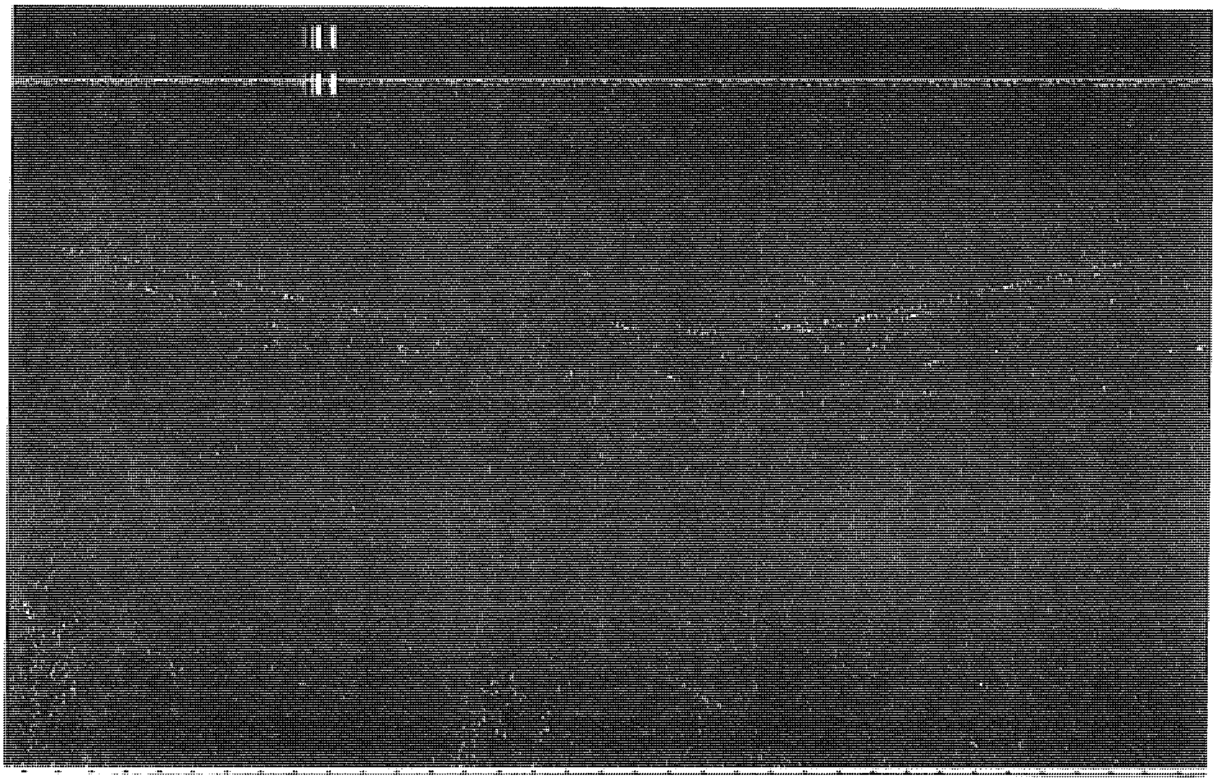


Figure 8. A segment of profile data recorded over a crevasse near the head of the Skelton Glacier using the transducer configuration shown in Figure 7. Airspeed and altitude were 25 knots and 5 m, respectively.

appear as unchanging horizontal bands and have been removed with post-processing techniques (discussed above). Further discussion and examples of post-processed data may be found in the companion paper by Arcone et al. (1996).

RECOMMENDATIONS

Reliable crevasse detection with ground-penetrating radar depends upon operator experience, understanding of general geophysical concepts, and familiarity with electronics. Sound experimental technique is also required, the radar equipment must be maintained, and it must be installed in a manner to ensure that unwanted reflections (clutter) and noise are not introduced into the signal. These reflections could have amplitudes much higher than those from the snow/air interface, and radar gain compensation would not permit adequate amplification of the desired signal.

Crevasse detection from low-flying aircraft is primarily a reconnaissance tool that can aid the route selection process and estimate crevasse density and dimensions for mitigation planning. Surface radar profiling can provide real-time information on snow-bridge thickness and crevasse location at vehicle speeds up to 10 mi/h. Although surface profiling can precisely locate crevasses, the reader is reminded that crevasse signatures can only be detected when the antenna is in motion.

GPR equipment has been commercially available for about twenty years, and there have been vast improvements in instrumentation, versatility, and reliability. A new

GSSI System 2 provides a compact, user-friendly system that may find application as a crevasse detector when conducting profiles from the surface. However, project objectives must be carefully evaluated to ensure that a given GPR system meets the anticipated needs. Furthermore, GPR will be accepted as a crevasse detection tool in Antarctica only if used routinely and an operator confidence level is established.

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IFRTP - ENEA
GENERAL ORGANISATION of LOGISTIC TRAVERSES

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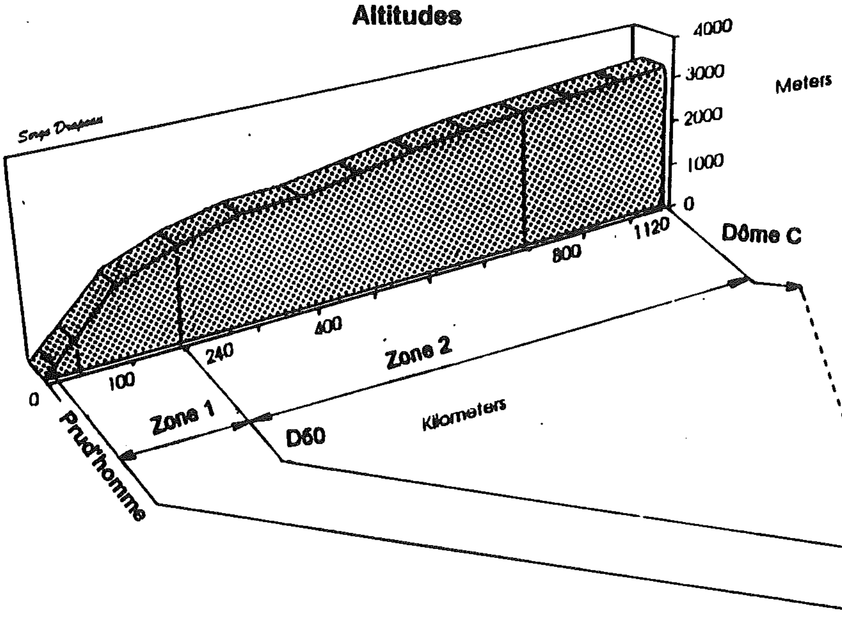

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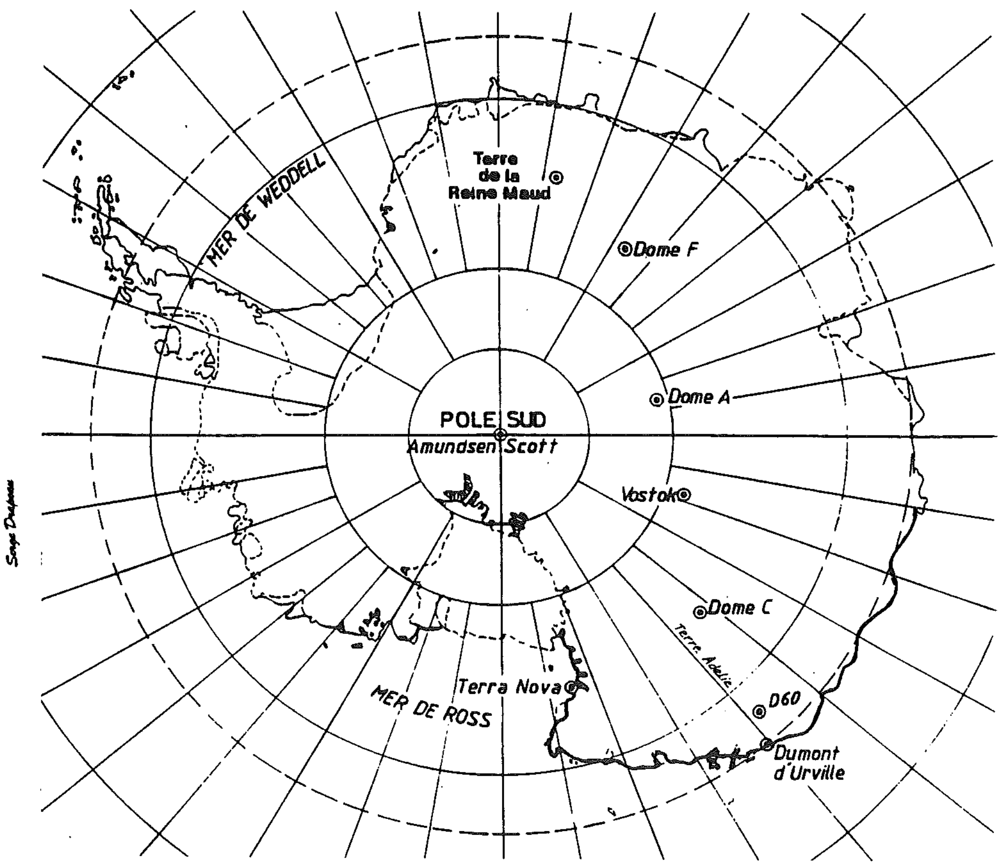


IFRTP - ENEA

I - GENERAL ORGANISATION of LOGISTIC TRAVERSES

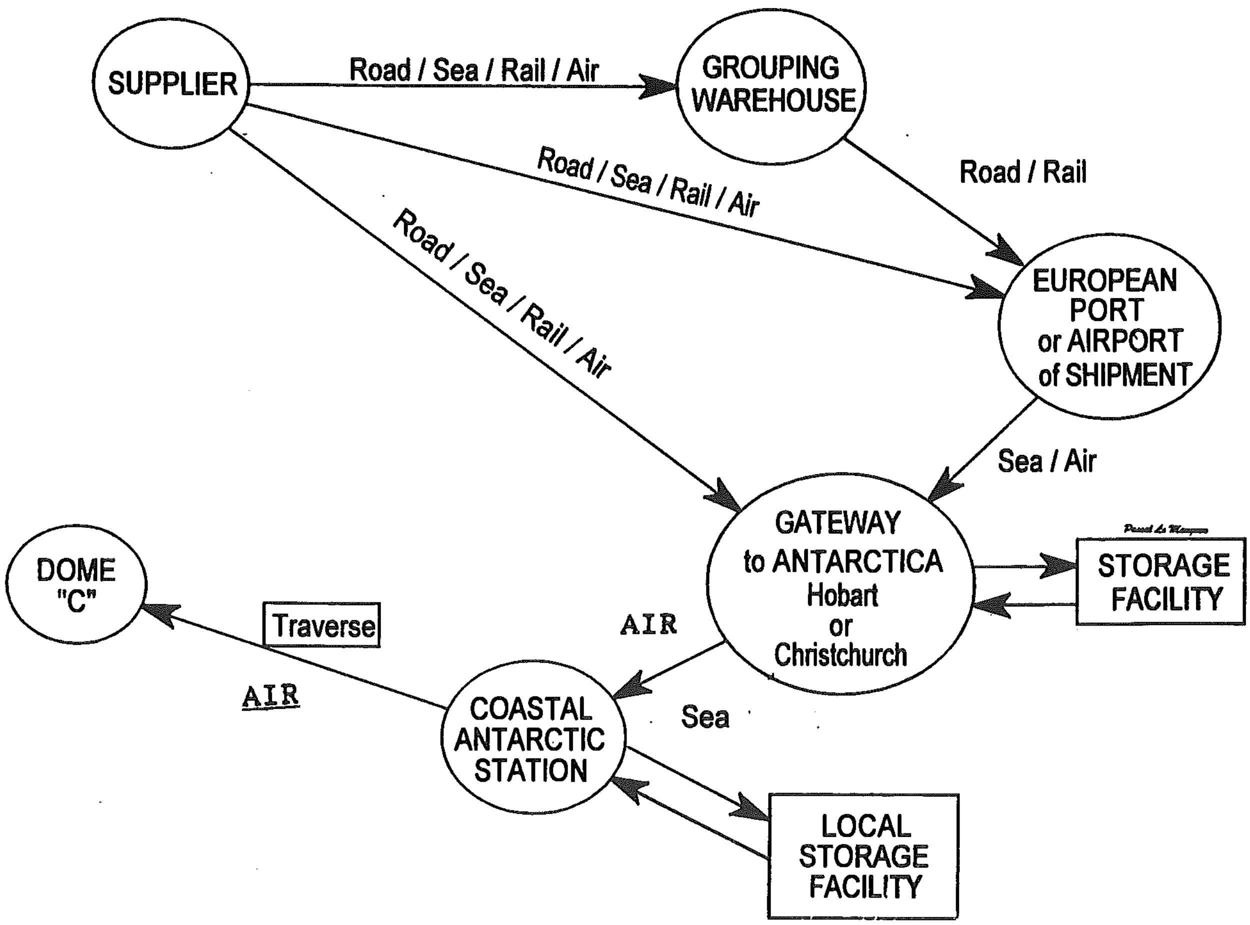
The present paper summarises the experience gained since the start of the CONCORDIA / EPICA project in the organisation of LOGISTIC TRAVERSES on the Antarctic plateau.

The project to build a station at Dome C (CONCORDIA) and the associated deep European ice core program (EPICA) involve the initial transportation of about 1800 tonnes of equipment to the site, 1120 km inland. Then every year the normal operation of the site will require the transportation of about 300 tonnes of supplies (food, fuel, various equipment).

The characteristics of the transport system needed are dictated by:

- The acceptable net delivery rate;
- The departure point;
- The route used;
- The intermediate passage points;
- The point of delivery;
- The nature of goods to deliver;
- The transport personnel;
- The safety conditions.

The organisation of the global transport operation, all the way from the manufacture or production site to Dome C is outlined in the following diagram.



The present paper deals specifically with the last step of the transport system, the "Traverse", logistic traverses differ markedly from scientific traverses, logistic traverses are similar to commercial transport operations in the sense that they have to:

- Deliver cargo **ON TIME**, and **IN GOOD CONDITION**;
- Provide a reliable routine service;
- Achieve the best **COST PRICE**.

Organising the traverse operation involves finding proper answers to the following questions:

- What will the cargo be composed of, and what will the packaging be ?
- What transport vehicles will be used? What is the optimum delivery rate ?
- What drivers? How to satisfy their needs ?
- What solutions to the maintenance problems ?

The next pages will present the answers given to these questions and outline the general organisation of the traverses to Dome C as operated by IFRTP and ENEA.

A - PACKAGING

To maximise efficiency, the basic packaging unit preferred for the traverse is the standard 20 foot shipping container. The sleds, trailers and handling equipment, including the unloading installations on the shore, were designed for the manipulation of such containers. Upstream, the items to send to Dome C are designed or selected for inclusion in 20 foot containers whenever possible.

B - VEHICLES

Two options were possible: load the cargo on the deck of a self-propelled vehicle, or load it on sleds or trailers towed by a tractor. In either case, there were no vehicle readily available on the world market for traverse operation. Our choice criteria were:

- Adaptability to the environmental conditions;
- Ease of use;
- Reliability;
- Ease of finding and obtaining spare parts close by (in Australia and New Zealand);
- Useability with respect to ground conditions (ground pressure, operational speed, ground levelling requirements);
- Load capacity, towing capacity;
- Fuel consumption.
- Costs

The relative importance of each criterion varies depending on the main usage envisaged for each vehicle.

To avoid excessive difficulties it was first decided not to engage into designing a prototype, but to look for commercial vehicles to adapt to our requirements. We didn't find any suitable self-propelled decked vehicle. The choice of tractors useable on snow and ice in low temperatures is quite limited. Our search for tractors concentrated on:

- Civil engineering tractors ("pushing");
- Agricultural tractors ("towing");
- Ski field snow grading tractors, but specialised for snow);

while our search for towable load carriers concentrated on:

- Sleds;
- Tracked trailers.

B1 - TRACTORS

On the world market, only 3 categories of tractors held our attention:

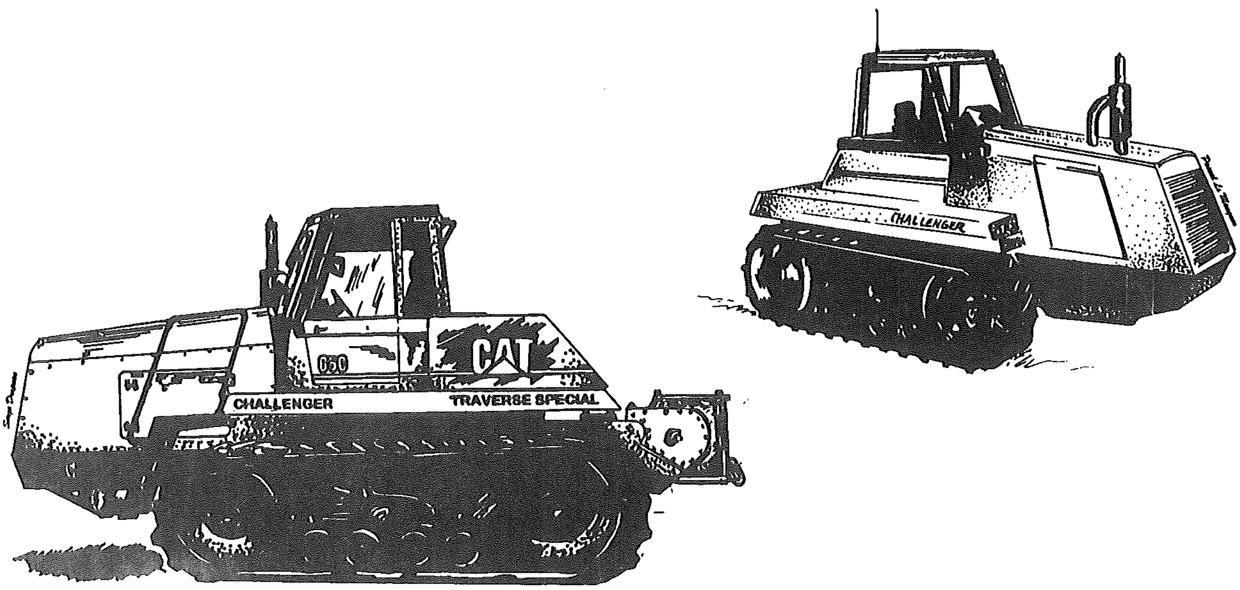
- The Caterpillar D series "pushing" tractors (bulldozers);
- The Caterpillar Challenger series agricultural "towing" tractors;
- The Kassbohrer Pisten Bully (PB) series "snow grading" tractors.

The Caterpillar D series tractors, although being excellent machines, ended up being ruled out because of their high price and their low speed. The Caterpillar Challenger series tractors are agricultural tractors with rubber tracks designed to tow loads on soft ground. Simple modifications allow their use in summer on the Antarctic continent. The Kassbohrer PB series tractors are not towing machines. They are built to grade snow on ski fields and have an incomparable ability to work with their blade. They have a very low ground pressure.

<u>B1.1 Caterpillar Challenger series tractors:</u> The Challengers take advantage of the Caterpillar savoir-faire in civil engineering machinery. They have a low ground pressure (300 hPa), a powerful engine (215 kW), and a simple robust design. It is a conventional direct drive powershift transmission (hydraulic clutch, semi automatic gear box). The Challengers have an operating weight of 15500 kg, a maximum speed (with no load) of 30 km/h and an operational cruising speed of 10 to 15 km/h when towing loads.

The use of Challengers in Antarctica is recent. Tests performed with a Challenger 65A and six different towing loads on a ground surface similar to what is found on about 80% of the traverse route from Dumont d'Urville to Dome C indicate an available towing capability (or pull) of about 6500 daN (tracks slipping limit).

<u>Caterpillar Challenger</u>



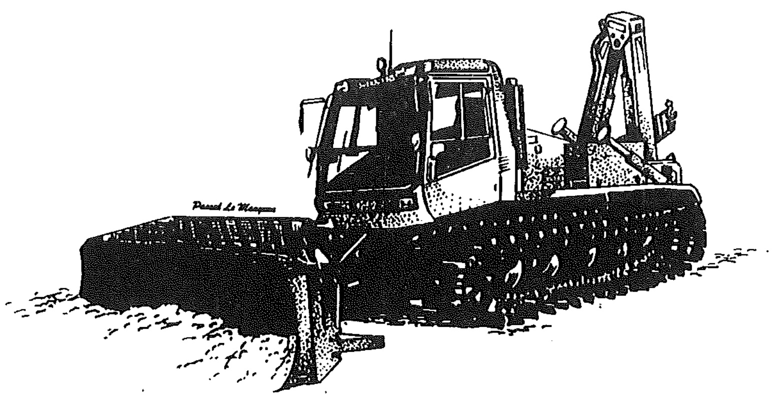
A quick calculation using a pull of 1500 daN utilised by the tractor to move itself and a towing force of 6000 daN gives a moving speed V of:

V = Power / Force = 215000 W / 75000 N = 2.87 m/s or 10.32 km/h

It is in accordance with what is achieved in the field in routine traverse operation.

B1.2 Kassbohrer PB series tractors: These tractors are snow grading machines designed for use in the ski fields. The PB 330 units are powerful (240 kW) to be able to push large amounts of snow and light (9000 kg) to be able to go up steep slopes. The ground pressure is extremely low (60hPa) so that the machines won't compact snow too much on the ski runs. Transmission is via hydrostatic pumps and motors, with electronic controls. The blade, very easy to handle, is designed for snow. The maximum speed is of about 15 km/h with no load.

Kassbohrer PB 330



B1.3 General assesment of Challenger and PB series tractors

The PBs are designed to move on all types of snow, but lose some towing capability because of their low ground pressure on very light snow. Their technical sophistication makes them fragile for such a use far from well equipped workshops. The interval between major service operations is only of about 3000h. Experience shows that towing heavy loads with a PB is damaging to the hydrostatic transmission, and that you shouldn't tow more than 13 tonnes on one sleds.

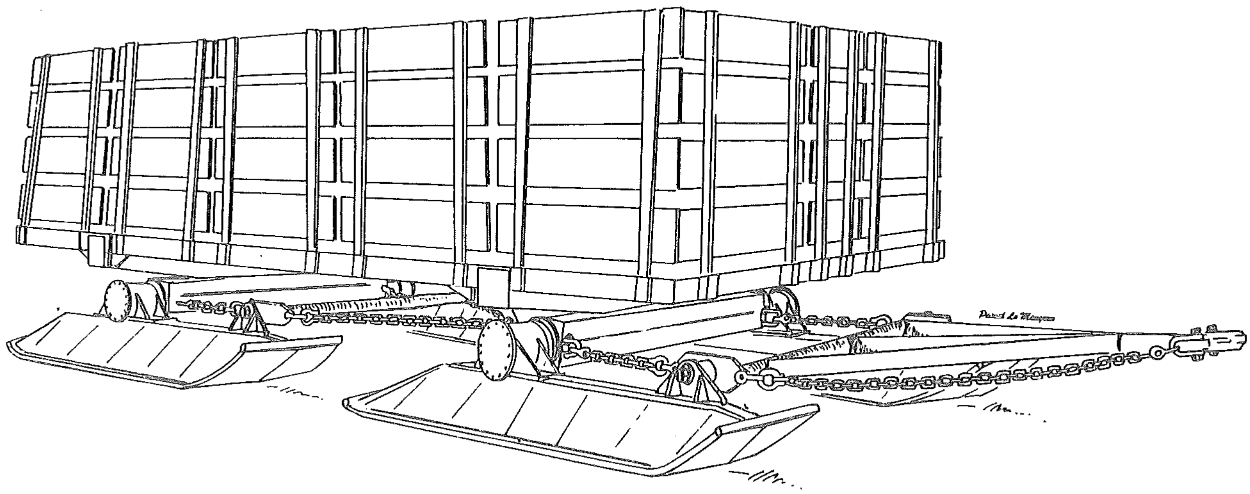
But it is the most versatile machine, designed to manipulate snow, fast, with two seats and providing a comfortable ride with the flexibility of its large tracks. It is the best machine to manoeuvre on difficult terrain.

The Challengers are designed to tow loads and it is possible for them to tow loads continuously without any durability problem. But they can lose some towing capability in dry "little-cohesive" snow. Being of simple robust design, they are low maintenance. They are not originally equipped with a blade, and attempts to fit one were not successful (pitching too important, lack of visibility). They can (mechanically) safely tow at maximum capacity as track slip will occur before any excessive mechanical stress. Towing at maximum capacity can occasionally cause the tractor to get bogged in irregular ground (bumps, sastruggis...). A winch mounted at the back of the tractor can help unbogging the tractor itself (The winch allows the tractor to free itself from the load when necessary) and can also be useful in rescuing another vehicle. We won't mount a winch at the back of a PB as it wouldn't be visible from the driver's seat.

Both types of tractors use about 6 litres of diesel fuel per kilometre when towing their load. However because of their hydrostatic transmission, PBs use 4 l/km when not towing any load while Challengers will only use 2 l/km.

B2 - SLEDS

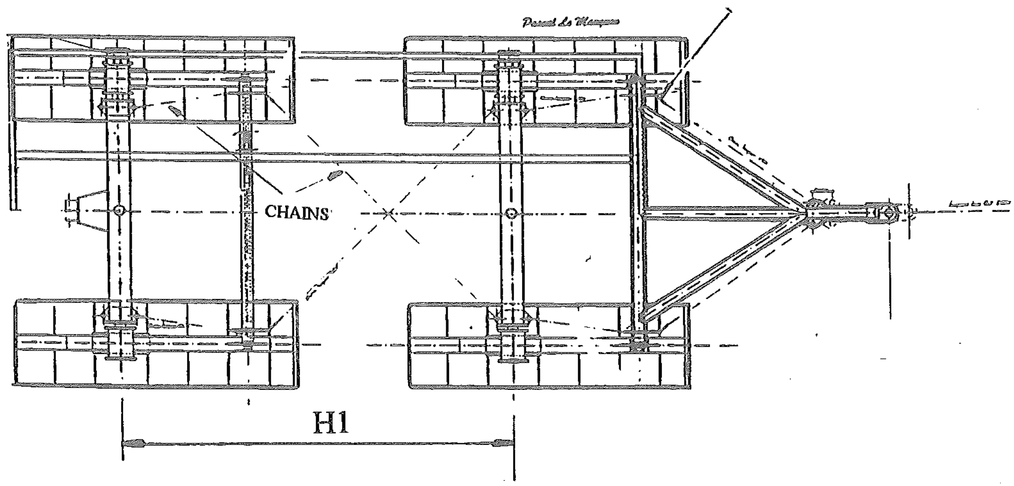
15 Tons sled



The traditional tow used to carry loads on snow or ice is the sled. The sled was invented in prehistoric times and preceded the wheel. By instinct the first designers had conceived a simple low ground pressure device taking advantage in snow fields of the low friction of the snow.

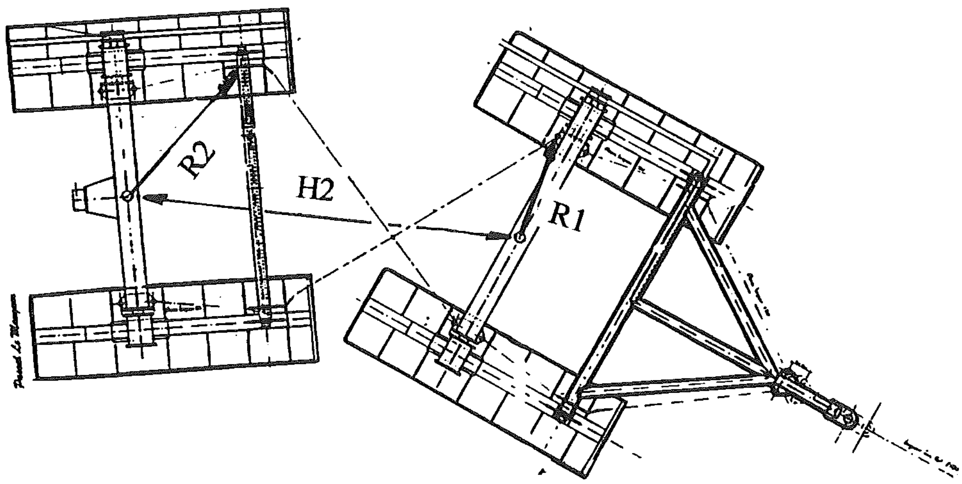
All traverses on ice caps have used sleds. If about every expedition had its own design of light sled, there are only few heavy sled designs. We have used Otaco and Aalener articulated models, but also use models of our own design: an articulated decked sled of 15 t capacity and a "tank sled" for bulk fuel. We are also using a simplified sled in the local handling of loads.

Sled - Ski assemblies

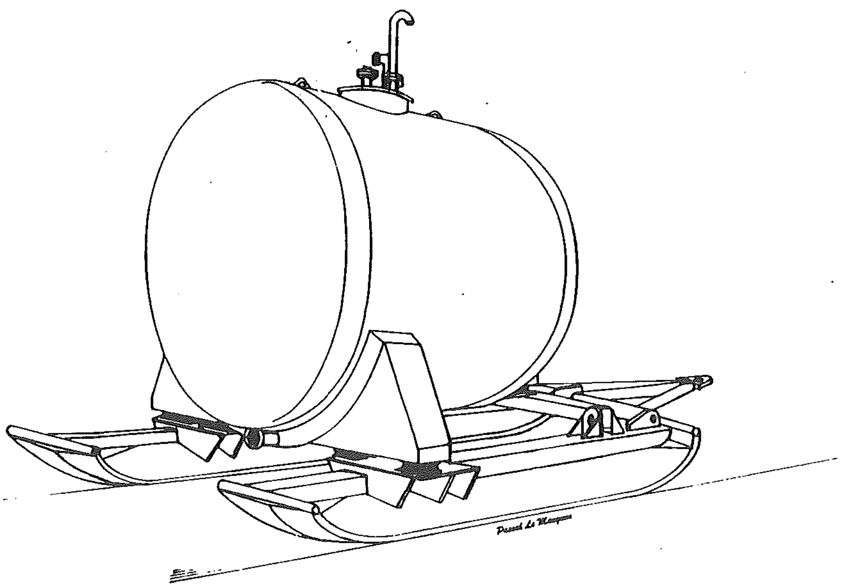


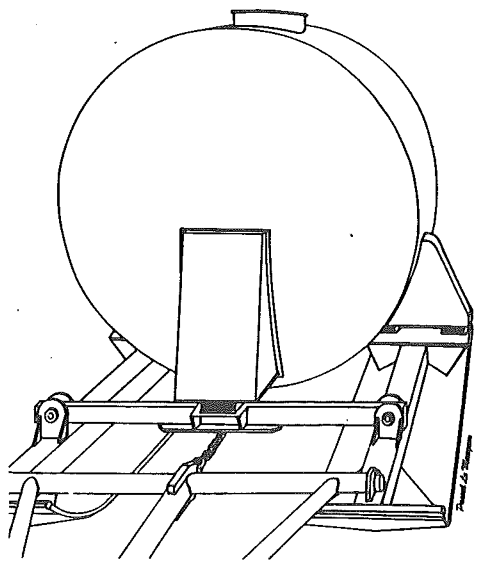
To limit friction, sleds should have a minimum deadweight. Articulated sleds are then designed to avoid having the towing effort transiting through the deck via a turntable or turning axle as this would necessitate a strong hence heavy deck. Instead, the effort transits via chains and sliding plates through to the front and the rear ski axles. The disadvantage of this system is that the front ski assembly turns around a radius R1, the back axle around a radius R2. R1 and R2 are different and turning requires a geometrical compensation, given by the longitudinal translation of the front ski assembly under the deck.

Sled - Ski assemblies When turning



The tank sleds are dedicated to fuel, the product most transported on the traverse. The relatively small 12 m3 tank sits on a single pair of skis via elastic suspensions. A pair of tank sleds can carry about the same volume of fuel than a decked sled would, but with a better net weight / grossweight ratio. In addition the tank sleds, with no moving components, save on mechanical problems.





12 m3 Tank sled

This 12 m3 volume is obtained by using standard components, with a 2000 mm long, 2400 mm diameter tube. The steel chosen for the parts that can suffer shocks and/or high stress is following French standard NF A42 FP (resilience measured at -50 degC).

The simplified sleds (also called martyrs) were designed to hold (store) and/or move locally loads without having to manipulate them with a loader or crane. These sleds allow easy loading/unloading of the loads on the heavy sleds or tracked trailers, using just a winch and a simple snow pit. But it is very difficult to use these light sleds as traverse sleds, even for light loads.

B3 - TRACKED TRAILERS

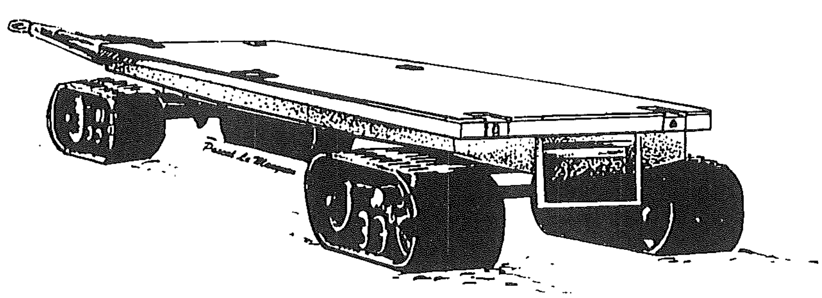
If sleds are typically rustic devices, hence considered generally solid, they become fragile as you increase their size, capacity and moving speed (10 km/h is a high speed). Increasing reliability along with performance requires to list all points subjects to stress loads and either limit the number of fragile points or find technical solutions to avoid stress concentrations. This leads to a heavy design. The sled stops to be a reasonable option when you have to carry heavy loads.

Historically, rolling succeeded sliding. It makes sense to try to replace skis by a rolling system involving less towing resistance. Rolling on soft ground can be achieved using tracks. The tracks make the link between rotating wheels and the soft ground, spreading the weight over a large area to achieve low ground pressures. Tracks are a well known solution for traction in self propelled vehicles, but were practically unknown as passive option in towed vehicles.

The spread of passive tracks was triggered by the availability of continuous rubber tracks, appearing in the late eighties in catalogues of several manufacturers. Until then only existed tracks made of steel elements connected together or tracks made of elastomer strips placed side by side and mechanically connected. The continuous rubber track came with high mechanical reliability and a motion resistance lower than skis.

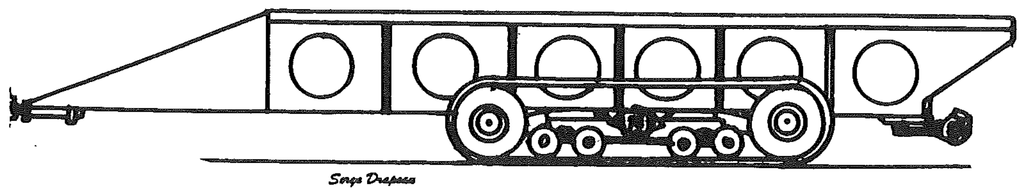
We acquired for the traverse in 1994 three trailers equipped with such rubber tracks. The first unit was designed to carry the "Living" module while the second unit had a 40 ft flat cargo deck and the third one a 20 ft flat cargo deck.

40 ft Decked trailer

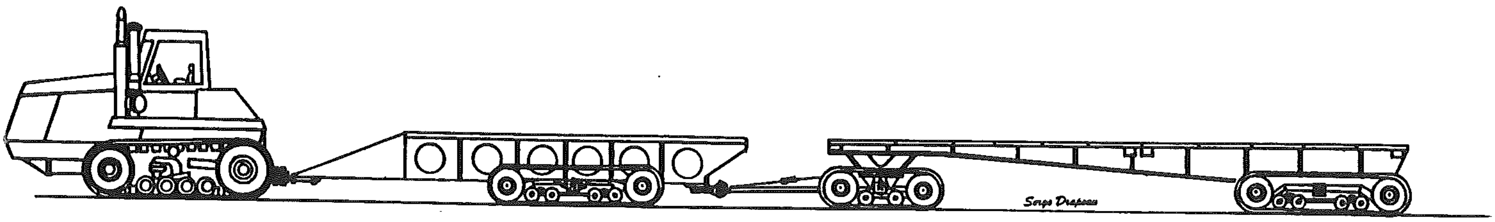


We acquired for the traverse in 1995 a fourth unit. The fourth unit had a 20 ft cargo deck, it is equipped with an hydrostatic motor located in the rear drive wheel axles. The power is supplied by the implement pump of the challenger. The system will assist the tractor when an additionnal drawbar pull is needed *(more details are given in Chapter IV-C).*

***20 ft Decked trailer** - Powered and no powered -*



40 ft trailer & 20 ft Powered trailer with Challenger



C - FACILITIES and LIVING QUARTERS

The "Living" module is divided into two four-berth cabins, one surgery/radio room, one kitchen/dining room and one cold porch.

The "Store" module was added to the traverse in 1995. It is divided in two rooms, one for provisions and one for spare parts. For a one month traverse of eight persons, the food and drinks needed represent 1200 kg or 2 m3.

The "Energy" module houses the generator set, the water production (snow melter) and distribution systems, the workshop, the bathroom and a warm store for medical supplies. The generator set rated at 30 kW powers the two "Living" and "Energy" modules as well as the tractor engine heaters during stops to keep engines warm.

A fuel pumping unit is located on the outside of the module and is used for refuelling the tractors which needs 4 m3 a day. The unit includes filtering and metering of the fuel.

D - TELECOMMUNICATIONS

Each tractor as well as the "Living" module have fixed VHF transceivers for local communications within the traverse or with close parties. The fixed transceivers are completed by eight individual hand-held VHF radios.

The traverse has three different systems for long distance communications. An INMARSAT C is used to send by telex position reports and other general work messages. An INMARSAT M is used for phone and fax, for both work and private communications. Traditional HF radio is used as back-up for INMARSAT but also for regular HF voice communications with the stations when out of range of the VHF system (about 20 km). There are three HF radio units, one in the "Living" module and two in different tractors.

E - NAVIGATION

Four GPS receivers are placed in four different tractors, all of the tractors being equipped with a GPS antenna. There is also a theodolite and a solar compass on the traverse.

F - TYPICAL CONVOY - The LOAD

The final choice of the number of tractors was made on three different grounds: technical, psychological and financial.

Technical criteria included considerations such as convoy length, maintenance operations during stops, personnel accommodation requirements and break-down probability.

Psychological aspects concentrated on the organisation of a wandering group subject to a rythmed routine. Both technical and psychological evaluations used our past traverse experience.

The final choice is of 7 to 8 tractors operated by a team of 8 persons.

A typical convoy will at least include 7 tractors towing the three "Living", "Energy" and "Store" modules and enough fuel for a return trip. The safe amount of fuel calculated for a return trip is 70 m3, 46 m3 for the outward journey towing loads and 24 m3 for the return journey. These 70 m3 can be housed in six tank sleds. A simplistic calculation shows that the traverse starts carrying "useful" load from 3.6 tractors, the front PB tractor towing one tank sled, one Challenger towing the 3 modules, a second Challenger towing 3 tank sleds and "60%" of a third Challenger towing 2 tank sleds.

The fuel consumption is high and the amount of fuel transported at the start of the traverse limits the net load of the convoy. On the outward journey tank sleds are left along the traverse route once they are empty, and picked up on the way back. Also, based on the estimation of the progressive consumption of the convoy, some full tanks can be left along the route for use on the return journey.

The traverse route is divided in two main zones: the coastal zone from the shore to the point D60 (240 km) and the plateau zone from D60 to Dome C (880 km).

The coastal zone is difficult. It comprises noticeable slopes and uneven ground that can be of several metres amplitude. The average speed of the convoys is around 6.5 km/h compared to 9.5 to 11 km/h in the plateau zone. Also, as demonstrated every year the coastal zone is subject to climatological turbulence. About every season an important snow fall or a rise in temperature will disrupt the start of one or even two traverses. The high initial fuel load, slopes, uneven ground and climatological disruptions of the first part of the traverse combine to limit the net useful payload of the convoys.

G - OPTIMISATION of THE TRAVERSE PAYLOAD

G1 In the coastal Zone:

One solution envisaged is to divide the traverse system into two separate traverses, a "short" one covering the difficult coastal zone and a "long" one covering the 2 zones. This solution has been set aside for the time being as it would require additional modules and tractors.

The other solution is to add an eighth tractor to the traverse in the coastal zone only, then leave the tractor at D60 and transfer its load onto the other machines. On the way back, the traverse pick-up this eighth tractor and load it onto an empty sled. This additional machine could be a Challenger or, because of the slow speed imposed in this zone, a Caterpillar bulldozer D8 or D7 LGP. This machine which would be driven by the eighth traverse staff member, could help with the "opening" of the route by assisting the front Kassbohrer PB tractor. This assistance wouldn't be superfluous as the hardness of the ground in the coastal zone can sometimes excess the capacities of the PB.

G2 Real fuel needs

The 70 m3 of fuel transported by the convoy as it leaves the coast correspond to the maximum volume that could be consumed on a return trip (estimate based on trials including a safety margin). A new system to be tested next season will consist in installing two 20 m3 tank container along the traverse route and get returning convoys to dump some of their excess fuel in these two tanks. One tank will be placed at the junction of the coastal and plateau zones *(D60)* and the other halfway between the coast and Dôme C.

This will allow subsequent convoys to reduce their initial fuel load to increase payload as they will be able to tap into the tanks if necessary.

II - THE TRAVERSE TEAM

The traverse team requires a specific personality and profile. It must be able to perform many duties: drive, level the ground, determine its position and navigate, eat well, communicate, maintain and fix equipment, attend patients and form a coherent, responsible team.

A - The work on the traverse

Some of the duties have to be fulfilled by all eight members of the team while some other duties only need to be fulfilled by one person.

- **Drive:** The eight team members must be able to drive a vehicle towing a load while being attentive to onboard indicators and instruments. They must in addition be intuitive and attentive to feel the machine and react promptly to any problem.

- **Level the Ground:** Two persons must be able to level the ground with the Kassbohrer's blade, continuously and well enough to provide a good track for the six tractors that follow. This levelling determines the speed of the whole convoy. It is an exhausting job and the operator should be replaced every four hours. This is why there are seven tractors for eight team members.

- **Determine Its Position And Navigate:** Two persons must be able to navigate using GPS and understand simple astronomical phenomena. One person must be able to determine a position using a theodolite, the astronomical tables and a logarithm table.

- **Eat well:** Two persons must be able to organise proper meals for the team.

- **Communicate:** One person in charge of telecommunications must be able to use Inmarsat as well as HF radio equipment.

- **Maintain Equipment:** Seven persons (one per tractor) must be able to carry out basic maintenance on the tractors and their loads (refuel, clean, clear snow, maintain loads secure, check couplings).

- **Fix Equipment:** The traverse is a technical adventure with 220 KW tractors, a diesel generator set, 18 to 25 loaded sleds or trailers. Four persons must have sufficient experience to intervene on a fully loaded sled or trailer deck. At least four persons must be experienced diesel mechanics, one of them must have a good knowledge of the Kassbohrer's hydrostatic systems. One person must be a good welder, and another one an electrician/electronics specialist.

- **Attend Patients:** The presence of a medical doctor on the traverse is necessary.

- **Form a Coherent, Responsible Team:** In such isolation and difficult environment, the team must be coherent and responsible. This requires a careful choice of all members, but more importantly requires the presence of a very good assertive leader accepted by all, capable of taking initiatives and making decisions. This leader organises the everyday life of the traverse and takes the decisions when problems occur.

The team chosen to fulfil all these duties comprises:

- **Four Diesel Mechanics,** for maintaining and repairing all mechanical equipment, with at least one skilled in hydraulics.

- **One Navigator and Telecommunications Officer,** capable of maintaining his equipment. This member is usally the electrician / electronician of the team. This position involves a fair amount of work during traverse stops.

- **One Medical Doctor,** who can possibly also be Navigator. He is usually in charge of the cooking. It is common practice to keep the doctor away from dangerous activities.

- **One Traverse Leader,** It can be one of the Diesel Mechanics, but it cannot easily be the doctor or the Navigator and Telecommunications Officer. The traverse leader must have a good knowledge of the project. He must know all the equipment perfectly and be able to assess its condition in order to take the right decisions.

- **One "Open" Member,** who only has to be able to drive a tractor and have good physical abilities. This person can be a scientist doing en-route studies, a journalist that will report on his trip, a supplier of equipment, a VIP, a technician in training or a fifth diesel mechanics etc... He is usually there "au pair" rather than as a full staff member. It "opens" the traverse to the outside world by allowing various one-off members to join the team.

B - SOCIAL CONSIDERATIONS

As previously mentioned, the traverse team must be coherent and cohesive. Its members must really work "together". The personnel turnover should be low while still allowing the creation of a sufficient pool of experienced traverse personnel. The problem is to create a pool of experienced, rigorous professionals and avoid the succession of strong personalities coming along for the adventure without caring for the group.

Both professional and personal qualities are essential. The cohesion of the team requires respect for each other, and the understanding that every action not carried out properly can result in extra work load, equipment failure and/or high risk situations for somebody in the course of future traverses.

Traverse work starts with the preparation of vehicles and loads before departing and ends with the conditioning of vehicles for the winter upon return of the last traverse of the season. Bad conditioning for the winter, rough operation of vehicles or postponed repairs will sooner or later show their due.

C - TRAINING

It is difficult on the employment market to find people with personal and professional capacities that can make them good "traversers". There are no formal selection criteria, but we consider aptitude to the environment to be an important issue and we tend to give preference to people that have the requested professional abilities along with a successful wintering past in Antarctica or mountain work experience. Then, we complement their skills as required by additional specialised training sessions. Such sessions include specific training on the Kassbohrer PB and Caterpillar Challenger tractors organised by the manufacturers, navigation courses at specialised institutions such as the French National Geographic Institute or first aid courses.

III - THE SAFETY

A - Risks and Associated Prevention Measures

Total safety can never be reached, but we are making every effort to reduce risks as much as possible. Risks can derive from the following sources:

- Crevasses
- Fire
- Loss of food stocks
- Loss of energy production systems
- A vehicle or the whole convoy getting lost
- Cold, Altitude, Sun
- Exhaustion
- Psychological disorders
- Illness
- Physical accidents

A1. Crevasses: There are crevasses along the traverse route between km 3 and km 30 (from the coast). The most delicate zone is between km 6 and km 15. *The crevasses are checked and surveyed every year. A marked route has been maintained until now.*

To better survey and locate the crevasses, a differential GPS system was acquired in 1995. The fixed reference station will be located at Dumont d'Urville station and the precision obtained in the crevasses zone will be under 3m. This will also allow a more precise navigation by low visibility.

A2. Fire: Fire is the most serious risk as it can cause the loss of one of the three modules or one vehicle. *To minimise risks, the main personnel facilities were divided into two modules that separate the energy production area from the living area. The two "Energy" and "Living" modules have no link and personnel has to go outside to get from one module to the other. The fuel tank for the generator set is on the outside of the Energy module. The third module is the "Store" which doesn't contain any dangerous combustible materials (no petrol, propane, diesel fuel...) and has no supply of electricity. The three modules are made of auto-extinguishing material classified "M1". All electrical installations follow maritime regulations.*

A3. Loss of food stocks: This can be caused by fire or the accidental disconnection of the sled or trailer carrying the stocks. *To prevent a total loss of the stocks, the food is usually divided in three lots placed in the living module, in the storage module and on a sled (safety stock).*

A4. Loss of energy production systems: This can be caused by fire or by a problem with the diesel fuel, such as congealing. *To prevent total loss of energy production capabilities, the traverse has at least one portable generator, propane, kerosene and petrol.*

A5. A vehicle or the whole convoy getting lost: This is a navigation problem. *There is one GPS receiver in each vehicle and each driver has a basic training in navigation. In case there was a problem with the GPS system network itself, the navigator is able to determine his position astronomically using the sun as reference.*

A6. Cold: The main risk is associated with the loss of heating capabilities following the loss of energy production systems. But there are also daily risks caused by loss of attention and risk awareness. *The training and briefing of new traverse members on this aspect is necessary. Clothes are appropriate and each person has sufficient amount of clothes to get changed as needed.*

A7. Altitude: Altitude related risks are mostly for personnel reaching Dome C by plane, not by traverse. Nevertheless, there can be daily risks on the traverse caused by loss of attention and risk awareness, notably over-estimation of one's physical capabilities. *The training and briefing of new traverse members on this aspect is necessary. The traverse is equipped with a compression chamber since the 95/96 season.*

A8. Sun: Sun related risks are mostly concerned with eyes and possible serious ophthalmia due to UV radiations, and personnel is provided with adequate sun glasses. *The training and briefing of new traverse members on this aspect is necessary. On the forward leg to Dome C, "night sun" is especially problematic for drivers as it is at windscreen height.*

A9. Exhaustion: Exhaustion is highly dependent on the schedule adopted, the environmental conditions and the problems encountered. *The medical doctor and the traverse leader should assess the level of exhaustion of the personnel and the traverse leader has all latitude to adapt the schedule and work program to the situation.*

A10. Psychological disorders: *These problems, or the possibility of their occurrence, should be detected beforehand in the selection process.*

A11. Illness: Traverse personnel is subject beforehand to thorough medical tests. The first main risk is food poisoning. *Food stocks are checked and sorted every year, and storage temperature requirements for refrigerated and frozen products are carefully enforced.* The second main risk is appendicitis, which the traverse medical doctor can deal with.

A12. Physical accidents: It is one of the most delicate problems. Physical accidents that would have benign consequences in a normal environment can take dangerous proportions in the traverse environment. This was showed in 93/94 when the doctor on the second traverse cut his finger while cooking. *Traverse personnel must be aware of their isolation and take special care in any activity.*

B - General approach

Safety is absolutely essential. There are several methods to prevent accidents and minimise their consequences. The actions taken in this effect on the traverse are:

- Multiply the number of shelters in the convoy, spread clothes and sleeping bags.
- Spread food into several stocks
- Link all vehicles and shelters with VHF radio.
- Have several INMARSAT and HF telecommunication systems spread in the convoy and regularly check them. *They are three HF systems and two INMARSAT terminals, M and C,*
- Have several GPS positioning receivers spread in the convoy.

- Have in the convoy enough Kerosene to refuel an aircraft coming for a rescue operation.
- Have a medical doctor on the traverse, have experienced personnel, train one or two traverse members at first aid technics.
- Have medical facilities
- Have the tractors equipped with "Dead Man" safety systems (Challengers from 95/96, Kassbohrers still to be equipped)

It is also worth mentioning an evident action: Use reliable vehicles and equipment that prevent to have the personnel living in permanent fear of breakdowns and being exposed to dangerous repair operations.

The traverse members have to be trained, informed and permanently aware of their situation. It can seem obvious, but we should still mention that on the traverse:

- In a blizzard, you should only go outside wearing sufficient clothing, and possibly attach yourself to a safety rope.
- You should never open the door of one of the modules while the traverse is moving (for the personnel on rest shift when the traverse operates on 24 hours a day mode).
- You should check before starting the convoy that every person is there and where they should be.
- You should respect the planned schedule for sending radio messages reporting the traverse position.

Safety can't be neglected but imposing excessive safety measures is not necessary as it could give a false impression of security. The environment is hostile and the traverse personnel should always feel it.

IV - TRAVERSE OPERATIONAL INFORMATION

A - GENERAL DATA

A1 - Driving times and average speeds

Four return traverses have been already completed. The traverse reported here are traverses purely logistic not involved in any other works (AWS, Glaciology, RTG ...). The average duration of a return traverse to Dome C, including a 2 day stop on the site, is of 25 days (13 days for outward journey, 10 days the return).

November 1994 traverse:
Outward (South) journey: 118 H 13 Min, average speed of 9.47 km/h
Return (North) journey : 107 H 15 Min, average speed of 10.44 km/h

January-February 1996 traverse:
Outward (South) journey: 126 H 00 Min, average speed of 8.9 km/h
Return (North) journey : 106 H 50 Min, average speed of 10.5 km/h

A2 - Geographic locations

Cap Prud'homme	:	66° 41' S - 139° 54' E
D60 (Junction plateau)	:	68° 27' S - 137° 12' E
Dome C Weather Station AWS 8989	:	75° 07.38' S - 123° 19.02' E
Dome C cargo depot	:	75° 07.38' S - 123° 19.02' E

A3 - Global fuel consumption:

The global fuel consumption of the last complete traverse was 54 m3 for a distance of nearly 2300 km. This traverse included 7 tractors (1 Kassbohrer PB 330 and 6 Caterpillar Challenger 65) and delivered the nominal amount of cargo to Dome C.

A4 - Daily schedule:

The current normal daily schedule is to get up at 06h00, drive from 07h30 to 19h30 or 20H00 except for a 40 to 50 minutes lunch break, spend 1h to 1h30 refuelling, maintaining the vehicles and checking the cargo, then have dinner and go to sleep. The total number of hours worked during the day is around 14 hours.

B - TRACTOR IMPROVEMENTS

B1 - CATERPILLAR CHALLENGER 65s

The six Challenger 65s operate satisfactorily. Howewer a fault appeared in the differential of our second Challenger tractor bought in 1993 but our Caterpillar Australian agent William Adams, with assistance from Caterpillar, conducted all necessary repairs on site under the warranty.

B1.1 - Main winterisation modifications

Theses modifications, undertaken in Tasmania by the Australian agent William Adams, are now a perfected technique.

ENGINE COMPARTMENT

* Installation of a fuel priming pump, a water separator and a fuel line heater in fuel system, addition of a man hole on the fuel tank, a water collector at the bottom and a drain pipe and tap.

* Modification of the engine air intake and exhaust system to include snow separator
* Installation of a 12/24 v alternator and a 50 MT starter motor
* Installation of Fleetguard heaters in all oil compartments and tank type heater to cooling system,

CABIN

* Installation of a marine type roof escape hatch with adjustable hinge, including external handle and lock facility;
* Manufacture and installation of a double glazed front windscreen (original curved unit is replaced by 3 smaller flat units fitted in an adapted frame);
* Revision of the front and rear window demisting system including a second water type heater for rear window. Installation of heating air pipes around windscreens;
* Installation of a new locker and silicon seals on the cabin door;
* Installation of a pyrometer and electronic tachymeter on the right hand side of the cabin;
* Removal of all levers not used in instruments panel.
* Installation of a bench type driver seat, with 2 rewinding safety belts. The bench is mounted on a KAB seat base;
* Installation of a road truck type rearview mirror, mounted on the external handle of the right side of the cabin;

FRAME, BODY and BOGIES

* Manufacture and installation of a new bonnet assembly to improve engine compartment sealing and insulation complete. The bonnet assembly has large openings and lift off doors for easy maintenance.
* Manufacture and installation of a heavy duty roll up blanket for the coolant radiator air intake,
* Manufacture and installation of a sealed sump cover with relocated dipsticks and filters and transmission guard group
* Manufacture and installation of a heavy duty battery box with 2 x 210 AH batteries and fleetguard battery blankets. Batteries will are filled with acid density 1.3 kg/dm3 and connected to an external 24 V starting/charging plug
* Insulation of the Hydraulic tank
* Manufacture and installation of ice scraper for drive wheels
* Installation of silicone seals in drive and idler wheels
* Installation of metalic hubs on wheels
* Fitting of a 20 ton Hyster winch on some machines

B1.2 - Increase of towing capabilities

The maximum possible towing effort of the Challenger 65 is around 6500 daN. With the current engine, this effort allows a travelling speed slightly over 10 km/h. If this is fine for about 80% of the traverse route, an increased towing capability (through an increased traction, the two being directly linked) is desirable for the remaining 20% which present the following problems:

- Lower surface quality close to the shore (Very hard and rough surface and sometimes, melting snow) and next to Dome C (dry powdery snow with little compaction by the wind) giving lower traction capabilities;
- Noticeable slopes (1 to 4%) in the coastal zone, also subject to occasional fresh snow covering and Sastruggis too hard to be suitably levelled by the PB tractor, both increasing the towing effort required.

The first way to increase traction is to have a larger surface of driving tracks in contact with the ground. The first option would be to have longer tracks on the tractors. This has been ruled out as it requires major frame modifications. The option chosen is to hook to the tractor a tracked trailer equipped with driving tracks which hydraulic motors are powered by the tractor's hydraulic implement pump. The type of track used is the Caterpillar MPS 116' unit, similar to the MTS unit but with the addition of a Poclain hydraulic motor placed in the back wheels' hub.

The second way to increase traction is to improve the effectiveness of the tractor tracks' grousers. We will test next season a flat rubber track with bolted steel grousers.

B2 - KASSBOHRER PB 330s

B2.1 - Main Winterisation modifications

The two PB 330s operate satisfactorily. The modifications, undertaken by the **Italian agent "Kassbohrer Italia"**, are now a perfected technique.

ENGINE COMPARTMENT

* Installation of a fuel priming pump and a water separator in the fuel line, addition of a drain pipe and tap,
* Modification of the engine air intake and exhaust system to include snow separator,
* Installation of heaters in all oil compartments and tank type heater to the cooling system,

CABIN

* Installation of a roof escape hatch, including external handle and lock facility.
* Installation of a road truck type rearview mirror.

FRAME, BODY and BOGGIES

* Manufacture and installation of a sealed sump cover,
* Replacement of the original batteries by heavy duty batteries, batteries are filled with acid density 1.3 kg/dm3 and connected to an external 24 V starting/charging plug
* Insulation of the Hydraulic tank
* Installation of 2 x 300 l fuel tanks
* Installation of rubber filled tyres;
* Fitting of one machine with a 10 T x M Fassi crane
* Replacement of standard blade hoses by silicone hoses

B2.2 - New improvements *(On ENEA Machines)*

* Manufacture and Installation of double glazed front windscreen (original curved unit will be replaced by 3 smaller flat units fitted in an adapted frame).

C - TRAILER and SLED IMPROVEMENTS

C1 - TRAILERS

The Concordia project group bought in 1994 and 1995 four trailers built by **Elphinstone Engineering** in **Tasmania** to be used in Antarctica. The first two trailers are equipped each with two pairs of MTS 73 undercarriages, the third trailer with one pair of MTS 116 and the fourth trailer with one (powered) pair of MPS 116.

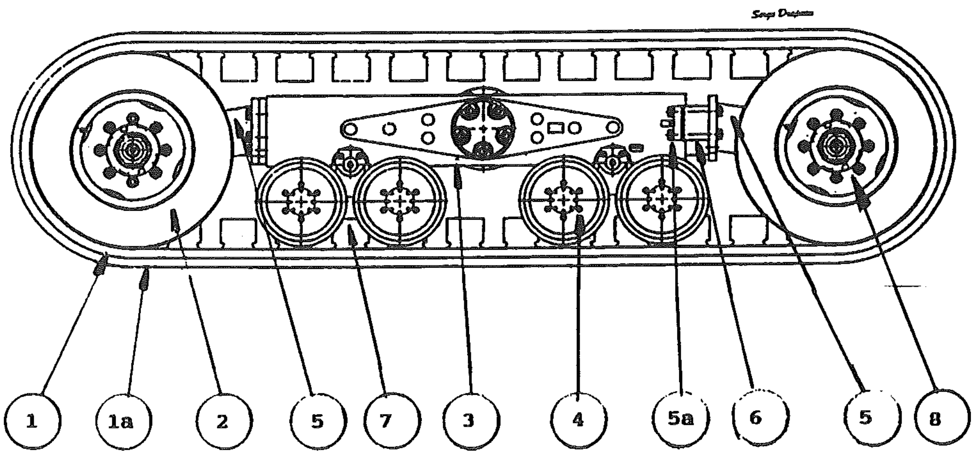
The powered trailer has a fuel tank located in the frame. Each MPS 116 is driven by an hydrostatic motor. the power is supplied by the implement pump of the challenger. The system will assist the tractor when an additionnal drawbar pull is needed.

A fifth trailer equiped with VFS undercarriages, generously lent by **William Adams**, was also used and tested during the 95/96 summer season. The VFS had two 116 inches belts. A temporary deck made out of a sled was bolted onto the trailer.

C1.1 - MTS and MPS Undercarriages:

Except for the hydrostatic motor, the MTS and MPS units are similar. They all have idlers made of inflated tyres, rubber belts and bogies. The undercarriages have travelled nearly 2300 km and show no sign of excessive wear. Several small problems appeared, technically minor but disrupting for the operations. The trailers are heavy and any gain on their deadweight would increase their net payload. The deck is high (1.65 m from the ground) to give the tracks sufficient pitching mobility, but it is detrimental to the stability.

Schematic of the undercarriage MPS and MTS 116.



1: belt. 1a: grousers. 2: idlers.
3: structure. 4: boggies. 5: arm.
5a: bolts. 6: shim. 7: belt blocks.
8: Hydraulic motor (if any)

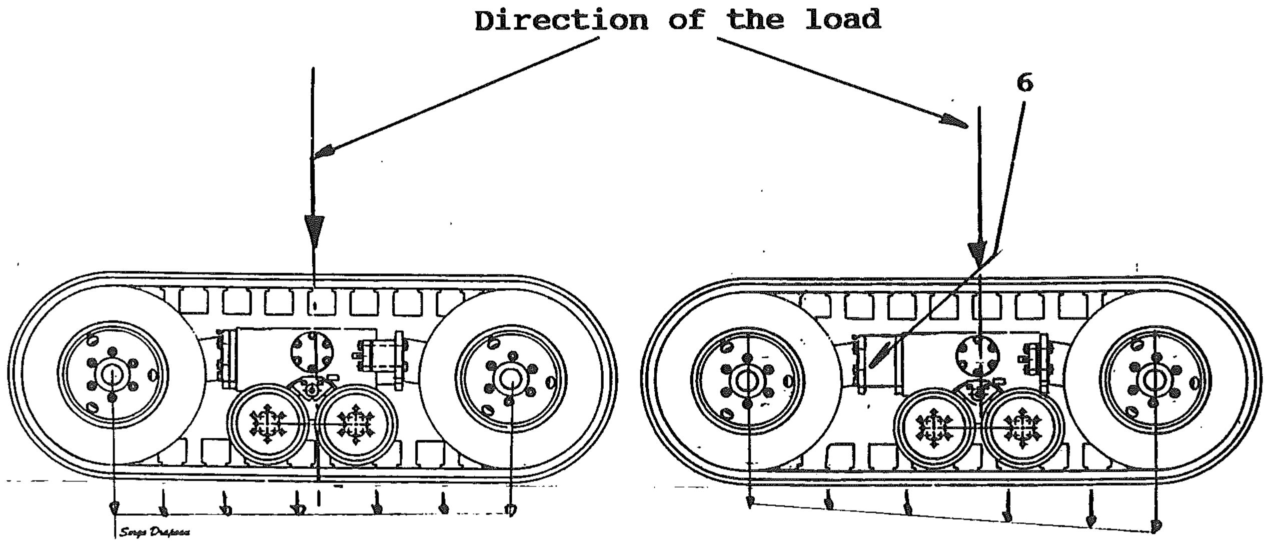
C1.11 The idlers are equipped with tubeless tyres. This technique used universally around the world showed its limits in antarctica as ice caught between the chassis and the tyres exerts pressure on the walls of the tyres, making them deflate.

C1.12 We should use tyres filled up with foam. The density and the elasticity of the foam would be equivalent to the tyre inflation pressure required (we could not use rigid tyres that would give too much resistance to deformation). The type of belts that we use have grousers, but we never get into a situation where these passive grousers are needed (except for the powered trailer). As the presence of the grousers increase the towing effort, a plain belt would be preferable.

C1.13 - The rubber the belt are made of gets stiffer below - 35 deg. celsius. This in addition to the thickness of the belt, to the thickness of the pitched grousers and to the "winding radius" of the 850 mm idler increases the towing effort.

A thinner plain belt made of low temperature rubber would be preferable, effectively replacing the standard belt designed for heavy abrasive soil with a belt more suitable for compacted snow. Also, a thinner belt would diminish the weight of the undercarriage and would improve the ratio payload / total weight.

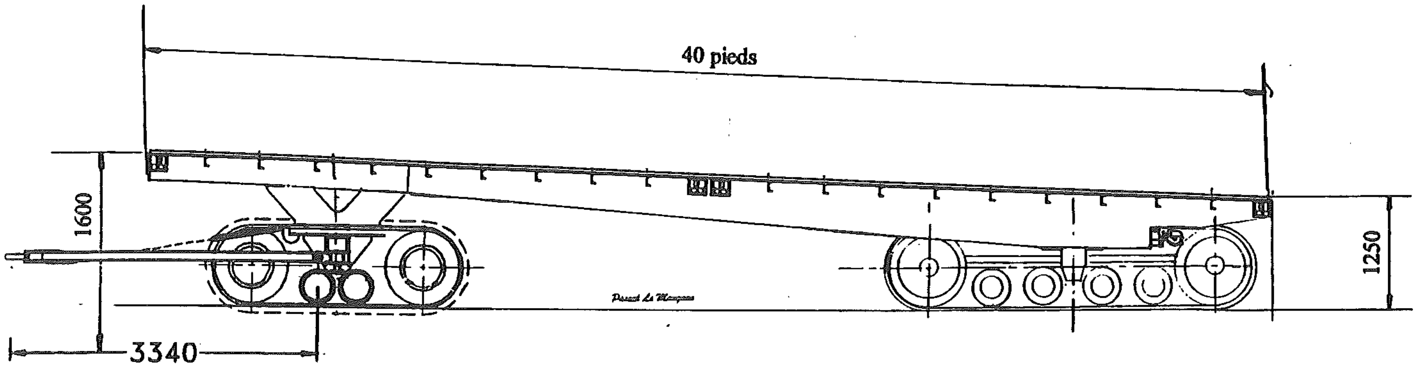
C1.14 - A loaded undercarriage moving on a 0.4 Kg/Litre density snow creates in front of the belt a roll of snow. Building up this roll, then crushing it again increases the towing effort. To minimise this roll, we need like for sleds skis to shift backward the load exerted on the undercarriages. This could be done by moving the shim (item 6 on figures) from the front to the rear.



C1.15 - MPS Hydrostatic motor. The MTS and MPS undercarriages are basically similar with for the MPS the addition of the hydrostatic motor. The motor is protected by steel covers on each side of the structure. These covers are not protecting the motor from the snow getting into it. When in contact with the hot motor, the snow melts then refreezes when the motor cools down during the stops. After a few cycles, all control systems around the motor are blocked up, covered with ice.

C1.2 - IMPROVMENTS

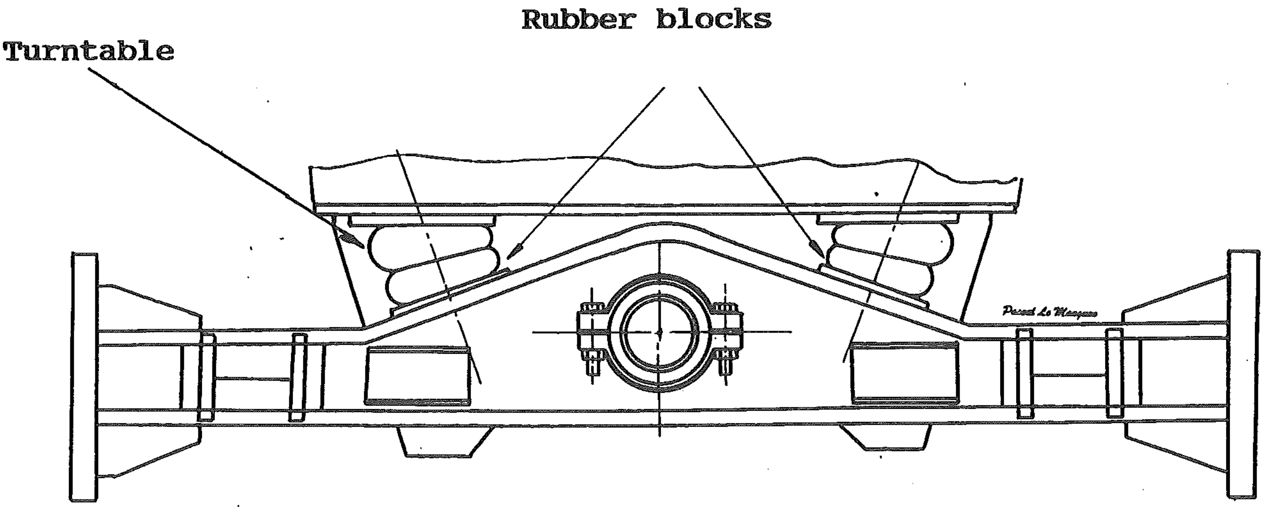
40 ft Decked trailer



Front: MTS 73 Back: VFS 50

In order to decrease deadweight, the next trailers will have a deck width of 2.6 m instead of 3 m, no timber decking and a back end lowered at 1.3 m above ground instead of 1.65 m. A system will limit the pitching of the back tracks. Stability will be increased by rubber blocks placed between the turntable and the transversal beam linking the front tracks.

Trailer front axle



C1.3 - VFS undercarriage

We were quite happy with the performance of the VFS units. The only problem encountered was similar to those described earlier for MTS and MPS belts (the belt was thick and getting stiffer in low temperature). The steel idlers are here well used because of the elasticity of the system, based on an air suspension similar to the challenger's.

C2 - SLEDS

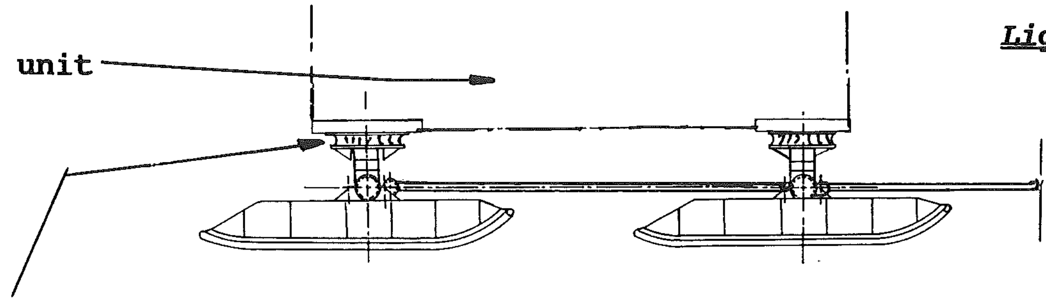
C2.1 - Cargo sleds

Trailers are heavy and typically have a low net payload to deadweight ratio. Trailers should only be used for dense loads and there is place for improved sled designs to carry light loads such as empty construction modules or insulation panels.

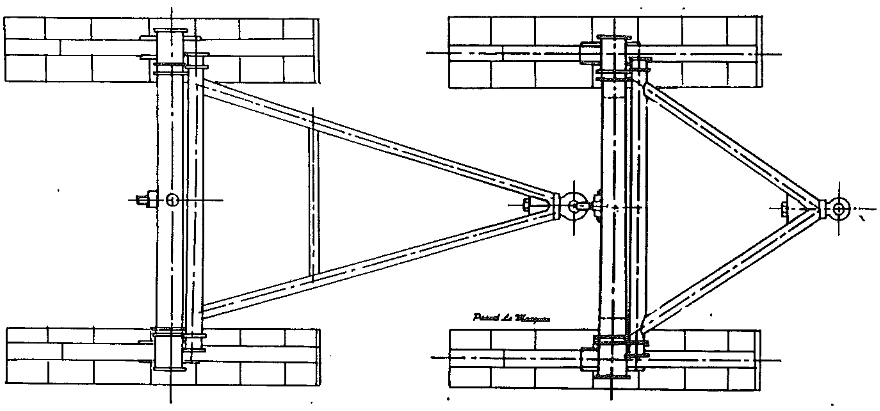
The kinematics (See chapter I-B2) of articulated sleds requires the longitudinal mobility of the front ski assembly under the deck. Depending on the load, this movement can induce very high efforts in the axles. But this design has the advantage of guiding the head of the skis on rough terrain and avoids having them plunging into holes or sastruggis. With an "opening" machine of the capabilities of the Kassbohrer PB 330 we can consider modifying for our convoy the usual sled design as follows:

Light sled

20 ft unit



Rubber blocks



- The deck is removed, and the sled then used only for 20 foot containers or handling sleds;
- Each ski assembly supports via rubber pads a transversal beam terminated by two container locks to secure the load.
- The front and back ski assemblies can be linked by a drawbar instead of chains. It holds together the two assemblies when the sled is empty;

C2.1 - Tank sleds

These tank sleds with only one pair of fixed skis can have problems travelling on rough terrain due to important pitching caused by the lengh of the skis. We minimise the problem by alternating tank sleds and trailers in the convoys, the trailer tracks smoothing the terrain.

A modified design of the skis of this sled will be tested during the 1996/97 season. The skis will be articulated around a transversal, horizontal axis. The ski ground pressure will be balanced along the ski through a set of springs.

D - ADDITIONAL EQUIPMENTS

D1 - NAVIGATION

D1.1 - SMOOTHING THE TRAVERSE LINE

It is always advantageous to find a way to "smooth" the traverse line followed by the convoy from the zigzags allowed by the general navigation system. We will test the use as marks placed every 10 km of snow mounts created with the blade of a PB 330. These marks stay actually visible from one traverse to the next in the same season. We even expect them to be still visible the following year.

D1.2 - SPOTTING TRAVERSE'S OLD TRAIL

All traverses completed encountered problems with the low "supporting" capabilities of the ground in the vicinity of Dome C (dry powdery snow with little compaction by the wind). In 95/96, the second traverse managed to spot the traverse's old trail and use it on about 90% of the distance, driving on snow previously compacted by the convoy and achieving a far better performance than usual in the vicinity of Dome C.

It is then important to find away to spot old trails when they have been covered by snow. Two options are currently investigated:

- Creation of a surface that would reflect radar signals;
- Precise physical marking of the trail.

D1.3 - NAVIGATING IN BLIZZARD

It is very difficult to move as a convoy in thick blizzard. A radar installed in one tractor could keep track of the positions of all vehicles and tows in the convoy and guide them by VHF radio if necessary. Also, the last tow of each vehicle will be equipped with a flashing light powered by a battery charged by solar panels.

D2 - FUEL

Water and particles in fuel are a threat to reliability and safety. even if vehicle tanks are built with water traps and modified fuel lines. A centrifugation unit was installed at the coast to purify the fuel before delivery to the traverse. In addition, the pumping unit used on the traverse to refuel vehicles includes a filtering system.

ACKNOWLEDGEMENTS

We wish to thank for their contributions the members of the Concordia steering committee ; Mrs Chanin & Mrs Debouzy, Mr Lorius, Mr Marino, Mr Ricci and Mr Zuchelli.

Thank you also to Pascal Le Mauguen and to Serge Drapeau who drew all the figures, and to Antoine Guichard who translated the paper in English.

G.I.S. for logistic applications at Terra Nova Bay Station

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** ENEA -- Progetto Antartide

1. Introduction

In the widest sense the term G.I.S. (Geographical Information System) indicates a powerful set of hardware and software tools for collecting, storing, retrieving, transforming and displaying spatial data and related attributes with the purpose to satisfy a wide range of applicative needs. Therefore the data set managed by GIS represents a model of the real world that can be used to study environmental phenomena, to plan interventions and to optimize decision processes. The data in the GIS are at scales normally used to represent features identifiable on the Earth's surface.

The role of the GIS in environmental management can be illustrated by a graph as in Figure 1.

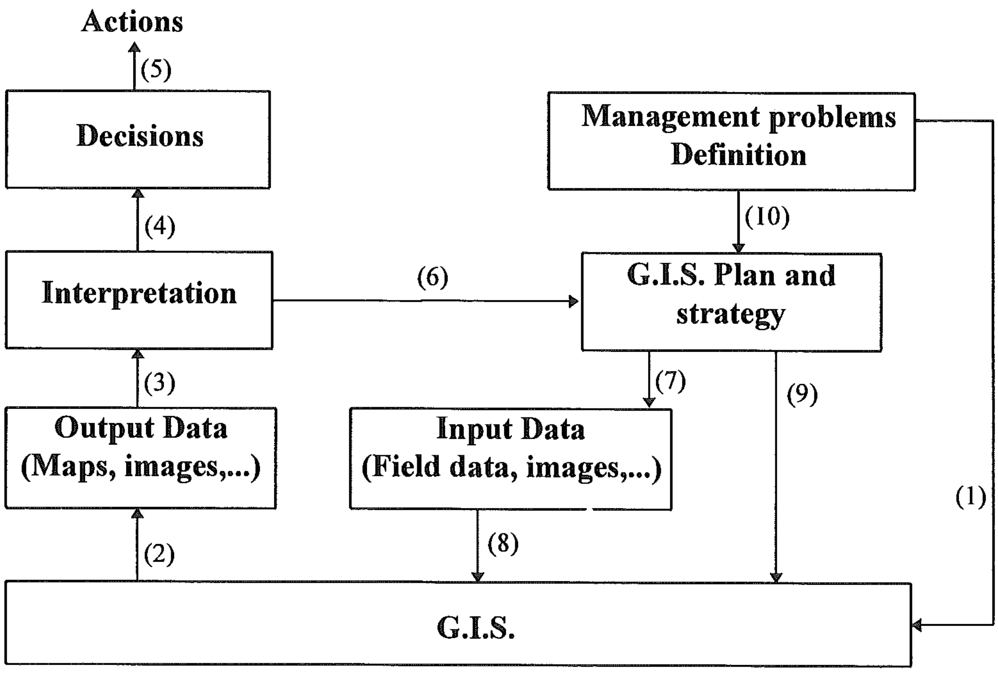

Figure 1

Existing data, field data, remote sensing data are stored into the GIS data-base and upon request (1) produce output data (2). These are interpreted (3) and can produce decisions (4) and consequent actions (5). If problems arise due to inadequate data or tools, a redefinition is necessary (6) and this leads to a new plan/strategy for the GIS: the simple acquisition of new data (7 and 8), an effective new operative method or the acquisition of the appropriate software/hardware tools (9) or all the possibilities together. Moreover the management staff's decision to obtain a different product may influence (10) the planning and the operating strategies for the acquisition of new input data (7 and 8) or tools and the development of new processing methodologies (9).

The real ground features can be represented by three fundamental elements (points, lines and polygons/areas) and described in terms of their:

- *localization* in a reference geographic coordinates system,
- *attributes* or physical data of each feature (velocity, temperature, radiance, etc.),
- *topological relations* between a selected feature and others of the same kind.

Therefore a modeling process that represents the geographic information on a plane is necessary. It can be made according to two different concepts: **vector model** and **raster model**. In the former case the space is assumed to be continuous and a point is a pair of coordinates, a line is a set of connected points and a polygon is a set of connected lines. In the latter case the space is represented by a regular (or irregular) grid of connected cells (pixels) and a point is simply a cell, a line is a set of aligned cells and a polygon is a set of contiguous cells. The selected data model influences all levels of operations performed by the GIS and sometimes the feasibility of certain operations is denied.

2. The logistic GIS

During the past eleven Italian expeditions at the Terra Nova Bay Station a great amount of experiences has been collected and a lot of environmental articulate data have been acquired.

The amount of geographical information that can be collected is practically unlimited, the threshold depending only on their (acceptable or desired) quality and effective cost. It is therefore necessary to plan proper geographic information acquisition strategies (which allow the collection of what is necessary with the adequate quality level) taking into account the scientific user needs and the environmental variables. A detailed plan of the resources, such as the organization, the available time and the costs, is also necessary to properly support the research activities and allow adequate logistic activities for the expeditions (harbours, landing sites, food, fuel, etc.). (Fig. 2).

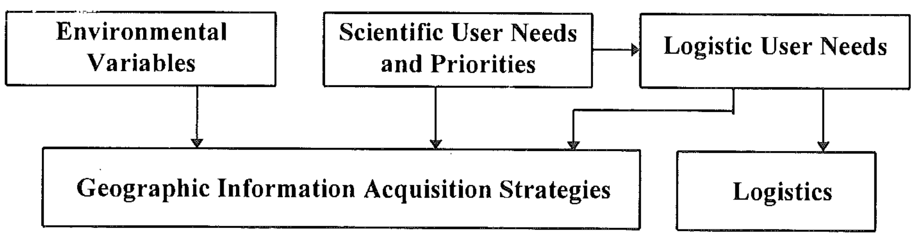

Figure 2

As the expeditions were over, the logistic management wanted to satisfy all the specific needs arosen. Most of these needs can be solved using the appropriate geographic information but they are very complex and cannot be satisfied with the usual carthographic methodololgies. They require the availability of an "ad hoc" logistic GIS.

The GIS, named **ILA** (Italian Logistics in Antarctica), will allow the logistic management to have an organic and immediate overview of the activities which are carried out in Antarctica. This fact will produce a better and more efficient logistic planning and permit the documentation evolution in time. Such characteristics are important with respect to the critical antarctic environment and to the high specific costs of the operations.

At Italian national level the GIS could be used by the several scientific disciplines as a "tool" for acquiring specific information.

Since the wide dimension of logistic problems in Antarctica is not met in an organic and structured manner in other national level programs, the logistic GIS will constitute a particular specialistic tool and will avoid superpositions of activities and wastes of human, technical and financial resources.

3. The Cost-Benefit Analysis

A very simple cost-benefit analysis (CBA) has been carried out at the feasibility study stage for the logistic GIS. A CBA is a tool for the management of the organization to evaluate the strategic and financial implications compared with the possible benefits.

Effectiveness and efficiency benefits are the CBA "measurements" tools taken into account. Table I shows some related items.

Efficiency benefits	Effectiveness benefits
Cost saving and avoidance	Strategic
Productivity gain	Operational
Better service	Managerial

Table I

The cost saving and cost avoidance is obtained by acquiring the existing maps, digitizing them and making them reliable. In fact a valuable time is spent to find maps, to add particular data to the map, to extract the produced information or, at least, to partially copying the new map. These operations have been estimated to require a few day/man for each expedition. The productivity gain was found in the automatization of map production by means of standard software procedure in order to have as many maps as requested with a small cost. Also the requests from the scientific community can be better satisfied (better service) if detailed maps for the antarctic sites where the research has to be carried out are available to the logistic management; that also means a very cost saving item taking into account what is necessary for the movement of people and devices in the antarctic environment. At the end another fact must be considered: the cost of the hardware and software tools has a lighter weight than the cost of the data. This is because the formers have a short period of life with respect to the latter which, if accurate and consistent, have a long validity.

The availability of the GIS (effectiveness benefits) will allow the Italian logistic management to increase the operative capabilities, adjusting them to the higher levels obtained in the international sphere. Furthermore the GIS will permit a more organic exchange of information between the national Programs of the various nations which are involved in activities on the North Victoria Land and its neighbourhood.

A few steps of the program of the logistic GIS were taken, once the CBA gave its approval. As soon as the project is approved the design will begin.

4. First requirements

The design of the GIS must satisfy specific application needs in order to produce an effective "working tool" for the logistic management. A very preliminary analysis of such needs led to the conclusion that a set of cartographic maps at different and increasing level of complexity was necessary.

There are very few antarctic geographic maps. Many regions need a relatively frequent updating because of the ice dynamics and the snow cover changes. The ice cover flows at relatively high velocity (tens of meters per year) and reaches its maximum in some glacier tongues (more than 1 km per year), moreover the continental margins and ice shelves change rapidly and substantially, depending also on the seasonal period.

The available maps from different countries sometimes are not updated and have great errors, especially in the small scales. Their quality and consistence also depend on the political objectives of the country that produces the map. Table II is a very small sample of the differences present in geographical names and locations of the same ground features - the names and the coordinate values are from different gazetteers of the several nations that delivered them. Clearly the production of antarctic maps will lead to similar (not equal) products with features such as glaciers, nunataks, and so on with different coordinates and names; consequently also the contour lines, the coasts, the shelves, and so on will be affected. Improved coordinate information could be acquired with a very little added investment when the data are collected.

Since large and medium scale maps of the regions of Italian interest don't exist, it is necessary to produce local maps for the logistic applications at a scale ranging from 1:10,000 to 1:50,000. These maps must have a good accuracy with errors of a few tens of meters at most. Particular attention must be put on the importing of data from other geographical databases for the reasons above indicated. A series of Ground Control Points (GCP's) acquisitions by means of Global Positioning System (GPS) equipments must be also planned. These reference points can be used to precisely georeferentiate the acquired satellite images in order to use them as carthographic background. If proper number and distribution of GCP's are lacking and errors are present in the maps, researchers often prefer a qualitative approach and process the raw images.

Feature name	Nation	Latitude	Longitude
Pico amarillo	Argentina	-61,9500	-57,8500
Brimstone Peak	Great Britain	-61,9167	-57,7500
Bruce Rice	Australia	-63,5000	101,2500
Bruce Rice	Russia	-63,8000	100,3333
Punta Fort William	Argentina	-62,4333	-59,5833
Punta Fort William	Chile	-62,4483	-59,6950
Canto Point	USA	-62,4500	-59,7333
Astrolabe, islote	Chile	-64,6017	-62,9100
Dobrowolski island	Great Britain	-64,6000	-62,9167
Guesalaga, islote	Chile	-64,2717	-61,9833
Bell island	Great Britain	-642667	-61,9667
Guesalaga island	USA	-64,2667	-61,9833
Hewitt Glacier	New Zealand	-83,4667	166,0000
Hewitt Glacier	USA	-83,2833	167,8333
25 de Mayo, isla	Argentina	-62,0000	-58,5000
Rey Jorge, isla	Chile	-62,0500	-58,2500
King George island	Great Britain	-62,0000	-58,5000
King George island	Russia	-62,0833	-58,2500
Kaiser, isla	Argentina	-64,2667	-62,0167
Alice, isla	Chile	-64,2667	-62,0500
Lecointe island	Great Britain	-64,2667	-62,0500
Wilhelm II land	Australia	-67,0000	90,0000
Wilhelm II, Kaiser land	Germany	-66,8333	89,5000
Wilhelm II land	Russia	-68,0000	90,0000
Wilhelm II coast	USA	-67,0000	90,0000

Table II

At this stage of the GIS design, the proposed levels of complexity are three:
1st level: maps obtained without any additional consistent information with respect to the already available ones; the first level maps are listed below

- remote field maps,
- food and gasoline deposits maps,
- landing strip on marine ice maps,
- activities and sampling sites maps,
- bathimetric maps,

- overland traverse tracks maps.

2nd level: maps that require the execution of appropriate surveys in order to acquire updated and correct information in addition to those of the first level; at this point maps of such kind are:
- crevasses map,
- yearly ice shelves and icy coast lines map,
- yearly updated general planimetry of the logistic installations map.

3rd level: maps that require the development of specific elaborating methodologies in addition to those required for the 2nd level; at this point they are individuated as:
- finding of the optimal tracks for overland traverses in standard conditions or in emergency,
- optimal positioning, on the ground, of specific devices (e.g.: antennas for the acquisition of the satellite signals),
- ground movement assessment,
- evaluation of the positioning of possible new buildings, deposits, and so on,
- definition and management of protected and special conduction areas,
- geographical names management.

5. The GIS Development

In order to properly develop a logistic GIS, the actions to undertake can be logically subdivided in three phases, in succession. They are respectively indicated as:
1. **design**,
2. **development**,
3. **management**.

Each phase is subdivisible in a series of working sets that can be done consequently or parallelly. The management phase practically coincides with the GIS routine activities and has to be considered out of the implementation phase. Fig. 3 shows the different subdivisions and the working sets of each phase.

The design phase can be subdivided into two working sets:
1. **detailed user's needs assessment,**
2. **design of the data base; this one can be further divided into:**
    - detailed definition of the needed software/hardware components
    - database architecture definition

The development phase will be subdivided into three working sets:

3. **Data Acquisition, Normalization and Validation**. The acquisition also includes the input of the data into the database. Normalization permits the removal of the errors present in the thematic layers and includes the actions (e.g. the visual inspection) to make them congruent in a geographic and cartographic sense. The validation will assure the data accuracy.

4. **Functions development**. The activities of this working set are directed to the design and the development of "ad hoc" processing methodologies to satisfy the required needs.
5. **Data accessibility and cataloguing**. The activities are referred to the implementation of procedures that, as a user-oriented interface, permit data accessibility and their protection from possible violations: the production of a catalogue will permit to easily know the database contents and to retrieve the requested information. In this phase the international connection has to be established.

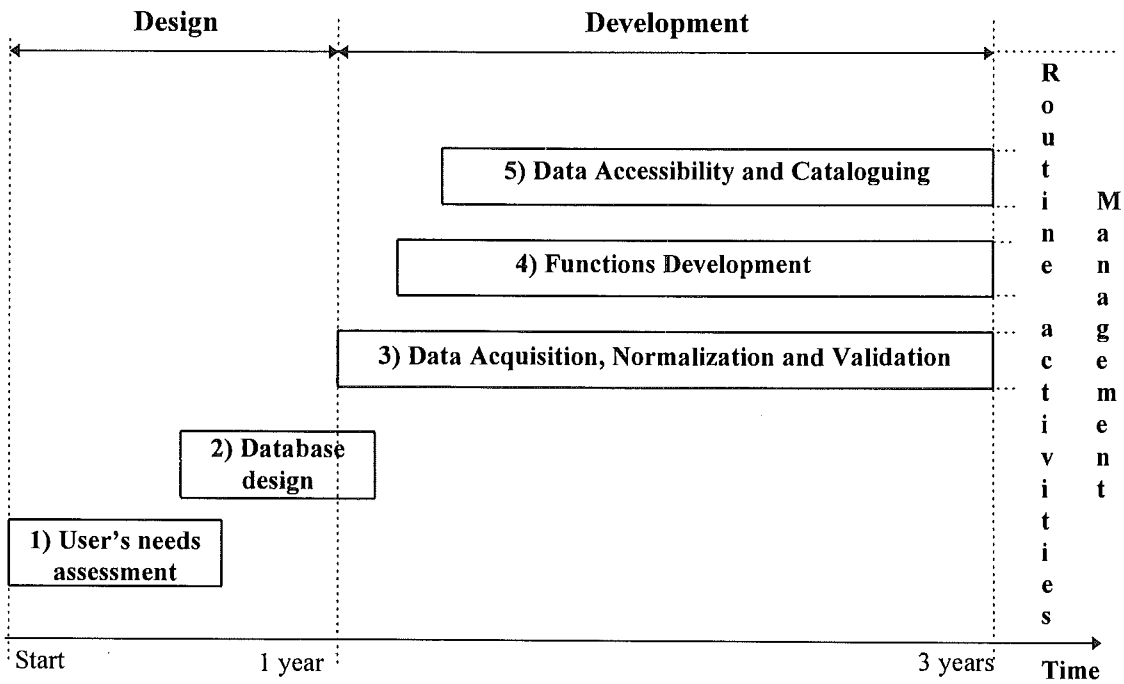

Figure 3

Working sets 3., 4. and 5. can be developed parallelly, each set starting with a little shift with respect to the preceding one.

A set of intermediate goals, internal at the mentioned phases, is also intended. The following list is an example of the intermediate goals for the first phase:

- interview to the user to acquire the detailed logistic needs,
- analysis of the needs and definition of the hardware/software tools needed; their acquisition,
- analysis of the needs and design of the database architecture,
- detailed note for the acquisition of field data in Antarctica.

The interview can be subdivided into two parts: a first interview to the management in order to identify the high requirements such as the strategy and scope of the GIS, the list of the desired decision functionalities, the inventory of the data source, and so on and a second interview to the Operative Units to assess the detailed needs such as particular procedures, the acquisition of particular data, and so on. Up to the present time, a simple interview that served to identify the main goals and some deeper information (as the association of particular maps to the three map levels) have been carried out.

At the end of each phase a report has to be provided illustrating the philosophy of the work, of the selected items, and so on.

During each logical phase of the GIS, feedbacks occour to verify that the developed products meet the requirements of the user (Figure 4).

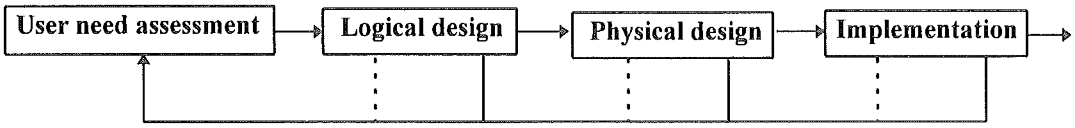

Figure 4

The design and development activities of the GIS can be grouped in the following four categories:
- management of the project,
- specific needs characterization and field data acquisition,
- design and development of the GIS
- international contacts.

The Operative Units will be involved in the activities of specific competence. The management of the project will be carried out by a coordination group of the participating Units. The second category activities will provide the detailed characterization of the needs (as formats, which data on which maps, and so on) and the planning of the GCP measurements on the field. The third category involves all the activities explained in the listed item. In the international contacts the activities will lead to the exchanges of information and data between the Italian Program and similar foreign Programs.

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Seventh SCALOP Symposium on
Antarctic Logistics and Operations

Feasibility of Establishing a Snow / Ice Runway in the 60°E - 120°E Sector of the Antarctic Coast

by
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Russian Antarctic Expedition
and
Jack Sayers
Australian Antarctic Division

The concept of an East Antarctica Air Network (EAAN) was presented at the Sixth SCALOP Symposium in Rome in 1994 (Klokov & Lukin, 1995). The introduction of an air transport system in East Antarctica, where there is a high density of stations and bases, would encourage national operators in more active collaboration. International collaboration in creating links between stations and bases would avoid unproductive duplication of facilities, improve safety and limit environmental impact. A joint-use air network, including airstrips and fuel depots, could maximise research productivity by transporting expeditioners and equipment from gateway countries to stations and into the field thereby reducing travel time for highly qualified professionals.

The EAAN concept met interest from several national Antarctic programs. As a consequence a feasibility study on establishing hard-surface runways at sites in East Antarctica, which could be used for intercontinental flight by wheeled aircraft, was undertaken under an agreement between the Russian Antarctic Expedition and Australian Antarctic Division. In January/February 1996 a field reconnaissance was undertaken to find suitable compressed snow/ice runway sites in the East Antarctic coastal zone between 60°E and 120°E longitude. The natural conditions at the four prospective sites, which were located near Casey Station, the Larsemann Hills, at Druzhnaya IV and Mawson, were investigated to identify the most favourable sites in relation to both construction and air operation requirements (Figure 1).

Four main criteria were applied to each site to determine the suitability for runway construction and air operations, namely:

- free of crevasses;
- suitability of natural surface gradients;
- snow stratigraphy and the relation of snow accumulation to melting; and
- potential for aligning the runway parallel with the prevailing wind with no limiting obstacles in the climb path.

In three of the four areas investigated (Larsemann Hills, Druzhnaya IV and Mawson) an S-76 helicopter was used to make a visual air reconnaissance looking for evidence of crevassing. Obtaining appropriate information from different altitudes was a major factor in making judgements of the suitability of the inspected sites. A surface survey was also conducted to detect small, invisible crevasses along the potential runway centrelines; probing the snow surface using a heavy ice chisel. The snow was probed in this way at one metre intervals. An aerial inspection was not available at the time of the visit to Casey but there was no indication of any cracks on the surface of the area surveyed. There were no records available from pilots or ground vehicle operators regarding any areas of crevassing between the S1 site and Lanyon Junction.

Sites suitable for landing heavy wheeled aircraft should be reasonably level and the surface gradients should be appropriate to airfield standards. Required surface gradients need to be within the specified limits that are 0.02 for longitudinal slope and 0.02 for transverse slope. The required information on natural relief was gathered partly by using large scale, 1:50,000 and 1:100,000, topographic maps issued for the permanent station areas. Useful data was also obtained by analysing the reports of previous surveys which were made in 1987-1988 south of the Larsemann Hills and in 1987 at the north-east corner of the Amery Ice Shelf by Russian surveyors, and in 1990 south of Mawson Station by Australian surveyors. During the reconnaissance in the Mawson area, the surface gradients were measured on a large blue-ice field using GPS satellite positioning equipment As an example, Table 1 gives the values of the longitudinal and transverse slopes in the runway alignment in the Druzhnaya IV area.

A SIPRE corer was used to study the snow structure at the investigated sites. A stratigraphic study of the layering of snow, firn and ice lenses enabled the relationship between snow accumulation and melting to be determined. If the snow accumulation is extremely high or very low, then the effort needed to build and maintain the runway is likely to be too labour intensive and difficult. An acceptable range of rate of snow accumulation is 30-60 cm/yr. The degree of summer melting has a dominant influence on the usefulness of the runway and its ease of maintenance in the summer months. The acceptable limit of melt is about 20% of the annual volume of snow accumulation. As an example, the layering of snow, firn and ice lenses revealed in the cores taken near Casey is given in Figure 2.

One major requirement is to align the runway in the direction of the strongest winds. In practice this is not an easy task because, while the actual length of a runway handling heavy aircraft is around 3000 m, the total airfield area subject to safety regulations and operating standards covers the surrounding terrain up to 25 km in length and 9 km in width including the approach and climb-out path (Figure 3). The standard climb-out slope for most heavy aircraft operating in Antarctica has to be less than 1/60 (0.0166). Large areas of the Antarctic coast have ice sheet relief limitations or local peculiarities, such as high mountains or nunatacks, that restrict the possibility to align the runway parallel to the prevailing wind. Mostly, the choice of runway alignment involves a compromise between heading away from a high obstacle and heading into the prevailing wind.

To decide on the optimum runway alignment, a combination of map analyses (1: 200,000 or 1: 250,000), field reconnaissance reports and a synopsis of the standard meteorological data were used. Comprehensive data on wind speed and direction was provided by the Australian Bureau of Meteorology. Surface meteorological data at Zhongshan Station (69°22' and 76°22'), published by Chinese Academy of Meteorological Sciences, was used to characterise the general features of the meteorological regime in the Larsemann Hills area. During field work the centrelines of all runways were marked using bamboo canes about 2.5 m height with black flags. All canes were labelled on the top as follows: "1996,41 RAE - 49 ANARE".

The general characteristics of the sites investigated are given in Table 2 (Klokov, 1996). This information enables a general comparison to be made of the relative merits of each of the four runway sites that were investigated. The Casey area demonstrates the best opportunity for the construction and operation of a compacted snow runway. Unfavourable weather conditions (compared with the other alternatives) is the single negative factor for the Casey area. The recent development in the local observational network and the establishment of the AWS on the proposed runway site at Casey will, however, lead to significant improvements in operational forecasting for this area.

Another prospective location is on Amery Ice Shelf near Druzhnaya IV , however at the present time, there is an absence of adequate logistical infrastructure at this site. Both the Larsemann Hills area and the Mawson area are much less suitable for use as sites for intercontinental air operations.

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Figures

Figure 1. Distances in Kilometres from entry points in Australia and Africa to potential runway sites in East Antarctica .

Figure 2. Stratigraphy of the upper layers inland of Casey Station. Core were taken on Jan. 27 and on Feb. 26,1996.

Figure 3. Druzhnaya IV area and proposed runway site. The runway centrepoint position: 69°45'S ; 73°37'E.

Station (m)	Elevation ASL (m)	Longitudinal Gradient	Traverse Gradient
Chainage 00 #	32.54		
Chainage 400	32.74	0.00050	0.0047
Chainage 600	32.35	0.00195	
Chainage 800	32.51	0.00080	0.0037
Chainage 1000	32.01	0.00250	
Chainage 1200	32.24	0.00115	0.0041
Chainage 1400	31.93	0.00155	
Chainage 1600	32.42	0.00245	0.0039
Chainage 1800	32.34	0.00040	
Chainage 2000	32.58	0.00120	0.0053
Chainage 2200	32.44	0.00070	
Chainage 2400	32.39	0.00025	0.0069
Chainage 2600	31.86	0.00265	
Chainage 2800	31.71	0.00075	0.0085
Chainage 3000	30.92	0.00395	
Chainage 3200	30.49	0.00215	0.0110
Chainage 3400	29.86	0.00315	
Chainage 3500 ##	30.00	0.00140	0.0160

Table 1. Surface gradients along the runway alignment at the SE corner of the Amery Ice Shelf (Druzhnaya IV Base, Sansom Island).

\# NW end of the 1987 runway alignment

\## SE end of the 1987 runway alignment

Site Characteristics	Casey	Progress/ Zhong Shan	Druzhanaya IV	Mawson
Position of runway centrepoint	66°17'S 110°47'E	69°26'S 76°19'E	69°45'S 73°37'E	67°45'S 62°41'E
Elevation (m)	400	245	32	475
Airfield site location	slope of the ice sheet	slope of the ice sheet	ice shelf	blue ice field
Runway type	Compacted snow	Compacted snow	compacted snow	ice
Weather Conditions	Moderate	Good	Good	Moderate
Runway orientation	90	54	122	155
Strong winds direction	E	ENE	SE	ESE
Snow accumulation (cm)	30	30-40	60	0
Melting	Low	Moderate	Low	High
Surface gradients	Appropriate	Inappropriate 0.002-0.028	Appropriate 0.005-0.016	Inappropriate 0.019-0.038
Crevassing	No	Yes	No	Yes
Existance of high mountains upwind of runway	No	No	No	Yes (Masson Range)
Distance from logistics base (km)	11	4	4	18
Distance from airports outside Antarctica (km)				
• Hobart	3431	4888	4956	5463
• Albany	3515	4583	4642	4992
• Cape Town	6699	5278	5253	4693

Table 2. General characteristics of the investigated runway sites

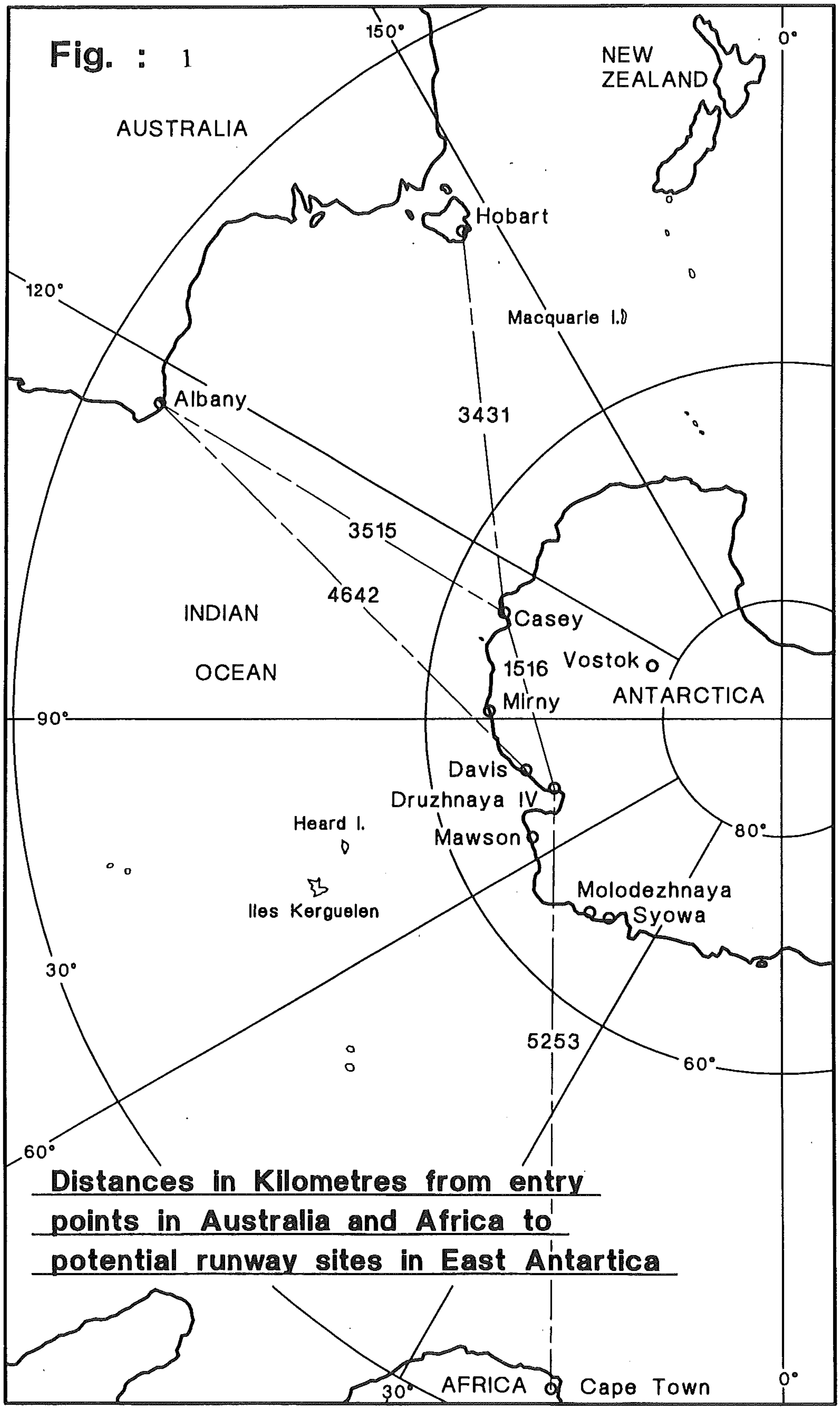
Fig. : 1
AUSTRALIA
NEW
ZEALAND
150°
0°
Hobart
Macquarie I.
120°
Albany
3431
3515
4642
INDIAN
OCEAN
Casey
1516
Vostok
Mirny
ANTARCTICA
90°
Davis
Druzhnaya IV
Heard I.
Mawson
80°
Iles Kerguelen
Molodezhnaya
Syowa
30°
5253
60°
60°
Distances in Kilometres from entry points in Australia and Africa to potential runway sites in East Antartica
30°
AFRICA
Cape Town
0°

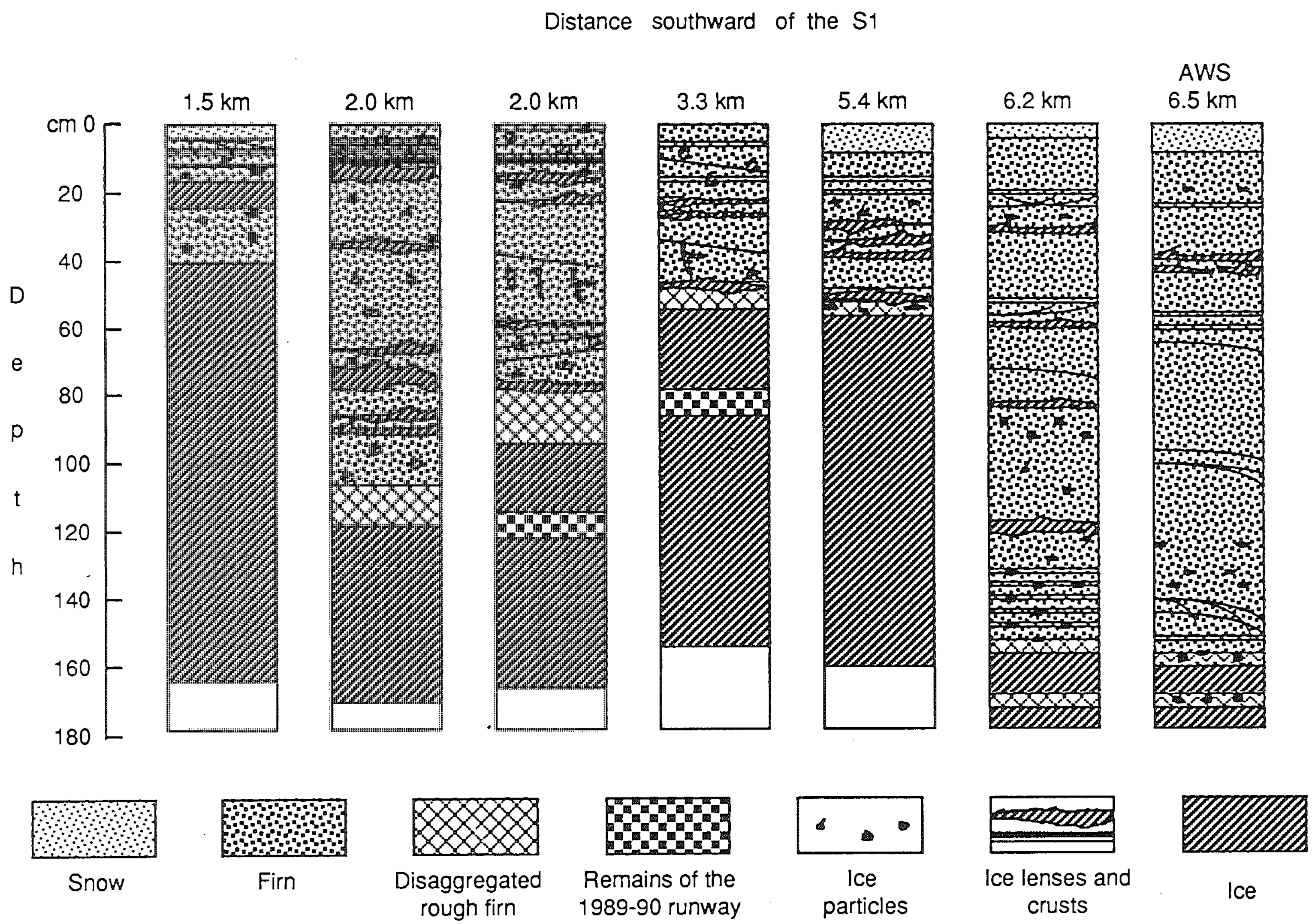

Fig. 2 Stratigraphy of the upper layers inland of Casey Station. Cores were taken on Jan 27 and on Feb 26,1996.

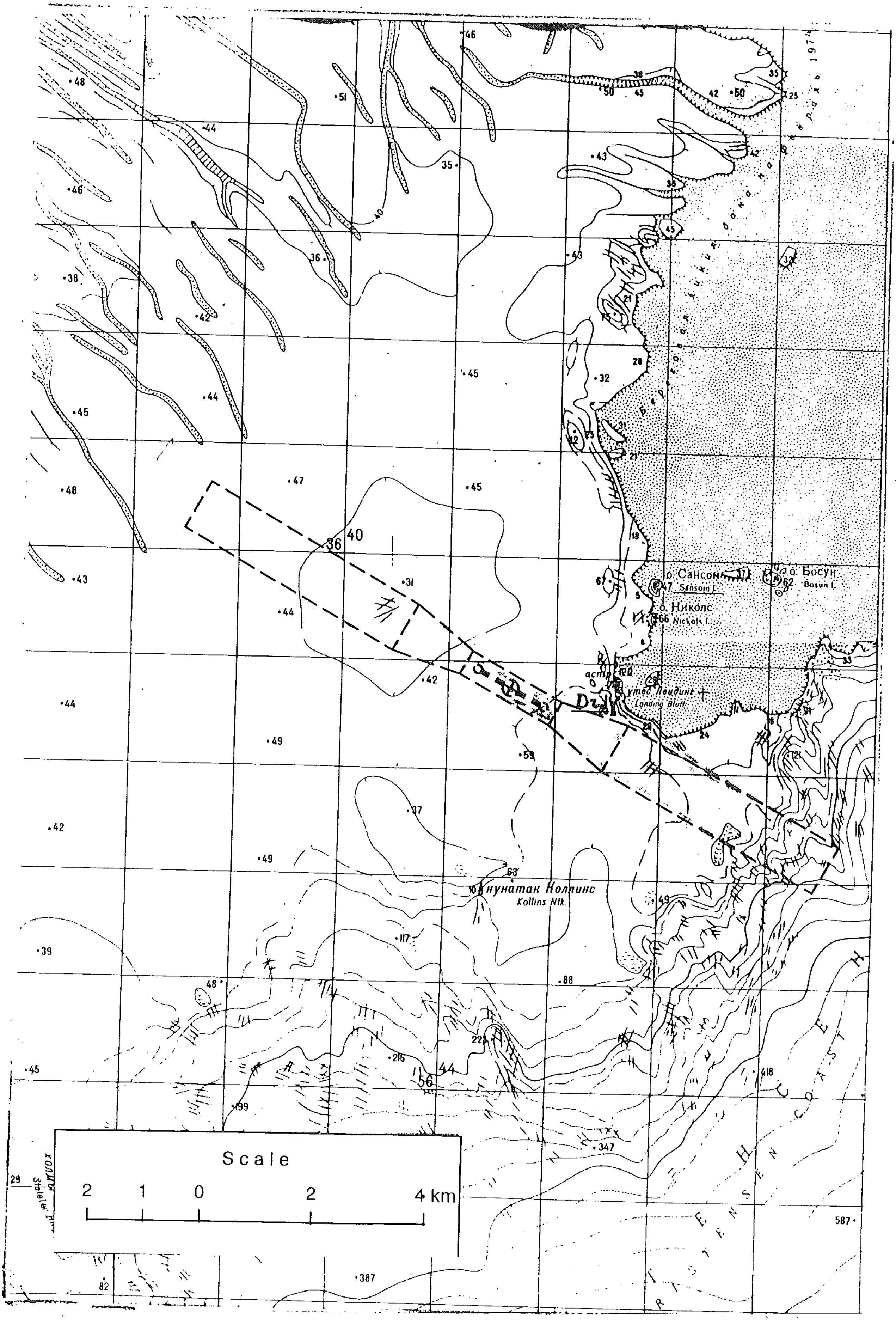

Fig. 3 Druzhnaya IV area and proposed runway site.
(The runway centrepoint position : 69°45'S ; 73°37'E)

Continuous Observations of Surface Strain Changes for Safe Working on Sea Ice

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ABSTRACT

The British Antarctic Survey resupplies its Halley Research Station (75° 35'S 26° 25'W) on the Brunt Ice shelf every year by unloading cargo from the RRS *Bransfield* directly onto the sea ice. Cargo is moved either under its own power or on sledges to the research station across the sea ice and up onto the ice shelf. The sea ice is typically around 2 m in thickness. Typical loads on the ice are from 2 to 20 tonnes.

To improve the safety of the unloading operation, a system for monitoring the surface strain changes on the sea ice is under development. The system uses BP strainmeters to monitor strain changes continuously and it is intended to use these signals to provide early warning of potential failure.

The paper presents the examples of observations made and compares the observations to theory.

INTRODUCTION

Each year the British Antarctic Survey (BAS) resupplies its research station at Halley (75° 35'S 26° 22'W) by ship. Cargo is unloaded onto the fast ice alongside the Brunt Ice shelf and taken by sledge up to the research station. Typical ice loads in the 1995-96 season were from 2 to 20 tonnes.

The sea ice off the Brunt Ice shelf is also prone to break-up by the action of waves formed on the large seasonally polynya off the ice shelf.

To improve the safety of sea ice operations, BAS has been testing methods for improving the real time information made available to those responsible for the unloading and loading operations. A simple system for continuously monitoring the surface strain changes due to both wave action and to static and moving loads has been deployed. This system could be developed to provide real time warning of potential failure of the sea ice due to either sea waves or overloading.

METHOD OF OBSERVATION

During late December 1995 and early January 1996 the BAS vessel the RRS *Bransfield* unloaded cargo alongside fast ice close to the edge of the Brunt Ice Shelf at a site designated by BAS as N9 (75° 06'S 25° 06'W). Cargo was loaded directly onto sledges drawn by Snocats on the fast ice by the ship's crane. Near to the loading operation a BP strainmeter array was set up to monitor continuously the surface strain changes (figure 1).

The BP strainmeter is an instrument which uses three 0.5 m carbon fibre tubes as length standards. Inductive displacement transducers monitor displacement changes on the sides of an equilateral triangle formed by the carbon fibre tubes (Duckworth and Westerman, 1989). Strain changes of 1 microstrain can easily be resolved. The strainmeter is fixed to the ice with magnetic clamps clamped onto ice screws with large heads. It can be quickly deployed and retrieved. Signals from the inductive displacement transducers are fed through an amplifier to an A to D converter connected to a laptop which sampled the strain signals every 200 ms.

During the second visit to N9 on 2 January, 1996 an ice core was taken to determine the salinity profile and examine the crystalline structure. The ice thickness varied from 2.0 to 2.3m. The average salinity was 4 parts per thousand.

Figure 2 shows a sketch of the layout of the instruments and the position of the strainmeters. Several active cracks were seen running perpendicular to the ice edge and these are shown on the sketch.

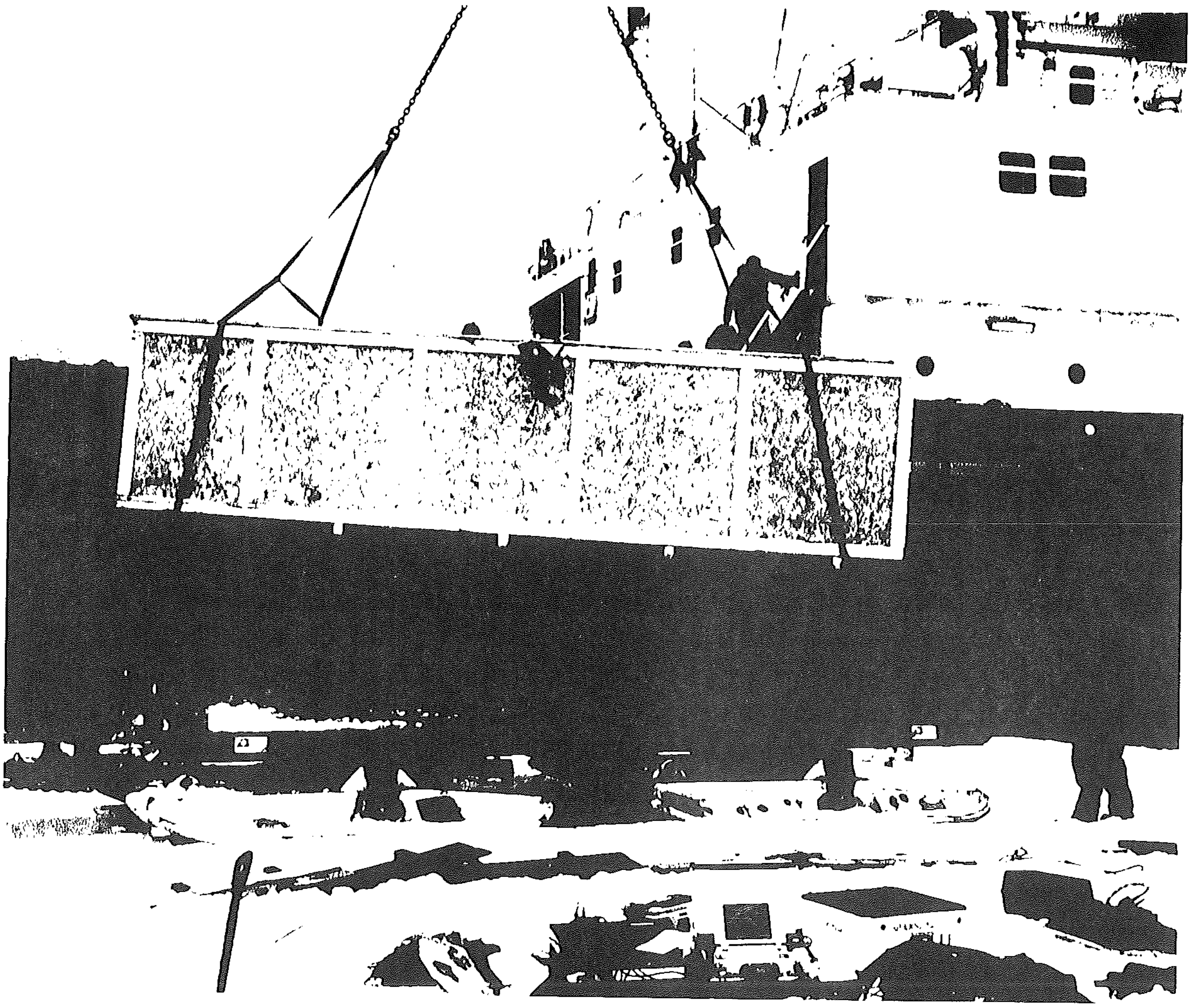

Figure 1: Strainmeter array monitoring surface strain changes as the RRS *Bransfield* was unloaded at N9.

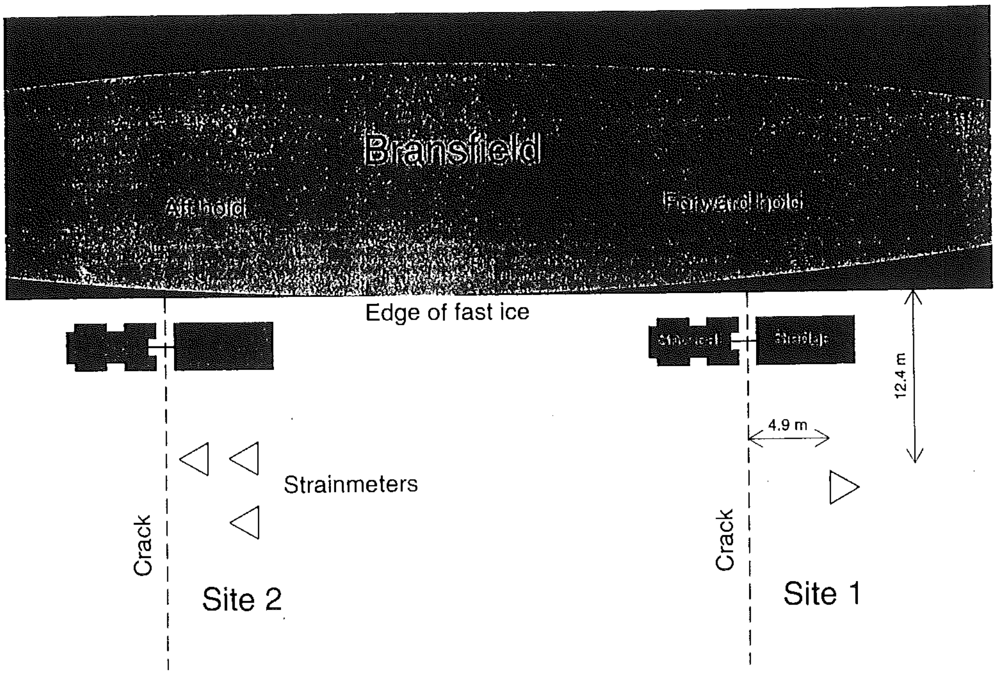

Figure 2: Sketch of layout of the instruments at N9.

FAILURE MODES

The fast ice can break-up in three ways - excessive static load, wave induced failure, or coupled vibrations created by a moving vehicle. Vehicles and sledges are particularly at risk when travelling near a free edge either at the edge of the fast ice or when crossing cracks between floes or between the sea ice and the ice shelf. Careful survey of routes, strict observation of safety rules - escape hatch open, doors open, driver only to ride in the vehicle - can reduce the risks of sea ice operations. Risks are increasing as modern vehicles and containerised loads used in resupply increase in weight.

OBSERVATIONS AT N9

FAILURE DUE TO A STATIC LOAD

When a load is placed on a sledge by the crane of the ship, the sea ice will first respond elastically and then stresses will be relaxed and redistributed by creep in the ice. Failure is likely to occur either during the initial loading before the stresses have relaxed or, for a heavy load, after a prolonged period when creep deformation allows the surface to flood.

The surface stresses will be increased if active cracks are present. These limit the area over which the load is supported increasing the surface stresses. At the observation site several long cracks were observed running perpendicular to the fast ice edge. Such cracks form easily when the wave direction is at an angle to the fast ice edge.

Two failure cases apply for a load acting at the edge of the fast ice - (a) if the load is concentrated on a small surface area then the maximum stress will occur immediately underneath the load on the lower surface of the ice or (b) when the load is distributed then the peak stress occurs on the upper surface at a distance from the load. In most cases the load is distributed by the use of Snocats and sledges with wide tracks and skis. Therefore here we will consider only case (b).

For a semi-infinite sea ice plate floating on the sea loaded with a load, F, at the a distance, x_o, perpendicular to the edge, the solution for the bending moment, M, as a function of the perpendicular distance, x has been determined (Kerr and Kwak, 1993;). The maximum bending moment per unit width, M_{max}, occurs at a distance perpendicular from the ice edge when $x_o = 0$ and equals:

$$M_{max} = 0.13\ F \qquad (1)$$

Interestingly M_{max} is independent of the ice properties and thickness (Calladine, 1982). If the ice is homogeneous as a function of depth, the maximum surface strain, ε_{max}, due to this bending moment equals:

$$\varepsilon_{max} = 0.78\ F / (E/(1-\nu^2))h^2 \qquad (2)$$

where F is a load at the ice edge in Newtons, E Young's modulus, ν Poisson's ratio and h is the thickness in m. ε_{max} occurs at 0.786 of the characteristic length, λ, in a direction perpendicular to the ice edge (or about 20 $h^{3/4}$). The characteristic length is given by:

$$\lambda^4 = 4\ (Eh^3/12(1-\nu^2)) / \rho g \qquad (3)$$

where ρ is the water density and g is the acceleration due to gravity.

E will depend on the salinity and temperature profile in the ice. Sea ice contains vertical brine channels which contain an equilibrium concentration of salt for a given temperature. Changing the temperature leads to either pure ice being deposited onto the walls of the brine channels or melting of ice from the walls and dilution of the salt solution. The stress is supported by the pure ice matrix so as the sea ice warms up during the spring the pure ice matrix shrinks increasing the local stress (Sanderson, 1988). Sudden rises in temperature followed by a cold period require particular caution for vehicle operations because the brine channels will have expanded increasing the stress on the ice matrix and are often accompanied by surface cracks formed on cooling. Strain observations can detect such changes in the sea ice. For the same load change a larger strain change will be observed.

Putting in reasonable values for E = 9,000 MN m^{-2}, ν = 0.34, ρ = 1 kg m^{-3}, g = 9.81 m s^{-2} gives:

$$\lambda = 24\ h^{3/4} \qquad (4)$$

and

$$\varepsilon_{max} = 77\ F / h^2 \qquad (5)$$

where ε_{max} is measured in microstrain, F is measured in MN and h in m.

For a typical load of 0.04 MN (the weight of a Snocat tracked crane used by BAS at Halley) and the observed ice thickness of 2.3 m, ε_{max} equals 0.6 microstrain and occurs at a distance of 37 m perpendicular from the edge. The characteristic length in this case is 44 m. The variation of strain with ice thickness and distance from the ice edge is shown in figure 3 for this case.

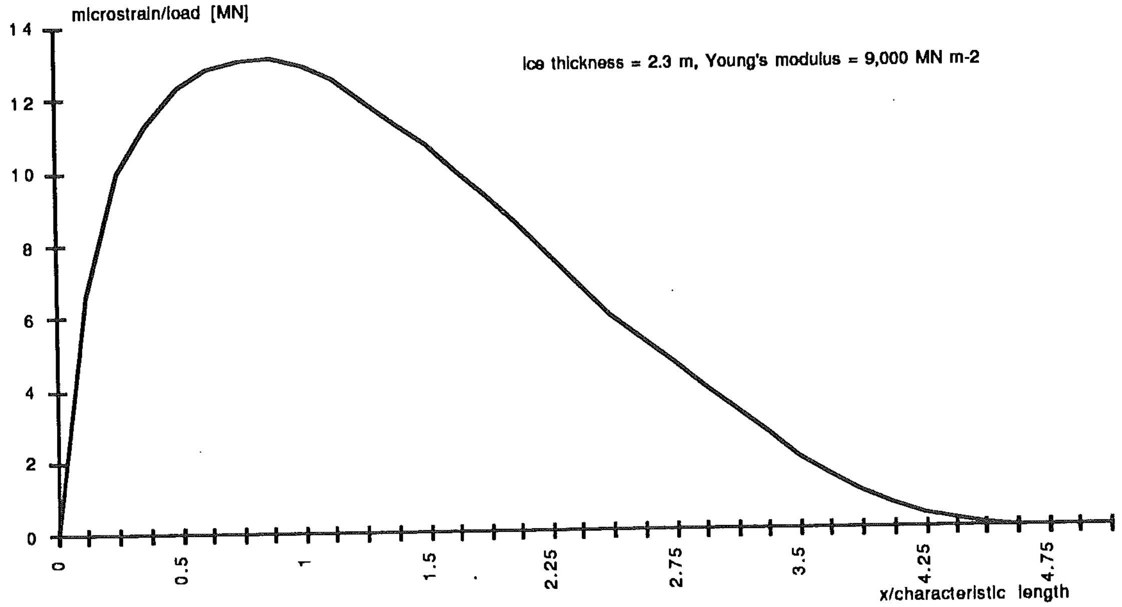

Figure 3: Distribution of microstrain per unit load [MN] for an ice thickness 2.3 m as a function of the perpendicular distance from the ice edge with a Young's Modulus of 9,000 MN m^{-2} derived from figure 6 of Kerr and Kwak (1993).

The maximum strain change occurs at a distance from the load and the ice edge. Ideally the location of strainmeters should be made at around 80% of the characteristic length from the ice edge. The characteristic length can be estimated by taking ice thickness measurements and estimating E and ν before they are deployed. If multiple strain observations can be taken in a perpendicular line from the ice edge then it is possible to find where the maximum strain changes occur and hence estimate the characteristic length. From the characteristic length and a thickness measurement an estimate of the modulus, $E/(1-\nu^2)$, can be deduced.

Observations of this kind were attempted in the field but due to power problems not all the strainmeters functioned. However, a good record (figure 3) was obtained from one array (site 1 in figure 2).. In this case a Snocat (0.04 MN) and sled were driven slowly past the array and stopped in line with the ship near the ice edge. In figure 3 the strain signal has been smoothed to remove the flexural wave signal from the sea waves to look at a vehicle and sledge that were brought up alongside the ship. From the three observations of strain change after detrending the principal strain changes and orientation have been calculated. The strain signals observed are greater than those expected from the theory because the effective modulus has been reduced by brine channels and the proximity of an active crack running 4.5 m from the strainmeter array.

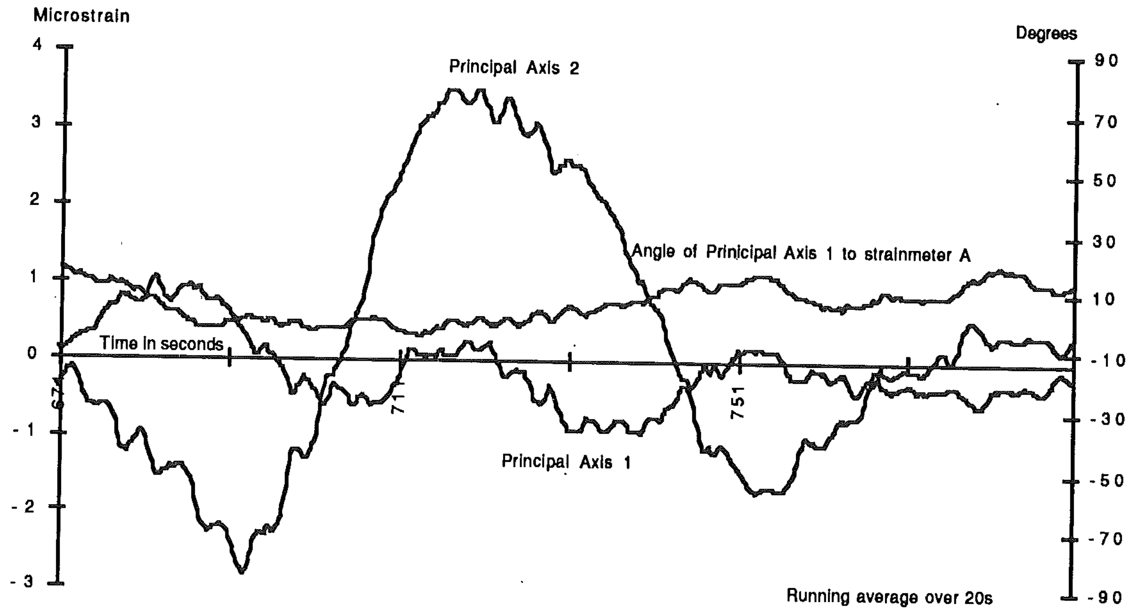

Figure 4: Strain observations as Snocat and sledge went slowly past the strainmeter the array at site 1.

If we assume that tensile stress at failure σ_0 is 1 MN m^{-2} for a sudden loading of the ice (Sanderson, 1988) and a Young's modulus of 9,000 MN m^{-2}, failure would occur at around 100 microstrain. Allowing a safety factor of, say, 4 operations would be suspended if sudden strain changes of around 25 microstrain were observed. Deteriorating ice would lead to higher strain changes for the same load change.

A failure of 25 microstrain is equivalent to the rules of thumb for ice operations that recommend that the safe load, F in MN for an ice thickness in m is given in many publications (see for example Ashton, 1986) by:

$$F < 0.35\ h^2 \tag{6}$$

which can be derived from equation 5 by setting ε_{max} to 25 microstrain. The factor 0.35 will be smaller for warm temperatures , the effects of brine pockets and crack geometry.

FAILURE DUE TO WAVE ACTION

At the end of the first unloading activity in December a heavy swell from the NE broke the fast ice up into floes with a width perpendicular to the old fast ice edge of between 20 to 30 m. This phenomena is well known and the wave height to induce failure can be estimated (Goodman et al, 1980).

During the second visit to N9 waves propagating into the fast ice were successfully observed with the strainmeters. A sample detrended record is shown in figure 5. The frequency spectrum derived from the whole record shows a dominant frequency of about 0.25 Hz which is to be expected for wind generated waves over the large polynya observed off the ice shelf.

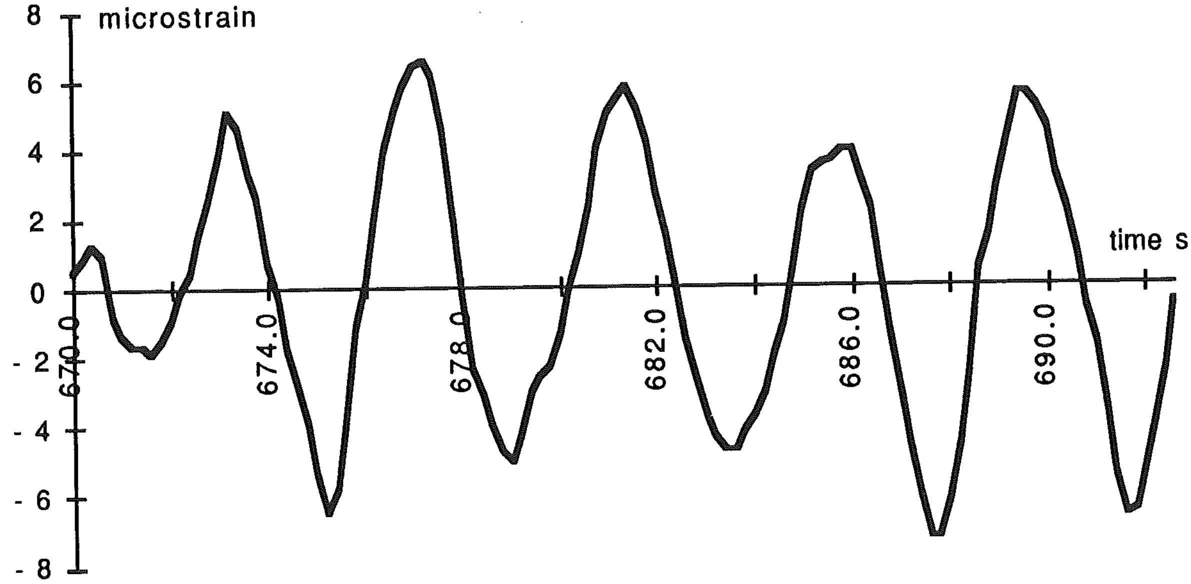

Figure 5: Typical flexural waves recorded at N9 with the BP strainmeter.

Waves signals could be continuously observed to provide an estimate of the likelihood of break-up by waves.

FAILURE DUE TO A MOVING LOAD

When a load is moved across floating ice it will generate waves under and in the ice. At a critical velocity the coupling will be a maximum and ice break-up can occur (Nevel, 1970). The critical velocity is a function of the ice thickness and the water depth. For thin ice the critical velocity is quite low. For ice 0.25 m thick the velocity is around 20 mph and for ice 2.5 m thick it is around 50 mph for deep water (but in shallow water, say 2 m water depth it is independent of thickness and only 10 mph).

DISCUSSION

Traditional analysis of ice loading has focused on the vertical deflection of the ice sheet. A very effective rule of thumb is that if the surface deflection is large enough to cause surface flooding then it is time to move the load! However, deflection measurements require a satisfactory datum. During ship operations there is no effective reference point. Continuous strain change measurements are an acceptable alternative to deflection measurements.

The BP strainmeter provides an effective tool for observing strain changes during cargo operations on sea ice. Deployment is rapid and could be even quicker by mounting sealed lead acid batteries in the cover and transmitting data back to a computer on board the vessel alongside the ice. This computer could provide real time output of reduced data for the cargo operations supervisor to use in his management of the safety of the operation.

Continuous strain observations could provide improved protection against sudden ice break-up and warning overloading of sea ice.

ACKNOWLEDGEMENTS
We are grateful to Vernon Squire, Arnold Kerr and Ken Croasdale for useful discussions and to Sarah Sibeon, the officers and crew of the RRS *Bransfield* and staff at Halley Research Station for assistance in carrying out the field work.

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Satellite Communication at Dome Fuji Station: Operation at High Latitude and Extreme Low Temperature Environment in the Antarctic Interior

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Abstract: The Japanese Antarctic Research Expedition (JARE) uses the International Maritime Satellite (INMARSAT) system for global telecommunications at Syowa Station (69°00'S, 39°35'E). In 1995, JARE started to winter over at the Dome Fuji Station (77°19'01"S, 39°42'12"E) to undertake the Antarctic Dome Coring Project. Dome Fuji is situated at an elevation of 3,810m approximately 1000 km inland from the coastal Syowa Station. The INMARSAT system is usually only suitable for areas where the satellite is tracked with an elevation angle of more than 5 degrees. Although the high latitude location of the Dome Fuji Station far from satisfies this condition, it was thought that it might be feasible to use the INMARSAT system because the conditions there would not result in "multipath fading" which can be experienced with ship-based systems. This is because snow contains many air bubbles and the snow surface does not behave as an insulator like the surface of the sea. To prove the above predictions, a field test was performed using a portable INMARSAT telecommunications device (Model JUE-45T made by Japan Radio Co., Ltd.). As a result, telecommunication using the INMARSAT system was proved to be feasible at Dome Fuji Station where the elevation angle towards the satellite is nearly horizontal.

Introduction

The International Maritime Satellite (INMARSAT) system uses four satellites to provide telecommunications coverage a over most of the world except for very high latitude areas (Fig. 1). Since 1981 the Japanese Antarctic Research Expedition (JARE) Syowa Station (69°00'S, 39°35'E) has used the INMARSAT Indian Ocean satellite for telecommunication services such as telex, telephone, facsimile, slow scan TV (SSTV), data transmission and so on.

In 1995, JARE constructed the Dome Fuji Station (77°19'01"S, 39°42'12"E) which is situated 3,810m above sea level and approximately 1000 km inland from the coastal Syowa Station. Dome Fuji station was established to support the "Antarctic Dome Coring Project" which aims to obtain drilling cores up to approximately 3000m depth for palaeoenvironmental studies (Fig. 2).

A stable telecommunication system is very important to manage such a remote inland station. However there was no guarantee that the INMARSAT system could be used at this very high latitude inland location. Therefore, before constructing the station, a feasibility study was undertaken which included a field test using a portable INMARSAT unit at the remote site.

In this paper the results of the field test using a portable INMARSAT unit at the high altitude location are presented. The present status of the telecommunication system which has been installed at the Dome Fuji Station is also described.

Telecommunication system at the Dome Fuji Station

Dome Fuji Station

The Dome Fuji Station is the fourth Japanese station to be constructed in Antarctica. The station is at the highest point among all Antarctic stations and experiences an annual mean air pressure of 598.2 hPa. During the first wintering season in 1995, the minimum air temperature recorded was -79.6°C. As the station is higher than Vostok, it is likely to that the world's lowest temperature will be recorded there in the near future . An annual mean wind speed of 5.8 m/s has been recorded there. The station consists of eight huts; six above and two below the snow surface (Fig. 3). Nine expeditioners winter over at the station each year.

There are three communications systems operating at the station, namely:

a) 150MHz VHF band transceivers for communication within 50 km area.

b) 600W HF band transceivers for communication in the Antarctic region.

c) INMARSAT system for the global use including communication with Japan.

Feasibility of using the INMARSAT system

The INMARSAT system provides a communication service between a "Ship Earth Station" and a "Coast Earth Station" via the geostationary Satellites above the equator. Whilst INMARSAT was originally intended for marine applications, the INMARSAT Organisation allows the system to be used for terrestrial stations.

The difficulties of operating INMARSAT at Dome Fuji Station are twofold; (1) low temperature and (2) high latitude resulting in very low tracking elevation.

1) Most electronic devices are not designed to be operated at very low temperatures, especially approaching -80 °C. The minimum operating temperature recommended for INMARSAT equipment is -35 °C. It was therefore decided to install the antenna in a heated radome made of fibre reinforced plastic (FRP).

2) In general the INMARSAT system is only suitable for areas where the satellite is tracked with an elevation angle of more than 5° (Fig. 1). The angle at the Dome Fuji Station is calculated to be 2.9° which far from satisfies this requirement.

It is well known that marine use of the system for elevation angles of less than 5° decreases the stability of transmission due to interference of the direct radio wave from satellites with the radio waves reflection from the sea surface, which is called "multipath fading" effect. The "multipath fading" effect was the most serious problem that needed to be considered for the Dome Fuji INMARSAT installation.

However, it was expected that there would be less effect of multipath fading at the "Earth Station" on the ice sheet compared with the standard "Ship Earth Stations". This is because there is much less diffused reflection on the snow surface than on the sea as snow containing many air bubbles absorbs radio waves. Moreover, the diffused reflection effect due to high ocean waves and the instability of the elevation angle due to the rolling and pitching of the ship does not occur with terrestrial stations. Therefore it was concluded that telecommunication with INMARSAT was possible on snow surfaces under conditions of very low elevation angle.

INMARSAT Transmission Test at Dome Fuji Station

Method of transmission test

In order to prove the above predictions, field experiments were conducted at the site of the Dome Fuji Station in 1993. A portable system (Model JUE-45T made by Japan Radio Co., Ltd.) was used for the test. Since the antenna was located outside at ambient temperature, a 300W heater was installed in the pre-amplifier assembly at the base of the antenna.

In order to obtain the electric field strength data of radio waves from the satellite without any special instruments, the intensity of the tracking signal from satellites was monitored. According to the instruction manual for the system, under conditions of less than 50, the S/N ratio significantly decreases and the system is not suitable for practical use.

As the present system was not equipped with an automatic tracking device, the intensity of signal shown on the digital indicator (having a 100 point scale) was recorded after manually searching the direction of strongest intensity.

Results and Discussion

From 12th December to 27th December 1993, measurements of signal intensity and transmission tests of voice and facsimile to Japan were carried out. Fig.4 shows the results of hourly measurements of the intensity of signal from 9 am to 7 pm (local time) for 12 days.

It is worth noting that the daily variation of intensity is significant. Except for the two hours in the afternoon, the intensity of signal was more than 50 points and the communication with voice and facsimile to Japan was successfully performed during these hours. The decrease of the intensity of signal for a couple of hours each day is considered to result from variations in the satellite position .

While the INMARSAT satellite is geostationary above the earth at the equator, it is well known that there is a discrepancy between the actual position of the satellite in relation to the equator(Fig. 5). Therefore, viewing from the earth's surface, the location of the satellite is not fixed in the sky and the elevation angle changes with time (Fig. 6). At the Dome Fuji site, the hours unsuitable for telecommunication correspond to the hours of the lowest elevation angle. This situation may cause the decrease of signal intensity. It is noteworthy that the elevation at the times unsuitable for transmission is nearly 0° elevation.

In summary, telecommunication using the INMARSAT system is possible even at the Dome Fuji Station where the elevation angle towards the satellite is almost horizontal.

Present status of telecommunication at Dome Fuji Station

In January, 1995, the Dome Fuji Station was established and the satellite system started to operate. The equipment installed (JUE-45A Mark II) is basically the same as that used in the trial except that the antenna is installed in a radome with a 1.3kW heating system. This improvement keeps the air temperature of the radome at about -30 °C compared with tan outside temperature of up to -80 °C . In addition an automatic satellite tracking system has been installed which improves the reliability of transmission.

At present the second wintering is in progress at the Dome Fuji Station. Since starting the wintering in February, 1995, the system has worked well and no serious problems have occurred. We are now planning to install the INMARSAT system on snow vehicles for use during traverses.

Acknowledgements

We thank Mr. R. Nishibun, a radio operator of JARE-34, for taking data under the harsh condition at the Dome Fuji Station. We are also grateful to Mr. Jack Sayers and Dr. Kazuyuki Shiraishi for their improvement of the draft.

Figure captions

Fig. 1. Coverage area of four INMARSAT satellites with elevation angle of more than 5°. Note the Dome Fuji Station is plotted at the outside of the coverage area.

Fig. 2. Location of the Dome Fuji Station and the glaciological study area in Dronning Maud Land by JARE.

Fig. 3. Cartoon showing the Dome Fuji Station.

Fig. 4. Daily variation of the intensity of signal from satellites at the Dome Fuji Station during 12 days in 1993.

Fig. 5. Relationship between the actual orbit of INMARSAT satellite and the equatorial surface. The inclination causes the daily variation of intensity of signal from the satellite.

Fig. 6. Calculated elevation angle of the satellite at the Dome Fuji Station.

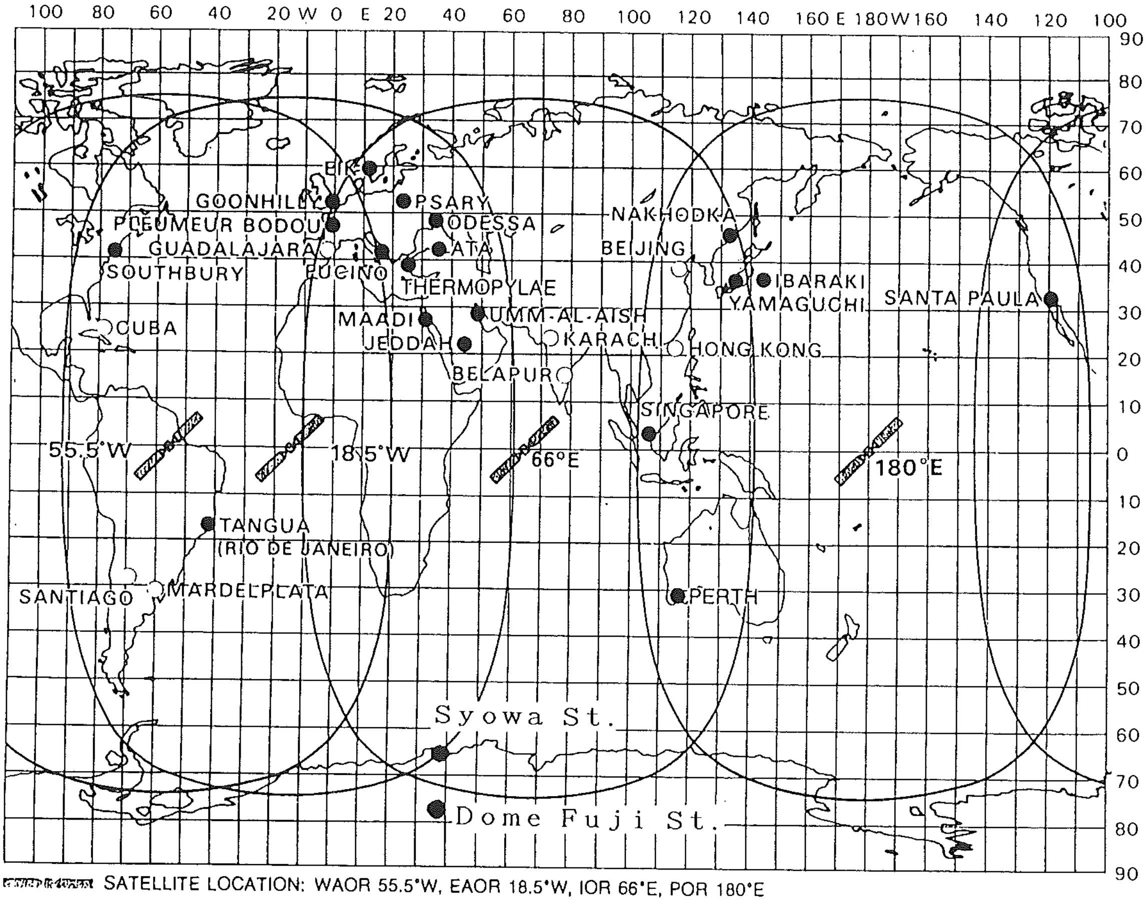

Fig.1 *Coverage area of four INMARSAT satellites with elevation angle of more than 5° .*
Note the Dome Fuji Station is plotted at the outside of the coverage area.

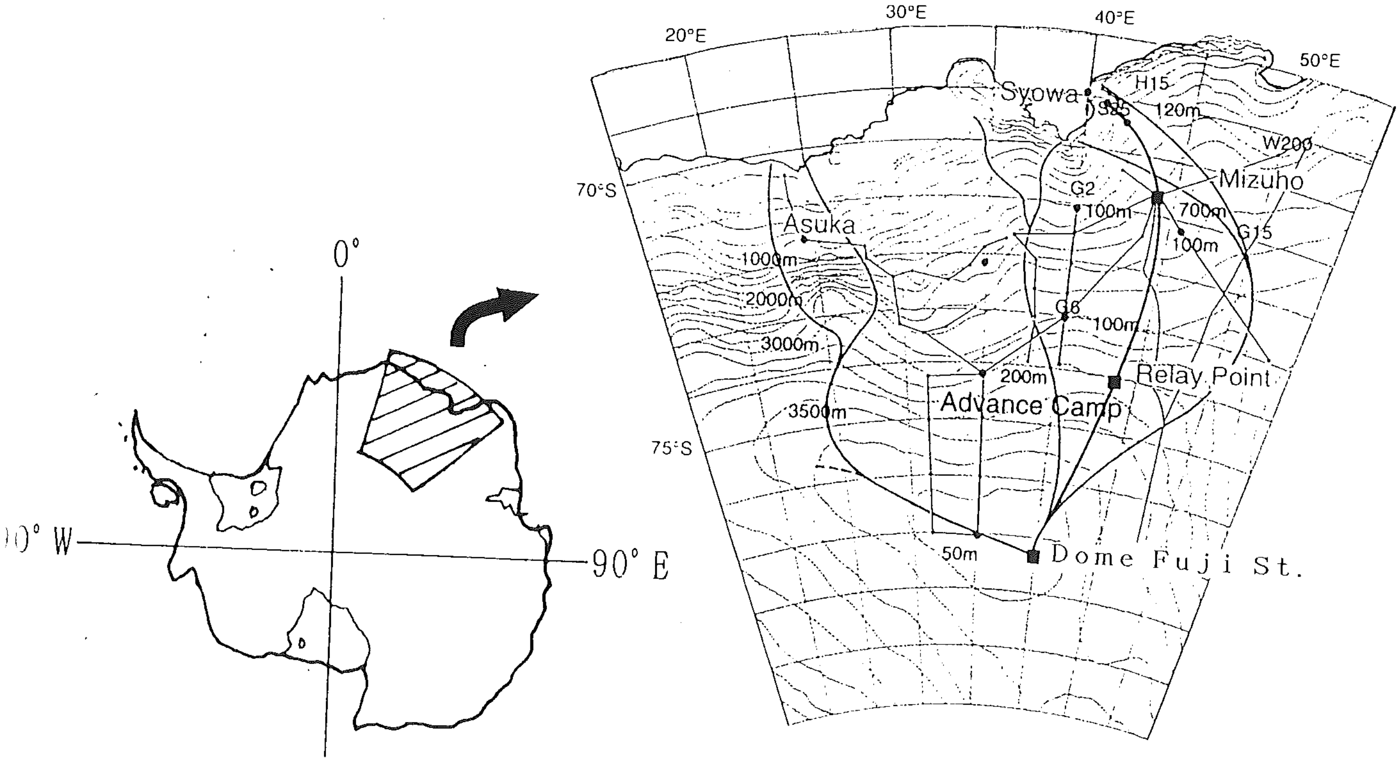

Fig.2 *Location of the Dome Fuji Station and glaciological Study area in Dronning Maud Land by JARE.*

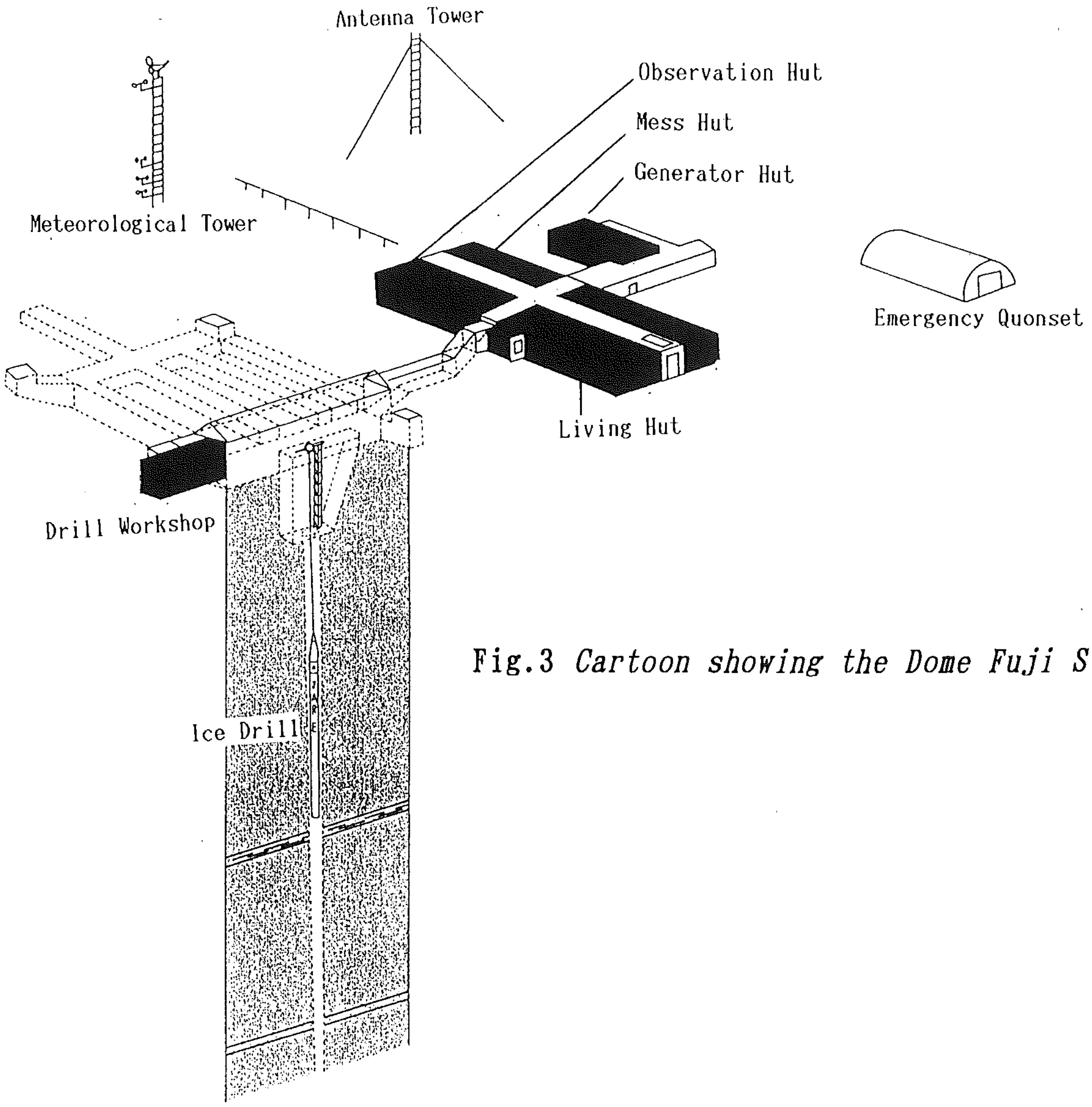

Fig.3 *Cartoon showing the Dome Fuji Station.*

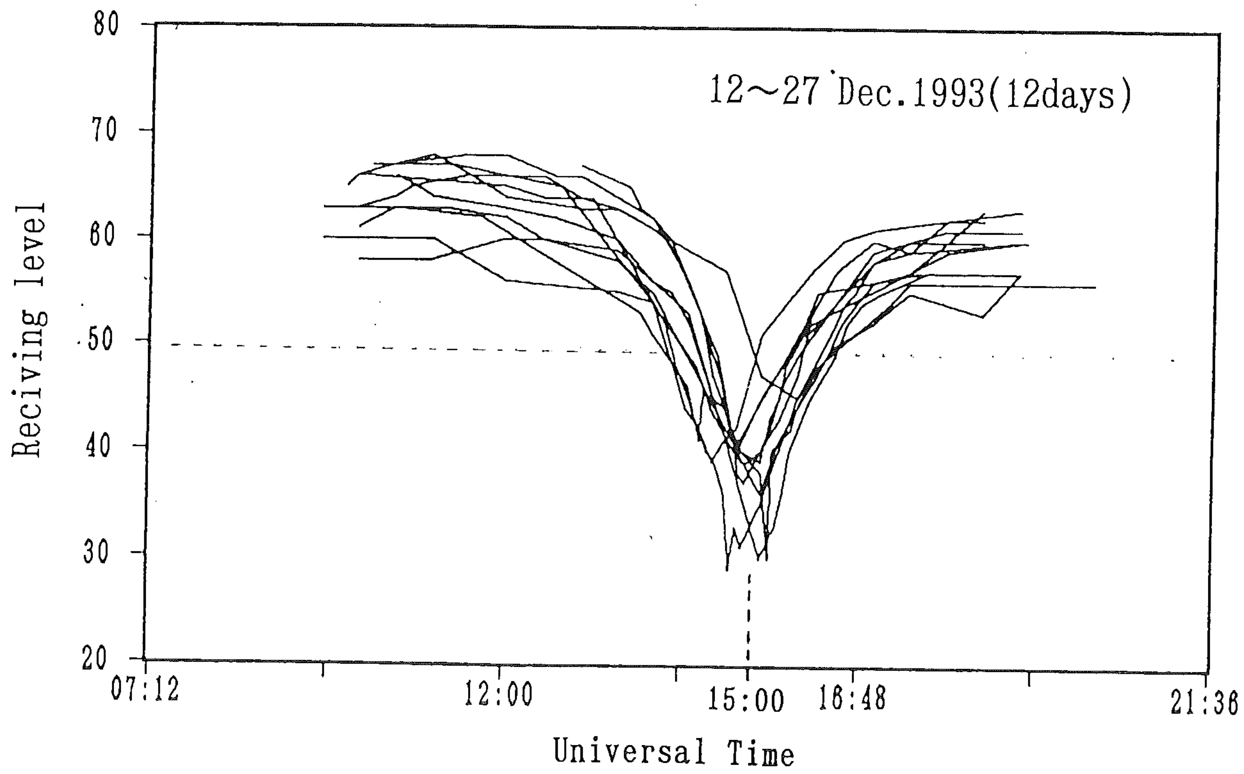

Fig.4 *Hourly variation of the intensity of signal from satellites at the Dome Fuji Station during 12 days in 1993.*

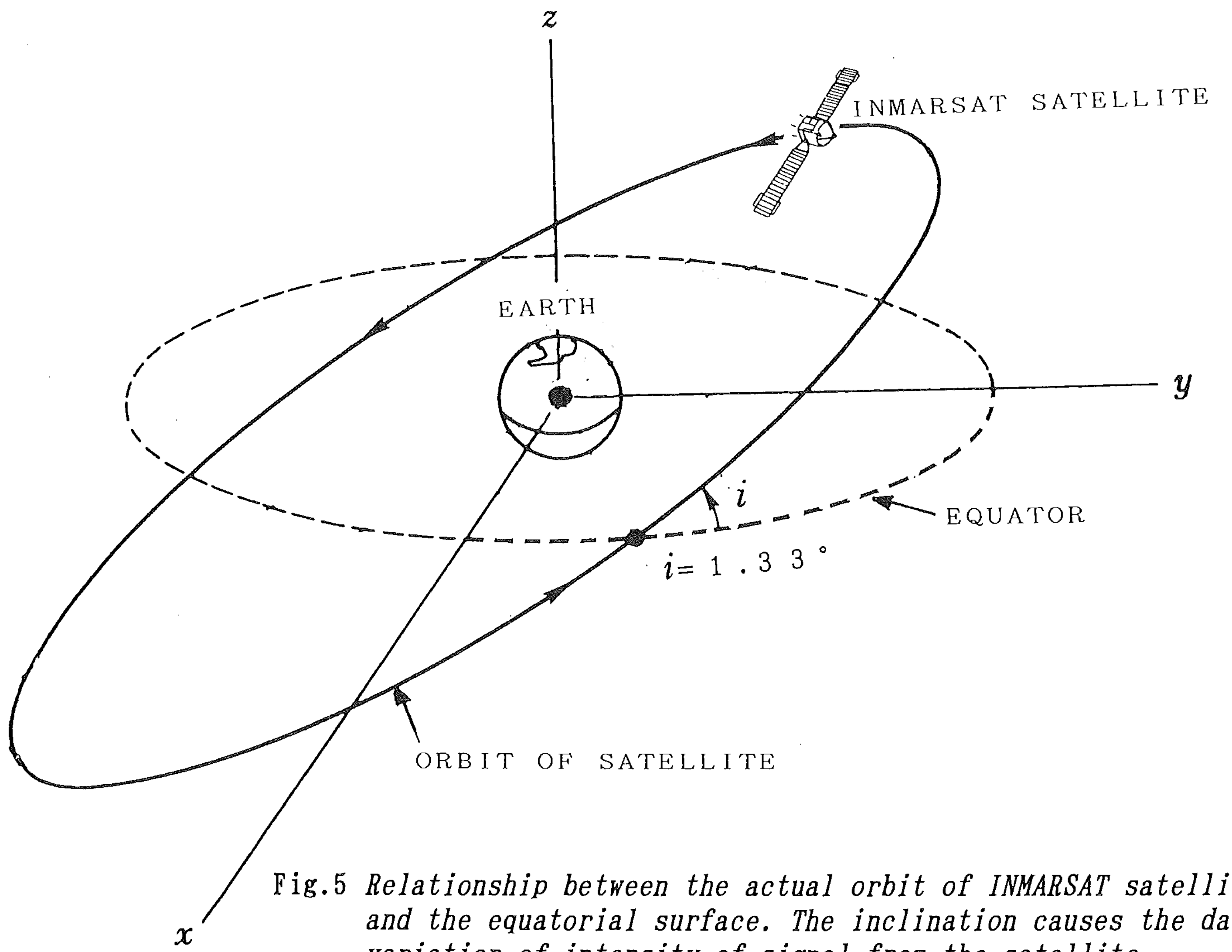

Fig.5 *Relationship between the actual orbit of INMARSAT satellite and the equatorial surface. The inclination causes the daily variation of intensity of signal from the satellite.*

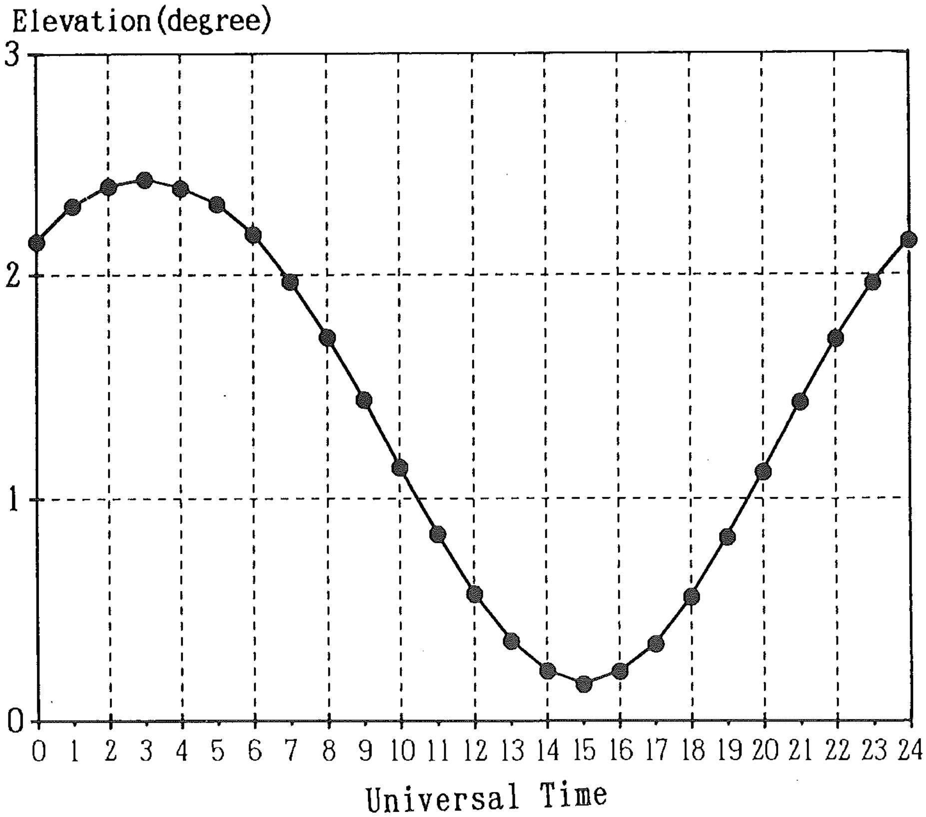

Fig.6 *Calculated elevation angle of the satellite at the Dome Fuji Station. The location is shifting with time in a day.*

VII SYMPOSIUM ON ANTARCTIC LOGISTICS AND OPERATIONS
CAMBRIDGE (U.K.) - AUGUST 1996

C.A.D. FOR LOGISTIC APPLICATIONS AT TERRA NOVA BAY STATION

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* E.N.E.A. C.R. CASACCIA - PROGETTO ANTARTIDE (RESEARCH FELLOW)
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1) INTRODUCTION/ABSTRACT

The Italian Antarctic summer station “Terra Nova Bay” (TNB) is an engineering system comprising civil works, technologic plants and networks, scientific laboratories and other facilities. The operation and maintenance of such a system require the precise knowledge of a lot of information related to the functional and technical features of each part; furthermore, they require the availability of a spare parts warehouse at the station, and skilful management.

A Computer Aided Design (CAD) tool simplifies the collection of information related to the “station” system, allowing the geometric modeling of it. A data base connected with the CAD tool retains the “non geometric” data of each element of the system and allows an easier management of the spare parts warehouse and of the maintenance operations. Furthermore, CAD becomes a powerful tool for preliminary engineering, architectural and environmental impact evaluations for new interventions on the station.

2) THE “TERRA NOVA BAY” STATION ENGINEERING SYSTEM

From a technical point of view TNB (Lat. 74° 41’ 42” S, Long. 164° 07’ 23” E) may be regarded as an engineering system made up by elements very dissimilar in kind, size and complexity such as buildings, yards, roads, technologic plants and networks, earth-moving and loading machines, general purposes and oversnow vehicles, watercraft, workshop and laboratory equipments. Table 1 lists the main facilities installed at TNB and gives the reader an idea of the size of such system. The system is even largerconsidering the utilization of conveyances such as helicopters, the Hercules C130 and the Twin Otter aircraft, the fuel tanker and the cargo ship. Furthermore, the C130 aircraft needs a 3.000 m x 70 m runway, which is prepared every year on sea ice.

The technical management of the TNB system requires many operations to be performed by the logistic operator. Yards and roads need recurrent interventions for reshaping the margins and the top, which suffer damages by wind and water. The buildings, made by using three different construction techniques, require periodic checks of some structural components and repeated treatments for restoring outside surfaces and casings damaged by wind effects. The technologic plants and networks, the telecommunication systems, the machines, the vehicles, the watercraft, the workshop and laboratory facilities need scheduled service and maintenance operations, including electric generators, incinerator, vehicles and machines refueling; occasional repairs may also be needed. Conveyances demand landing, take off, engine start up, loading, unloading and maintenance equipments, though their own service and maintenance operations are in charge of the suppliers. Aircraft and helicopters must be refueled.

In addition to the operational duties above mentioned, the technical management of TNB system involves the logistic operator also in engineering resources outside the station, for purposes such as planning site service and maintenance activities, designing improvements of the existing facilities in order to get them suitable for the needs of each expedition, designing new facilities for new logistic duties, procuring spare parts and materials stocks, tools and new equipments.

- Living quarters for about 70 people (400 m^2). - Laboratories, offices, control room, radio room, infirmary (1,700 m^2). - Technologic plants housings (450 m^2). - Warehouses, winter storehouses for machines, vehicles, watercraft (1,200 m^2). - Workshops, carpenter shop (500 m^2). - Yards for buildings (27,000 m^2). - Small materials open storage yards. - Roads connecting the yards (1,500 m).
- A quay for small watercraft. - Three helipads.
- Two, 600 m^3 each, fuel storage tanks. - Fuel additivation equipment, local fuel tanks, very short pipe lines connecting local tanks to electric generators and helipads. - Two main service power generators, 300 kW each; two emergency power generators, 140 kW each; around 30kVA/20 minutes back-up electricity supply system ; electric network; small rating power generators. - A device for the automatic generation of no more than 7 kW rating power (AIM), used to supply data acquisition and transmission equipments when the station is unmanned. - A main power generators waste heat recovery, max 160,000 kcal/h rating, plant; it supplies the heating devices of the main building of the station, and the sea water desalinator.
- VHF, HF and satellite telecommunication equipments, including an HF aerials field about 3 km far from the station. - Data processing systems and network. - Alarm and fire-fighting equipments.
- Two sea water desalinators, 28 m^3/day and 7 m^3/day respectively; sea water suction station; fresh water distribution pipe lines. - Sewage treatment plant. - Waste incinerator and compactors.
- 53 different types and sizes earth-moving, loading and fire-fighting machines. - 44 general purposes and oversnow vehicles. - 15 m long oceanographic boat; 6 various lenghts inflatable rubber boats. - Workshop tools and machines. - Carpenter machines.
- Astronomical observatory. - Marine aquarium equipped with thermostatic tanks. - Laboratory sized liquid nitrogen and helium production plants. - Clean room.
TABLE 1: *Main facilities installed at "Terra Nova Bay" station.*

3) ADVANTAGES OF CAD FOR THE TECHNICAL MANAGEMENT OF TNB

The activities for technical management of TNB require the availability and the quick retrieving of a very large set of data in the course of both site and planning operations. Furthermore, the management activities themselves generate new informations, which must be recorded. Traditionally such data are stored in paper documents as:

- site plans and maps, which allow to plan the arrangement of new buildings or plants with regard to the ground surface and to the facilities already installed; moreover they let engineers to evaluate lengths, areas and volumes for the provision of materials and the estimation of works;
- technical drawings, which display geometric and functional data about the entire facilities or some detail, and help the operator to understand the structural or functional performances of the facilities themselves;
- service and maintenance manuals, which give the detailed description of the facilities using drawings as graphic reference, and indicate the proper operational procedures based on builder experience for the best utilization and the longest duration of the products;
- materials, parts and devices data sheets, which gather every meaningful information about available products and provide the designer with the data for planning their use for new applications.

Computer technology provides new specific solutions for storing, processing and consulting data, which become more and more powerful, effective, cheap and therefore widespread. The Italian logistic operator in Antarctica has adopted such market trend for some time, providing informatic tools for documents processing such as general purpose office automation products (words, simple images and data processors) and Computer Aided Design (CAD) tools, the former ones already well known and widely used everywhere, the last ones more specialized, and suitable not only for printing and consulting purposes, but particularly for the technical documents' conceptual development stage.

A CAD system works at the logistic operator's C.R. Casaccia (Rome, Italy) offices as a tool for TNB engineering services. It is made up by a dedicated personal computer and a general purposes, multidiscipline oriented, software product with two-dimensions and three-dimensions capabilities. A color printer and a plotter output the documents on traditional paper sheets. This system, though limited as for performances because of the lack of specialized graphic tools for monodiscipline applications like mapping, electrical, piping, complex surfaces modeling, etc, and the lack of tools for numeric analysis, anyway provides for a satisfactory set of interesting applications such as technical documents editing and updating, geometric and weight evaluations, three-dimensions modeling and graphic interaction with the data base.

Some meaningful examples of such applications are described in this paper, with no claim of proposing a unique or innovatory technology, but only with the aim of focusing the attention of the logistic operators of other countries, especially of those who are not yet CAD equipped, upon a useful and effective engineering tool which is becoming more and more economically approachable.

4) TECHNICAL DOCUMENTS EDITING AND UPDATING

The more usual application of CAD equipments is the editing of technical drawings in both two and three dimensions environments, in substitution of the traditional drawing table.

The computer operator interacts with the system by user friendly, icon type, palettes of software functions which provide the progressive recording of the graphic elements (vectors) into a file. The set of elementary vectors available is very small and includes lines, ellipses, arcs, curves, polygons, text. The operator assigns the size, the position and the orientation of each vector referring to a Cartesian geometric system which conceptually play the role of the traditional drawing sheet; furthermore the operator assigns the value of the visual parameters of each vector such as the colour, the edge width, etc. The evolution of the drawing is continuously graphically monitored on the screen of the computer, which works as the display of a camera vertically pointing the Cartesian reference plane, which is able to output the vectors already inserted into the file lying inside its field of vision. View control functions move the position of such imaginary camera's optical axis and widen or tighten its visual angle: in other words they allow the operator to choose what portion of the drawing to see on the screen; such functions are very useful for zooming on the drawing, so viewing just a detail or the whole elements all together.

A very appreciable capability is the one to put vectors on different conceptual working levels, each identified by a number or a name, and to define the set of levels to visualize: such capability allows the simulation of the traditional superposition of transparent paper sheets.

However, the operational functions which make CAD a drawing tool really more powerful than traditional methods are the ones for the manipulation of the existing vectors. Commands such as copy, move, rotate, rescale, stretch, change color, delete, etc., applyed to single elements or to graphic groups indicated by the operator, simplify and speed up drawings updating because only the vectors to be modified must be handled, while the duplication of the unchanged vectors becomes a prompt automatic operation. The capability of duplicating an operator defined vectors' set from both the working file into special stacking files, and vice versa, allows the generation of customized graphic modules collections, or the utilization of purchased standardized or normalized symbols libraries: this tool makes really very quick the execution of technical drawings set up by graphic modules such as plants diagrams. Hatching or patterning surfaces, and dimensioning, become very fast automatic operations.

Once the document has been electronically edited, it may be plotted or printed on proper sheets, or it may be transferred to other CAD systems by disks or by network, for consulting or new editing purposes.

A meaningful product of the above application on the CAD system used for TNB is the site plan of the station as in Figure 1. The drawing is edited each year, at the conclusion of the expedition, to document the updated situation of the site. Other interesting examples of the application are the technical drawings of buildings and plants included in the service manual of the station.

5) GEOMETRIC AND WEIGHT EVALUATIONS

CAD provides for automatic calculation of distance between two points, length of non straight, linear graphic elements, angle enclosed between two lines, area of closed graphic elements. Therefore the evaluation of actual lengths and surfaces extents becomes very simple and fast, so engineering jobs such as the planning of the amounts of electric wires and cables, pipes, panels, coating and flooring layers, and other materials to be supplied for the execution of works at the station become more simple and accurate.

The CAD system used for TNB is not equipped with functions for the automatic calculation of volumes, which is a powerful tool available on more specialized CAD products. Despite such limitation the evaluation of actual volumes is anyway simplified taking advantage of the tools for automatic computation of lengths and areas. So, operations such as the evaluation of the earth mass to move for the construction of civil works, or the estimation of the weight of parts, plants, buildings, etc., are somehow more easy.

6) THREE-DIMENSIONS MODELING

The most attractive application of the CAD system for TNB is the generation of realistic three-dimensions numerical models of objects. The actual extent of such application suffers two limitations. The first is the lack of specialized and powerful modeling and computing tools, usually provided for single-discipline specific CAD products: so a rough approximation must be accepted for terrain and other complex surfaces models, moreover, operations such as automatic generation of sections and intersections are not performed. The second limitation involves all CAD systems: three-dimensions modeling is a heavy hardware resources consuming software tool, so the quality of performances rapidly falls as soon as the detailing and complexity level of the model rises. Despite such limitations, the system used for TNB gives satisfactory results taking advantage of each software capability. For example, if the working file becomes too large, the time requested for processing specially hard functions at editing stage rises too much: this trouble may be partially overcome by splitting the model into two or more files, which may be superimposed just at rendering time, without having them actually merged.

By taking advantage of such contrivances, a model of TNB is growing on, which will reproduce all what is indicated in the site plan of the station of Figure 1. As first step of the work, the terrain surface model has been developed: homogeneous triangulation has been performed from contour lines, using a specific tool. Figure 2 is an isometric sight of such model, viewed from a point near the quay (not visible), about 30 m over sea level; such drawing has been rendered by a function which displays only the visible surface elements' edges, and ignores hidden elements. The second step of the work, not yet completed, has been the modeling of buildings. Figure 3 is a perspective view of the terrain model with the buildings superimposed on it; this image has been produced by a rendering function which colours the visible surface elements and ignores the hidden ones. Such function simulates a sort of shadowing effect, too: an imaginary lighting source is positioned by the operator around the model and the rendering function computes the brightness of each visible surface element assigning the highest value when the light direction is perpendicular to the element plane, while colouring black the elements whose plane is parallel with light direction. The model of TNB will be implemented as soon as possible with plants and networks.

Such model has many useful applications. It can more efficiently replace plastic models for showing and educational purposes, but it can be especially powerful for planning new works at TNB. because it let the engineers to check the geometric and architectural compatibility with existing facilities, the visual impact onto the site, and some desired functional performance. Figure 4, for example, is the check for the translation of the operative room of the station about 14 m north and 3 m higher than actual position: such new position let the control officer see the platforms for helicopters and the quay, too.

7) GRAPHIC INTERACTION WITH THE DATA BASE

The last capability of the CAD system which may be useful to propose is the connection between the graphic elements of the working file, both in two and three dimensions environment, and the alphanumeric data stored in a data base product. This connection allows such useful performances:

- the CAD operator may retrieve informations from the data base selecting them from the graphic environment, using the vectors themselves as data selection criteria together with others geometric criteria: for example, informations such as the supplier, the material, etc., of a desired part may be selected and shown on the screen together with the drawing of that part, and more, the tool can list the parts related with a drawing limiting the extention of the list to those elements geometrically fenced by the operator on the screen;
- the alphanumeric informations may be checked as for geometric references before inserting them into the data base.

8) CONCLUSIONS

The CAD system used for the technical management of TNB has produced the following results:

- editing and updating the technical documentation,
- the carrying out of engineering studies for the installation of new equipment,
- the three dimensions modeling of the terrain and of the buildings of the station.

As soon as possible the 3D model will be completed including facilities, electric network and piping.

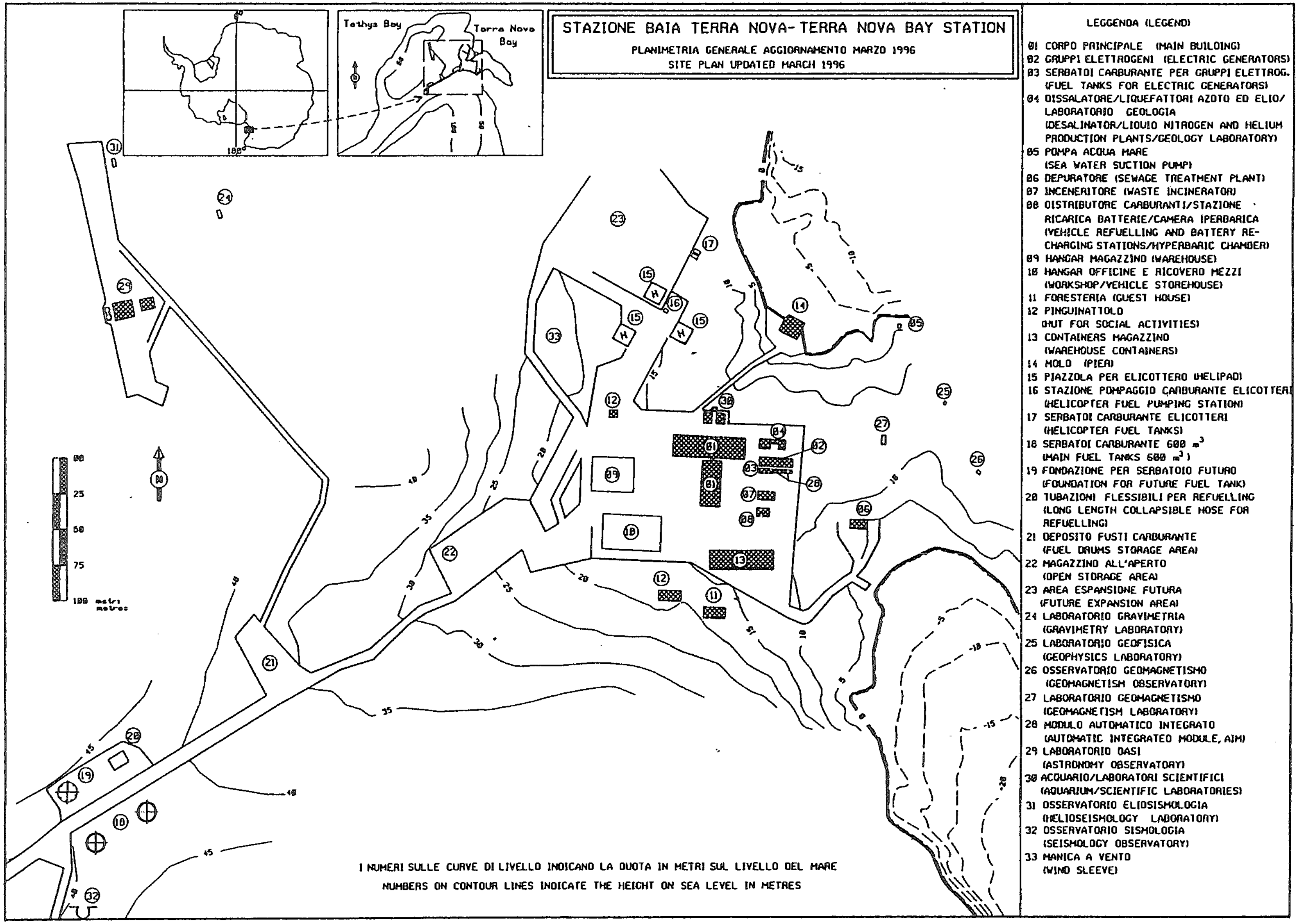


FIG.1 TERRA NOVA BAY STATION - SITE PLAN

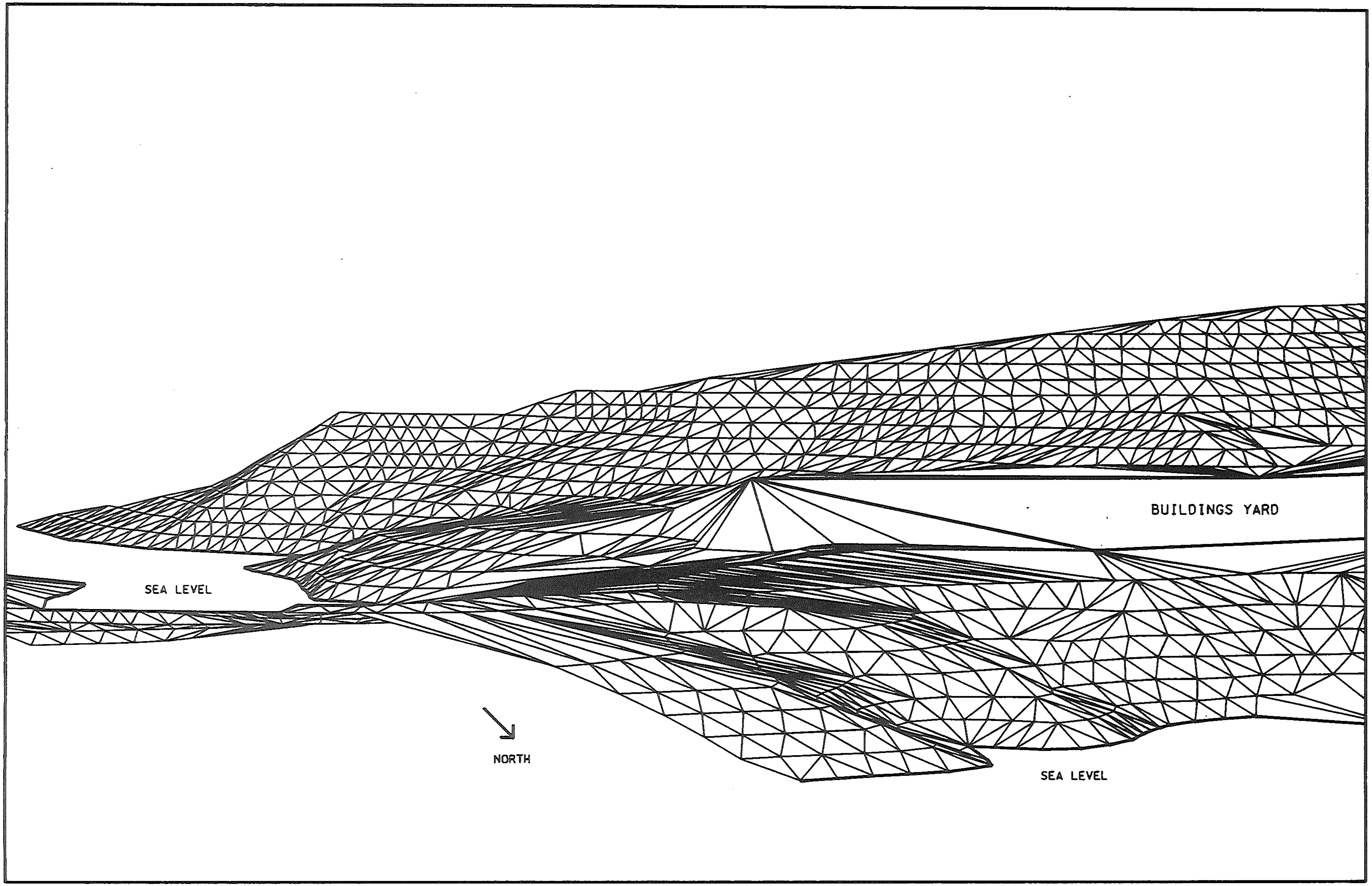


FIG. 2 ISOMETRIC VIEW OF 3D TERRAIN SURFACE MODEL OF TNB SITE

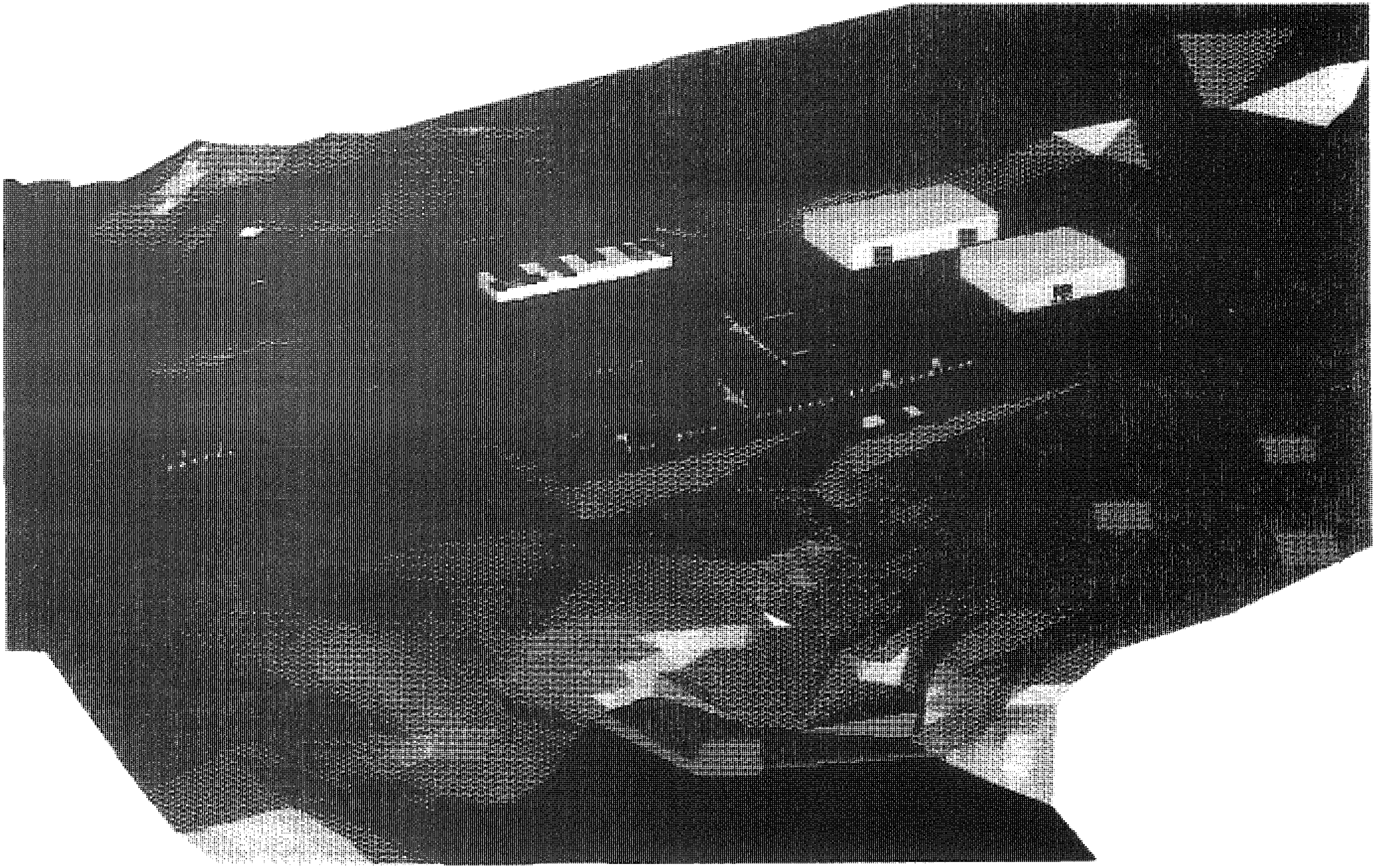
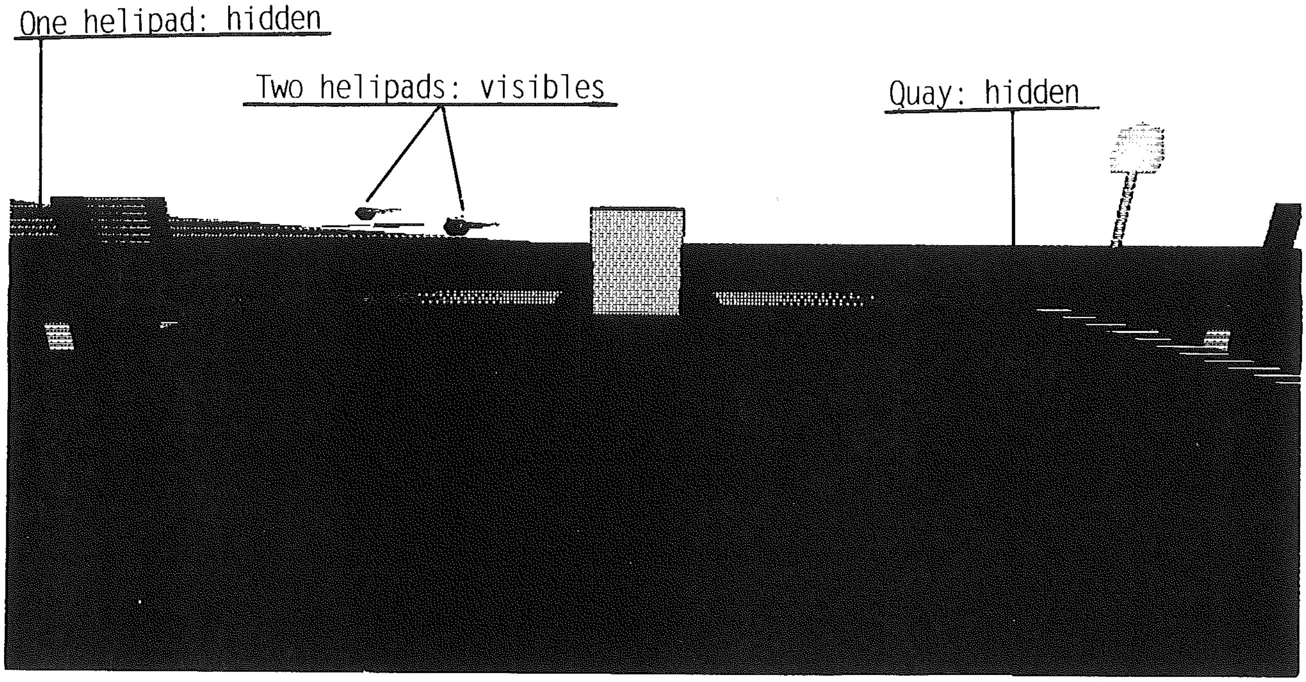
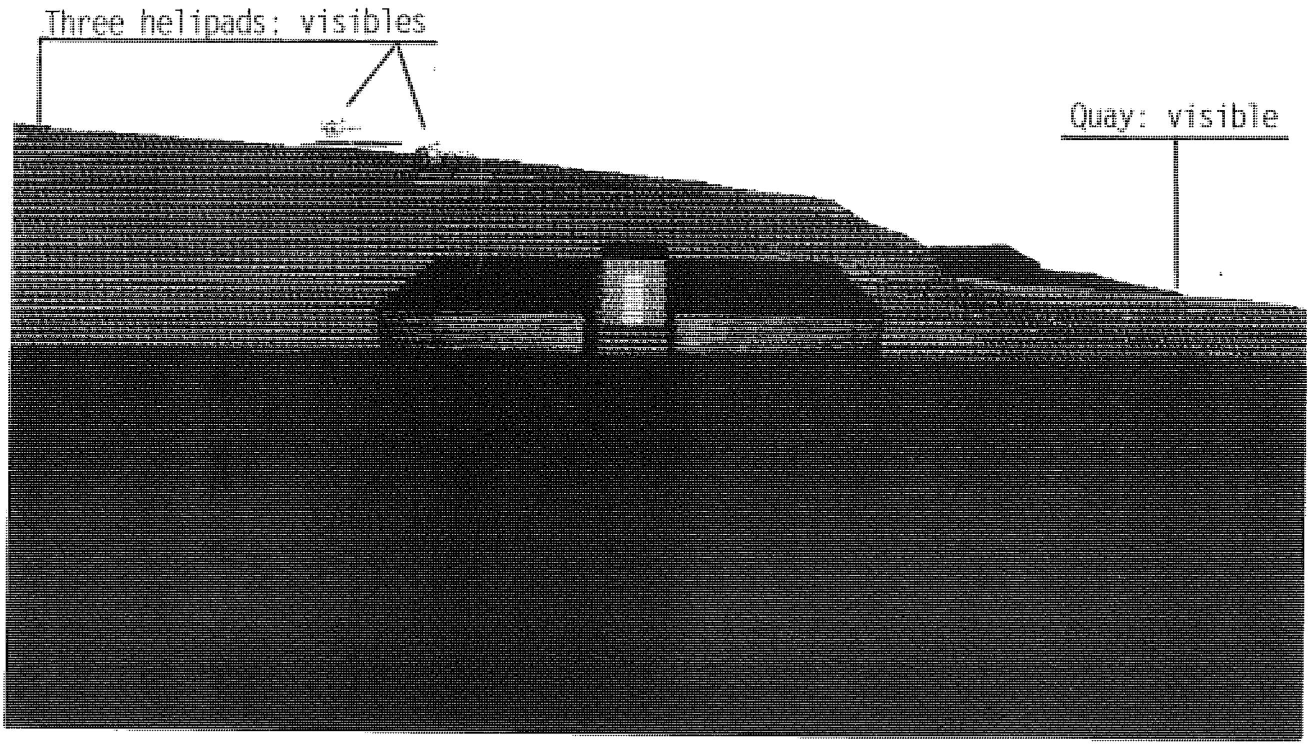


FIG.3 Perspective view of TNB station 3D model



Visual field towards the helipads and the quay from the actual control room position.



Visual field towards the helipads and the quay from a more suitable control room position.

FIG.4 Check for the replacement of the station's operative room

Automatic Geophysical Observatories

Ron Rainbow
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Antarctic Support Associates

INTRODUCTION

The United States Antarctic Program (USAP) population of Automatic Geophysical Observatories (AGO's) has grown to five operational units , and one unit ready for deployment this coming season. The original concept, proposed a decade ago for six unmanned observatories distributed about the polar plateau, is poised to become a reality. The investigative program utilizing the AGO's was called the Polar Experiment Network for Geophysical Upper-atmosphere Investigations (PENGUIn), the product of U.S.-Japanese cooperation in polar auroral research.

The near completed AGO network has already provided data for the coordinated investigation of high-latitude ionospheric and magnetospheric events through the synchronous observations of a suite of experiments housed at each site. These experiments were provided by a consortium of research centres, all engaged in the central study of auroral phenomena. The AGO unit was designed to provide a reliable research facility for locating experiments in the hostile and remote polar environment.

A brief historical review is in order here. The proposal by the Lockheed Martin, Palo Alto Research Laboratory to design and produce an independent, unmanned observatory capable of sustaining experimentation on the electromagnetically quiet Polar plateau was accepted and funded by the National Science Foundation (NSF) in 1988. This was part of the U.S. program to expand the existing network of experiments located in manned polar stations, and also to complement other AGO's at lower geomagnetic latitudes established by the British and Japanese Antarctic communities. This would create two meridional arrays separated by 1.6 hours magnetic local time, and a longitudinal array at 80° geomagnetic latitude utilizing the the partial instrumentation at the coastal sites at McMurdo Station and Dumont D'Urville. See Figure 1. The AGO data would also complement the data being gathered from the ever growing population of orbitting satellite experiments, allowing temporal and spatial analysis of polar cap events.

Over the last two years, Lockheed Martin and NSF's support contractor, Antarctic Support Associates (ASA), Denver, have cooperated in the servicing and installation of the units with the objective of ASA assuming the responsibility of maintaining the USAP AGO network.

THE AGO CONCEPT AND DESIGN

The proposed AGO design was influenced by the availability of the Hercules LC-130 transports to deploy and service the sites. Payloads up to nine thousand pounds could be delivered at 6000 feet elevation, dropping rapidly at higher elevations and poor surface conditions. The current AGO design centres around a fibreglass shelter with four inch thick polyurethane foam core to give strength and insulation in a lightweight structure. The shelters are 16'x8'x8' and maintain a thermally controlled habitat of about 20°C for the experiment electronics and the data acquisition system while experiencing external temperatures of minus 70°C and winds of 90 kilometres per hour. This interior environment permitts the use of low-cost, commercial-grade electronics. It can also house up to four persons during the annual service visit providing functional working, cooking and sleeping facilities. Double glazed, hinged windows are located at each end of the unit and access is through an industrial freezer door. To minimize snow drift problems, the AGO structures are raised above the snow surface using corner posts. See Fig 2.

The choice for a year around source of heat and power was a liquid propane fueled thermo-electric generator (TEG). The other options were a Stirling engine application, a diesel powered generator and a wind and/or solar co-generative system. The TEG chosen was a modified Teledyne Energy Systems TELAN 2T series generator producing 55 watts of electrical power plus thermal heat by-product. The excess heat is transferred to the outside via a heat exchanger medium, controlled by a thermally regulated flow valve. Once again the availability of the Hercules transport made it feasible to transport the annual 800 gallons of propane fuel to the site. This is done in ten 100 gallon propane tanks, which together with an eleventh tank containing compressed nitrogen driver gas are loaded on aircraft compatible pallets. The driver gas is for when the winter temperatures fall below the boiling point of liquid propane (minus 42°C).

The AGO related electronics consist of the Data Acquisition Unit (DAU) and the Data Control Unit (DCU). The DAU provides the interface between the scientific experiments and the data recording system, providing 31 data channels. A single data channel is reserved for handling 32 housekeeping parameters. The DAU also provides a GPS clock based time reference for the experiments and the DCU. Using a laptop computer interface to the DCU, the field service team can monitor the overall system operation and retrieve on-line data in real time. The DCU also directs the science data files to the next available optical WORM disk drive storage. There are seven drives storing 2.7 gigabytes of data. Additionally, the DCU controls the prime power distribution to each of the scientific instruments, and directs the 32 housekeeping parameters to the ARGOS satellite transmitter which sends out this data approximately every hour.

The AGO experiments include optical and radio frequency auroral imagers, narrow and wide-band receivers, and two magnetometers. Specifically, the experiments consist of a ELF/VLF receiver (Stanford University), a LF/HF receiver (Dartmouth

College), an imaging riometer (University of Maryland), a low light level auroral all-sky imager operating at two wavelengths (Lockheed Palo Alto Research Laboratory), a fluxgate magnetometer (AT&T Bell Laboratories) and a search-coil magnetometer (Tohuko University). The instrumentation suite also includes wind speed and direction and barometric pressure which are transferred along with housekeeping data via the ARGOS satellite network.

The ELF/VLF receiver consists of one digital broadband snapshot channel, five narrowband channels or "hiss" filters, and two additional narrowband channels tuned to the frequencies of two selected, high power VLF transmitters. The LF/HF receiver is a sweep frequency receiver covering the nominal frequency band from 0 to 5000 kHz. The imaging riometer (Relative Ionospheric Opacity meter) is a 16- beam phased-array receiver that maps the radial variation in cosmic ray absorption by the Earth's atmosphere. The tri-axis search-coil magnetometer monitors ultra low frequency (ULF) magnetic variation (<1.0 Hz), while the fluxgate magnetometer tracks the dc level activity.

AGO DEPLOYMENT

A typical AGO installation requires the early deployment of two field personnel to groom a ski-way for the incoming LC-130 aircraft delivering the AGO unit and team. The need for a prepared ski-way was established after the open field landing and takeoff at the first deployment (AGO-2) was deemed too harsh for routine LC-130 field operations. It usually takes a single Twin Otter flight to put in the skidoo and snow groomer, fuel, personnel and supplies. A new site will require about a week depending on surface conditions, resulting in a 9,000+ feet ski-way and an associated taxi-way leading to the proposed AGO site. See Figure 3.

The Hercules aircraft now delivers the AGO unit and all associated hardware, the experiment construction and electronic hardware, the AGO team (5 persons optimum), and supplies. The grooming team leaves on the outgoing flight. The installation proceeds after establishing the camp essentials and igniting the generator. The AGO interior takes about five hours to reach 20°C.

The AGO unit is usually oriented, raised and secured in about 36 hours. After 5-6 days all the experiment field installations are complete, leaving the internal installation, fine tuning and calibrations to be completed. Barring no problems, this is completed after 8-10 days. At this time, the final Hercules flight is called in with the year's fuel supply and returning to base with the AGO service team. The typical on-the-ground time for this visit is 2 hours in which the fuel supply is hooked up, checked for leaks, and the team and it's returning gear are loaded up.

The typical AGO service visit is accomplished with two put-in Twin Otter flights, carrying two field groomers, 3-4 AGO personnel and all the associated supplies. The current site visit lasts about 7 days, terminated with a Hercules fuel delivery flight. The higher elevation sites require 2 fuel flights due to the limits imposed on the returning cargo. AGO's 4, 5 and 6 appear to be at the performance limits of the aircraft and the recent site visits have been monitored closely. The concept of traversing to the sites using surface vehicles is currently under review.

The first unit, AGO-2, was deployed in December 1992 after two years of trials on the Ross Ice Shelf near McMurdo Station. These trials resulted in modifications to the exhaust and heat dissipation mechanisms and some effort to eliminate interference between the experiment channels. The remaining units were deployed as indicated in Table 1 below. The sixth unit was only partially deployed during last season, because of the late timing of the effort and the less than ideal conditions at the site. It is planned to complete this installation this upcoming season.

Table 1 - AGO installations

Date	Site	Geographic		Geomagnetic	
		Lat	Lon	Lat	Lon
12-92	AGO-2	S 85.67	E 313.62	S 69.81	E 19.21
01-94	AGO-1	S 83.86	E 129.61	S 80.14	E 16.75
01-95	AGO-3	S 82.76	E 28.58	S 71.78	E 40.09
01-94	AGO-4	S 82.01	E 96.76	S 80.00	E 41.51
01-96	AGO-5	S 77.23	E 123.52	S 86.74	E 29.44
01-97	AGO-6	S 69.51	E 130.01	S 84.92	E 215.16

PROGRAM EVALUATION

The network has proved to be a reliable research facility for locating experiments in the hostile and remote polar environment. The frequency of inquiries from other experimenters is on the rise and the first non auroral package was installed last season. A LIDAR based experiment is scheduled for installation this coming season and there are plans for establishing a seismic site during the 1997-98 season. The primary limitation on these requests will soon be the present level of available power.

The first AGO units have now withstood up to six winters and it is safe to conclude the design of the unit itself is solid. This was proven when the first unit (AGO-2) tumbled in the LC-130 propeller-wash when delivered to the site without sustaining damage. A second incident involving the AGO-6 unit being rolled several times during a storm at McMurdo, suffering extensive surface damage, but remaining structurally intact. It was restored to operating status.

The interior design for hosting the electronics, both support and experimental, and the four service team members has proven to be very workable. The TEG maintenance task was the only operation that is difficult in terms of convenience and accessibility and is due to the TEG design itself.

The concept of raising the units above the snow level has worked well, and to date only one unit (AGO-2) has required raising after four years in service. The combination of cable, winch and sheave at each corner pillar proved equal to the task of raising the 4000 plus pound structure.

The TEG, is a well developed product for applications in remote areas. In industrial placements, these units are typically recycled back to the manufacturer for maintenance, a luxury not available in polar work. Our experience has shown that the generator unit, even after modifications, has not been conducive to performing routine maintenance in the confines of the AGO unit. The unit is too heavy for casual removal from it's mountings which is compounded by having to lower the AGO unit to ground level. There has been a growing incidence of TEG component failures indicating that major maintenance should be planned every two to three service years. Lockheed Martin has been investigating a modification which would separate the burner assembly from the heat exchanger/back plane. This would allow the service team to replace the failing burner unit expediently, returning the old unit to McMurdo for reconditioning.

ASA has been monitoring this progress in addition to the development of a Stirling engine application and a promising thermo-photo-voltaic generator system. Should these systems maintain their promise, prototype testing may be implemented at a polar location.

The polar environment has exposed weaknesses in the fuel delivery mechanism which must perform continuously for twelve months. The majority of AGO failures have been caused by power loss due to fuel starvation. Leaks have developed mostly at the tank valve ports or at the many manifold connections. Last season, it was confirmed that the pipe dope used by the tank manufacturer when assembling the tank valves was drying out and becoming brittle after several temperature cycles associated with site refuelling. A procedure to rebuild the tanks at McMurdo Station will be implemented this season in addition to testing a new configuration of two 500 gallon tanks to replace the eleven 100 gallons tanks presently in use. This will more than decimate the potential leak sites.

The AGO electronics, namely the DAU and DCU units, and the ARGOS transmitter have all performed as designed. It is now a fact that the cutting edge technology of the 80's has long been superseded and some components have become obsolete. Add to this the proprietary nature of the system driver software, the servicing program is faced with some unsurmountable obstacles. The need to upgrade the components of the DCU is now quite pressing since replacements for the current optical drives are unavailable. Both Lockheed Martin and ASA are investigating the upgrade possibilities available to us with a view to commencing the site upgrades in the 1997-98 season. This will be accompanied by a significant increase in data storage capacity, a direct result of improved technology. This will be enthusiastically received by the science community.

In summary, the program has produced a creditable volume of scientific data, progressively increasing with the number of AGO units deployed. The community of investigators have had an ample sufficiency of data to analyse, but are always prepared for more. Since 1992, unit shut-downs have been caused by fuel delivery problems (3), TEG failure (1), exhaust venting problems (2), and DCU related problems (2). The power delivery related items heavily outweigh the electronic problems. It is estimated that the network has produced data for about 65% of the total deployed time.

The AGO support effort is focused on addressing the system weaknesses observed and enhancing the strengths now evident. It is anticipated the network will continue to service the original investigators' programs and also provide a vehicle for a growing influx of new participants.

Acknowledgements are due to T. J. Rosenberg, principal investigator, and to all the associated investigators in the PENGUIn program. Also to J. H. Doolittle, Lockheed Martin, and all individuals involved with the development and installation of the AGO facilities, at Lockheed Martin and ASA. The AGO program is supported by National Science Foundation funding.

Figure 1. USAP AGO Locations

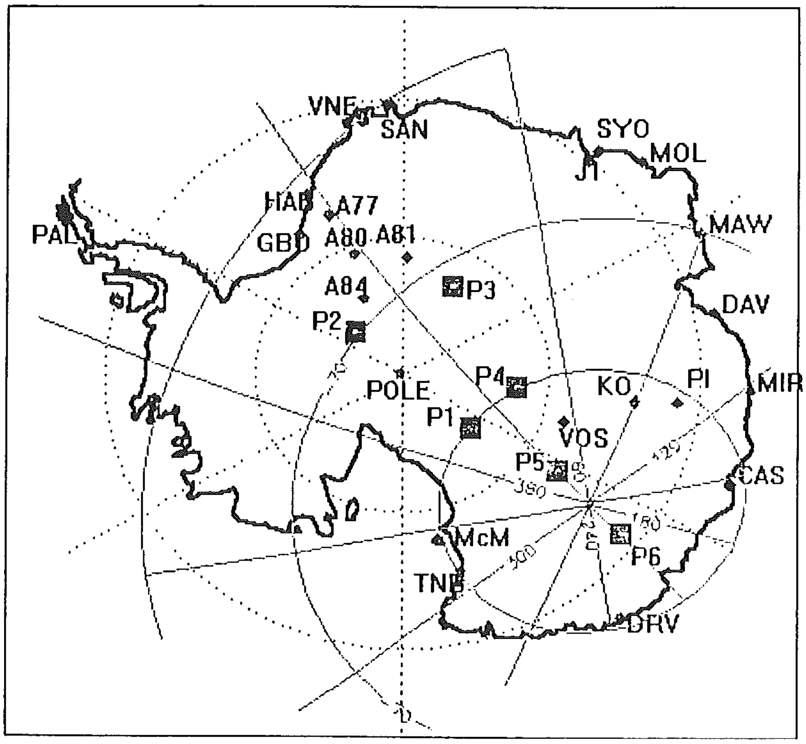

Figure 2. AGO Unit and LC-130

A Down-Wire Control and monitoring System for Scientific Nets

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Introduction

Scientific fishing frequently uses multi-sampling net systems which usually require some means of remote actuation. In addition to this function, it is highly desirable to be able to measure, display and record the net depth and other physical parameters.

The British Antarctic Survey, in common with many other science institutes, has for some years used the Institute of Oceanographic Sciences net monitor system. These units are battery powered and use a 10KHz acoustic link, from monitor to ship, to transmit net depth, sea temperature and flow data, and an acoustic command signal, from the ship to the monitor, to control the actuation of the various multi-sample net systems that may be connected to this device.

This system has several disadvantages in operation:

1) Reading depth, or any other parameter, with any degree of certainty is difficult since the data are displayed as 4, free running, traces on a chart recorder with the values indicated by measuring the gap between the "data" traces and the "reference" trace. This, combined with the delay whilst the traces come into view, makes it difficult for the operator to control the net depth with the accuracy required when trying to fish a particular layer.

2)The limitations of the acoustic link, and the way the data are encoded on that link, mean that only a limited data set can be transmitted to the surface.

3)Poor sea conditions or long range operation can make the acoustic link rather tenuous. This can make the "data" signal difficult to read and can frequently cause problems with firing the net due to the net monitor failing to detect the fire command.

The same circumstances can also lead to a situation where the latching relay, that fires the net release, is out of sequence. This will also cause net commands to fail.

4)The unit has to be disassembled frequently, to charge the batteries, thus having a detrimental effect on operational readiness and reliability, and increasing the potential for pressure housing leakage.

The main advantages of the acoustic system are:

1) Reflection of the acoustic link, off the bottom, often gives a good indication of seabed proximity. This is useful when working in shallow water conditions.

2)There are no special cable requirements - a non conducting cable can be used, which does not require a special winch, and which should be cheaper than a conducting cable of equivalent strength.

All of the disadvantages listed above can be overcome in a Down-Wire type system, but require the use of a more expensive cable.

A Down-Wire Net Monitor and Control System should, theoretically allow for greater certainty in net control along with greater measurement accuracy and the use of a more extensive suite of sensors-facilitated by the increased data transmission rate available. Careful design should also allow for the use of surface power, eliminating the requirement of recharging battery packs.

The Instrumentation and Systems Group, at the British Antarctic Survey, were approached by the British Antarctic Survey Marine Life Sciences Division to design and build a Down-Wire Net Monitor and Control System for the Antarctic research vessel R.R.S James Clark Ross, after market research failed to identify a suitable commercial system. The starting point of the design was communications and power interface to the pre-existing single conductor cable, which was not ideal.

The design also had to fit around the sensor selection which was already mostly pre-ordained.

System Requirements

The system has to be capable of interfacing to, and recording the data from, a suite of sensors, including (as a basic requirement) a pressure transducer, an inclinometer, a conductivity sensor, a sea temperature probe, a flow meter and a light cell (PAR measurement) whilst allowing for flexibility in configuration and future expansion.

These data should be available for real-time graphical and numerical display with simultaneous logging to the ship's centralised data logging system.

The system should interface to, and be capable of controlling, net release systems specified by the user (RMT[1], MultiNet[2] and LHPR[3]).

The system should work with the single conductor tow cable installed on the James Clark Ross and should, preferably, be powered via this cable.

System Overview

Refer to Figure 1.

The system comprises:

An underwater unit,
A winch with single conductor towing cable,
A lab mounted deck unit,
A lab mounted control and display PC.

The underwater unit interfaces, via underwater connectors, to the sensors required, in any particular configuration, and to the various net release systems already in use by the British Antarctic Survey at this time.

The net assembly and Down-Wire Net Monitor underwater unit are towed by a single conductor tow cable supplied by Rochester Cables Inc. Slip rings on the winch connect the cable to the system deck unit, via coaxial cable.

The deck unit supplies power, and is the data interface between the underwater unit and the control PC. It is located with the PC, in the winch control room of the James Clark Ross. This enables the net operator to pass verbal commands directly to the winch driver.

The deck unit is connected to the control PC, an 80386 type machine, equipped with a 20 inch, high resolution monitor. The use of the large monitor, and 1024x768 resolution graphics, allows for maximum clarity of data presentation, which is important during net control operations.

Calibrated data are transmitted from the PC to the ships' centralised archiving computer. This allows post real-time correlation with data logged simultaneously from other sensors and the ship's navigation instruments.

High level data processing tasks, such as calculating the volume of water filtered through the nets, are better performed in post real-time, on the main computer system of the James Clark Ross. Data displayed on the screen of the PC are for real-time monitoring and control purposes only.

Electronics Description

Underwater unit

Refer to Figure 2.
The heart of the system is the interface with the various sensors. The more common concept of analogue to digital converter (ADC) card and microprocessor, running a low level program, was rejected, for this application, in favour of a modular approach. The pressure housing contains up to 14 DGH[4] "D1000" type modules (the quantity and type depend on the required configuration).

Each of these modules is a self contained data acquisition system in its own right and they are available in many different forms for interface to different magnitudes and types of signal. In addition to their analogue functions each module also has 1 or 2 digital outputs and 1 digital input. These can be used for switching relays (for motor control) and monitoring logic signals or switch closures (such as those produced as confirmation of net operation).

Use of DGH modules allows us greater flexibility and reduces the development time as the technique we have used allows us to add, or change, modules as required and does not require any software development for the underwater unit. An additional advantage is that in most cases no external signal conditioning boards are required, thus reducing design complexity and build time.

The modules each have a unique address

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[1]Rectangular Mid-Water Trawl

[2] British Antarctic Survey MultiNet

[3] Longhurst Hardy Plankton Recorder

[4] DGH Corporation, Box 5638, Manchester NH 03108, USA.

programmed in to them because they all share the same pair of data lines and are normally interrogated sequentially via an RS485 data link. In this application the RS485 format is only used internally within the underwater unit as it would not be possible, within the constraints of our single conductor cable, to mix base band RS485 communications with the DC power supply from the surface.

To achieve the specified system requirements of real-time data and power, on the same single conductor tow cable, it was necessary to design a pair of frequency shift keying (FSK) transceivers, optimised for a high loss transmission cable and allowing half duplex operation. The final design achieved this, utilising a nominal carrier frequency of 50KHz and using a small inductor to separate data and power. The incoming data stream (at 9.6K baud) is separated from the DC supply (nominally 50V) and converted from FSK to RS485 standard. The outgoing response from the module is converted to FSK and superimposed on the 50V supply.

Because the communications are inherently half duplex, the transceiver circuit needs to detect the data direction in order to switch over the RS485 and FSK transceivers between transmit and receive modes. This function was achieved with only one additional IC.


Deck unit display

The power supply requirements in the underwater unit are met by a trio of DC-DC converters, supplying 15V at 1.3A, 5V at 250mA and 24V at 500mA. These converters will work with an input voltage range of 18-72V which is ideal for this job where the supply voltage at the underwater unit will vary considerably according to the amount of winch cable off the drum and the electrical load imposed by the underwater unit. Being switched mode power supplies means that they have a fixed conversion efficiency of 80% or more, so "extra" volts are available to meet additional current demand rather than being turned into heat.

Incorporating a power supply capable of providing the high current demanded by the motors, would be wasteful and expensive. The full capabilities of such a supply would only be utilised for maybe only 10 seconds per net haul. Therefore a set of Nicad batteries, trickle charged from the main supply, supply 3amps at 12V for running net motors and other high current, low duty cycle, items. These Nicads are under constant charge, even when the unit is on the deck (as long as it remains powered up) and therefore they do not require removal for charging or replacement, the average power drain on them being very low.

In addition to the transceiver and power supply boards there is an interface board which has the motor control relays and flow meter de-bounce circuit on it.

Ship based equipment

On the James Clark Ross, the winch slip rings are routed to the deck unit via a dedicated cable to the scientific hold, and then from there via coaxial cable. The signal connection into the system deck unit is via an ordinary BNC connector.

The deck unit (refer to Figure 3) consists of an FSK/RS232 transceiver, a 50VDC power supply and a small 5V power supply to power the local electronics (the FSK/RS232 transceiver). The transceiver board is similar to the one in the underwater unit but, due to the use of RS232 standard communications with the controlling PC, it is not necessary to have a half duplex system, thereby making the control slightly less complex.

Digital data, in FSK form, is superimposed onto, or isolated from, the power supply using AC coupling to, and from, the transceiver and a series inductor to give a high impedance between supply and transceiver.

A standard D25 connection is used to connect the deck unit to the serial communications port of the 80386 PC.

The second serial port of the PC is, in our application, connected to the ship's centralised data logging system.

Mechanical Description

Underwater Unit

The underwater unit consists of a cylindrical aluminium pressure housing with multi-way underwater connectors for connection to the sea cable, instruments and net release mechanisms. The inclinometer, flow meter and acoustic altimeter are attached to the net with the remainder of the instruments carried on a frame attached to the pressure housing.

Software Description (V2.0)

The software has been developed within the National Instruments[5] Lab Windows® environment and is written using the subset of Quick Basic available within Lab Windows. The Quick Basic code has been compiled.

The main screen of the software presents the user with graphical displays of some data, and numerical display of all the data. Pull down menus control all functions, with some commonly used actions available using "hot key" strokes. The menu enables selection of three other panels to enable the setup of certain parameters, such as sample rate or graphs, or to enable or disable particular instruments. As well as the display and control functions, the software also sends the data to the ships cenralised logging and archiving system.

Field Deployment Results

The prototype system was used extensively in the sub-Antarctic waters around South Georgia during cruise JR03 of RRS James Clark Ross. During this period two major problems were encountered. These were: controlling the LHPR motors accurately and being unable to use the altimeter.

The first problem, which was a software matter, was solved during the course of the cruise, but too late to enable the LHPR to be used for real data collection. The control of the motors was later modified to reset itself in hardware, removing the reliance on software timing.

The second problem required a hardware modification - the switched mode regulator, originally used to generate the 24V supply for this pinger, was too noisy when under load. It was replaced with a self contained switched mode power supply of 24V

Problems with the LHPR flowmeters reading incorrectly were solved by altering the time constant of the filter circuitry.

The system was used very successfully for the control of the RMT and the MultiNet, the positive communication ensuring that no net firing opportunities were lost.

The suite of instruments produced good quality data, with the accurate, real-time depth display making a significant contribution to the success of fishing operations.

Table 1: Instruments

Parameter	Instrument
Net Depth	TransInstruments BHL-4269-01
Sea Water Temperature	Sea-Bird SBE3
Sea Water Conductivity	Sea-Bird SBE4
Light (PAR)	Chelsea Instruments PR46
Flow 1	B.A.S radial flow meter / LHPR axial flow meter 1
Flow 2	LHPR axial flow meter 2
Angle 1	Sensorex 41600 Inclinometer
Angle 2	Not in use
Altitude	Simrad Mesotech Systems 807-12
Fluorescence	Chelsea Aquatracker
Spare 1	Not in use
Spare 2	Not in use
Spare 3	Not in use

[5] National Instruments, 6504 Bridge Point Parkway, Austin, Texas 78730-5839

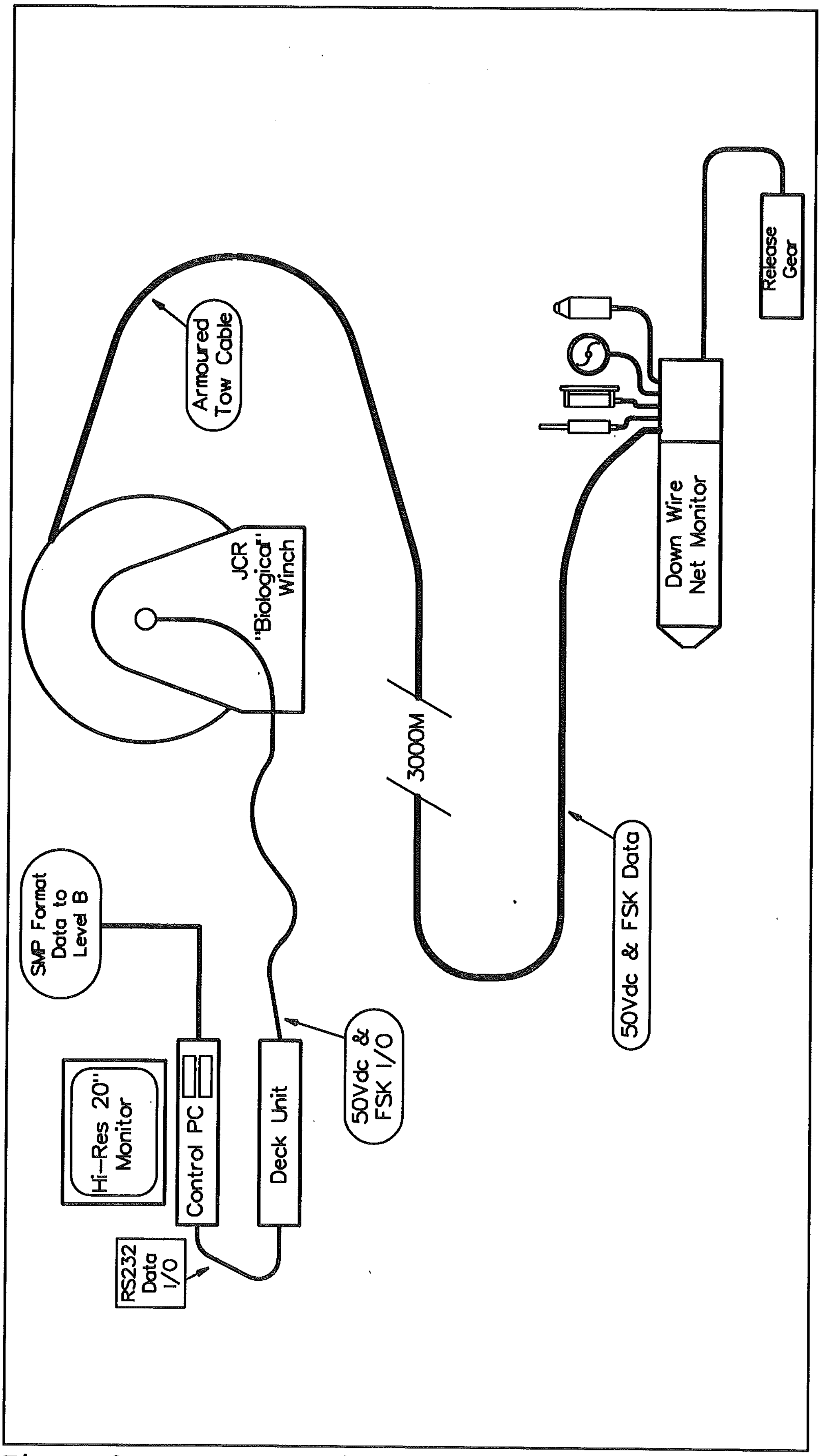

Figure 2: System Overview

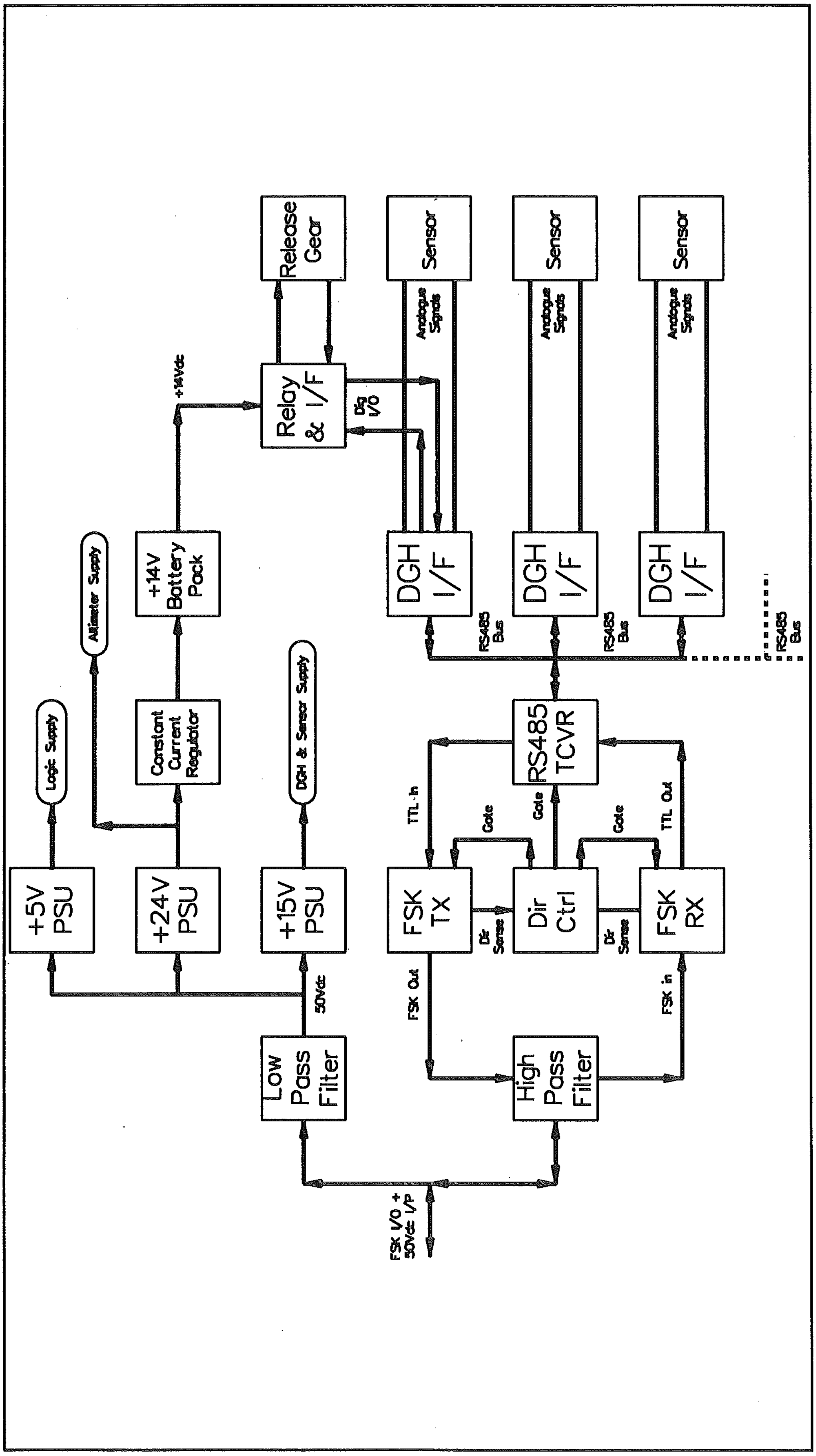

Figure 3: Block Diagram of Underwater Unit

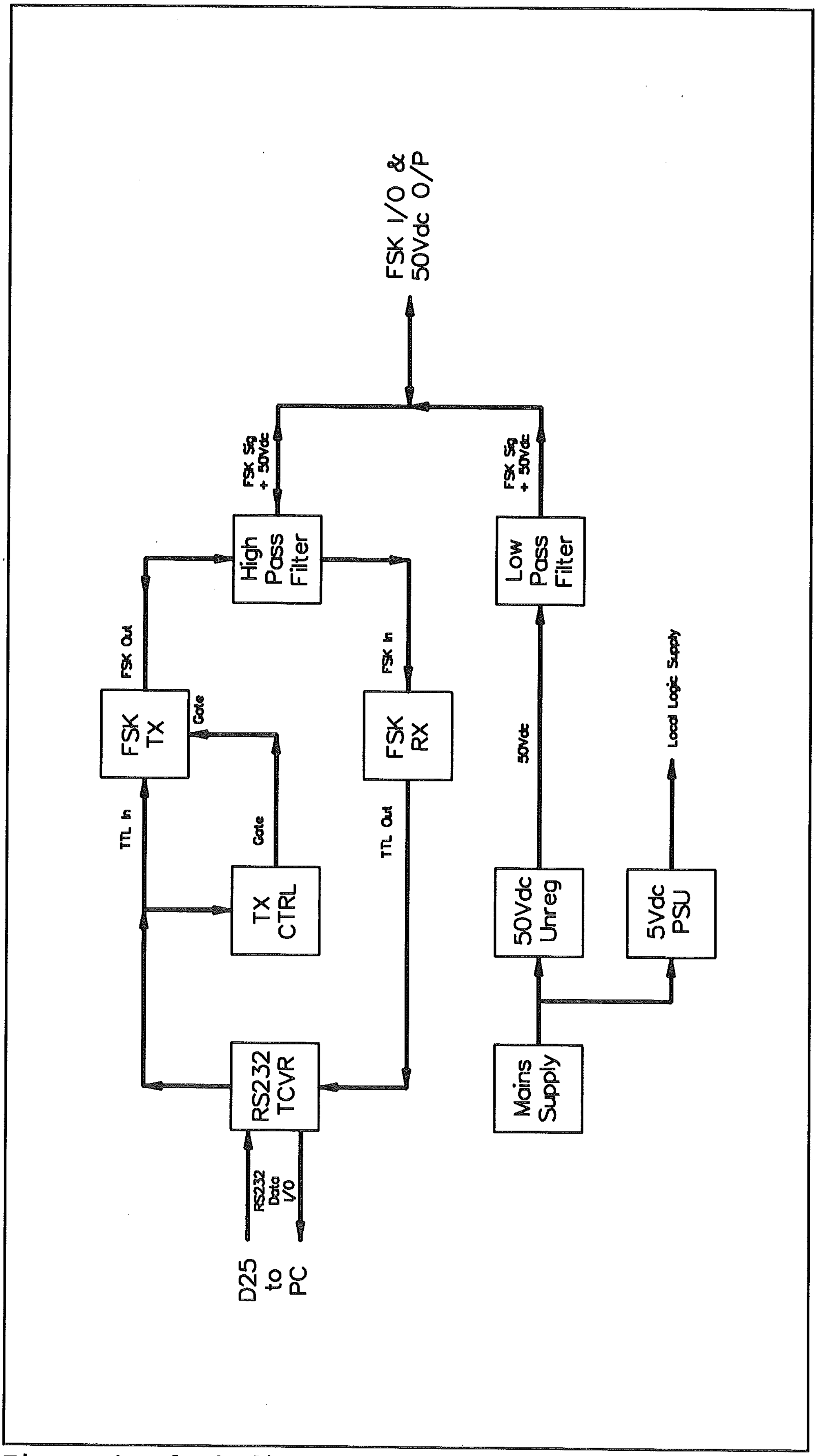

Figure 4: Block diagram of Deck Unit

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The Use of Remote Sensing and of Satellites in the Italian Antarctic Programme A review

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Italy

1. Introduction

Remote sensing in its many variations and the use of satellites have application in all aspects of Antarctic activities. Aerial photographs, satellite imagery, aerial surveys using electromagnetic waves of different lenghts, from infrared to microwaves, all have important application in Antarctic work, as well as in all kind of exploratory work in all parts of the Earth. The role of satellites in telecommunication and in navigation should also not be forgotten. It is indeed not easy to imagine modern science and logistics without the use of these technologies. This is specially true in Antarctica, where harsh climate, great distances and hostile environment combine in making all activities more difficult and dangerous.

This paper is a short review of some applications of remote sensing as used in the Italian Antarctic Research Programme, the PNRA.

Italian scientific activities in Antarctica began in the '85/'86 austral summer and in the following summer the construction of the research station at Terra Nova Bay (74°41'42" S, 164°07'23" E)in the Ross sea region was begun. The eleventh campaign was concluded in March '96 and the twelfth campaign is now (Aug. '96) in advanced preparation.

The TNB station is modern and well equipped and it is active during the austral summer, from mid-October to the end of February. With minor modifications it could be used also year-round. However, for the time being, the National Scientific Commission for Antarctica has decided not to implement activities requiring wintering over.

When the base is not manned a number of automatic stations collect data which are either stored or transmitted back to Italy. This stations are fed by an automatic electricity generating module, the AIM. The stations collect data on: metorology, mareometry, geomagnetism, seismic and volcanology (tiltmeters on Mt. Melbourne). An automatic GASCOD is also installed. It is planned to add to this automatic system an all-sky camera, a telescope system and the AVHRR station.

TNB station is the hub of a broad variety of research activities, ranging from geology and geophysics to glaciology, biology, oceanography, environmental studies and technological research.

Italy also takes an active part in several international programmes and projects, such as the Cape Roberts Project, the Concordia Project, the APE (Airborne Polar Experiment). A number of interesting applications of remote sensing have been used in support of these programmes. For example, Radio Echo Sounding has been used both from the air and from the surface in the Concordia Project, aeromagnetic surveys have been performed in the Cape Roberts area.

Obviously, the outcome of many types of remote sensing are in everyday use for logistics activities, such as maps, charts, ice charts etc.. GPS systems and satellite telecommunication equipment are of everyday use.

In this paper a number of these applications will be outlined.

2. Geomorphological and Glaciological Cartography.

The high quality of satellite images and the extreme environmental conditions in Antarctica combine in making satellite imagery an indispensable instrument of analysis for glaciological, geomorphological and geological studies.

A satellite image mosaic of the TNB area has been prepared in 1990/91 from 10 SPOT XS frames taken in the previous years. The image covers the TNB area and represents the coastal area between the Drigalsky and Parker ice tongues, including the Reeves and Priestley outlet glaciers and the basin of the Campbell glacier.

Another interesting application of satellite imagery is the study of the behaviour of the Drigalsky ice tongue. This is the floating seaward extension of the David glacier and it is the actual regulator of the size of the Terra Nova Bay polynia. The size of the polynia has a significant impact on sea ice production in the Ross Sea. The Drigalsky ice tongue has been described by several explorers during this century and the use of aerial photos and later of satellite imagery has allowed a much better definition of its movements and its calving (fig. 1). The analysis of historic maps and records, aerial photos and satellite imagery has combined in allowing a reasonably accurate record of the behaviour of this important glacial feature. The only major calving event occurred in 1957, when about 40 km of the tongue broke away. The average velocity of the tongue varied between about 700 m per year to the present about 800 m per year. These values can also be determined by comparative observation of satellite imagery and by the use of GPS.

Another useful application of stellite imagery is the possibility of studying the presence and the evolution of ice crevasses in areas which are crossed by traverse routes. This has been an important element of safety for the logistic operations between the coast and Dome C.

The mass balance of the Antarctic ice sheet is between the snow accumulation on one side and the calving of icebergs-basal melting on the other. A mass balance evaluation has been performed in the area of the David glacier-Drigalsky ice tongue and the Nansen ice sheet. In this evaluation both field data and remote sensing data have provided information on ice thickness, velocity and accumulation/ablation rates: Radio echo sounding and GPS measurements have provided ice thickness data, the velocity has been evaluated by comparing satellite images taken at different times, together with field measurements using precisely located stakes. These studies are in progress and will be continued in the next three year programme.

3. Surface (sea ice) and cloud imagery using the AVHRR

The NOAA satellites developed for measurements of the earth surface and atmosphere are equipped with Advanced Very High Resolution Radiometers (AVHRR), together with other instrumentation. The data collected by this instrument are transmitted to earth stations in real time, using the HRPT system. The AVHRR data are of high quality and are particularly valuable in the analysis of sea-ice coverage, sea surface temperature, cloud cover, albedo.

A NOAA-HRPT (High Resolution Picture Transmission) receiving station for NOAA satellites has been installed at TNB. The station is composed of :

- an acquisition system for satellite tracking and data acquisition;
- a processing system for image analysis and the display of data.

The system produces data which can be used for :

- climatological studies (mapping the surface albedo influencing the energy exchange between atmosphere and the earth surface);
- biological oceanography(sea surface temperature maps);
- atmospheric physics (mapping ozone and precipitable water vapour).

From a logistics point of view, the system is very useful in order to obtain sea ice mapping for navigation and short term weather forecasts. The images obtained have good quality and provide useful information almost in real time.

4. Radio Echo Survey

An interesting application of remote sensing has been the determination of the precise drilling point for the deep ice coring that will be carried out by the Italian and French glaciologists in the area of Dome C on the Antarctic plateau.

This activity falls within the framework of the EPICA Programme and the Dome C drilling belongs to the first stage of EPICA (European Project for Ice Coring in Antarctica). The drilling will be performed by a joint Italian-French team working in the Concordia Project, which has the double objective of the deep ice coring and the construction of a permanent research station on the plateau.

The location of the drilling point is critical to the project. It should be in an area where the horizontal flow of ice is at an absolute minimum and the thickness of ice is at a maximum. Therefore, it should be located at the topographic top of the area, i.e., at the topographic dome. Once the dome is located, it is necessary to investigate the bedrock morphology, the layering of the ice, its thickness and the horizontal velocity of the ice flow.

The survey of the area was planned on the basis of the first map showing the surface morphology of the Dome C area, obtained by ERS1 radar altimetry in 1993. On the basis of this map it was decided to fix the new Dome C point at the centre of the geometric top identified on the map and the survey was centered on this point. A GPS survey was carried out in order to obtain more details in the surface morphology.

The radar survey from the aircraft, a Twin Otter, was carried out in 1995. A groud based radar survey was also performed, both on a rectangular grid centered on the new Dome C point (fig. 2).

The radar equipment was designed and built at the SPRI in Cambridge. The field work was done between the 5th and the 15th of December 1995. 34 profiles were done by air and 21 on the ground.

The main results of this work have been:

- the dome area has been identified and well defined (fig. 3);
- the bedrock morphology has been surveyed and there is a central plateau (fig. 4);
- the ice layering is horizontal and well defined (fig.5);
- the ice thickness is of the order of 3.250 m;
- there are no lakes in the area selected for the drilling.

5. Aeromagnetic surveys

The main purpose of the geophysical and geological investigations in the Ross sector of Antarctica is to contribute data on three of the major aspects of Antarctic geology:

- the relationship of this area to Australia, Tasmania and New Zealand;
- the tectonics of the mobile belts at the fringe of the East Antarctica Craton;
- the Ross Sea and its development in connection with recent plate tectonics.

The aeromagnetic surveys are an important tool for these investigations.

This type of geophysical survey has been performed by the Italian PNRA for the first time in the 1988/89 season in the TNB-Gerlache Inlet area, using a helo-borne PPM (Proton Precession Magnetometer). Surveys of this type show the regional geologic patterns, the magnetic character of different rock groups and the major structural features.

In the1988/89 campaign a second survey was performed in the area of contact among the Wilson Terrane, the Dessent Unit and the Bowers terrane, in North Victoria Land. Twelve profiles were executed (fig. 6).

In the 1991/92 campaign the GITARA 1 (German Italian Aeromagnetic Research Antarctica) programme, part of LIRA (Litospheric Investigation in the Ross Sea Area) was carried out. This programme was a cooperation between the Italian PNRA and the German BGR. The area investigated was between the latitudes of 74°18'S and 75°18'S and the longitudes of 160°30'E and 164°30'E. An important feature of this activity was the greatly improved positioning system, based on the use of three radio beacons, located by GPS measurements. This survey covered an area of 6.500 sq.km.

During the 1991/92 and 1993/94 austral summers three helo-borne aeromagnetic campaigns have been performed. They have covered an area of 50.000 sq.km between TNB and Granite Harbour, going from the coast to about 200 km inland and were part of GITARA. The processing of the data relied not only on standard procedures but made use of a new microlevelling technique which substantially improves the signal to noise ratio, particularly low in polar areas. This makes possible the production of digitally enhanced maps for the first time in Victoria Land. The results of the analysis of these maps have been combined with three-dimensional analytic signals for the definition of the edges of the structures sources of anomalies and with those of the spectral analysis for the estimate of the depth of the magnetic layers. This technique could deliver very interesting results.

In the 1994/95 austral summer a closely spaced, low level aeromagnetic survey was performed in the Cape Roberts area. The survey was planned on the basis of previous seismic, marine magnetic and regional aeromagnetic surveys. This survey was an important contribution to the site survey in the area prior to the beginning of actual drilling. The results from this survey indicate a somewhat more complex geological situation for the Cape Roberts drilling area than previously anticipated. It appears prudent to collect also more seismic and gravity data in order to define with more confidence the precise location for the drill sites.

6.APE Airborne Polar Experiment

APE is a joint project of the PNRA and several Russian research institutes. It is sponsored by many national and European scientific institutions and industries, such as the European Science Foundation, the Italian National Research Council, ENEA.

The purpose of APE is to gain a better understanding of the physico-chemical phenomena at the root of the depletion of the ozone layer. To achieve this the APE project will perform "in situ" measurements using an aerial platform which is almost ideal for the purpose, an M-55 Geophysica stratospheric aircraft, capable of sustained flight at heights of the order of 22.000 m. This aircraft has an endurance of 6 hours and can carry a payload of 1.000 kg.

The main scientific objectives of APE are investigations on:

- the production and loss of the ozone in the Polar regions and in the atmosphere of the northern hemisphere;
- the atmospheric chemistry inside, outside and at the interface of polar vortices;
- the dynamic effects of the polar vortices on ozone distribution;
- the role of aerosols originating from volcanic eruptions on the mechanism of ozone depletion.

In its first polar missions in the northern hemisphere, the Geophysica will be equipped with very modern and specially developed remote sensing instrumentation. The main objective of the first Arctic mission will be the study of the polar stratospheric louds (PSC), which form at altitudes between 14 and 24 km. One of the instruments developed for this mission is the GASCOD/A which is a diode array spectrometer able to perform measurements of NO2, O3, BrO and OClO . The information gathered by this instrument should be useful for the study of the activation processes in the PSC which lead to ozone depletion. After this first Arctic campaign, the APE programme will conduct missions in the southern hemisphere.

7. Monitoring of Adelie penguins

Performed in the Edmonson Point area, this is a joint Australian-Italian activity. Its purpose is to look in detail at the foraging locations, at the duration of foraging and at the diet of breeding birds during the incubation and chick rearing periods.

During the incubation period tracking is done with the help of PTTs (satellite transmitters) supplied by the Australian Antarctic Division. During the chick rearing period the tracking is done using 5 PTTs and 5 TDR (Time-Depth Recorders). In general the transmitters worked correctly, all the data were collected and all the instruments were recovered. This activity has gone on for several years.

8. Conclusions

_The use of remote sensing and of satellites has more than proved its worth in practically all areas of Antarctic operations. The study of the territory, of the phenomena relating to to global change, the safe conduct of operations, their actal implementation, all of these depend heavily on these technologies. New satellites will be launched to improve communications and the collection of more and better data and they will also be a valuable tool in the further development of international cooperation.

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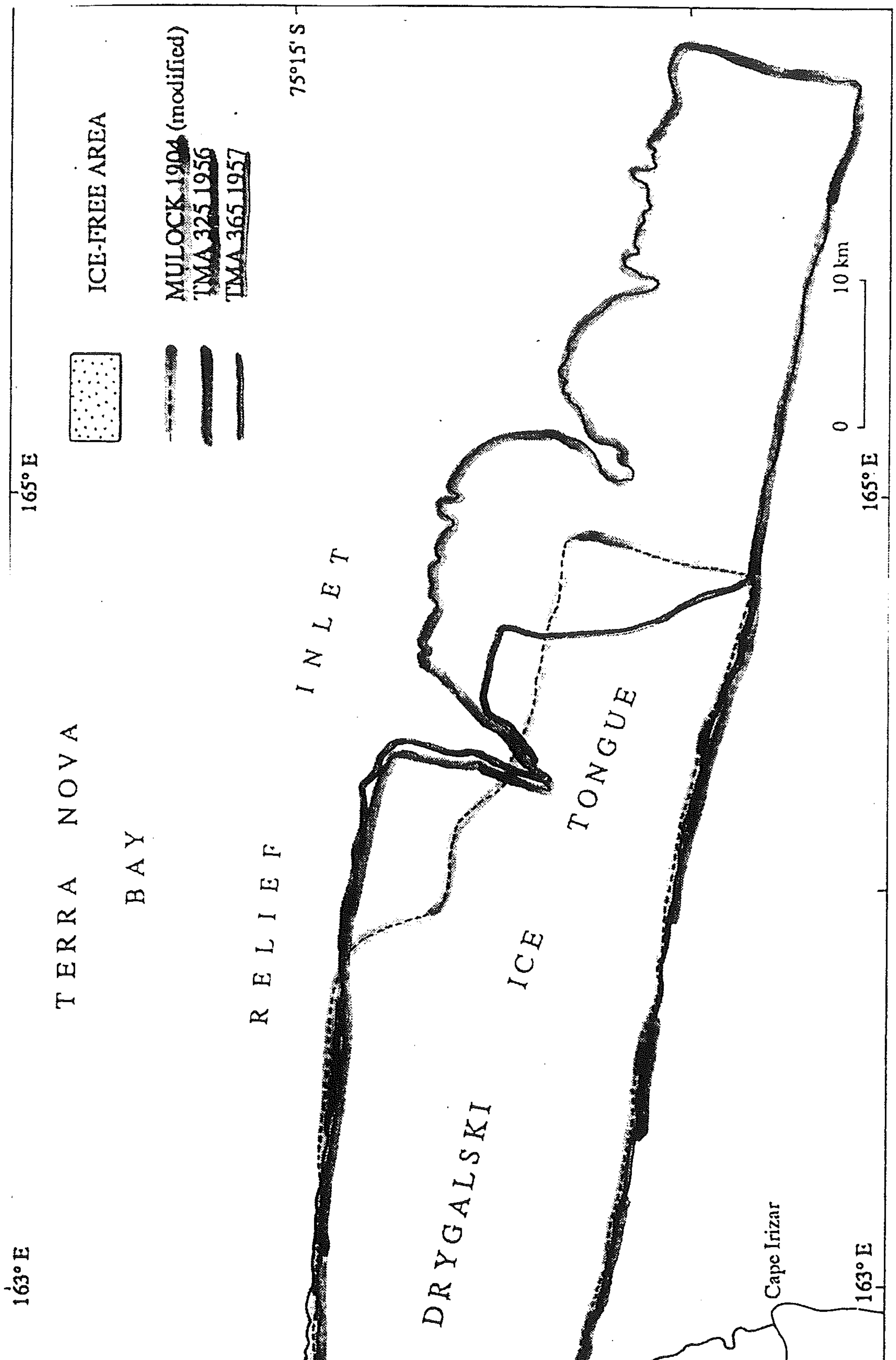

ICE-FREE AREA
MULOCK 1904 (modified)
TMA 325 1956
TMA 365 1957
0
10 km
165° E
163° E
75°15' S
75°30' S
TERRA NOVA BAY
RELIEF INLET
DRYGALSKI ICE TONGUE
LARSEN GL. TONGUE
CLARKE GLACIER TONGUE
Mount Neumayer
Hughes Bluff
Cape Reynolds
Cape Irizar

fig. 1

DOME C

Scheduled survey by air and by ground

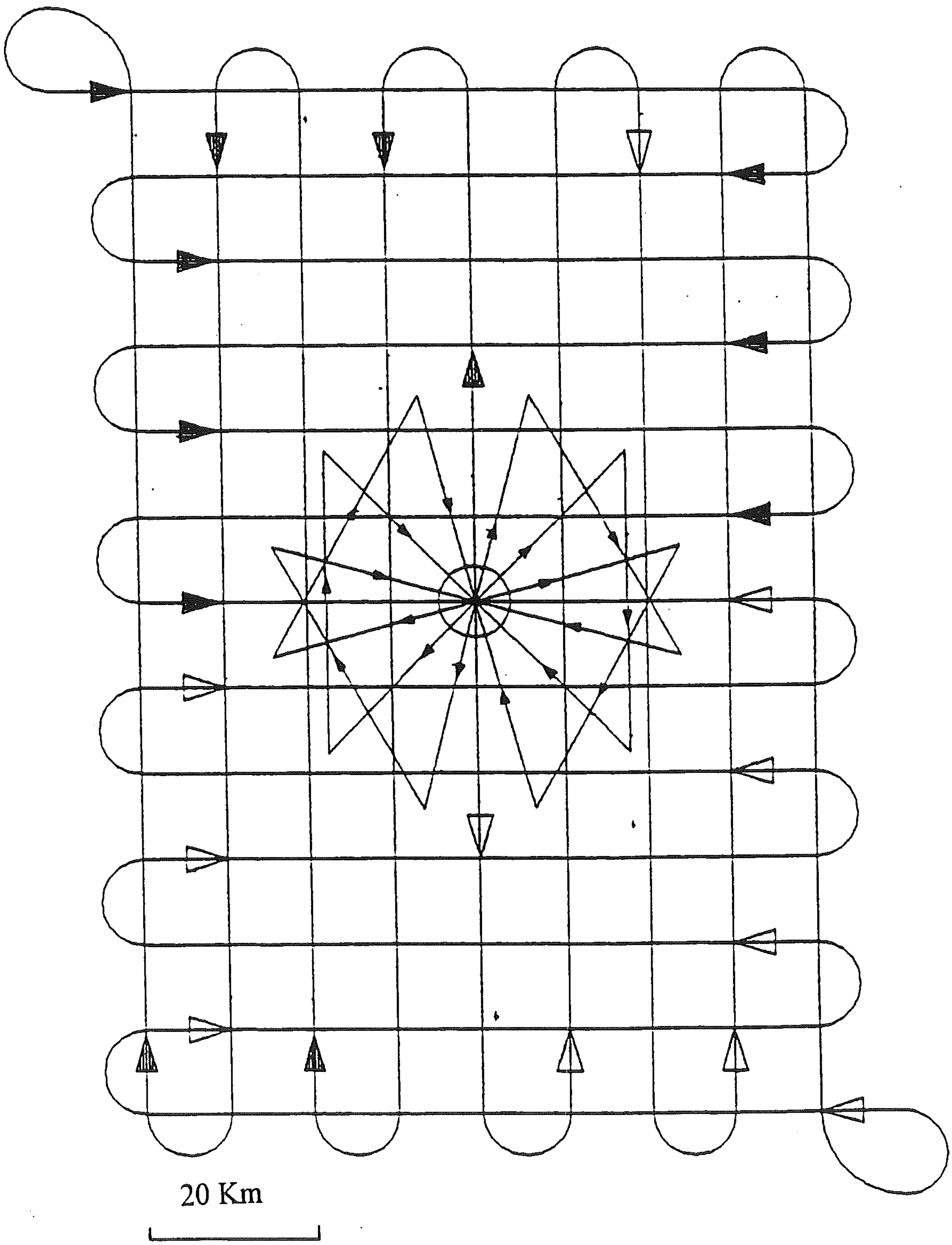
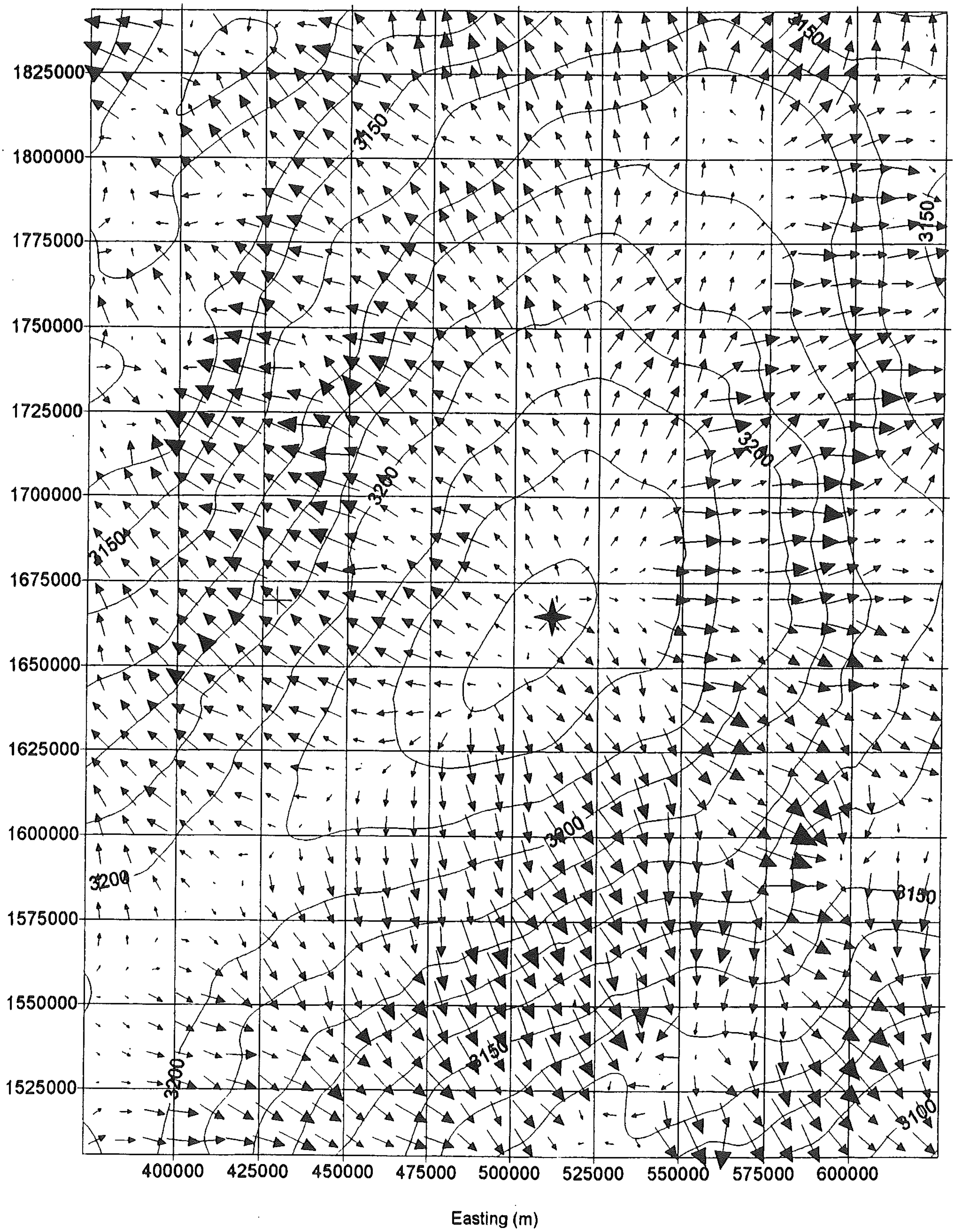


fig. 2

DOME C - Surface slope gradients



Contour line interval 10m

Gradient slope scale (‰)
0.1
0.5
1

DOME C

fig. 3

DOME C - Bedrock and Surface topography

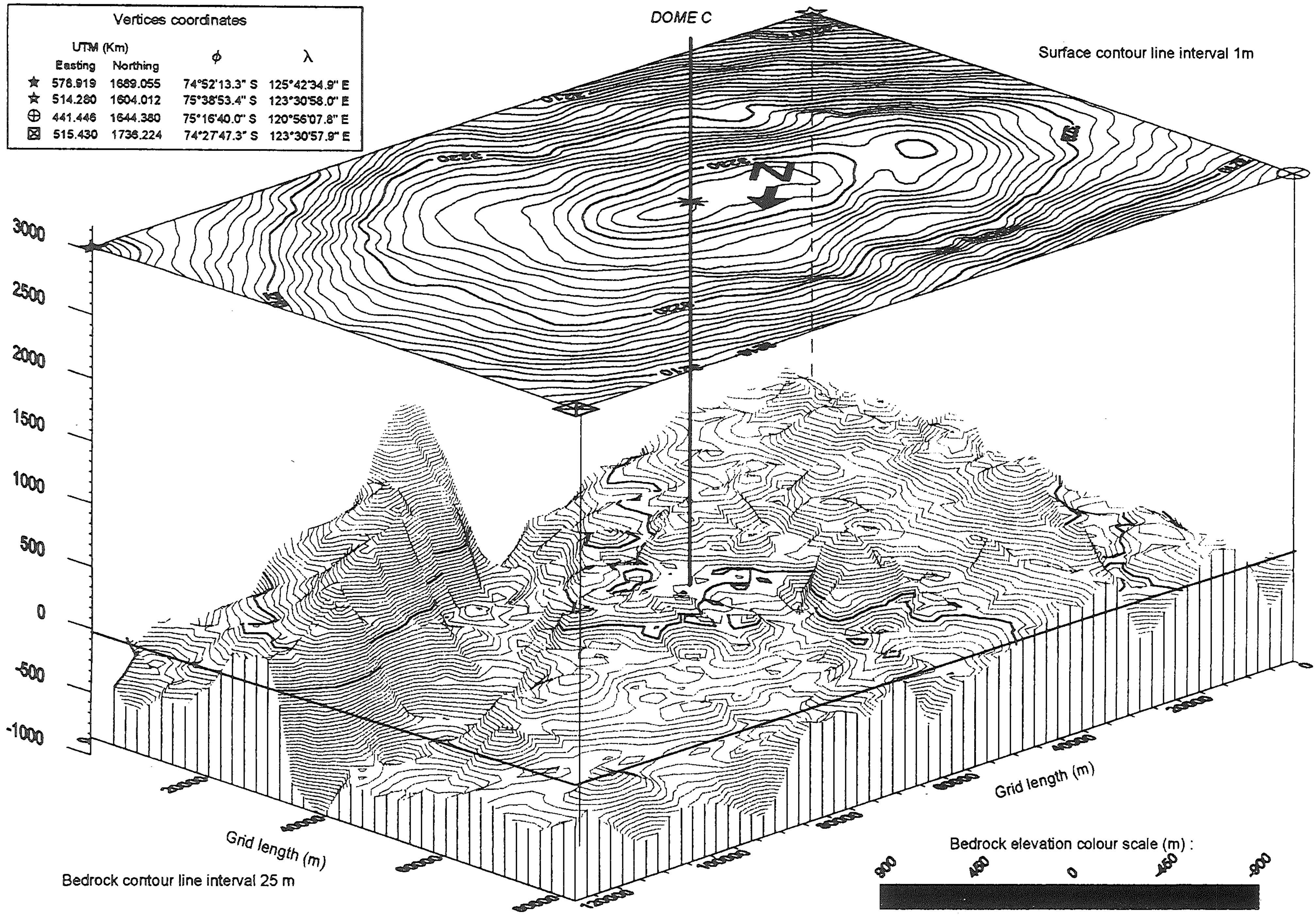
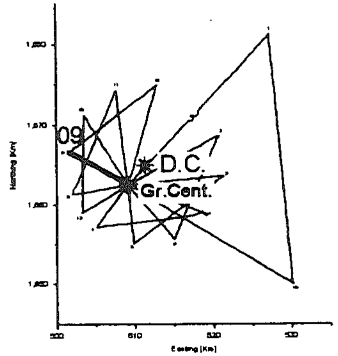


fig. 4

DOME C

Profile 09 → Grid Centre



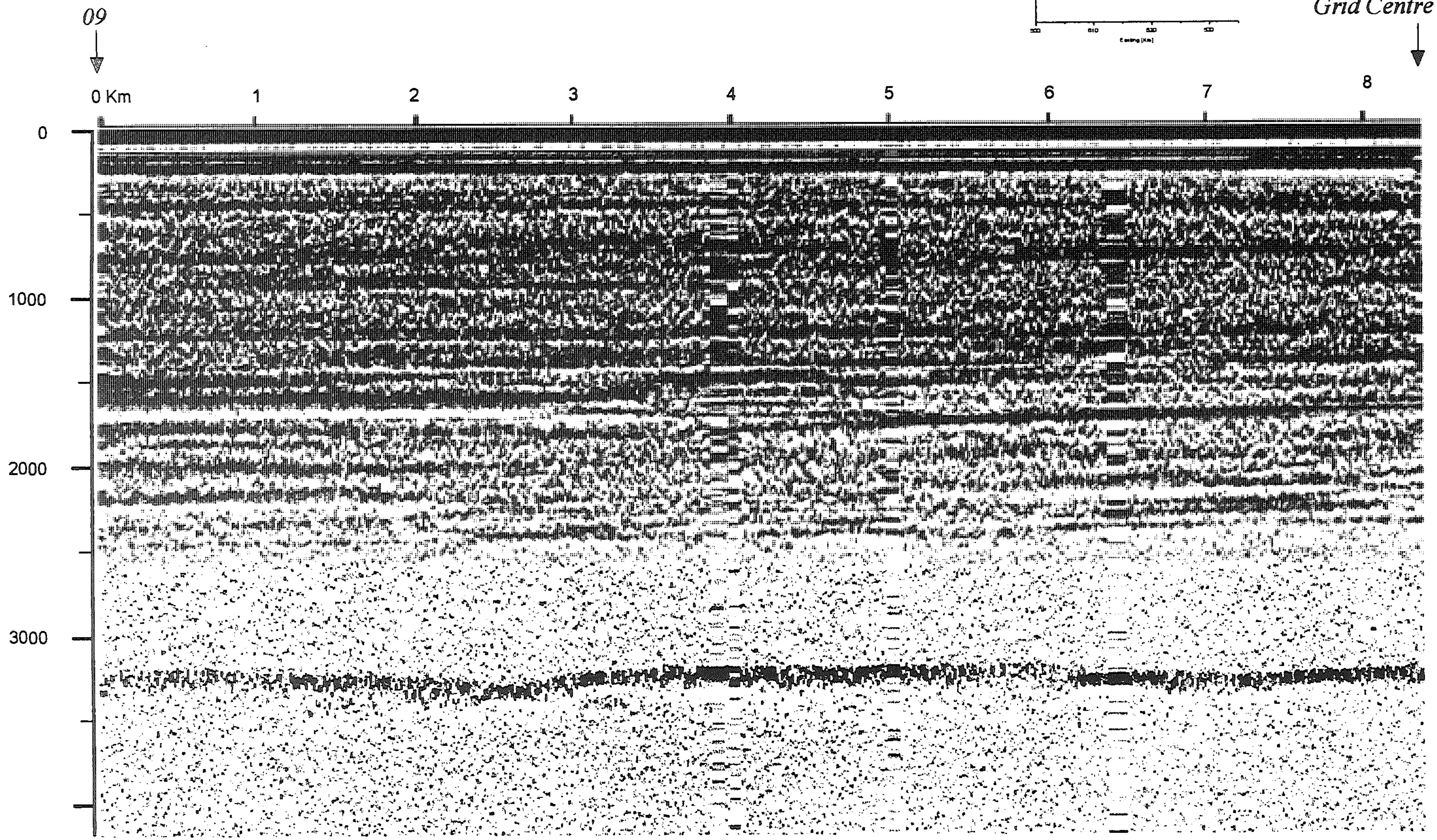


fig. 5

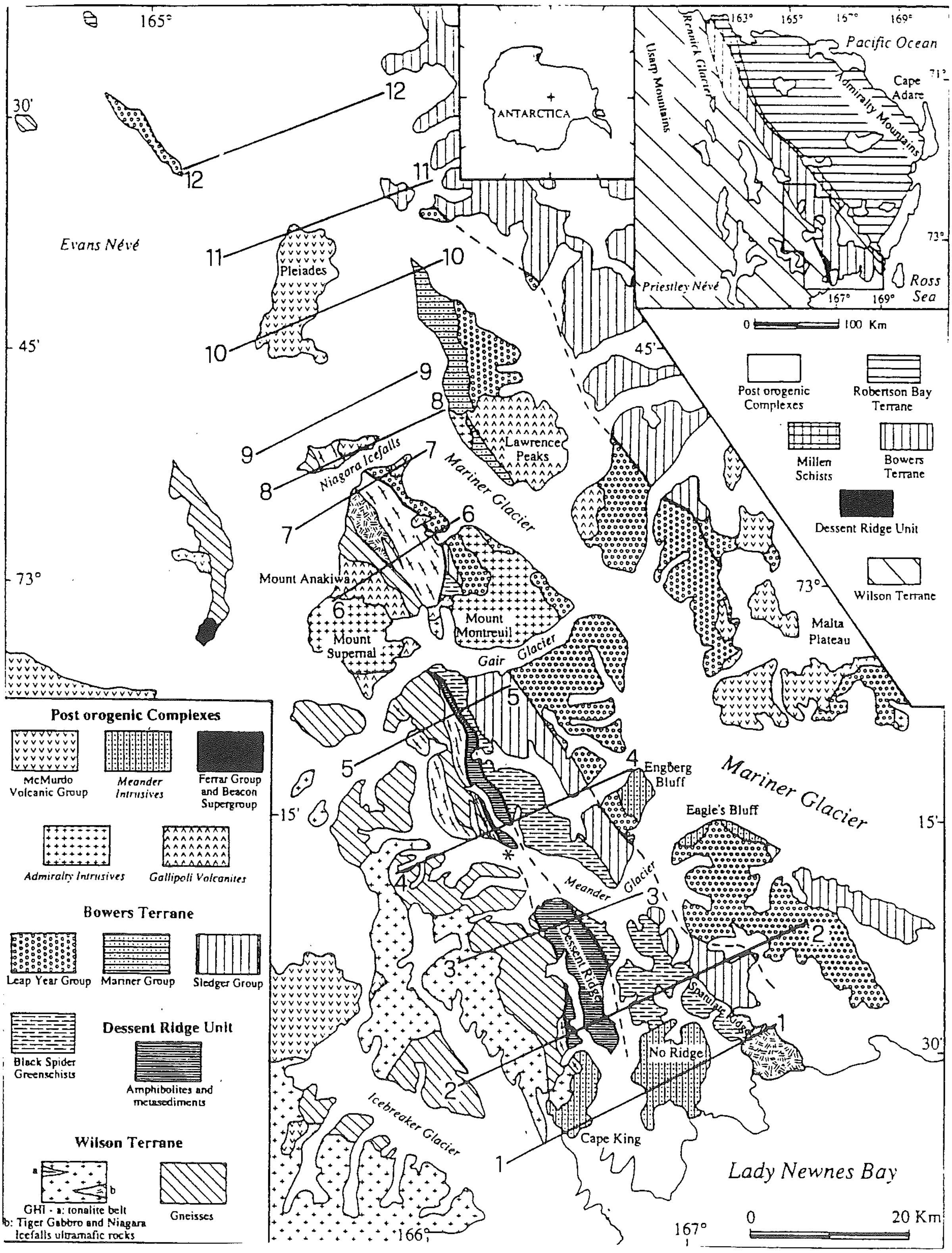

165°
30'
45'
73°
15'
Evans Névé
Pleiades
Lawrence Peaks
Niagara Icefalls
Mariner Glacier
Mount Anakiwa
Mount Montreuil
Mount Supernal
Gair Glacier
Engberg Bluff
Eagle's Bluff
Meander Glacier
Dessent Ridge
No Ridge
Cape King
Icebreaker Glacier
Lady Newnes Bay
166°
167°
0 20 Km
ANTARCTICA
Pacific Ocean
Cape Adare
Admiralty Mountains
Usarp Mountains
Rennick Glacier
Priestley Névé
Ross Sea
Malta Plateau
0 100 Km
Post orogenic Complexes
Robertson Bay Terrane
Millen Schists
Bowers Terrane
Dessent Ridge Unit
Wilson Terrane
Post orogenic Complexes
McMurdo Volcanic Group
Meander Intrusives
Ferrar Group and Beacon Supergroup
Admiralty Intrusives
Gallipoli Volcanites
Bowers Terrane
Leap Year Group
Mariner Group
Sledger Group
Black Spider Greenschists
Dessent Ridge Unit
Amphibolites and metasediments
Wilson Terrane
GHI - a: tonalite belt
b: Tiger Gabbro and Niagara Icefalls ultramafic rocks
Gneisses

fig. 6

The use of High Resolution Weather Satellite Imagery for the Support of Science.

Tom Lachlan-Cope

British Antarctic Survey

Abstract

The collection of Antarctic *in-situ* data for science is extremely expensive and there is great scope for the use of satellite observations in meteorology, glaciology and other disciplines. Early in 1993 a receiving station was installed at Rothera to pick up the High Resolution Picture Transmission (HRPT) data stream from NOAA series of polar orbiting weather satellites to help with meteorological research. The data stream contains information from several sensors but, perhaps the most useful is the imagery which has a 1km resolution in five spectral channels. From the beginning it was recognised that this facility would have applications for support of field operations. This has proved that to be the case and extensive use has been made of the image data received to support many scientific projects. Three applications of these data are described in detail:

1) The satellite imagery is used, in conjunction with standard meteorological data to nowcast the weather for air operations during the input of field parties to remote sites. The satellite data are found to be useful in detecting low cloud over snow and ice.

2) Satellite data can be used to calculate the sea surface temperature (SST) and fields of SSTs can be transferred from Rothera to marine biologists on research vessels in Antarctic waters in near real time.

3) The satellite images can be used to help with the navigation of ships through areas of pack ice.

1) Introduction

In February 1993 a satellite receiver was installed at Rothera Station (67° 34'S, 66° 08'W) to receive the High Resolution Picture Transmission (HRPT) data stream from the NOAA series of weather satellites. Its primary role was meant to be to provide data for meteorological research, however it was realized from the start that it would have an important role in operational research. The operational role has grown and it is now an essential tool for the forecaster who provides forecasts for the aircraft flying out of Rothera, as well as providing images that are used by the British Antarctic Survey's two ships.

2) The Satellite data

The main source of weather satellite data in the polar regions are the NOAA series of polar orbiting satellites. The geostationary satellites that are often used in the tropics and at mid latitudes have a very poor resolution at high latitudes. The NOAA satellites carry several instruments including the Tiros operational vertical sounder (TOVS) and the advanced very high-resolution radiometer (AVHRR). The AVHRR is an imaging instrument and produces images of the surface or cloud tops in five spectral bands in the visible and infrared regions. The resolution of the AVHRR imagery is around 1km directly below the satellite but gets worse towards the edge of the swath. Data from the NOAA satellites are transmitted down to the ground in two ways; one as a digital data stream at full resolution, the other as an analogue signal at reduced spatial resolution and with only two channels being present at one time.

3) The Satellite Receiver.

The Satellite Receiver was designed and built by Dundee Satellite Systems (part of Dundee University). It comprises a 2.4m steerable dish housed within a fiberglass radome. The dish itself is situated some way from the main buildings of the base so as to obtain a good view of the horizon. As Rothera is an operational airfield with vital radio equipment the problems of radio frequency interference (RFI) were carefully considered during the design stage of the receiver; both the satellite receiver interfering with the base radios and the radios interfering with the satellite receiver. To help reduce the problems of RFI the data and control links between the main building and the radome were made using fibre optic cables.

The control of the dish is split between two personal computers; one in the main building which acts as a remote slave for an industrial standard one in the radome. The industrial PC has no internal disk, its programs being stored on erasable programmable read only memory (EPROM). The industrial PC should be able to withstand cold temperatures better than a standard PC.

The electronics in the radome are housed in a heated cabinet. The cabinet is heated with a 1000-watt ceramic heater but is not insulated, making the regulation of the temperature much easier.

4) Operational products.

Although when the satellite receiver was installed its primary role for to provide data for scientific research it was recognized that the data would be very useful operationally. The main operational use for the imagery has been in support of the forecaster based at Rothera during the Austral summer. The forecaster provides a number of forecast products, but the main call on his time is to provide forecasts for the air operations. One of the more difficult tasks the forecaster is asked to carry out is to forecast condition at a remote site in the interior of the continent for the input of a field party. In particular, it is very difficult to distinguish between low cloud and fog from the underlying snow. However, using the high resolution imagery available and in particular the 3.7 micrometer channel it is possible to identify low cloud and fog, as can be seen if figure 1.

The infrared channels on the satellite can be used to extract a sea surface temperature (SST) field in areas that are cloud free. Several products have been developed from the basic sea surface temperature and these include a weekly mean SST image at 8km resolution and high resolution SST images of areas of interest. These products are transmitted to the ships over the satellite link for use during biological cruises.

One of the first uses identified for the data was to help the BAS ships navigate through pack ice. It was decided that the best way to use the data for this was to transmit the imagery to the ships via Inmarsat so that the interpretation could be done on the ship and the interpretation validated at once rather than the imagery being interpreted on the base and a coded map being transmitted to the ship. An area around the ship is selected, normally about 1000x1000kms, and imagery for this area is compressed using the JPEG image compression algorithm. This compression algorithm is a lossy one but the imagery it produces after compression shows very little loss to the eye and it can reduce the size of files to be transmitted by around 90%. Normally the ships are working in sea ice areas during the summer when there is 24hr daylight, so normally the visible channels are used (see figure 2 for an example). One of the problems with the AVHRR imagery is that it cannot see through cloud and unfortunately the fringes of Antarctica can be very cloudy. Some experiments have been made to use the difference between the two visible channels to reduce the effect of cloud.

5) Conclusion

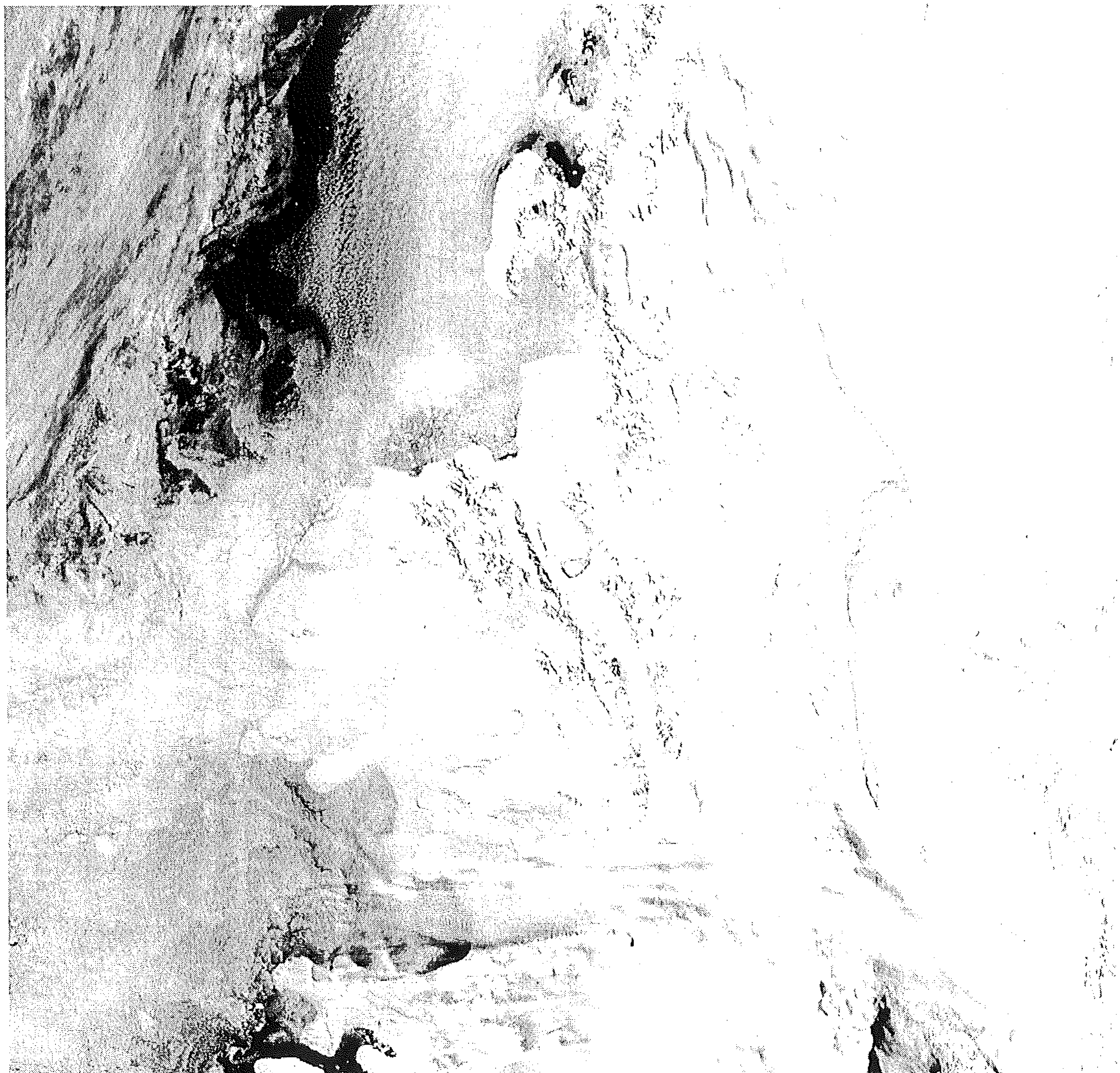
The Rothera HRPT satellite receiver has proved extremely useful for the planning and execution of operations in Antarctica. When it was first installed, although an operational role was foreseen, it was expected that it would be mostly a science instrument. Over the last four years of operation it has become more and more relied upon, replacing the existing APT receiver as the primary tool for forecasting for flying operations.

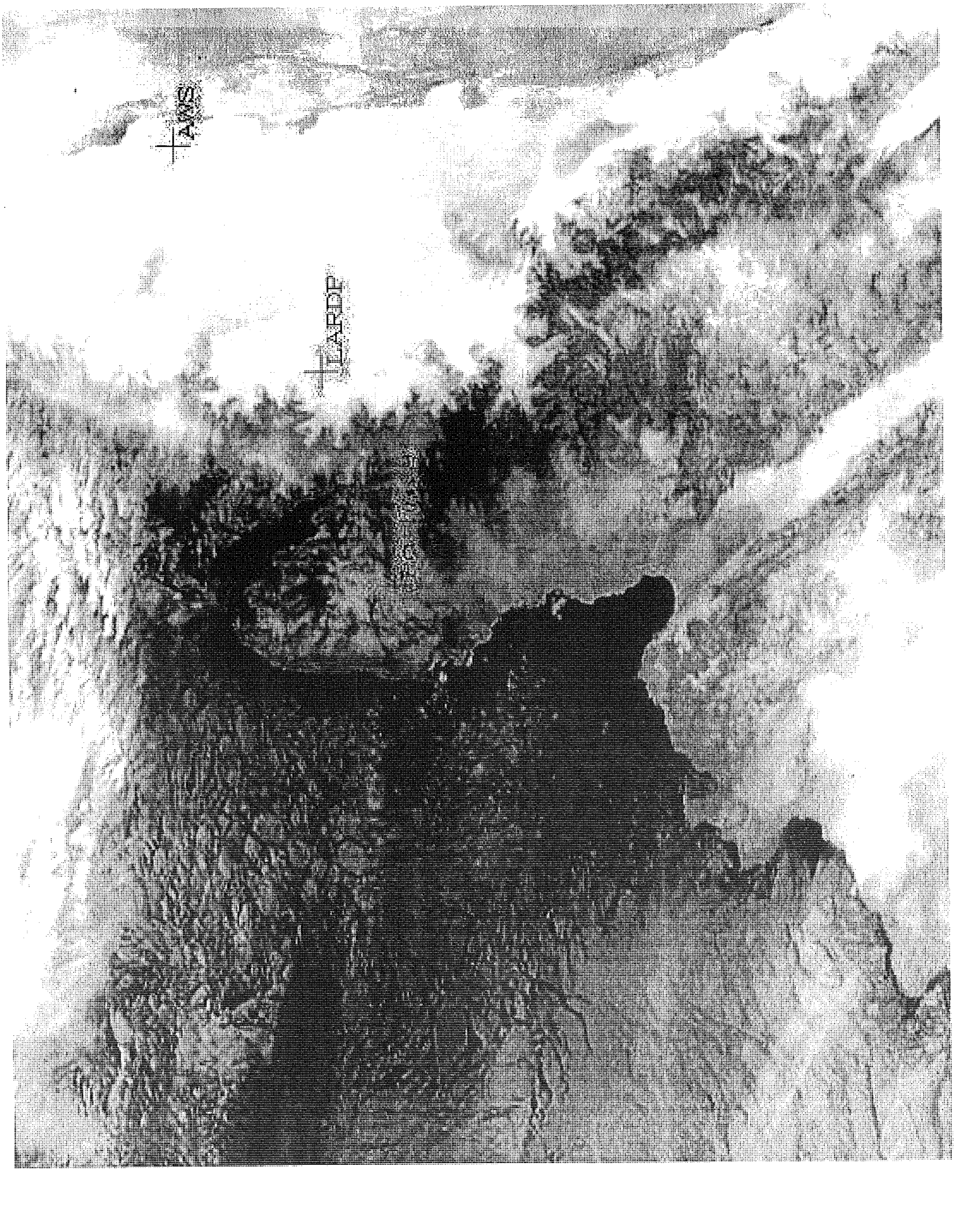
Figures

Figure1.a) Visible image of Alexander Island.

Figure1.b) 3.7 micrometer image of Alexander Island. An extensive area of low cloud or fog shows up white against the snow, which is dark at this wavelength.

Figure2. Infrared image showing sea ice close to Rothera base on 30th July 1997. The image compression algorithm has distorted the captions on the image.

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POTENTIAL FOR SIGNIFICANT WIND POWER GENERATION AT ANTARCTIC STATIONS

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Abstract

The Antarctic scientific stations are generally powered by conventional diesel boilers and generator sets which consume large amounts of fossil fuels. In addition to being difficult and expensive to ship, fuel can threaten the local environment.

The potential for wind power generation is high, but few commercial wind turbines can resist the harsh local conditions. The 10 kW "UM70X/GEV7.10" turbine was identified as the most suitable unit currently available. Its production potential was assessed and used as a basis for analysing several configurations of wind-diesel systems at the stations.

At some stations where conditions have been found to be favorable, modest investments in wind turbines would make significant contributions to the overall station energy requirements, while larger, more ambitious systems could make the stations near independent of fossil fuels.

Résumé

Les stations scientifiques de l'Antarctique utilisent généralement pour leurs besoins en énergie des chaudières et groupes électrogènes conventionnels qui consomment de larges quantités de combustibles fossiles. En plus d'être difficile et coûteux à acheminer, ce combustible peux menacer l'environnement local.

Le potentiel de production d'énergie éolienne est élevé, mais peu d'aérogénérateurs disponibles commercialement peuvent résister aux rudes conditions locales. L'aérogénérateur de 10 kW "UM70X/GEV7.10" a été identifié comme l'unité actuellement disponible la mieux adaptée. Son potentiel de production a été estimé et a servi de base à l'analyse de plusieurs configurations de systèmes éolien-diesel.

A certaines stations dont les conditions se révèlent favorables, des investissements modestes en aérogénérateurs contribueraient d'une façon significative aux besoins en énergie de la station tandis que des systémes plus importants et ambitieux pourraient rendre la station presque indépendante de tout combustible fossil.

1. INTRODUCTION

The Antarctic scientific stations require highly reliable power to ensure both the continuity of scientific activities and a suitable level of comfort for the expeditioners. Engineers have turned their minds to the use of renewable energy at the stations and, because of the high winds generally experienced, wind power has always appeared to be the most promising solution.

The early expeditions encountered reliability problems with wind turbines and found that conventional generator sets and boilers were the only satisfactory, practical answer to the reliable provision of the energy required at the stations. Although continually improved, the present energy systems still rely on the same basic principles. The primary power supply is diesel fuel based, with generator sets providing AC power as well as heat through jacket-water and exhaust heat recovery systems, supplemented by conventional boilers. This has the advantage of relying on well known highly reliable technology. The compactness of such systems is also an advantage at sites where space is scarce and where station installations have to share the area with local wildlife.

In addition to the atmospheric pollution caused by the exhaust gases, the operation of diesel power systems holds an inherent risk of fuel spills, notably during ship-to-shore transfers which can often take place under difficult circumstances. Sophisticated, expensive marine science vessels with tight schedules and numerous scientists on board can often be forced to spend several unproductive days at stations, while critical station fuel is transferred ashore. The absolute reliance of the station on imported fuel can exert pressure on logistic operations, and unexpected events, such as technical breakdowns or natural phenomena (storms, heavy ice cover), can threaten the closure or downgrading of station scientific activities and ultimately jeopardise the safety of expeditioners. This can be despite the existence of safety stocks and depots of fuel.

The pressure then is on to move away from the reliance on imported and environmentally unfriendly fuels by using renewables. Preliminary studies conducted in the framework of a cooperative French-Australian Project have identified wind power as the most promising solution for immediate implementation at the two nations' stations (Guichard, 1994a,b).

2. WIND CHARACTERISTICS AT STATION SITES

2.1 General conditions

Remote Antarctic stations generally have to face difficult wind conditions. Typical average wind speeds at coastal sites range from 5 to 10 m/s with a high frequency of strong winds and extreme top speeds where katabatic winds rush down the slopes of the ice cap. The area subject to the highest katabatic winds is the portion of the East Antarctic coast directly south of Tasmania. The average wind speed recorded by Douglas Mawson's Australasian Antarctic Expedition over 2 years (1912-13) at Cape Denison (66°59'S, 142°39'E) was 19.0 m/s, while at nearby Port-Martin (66°49'S, 141°24'E) Expéditions Polaires Françaises recorded over 1950-51 an average wind speed of 16.9 m/s (Parish, 1981). A record monthly average of 29.1 m/s was observed at Port-Martin in March 1951, which is three times higher than the highest monthly average recorded at Lerwick in the Shetland Islands, a place famous for its storms (Pettre & Andre, 1990). A record 2 minute average of 90 m/s has been experienced at Dumont d'Urville (66°40'S, 140°01'E) (Payan & Periard, 1991).

The Sub-Antarctic islands typically experience severe storms, with frequent gusty winds from 5 to 15 m/s, generally from the West. Top wind speeds are also very high with for example a highest gust of 80m/s recorded at Kerguelen Island (49°21'S, 70°14'E) in August 1970 (Météo France data), but temperatures are relatively mild. On the other hand, inland Antarctic sites are in the high pressure zone sitting on the Antarctic Ice Cap and face extremely low temperatures but moderate winds. For example, at South Pole, the minimum temperature recorded is -82.8°C with an average of -49°C, but the maximum wind gust is of only 24.2m/s for an average wind speed of 5.4 m/s.

Table 1 summarises temperature and wind conditions at French and Australian Stations plus some other selected Antarctic and Sub-Antarctic sites. Two Tasmanian sites are included for comparison. The table demonstrates how the average wind speeds encountered in Antarctic coastal and sub-Antarctic sites (5 to 19 m/s) are promising for wind power generation, but the maximum wind gusts (51 to over 90 m/s) threaten to destroy the turbines.

2.2 Wind Speed Frequency Distribution

The preliminary assessments of wind power potential presented in Guichard (1994b) were based exclusively on average wind speeds by assuming the wind speed frequency distributions to be a Weibull distribution of factor 2. Extensive data sets obtained since have allowed actual wind speed (at 10m height) frequency distributions to be determined for several stations. More stations will be added as data sets come in. The frequency distributions shown here were calculated by separating wind speeds into 20 bins of 3 m/s range between zero m/s (non inclusive) and 60 m/s (inclusive), plus the zero value and the values larger than 60 m/s.

Figure 1 outlines the shape of the frequency distributions obtained, at Casey, Davis, Dumont d'Urville, Macquarie Island and Mawson for all complete years of available data. Only complete years were used to eliminate the bias introduced by seasonal variations. Casey and Davis show a sharp peak located between 0 and 10 m/s while Macquarie Island shows a sharp peak between 5 and 15 m/s. Dumont d'Urville and Mawson have a larger spread of speeds from 0 to 20 m/s, with a larger concentration in the lower half (0 to 10 m/s) for Dumont d'Urville and in the higher half (10 to 20 m/s) for Mawson.

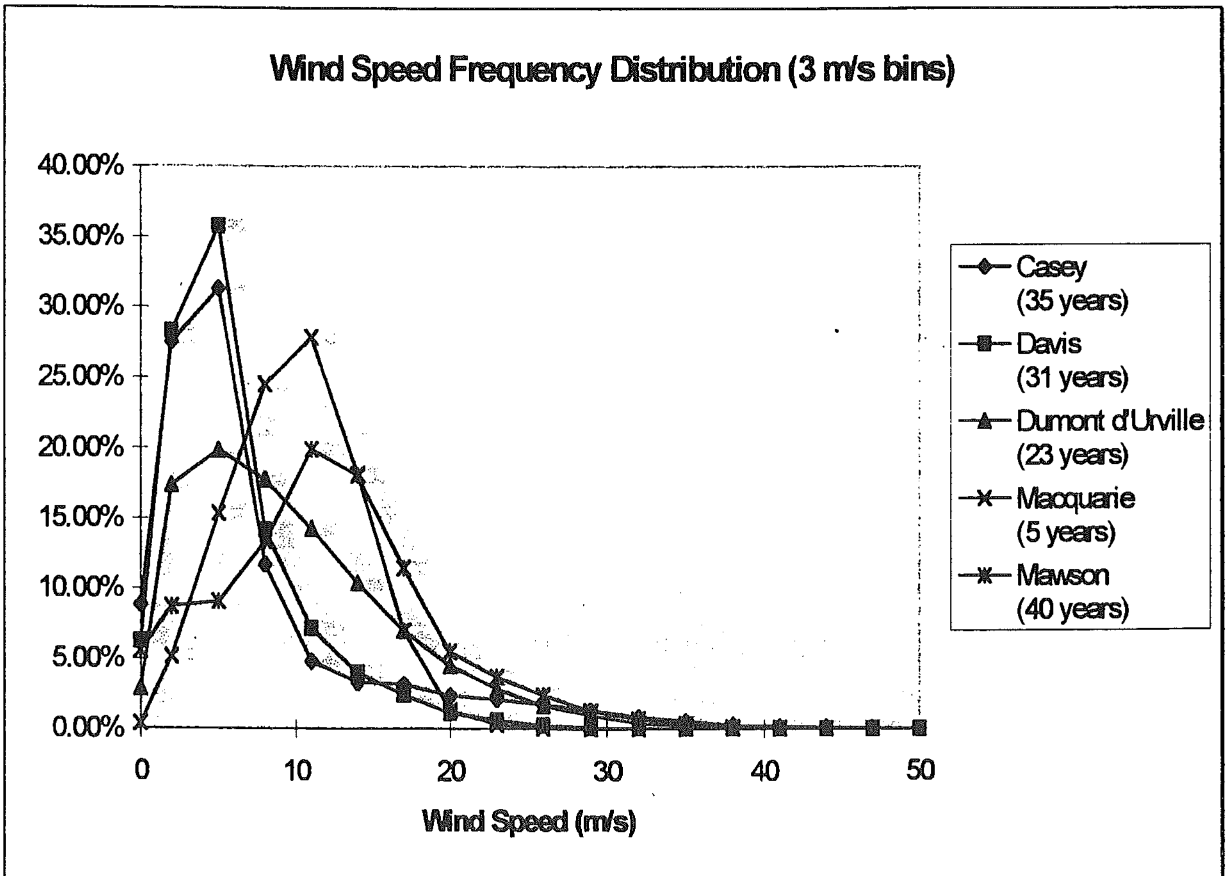

Figure 1: Wind Speed Frequency Distribution at Selected Locations

Air Temperature and Wind Speed Summary
at selected locations
(Antarctic, Sub-Antarctic & Oceanic, Tasmania)

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Location	Data Availability	Comment	Lat	Long	Elev.	Air temperature (Deg. C): Average: from 3h measures (1)	Air temperature: Average: from daily (Min+Max)/2 (5)	Air temperature: Average: (Mean Min + Mean Max)/2 (6)	Air temperature: Minimum: from spot measures (1)	Air temperature: Maximum: from spot measures (1)	Wind Speed (m/s): Average: from Daily Run	Wind Speed: Average: from 3h 10minAv (2)	Wind Speed: Maximum: from 3h 10minAv (2)	Wind Speed: Maximum: from spot 2min av. (3)	Wind Speed: Maximum: from spot Inst. Gust (4)	Highest Monthly Average (2)	Lowest Monthly Average (2)
Casey	from 1960	Antarctic, Coastal	66°17S	110°32E	12 m			(a) -8.85	(a) -41.0	(a) 9.2	(a) 6.77	(h) 6.5	(h) 50.9		(a) 80.76		
Davis	1957-64, then from 69	Antarctic, Coastal	68°35S	77°58E	12 m			(a) -10.25	(a) -40.0	(a) 13.0	(a) 4.88	(h) 5.1	(h) 47.3		(a) 57.1		
Mawson	from 1954	Antarctic, Coastal	67°36S	62°52E	8 m			(a) -11.25	(a) -36.0	(a) 10.6	(a) 10.66	(h) 11.2	(h) 50.9		(a) 68.9		
Dumont d'Urville	from 1956	Antarctic, Coastal	66°40S	140°01E	43 m		(e) -10.6					(p) 9.4	(p) 50.0	(k) 90		(e) 19.5	(e) 5.0
Port Martin	1950-51	Antarctic, Coastal	66°49S	141°24E	20 m							(m) 16.9				(n) 29.1	
Cape Denison	1912-13	Antarctic, Coastal	66°59S	142°39E	25 m							(m) 19.0					
South Pole	from 1957	Antarctic, Inland	90°00S	-	2 835 m	(f) -49			(f) -82.8	(f) -13.6		(f)? 5.4			(f)? 24.2		
Dome C	1980-82 & 84-92	Antarctic, Inland	74°40S	124°10E	3 200 m	(g)? -50.8			(g)? -84.6			(g)? 2.8			(g)? 17		
Macquarie	from 1948	Island, Sub-Antarctic	54°30S	158°56E	6 m			(a) 4.75	(a) -8.9	(a) 14.4	(a) 7.93	(i) 9.4	(i) 28.8		(a) 51.4		
Kerguelen	from 1951	Island, Sub-Antarctic	49°21S	70°14E	29 m	(b) 4.7		(b) 4.75	(b) -9.4	(b) 25.8		(b) 9.8			(b) 80		
Crozet	from 1956	Island, Sub-Antarctic	46°26S	51°52E	142 m			(c) 5.6	(c) -4.0	(c) 21.9		(d) 10.7			(d) 70	(d) 16.6	(d) 7.5
Amsterdam	from 1950	Island, Oceanic	37°50S	77°34E	28 m	(b) 13.8		(b) 13.9	(b) 1.8	(b) 25.2		(b) 7.4			(b) 56		
Hobart	?	Tasmania	42°53S	147°20E	55 m			(a) 12.5	(a) -2.8	(a) 40.8	(a) 3.14	(i) 4.0	(i) 16.5		(a) 41.67		
Maatsuyker	from 1891	Island off Tasmania	43°39S	146°16E	147 m							(i) 10.3	(i) 41.2				

Notes:

(1) Obtained from the set of standard 3hourly (3h) Temperature measures
(instantaneous measures taken every 3 hours, usually at 00h, 03h, 06h...UTC)
(2) Obtained from the set of standard 3hourly 10minute Average (3h 10minAv) Wind Speed measures
(averages over the previous 10 minutes, taken every 3 hours, usually at 00h, 03h, 06h...UTC)
(3) Highest 2minutes average over full time (that is, not restricted to set of standard measures)
(4) Highest instaneous gust over full time (that is, not restricted to set of standard measures)
(5) Obtained by averaging of all the daily "(Absolute Daily Temp. Maximum+Absolute Daily Temp. Minimum)/2"
(6) Equals "(Mean of all Absolute Daily Minimums + Mean of all Absolute Daily Maximums)/2"

(?) Method used to measure/process data not confirmed

(a) in Australian Bureau of Meteorology (MetBureau) Summary Data Sheets for all years of record to the end of 1991
(b) in Météo France Summary Data Sheets for all years of record to the end of 1993
(c) computed from Météo France Summary Data Sheets for individual years 1989,90,91,92,93
(d) in Météo France Summary Tables of Monthly Mean Wind Speed and Monthly Maximum Gust for 1966 to 1990
(e) computed from Météo France Summary Tables of Monthly Mean Wind Speed and Temperature for 1956 to 92
(f) Originates from U.S. Meteorology data, no details on original data set
(g) computed from AWS data 1980-82 & 84-92 found in Keller et al., 1994 and previous years
(h) computed from MetBureau standard 3hourly data for all complete years available
(Casey: 61-94, Davis: 58-63 & 70-94, Mawson: 55-94)
(i) computed from MetBureau standard 3hourly data for 5 complete years (1990-94)
(k) in Payan & Periard, 1991
(m) in Parish, 1981
(n) in Pettre & Andre, 1990
(p) computed from Météo France standard 3hourly data for all complete years available (1970-87 & 88-93)

Table 1: Air Temperature and Wind Speed Summary at Selected Sites.

3. TURBINE PERFORMANCE

The problems of finding suitable turbines for Antarctic sites have been discussed comprehensively (in Guichard & Steel, 1993; Guichard, 1994a & 1994b; Guichard, Magill, Steel & Lyons, 1995; Guichard, Magill, Godon, Lyons & Brown, 1995). The following account is an up-to-date summary of these discussions.

The potential for wind power generation was recognised during the first expeditions and wind generators were tested and used. The powerful gusty winds combined with low temperatures brought high failure rates. This, as well as energy storage problems and the continuing need for complete back-up systems, led to the withdrawal of wind turbines from Antarctic operations, with the exception of a few small remote field installations for powering limited scientific and communication equipment. The small turbines which worked in field installations were usually rugged oversized turbines. They are not a realistic option for larger systems designed to power the permanent stations. Several interesting developments and trials of prototypes have taken place, notably since the mid eighties, but with mixed results.

At Amsterdam Island (37°50S, 77°34E, Sub-Antarctic to Oceanic conditions) in December 1986 an experimental vertical axis 10m diameter Darrieus rotor "CEA30-AD10" (3 blades, 67.7 m2 swept area, rated 30 kW at 13.5 m/s) was installed. It showed early promise with daily energy production of 400 kWh recorded for wind speeds ranging from 12 to 25 m/s (Perroud et al., 1991). But serious braking problems threatened on several occasions to destroy the machine. These problems were not solved, partly because of their difficulties and also because the main engineer supporting the project retired. The rotor was locked, then scrapped, the project having lapsed in an atmosphere of general indifference and lack of support.

At Georg Von Neumayer Station (70°37S, 8°22W, Coastal Antarctic) in 1991 a vertical axis 10m diameter H rotor "HMW-56" (3 blades, 56 m2 swept area, rated 20 kW at 9 m/s) was installed. It is characterised by simplicity (permanent magnet, no mechanical transmission), has a survival wind speed of 68 m/s and a minimum operating temperature of -55°C (Heidelberg et al., 1990). In its second year of operation, it was running continuously without interruptions and breakdowns and producing roughly 5 to 15% of the energy requirement of the station (Kohnen, pers. com., 1993).

Meanwhile, a small number of manufacturers have developed mature commercial products for the limited and specialised market of stand-alone operation in very difficult wind conditions, cold and/or corrosive environments. These high quality products have already proven their reliability and cost effectiveness in conditions nearly as difficult as the East Antarctic coastal stations and Sub-Antarctic islands where they are now starting to show satisfactory results.

In McMurdo Sound, deep in the Ross Sea, Northern Power Systems "HR3" horizontal axis turbines (3-bladed, 5m diameter, 19.6m2 swept area, 3 kW at 12.5 m/s, DC output, rated survival wind speed of 74 m/s -gusts-) have operated since 1985 in gusts of up to 71 m/s (256 km/h), contributing to a wind-solar-diesel hybrid system powering communication facilities at Black Island near McMurdo Station.

At Heard Island (53°6S, 73°57E, Sub-Antarctic) in 1992/93, a 10kW horizontal axis Aérowatt "UM70X" turbine (2-bladed, variable pitch, 7m diameter, 38.5 m2 swept area, 3-phase 380/415V AC output, rated survival wind speed of 110 m/s -gusts-) was used successfully for 3 months, at times producing all of the electrical needs at the five persons Spit Bay station.

This same UM70X unit was reerected in March 1995 at Casey Station (66°17S, 110°32E, East Antarctic Coast) and upgraded in May 1996 to its new improved version, the Vergnet "GEV7.10". The turbine operation initially encountered problems which although sometimes difficult to identify ended up being minor and relatively easy to fix. For example, insufficient sealing resulted in snow filling up one of the inertia bars, significantly unbalancing the rotor. The turbine is now running smoothly and despite the initial problems has generated around 10 MWh in the year July95-June96, with a peak of 2 MWh in April 96.

The Vergnet turbines are well designed for extreme wind conditions and, to the best of our knowledge, currently offer the highest resistance to extreme winds in the medium power range together with high efficiency and low maintenance requirements. They have proved their effectiveness in difficult conditions, have survived 90†m/s gusts in the Indian Ocean at Tromelin and have operated satisfactorily since early 1995 at Kerguelen Island (49°21S, 70°14E, Sub-Antarctic).

Although long term reliability has not yet been fully demonstrated at the stations, these last two examples tend to indicate that satisfactory operation can be achieved with selected high quality products after proper trials and minor adaptations.

Table 2 lists the characteristics of the two successful horizontal axis commercial turbines HR3 (3kW) and GEV7.10/UM70X(10 kW), the two experimental vertical axis turbines "CEA30-AD10" (Darrieus Rotor, 30 kW) and "HMW-56" (H Rotor, 20 kW), two medium size Australian machines "BW-10" (10 kW) and "S-20000" (3 kW equivalent -no official rating-) as well as the Danish 'Utility Size' Vestas "V29" (225 kW). We have to note that the last three machines are not designed for extreme conditions such as those encountered down south, and that the V29 would not even be suited to the size of the stations and to the associated logistic support. The V29 is definitely not an option for Antarctica but can act as an interesting benchmark.

The respective power curves which provide a qualitative measure of the various turbines' potential output and suitability to various wind conditions are shown in Figure 2. The following points should be noted: the relatively large curve envelopes of the V29, S20000 and GEV7.10/UM70X which could generate large amounts of power in windy areas, and the very early start of the S20000 which allows good production in areas of moderate winds.

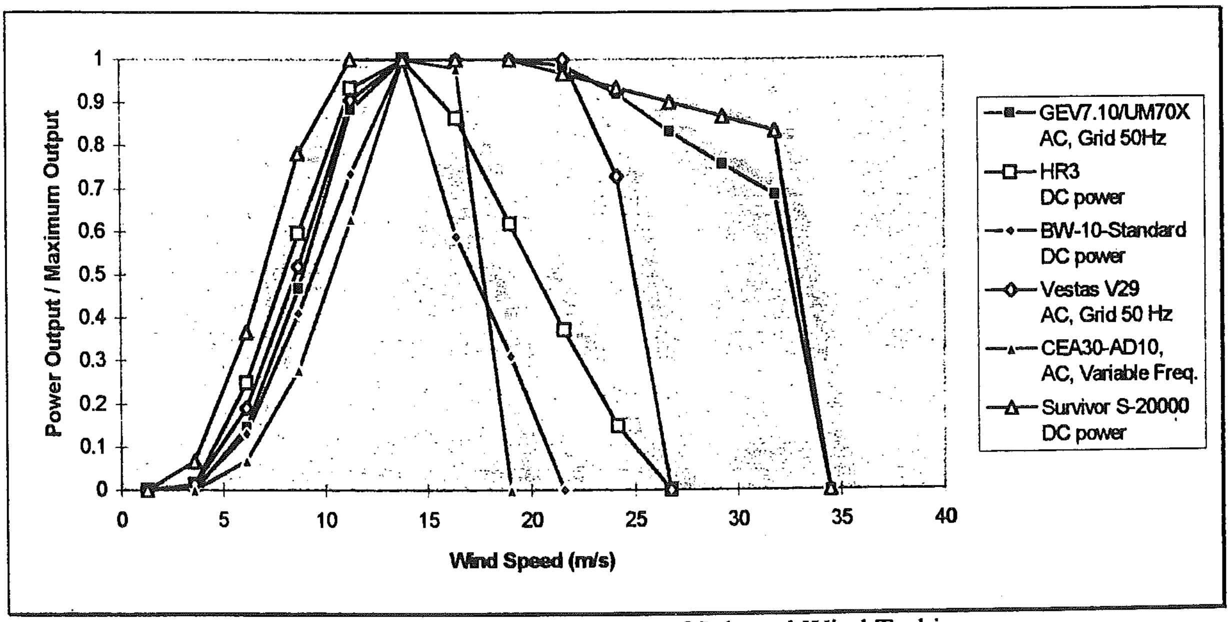

Fig. 2: Normalised Power Curves of Selected Wind Turbines

4. WIND POWER POTENTIAL

The outline power curves and purchase costs were used to assess the relative potential output and power generation cost of these turbines at Casey, Davis, Dumont d'Urville, Macquarie Island and Mawson (in Guichard, Magill, Godon, Lyons & Brown, 1995). The relative cost indicators combined with the proven or expected reliability of the turbines at such sites led to the conclusion that the Aérowatt UM70X / Vergnet GEV 7.10 was currently our best option.

TURBINE	Rotor Type:	Rotor Diameter (m)	Swept Area (m2)	Hub Height (m)	Nb of blades	Output:	Rated Power (kW)	Max Power (kW)	Min. Operating Temp. (°C)	Survival Wind Gust (m/s)	Priced Configuration	Listed Price	Purchase Price Est. ($A)
GEV 7.10 / UM70X (Vergnet S.A.)	Horizontal Axis, Upwind, Stall Regulated Rotation Speed by Blade Pitch Control	7,0	38,5	18, 24 or 30	2	AC- 3 phase grid compatible, Asynchronous Generator 220-240V, 380-415V, 50Hz	10	12,44	?	90	Turbine, 18m tower : with Grid Connection :	224 800 251 600 (FRF)	59 200 66 200
HR3 (Northern Power Systems)	Horizontal Axis, Upwind, Fixed Pitch, Variable Axis Control, Direct Drive	5,0	19,6	12 to 30	3	DC - 24, 48 or 110V, 3 phase synchronous generator	3	3,10	-60	74	turbine, tower & controller :	17 000 (USD)	22 000
BW-10-Standard (Bergey/Westwind)	Horizontal Axis, Upwind, Auto Tail Furl, Direct Drive	7,0	38,5	12 or 18	3	DC - 96 or 120V, Permanent Magnet Generator	10	9,95	-40	60	turbine, 18m tower, controller, extra stiff blade option :		36 125
Survivor S-20000 (Synergy Power Corporation)	Horizontal Axis, Downwind Variable Rotor Area, Gearbox 2.78:1	5,8	26,4		3	DC - 24 or 48 V Permanent Magnet Generator	3	3,00	?	?	turbine, 25m tower, Control Panel :		22 863
HMW 56 (Heidelberg Motor et al.)	Vertical Axis, H-Rotor Direct Drive	10,0	56,0	10,0	3	AC- Variable Frequency, Permanent Magnet Travelling Field generator	20	?	-55	68	n/a	n/a	n/a
CEA-30 AD10 Variable Speed (CEA-Grenoble)	Vertical Axis, Darrieus Rotor, Gearbox	10,0	67,0	15,0	3	AC - 3 phase Variable Frequency, Synchronous Generator	30	29,10	?	?	n/a	n/a	n/a
Vestas V29 (Vestas Wind Systems A/S)	Horizontal Axis, Pitch Regulated, Gearbox 24.6:1	29,0	661,0	31,5	3	AC - 3 phase Grid Compatible, Asynchronous Generator 420V, 50Hz	225	225	?	?			

Antoine Guichard - July 1996

Table 2 : Main Characteristics of Selected Wind Turbines

4.1 Average Output

The estimation of the average output (and average load or utilisation factor) of this turbine at the stations is the first step towards the assessment of complete production systems, and is a good way to overview the potential for wind generation, notably as a simple additional contributor to the existing systems. The utilisation factor is the proportion of the rated output that will effectively be produced by the turbine on average.

Table 3 summarises the general wind parameters at our five stations along with the average utilisation factor currently estimated for the UM70X/GEV7.10 turbine. Casey and Davis show reasonable although limited potential while Dumont d'Urville, Macquarie and Mawson show high potential.

	Average Wind Speed [3h data] (m/s)	Maximum Wind Speed [3h data] (m/s)	Maximum Recorded Wind Gust (m/s)	UM70X /GEV7.10 Utilisation Factor
CASEY	6.5	50.9	80.8	26.6%
DAVIS	5.1	47.3	57.1	22.8%
DUMONT D'URVILLE	9.4	50.0	90.0 *	59.8%
MACQUARIE ISLAND	9.5	28.8	51.4	68.6%
MAWSON	11.2	50.9	68.9	76.5%

Note: * 2 minute average

Table 3: Wind Conditions and Estimated Utilisation Factor of the UM70X/GEV7.10 Turbine

4.2 Optimum Wind-Diesel System Options

The average output is only significant if all of the turbine's output can be used. In a Wind-Diesel system, it means being able, at any given time, to feed whatever amount of power is produced by the wind farm into the grid, without affecting the operation of the diesel generators. The practical limit is generally estimated at 40% penetration of wind power, corresponding to 60% of the grid being still supplied by the diesel generators (Brown, 1997).

Different system options were extensively investigated by Brown as part of an MSc project at IASOS (Brown, 1997; Brown et al. 1996a,b). In addition to the direct connection limited to 40% penetration, Brown has considered:

- The addition to the grid of limited power regulation equipment allowing 100% penetration of wind power and intermittent operation of the diesel generators (excess wind power is dumped).
- The inclusion of battery storage with two way inverters sized to take all excess wind power and take all station load (excess wind power is dumped once storage is full). Diesel generators only come in when the amount of energy stored is too low to supplement the wind farm to the level required by the station.

Table 4 summarises some of the optimum options identified by Brown for the four Australian Stations (in Brown, 1997; Brown et al., 1996a). The wind capacity is proportional to the physical size of the wind farm but also to the capital outlay, the proportion of station load met by wind energy is proportional to the diminution of fuel needs and atmospheric pollution while the utilisation factor is proportional to the effective usage of the wind farm then also to the return on the capital outlay. On a financial point of view, it must be remembered that each system evolution considered below involves an additional cost for existing stations.

	Installed Wind Capacity (kW)	Portion of Station Load Met	Annual Fuel Savings (ltrs/yr)	Wind Farm Utilisation Factor
- CASEY -				
Direct (up to 40% Penetration)	75	8%	37 776	0.19
with Additional Load Regulation	200	20%	94 440	0.18
- DAVIS -				
Direct (up to 40% Penetration)	100	10%	56 708	0.23
with Additional Load Regulation	200	20%	113 417	0.23
- MAWSON -				
Direct (up to 40% Penetration)	110	25%	164 602	0.61
with Additional Load Regulation	250	60%	394 995	0.65
with 6 hours Storage Capacity	450	80%	526 661	0.48
with 1 day Storage Capacity	525	90%	592 494	0.46
- MACQUARIE -				
Direct (up to 40% Penetration)	55	30%	57 170	0.37
with Additional Load Regulation	70	60%	114 337	0.58
with 6 hours Storage Capacity	100	80%	152 450	0.54
with 1 day Storage Capacity	125	90%	171 506	0.49

Table 4: Some Optimum Wind-Diesel System Options [from Brown (1997) & Brown et al. (1996a)]

The figures clearly show that significant fuel savings can be achieved at Casey and Davis with simple systems while the potential is high to make Mawson and above all Macquarie near independant of fossil fuels.

It should be noted that a large increase in installed wind capacity (250 to 450 kW) is required at Mawson to go from 60 to 80% fuel savings, and that there is relatively little performance effect brought by extending storage from 6 hours to 1 day capacity. The decrease of the utilisation factors (and hence of the financial returns) is linked to the dumping of excess power. Future studies will add to the system options ways to meet some station needs with this excess power.

It is especially important to note how modest installed capacities of 110 and 55 kW simply connected to the existing systems could immediately meet 25 and 30% of the station load at Mawson and Macquarie Island respectively.

The configurations were identified as "optimum" with respect to various parameters, notably with a view towards meeting a high proportion of the load with wind power (priority to fuel savings). Giving the priority to other factors such as the return on investment independantly of the fuel cost would lead to different optimum configurations. Future studies will include the costing of all system components and assess the different configurations with respect to a wide range of parameters.

5. CONCLUSIONS

There is considerable potential for the application of wind power at Antarctic station sites, particularly given the need for environmentally sound, locally produced power. But experience shows that very few turbines will survive the severe conditions. The high failure rates of the past have not only led to the withdrawal of turbines from the stations but have seriously discredited wind power and its ability to serve Antarctic stations.

Recent and ongoing trials of selected machines have showed promise. Further trials and progressive installation of wind generators, connected to the existing grid or powering specific buildings or applications can allow a progressive increase of wind power generation. The introduction of further load regulation or energy storage systems can then lead to significant energy sustainability at the Antarctic stations.

6. ACKNOWLEDGMENTS

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WASA - ANALYSIS OF ENERGY REQUIREMENTS FOR THE SWEDISH RESEARCH STATION IN ANTARCTICA

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ABSTRACT

The object of this project was to investigate how the consumption of diesel oil for the station can be minimised by building technological measures and replacement of the existing energy supply by solar and wind power. All electric power is today produced by a diesel driven generator. Energy calculations based on readings were performed with the computer program DEROB-LTH. Comparisons were made with the measured consumption. Using DEROB simulations, parametric studies were carried out. If all the measures set out were taken -which are all considered to be carried out reasonably easily-, total energy consumption by the station would be reduced from 94 to 44 MWh annually, a saving of 53%. In terms of diesel oil, this represents a drop from about 21 m^3 to just under 10 m^3. By far the most important measure appears to be utilisation of generator losses.

1. INTRODUCTION

There is today an increasing awareness of the sensitivity of the Antarctica environment. This causes an increasing attention to the environmental impacts of all activities in the region. The object of this project was to find how the consumption of diesel oil can be minimised at the Swedish research station in Antarctica.

The project is a part of a larger project with participating researchers from the technical universities at Lund, Göteborg and Luleå. They have studied and evaluated the influence of climate on materials and constructions, conservation of heat and energy improvements in order to utilise solar energy and wind power for the operation of the station and methods of water saving and waste water treatment.

This paper, based on Thormark et al. (1996), presents the research concerning the energy requirements; building technological measures as well as the possibilities to use solar energy and wind power.

Measurement data from field investigations were collected. Climate data have been used as input in physically based models which describe the station. Other measurement results have been used in verifying the model. When the model worked reasonably well, studies were made of e.g. the effect of different technical measures or the way the Wasa station operated during the hole year.

2. DESCRIPTION OF WASA STATION

2.1 The building

The research station, named Wasa, was built in 1988/89 in Queen Maud Land and is situated on a nunatak, i.e. a rocky peak projecting from the 700 m thick ice sheet.

In designing the station, great importance was given both to environmental and energy issues and to a high degree of reliability and low maintenance. The main building, 117.6 m^2, is prefabricated and has sleeping accommodation for 12 people. It is a highly insulated and windtight timber building, based on experiences gained in traditional Swedish timber construction. The building is founded on steel columns and piers. The bottom of the floor construction is over 1 m above ground level in order to reduce load due to snow and wind. The station also has a building with a workshop and store, made up of three steel containers.

A total of 36 sensors/transducers were installed in the main building to record temperature, moisture and relative movements between the prefabricated sections.

2.2 Description of the technical systems

Energy is primarily supplied by a diesel driven generator. The building is heated by direct acting electric radiators. Hot water is produced by an electric water heater. The ventilation system is connected to a heat exchanger. The total connected load of the station was 50,140 W.

Fresh water supply was planned to be provided for by melting ice by pouring hot water over it. However, water in the liquid phase was available at the site during the summer. All equipment as tabs, dishwasher etc. were carefully chosen in order to minimise water consumption and dry closets were installed. The principal task for wastewater was to separate and purify all of it in an experimental plant for evaporation in order to minimise environmental effects.

2.3 Solar collectors

The Department of Building Science has produced air heating solar panels for space heating. The panels are constructed of three layers of polycarbonate sheets with two intermediate air gaps and air is drawn by fans through the inner gap. The panels have only been used to heat the container building.

3 INVESTIGATIONS IN THE FIELD

3.1 Description of method

Measurements were made using programmable data loggers and no manual readings was considered to be necessary. The measurement interval varied from 10 seconds to 5 minutes depending on the measurement point. These measurements were then integrated over 1 hour, stored in the data logger and transferred to a PC once a day.

Indoor and outdoor temperatures were measured continually over three years. Supplementary measurements in the main building were made concerning windtightness, infiltration and ventilation. Measurements were also made on solar panels, solar cells, wind generator and outdoor climate. Measurements on the wind generator, however, were interrupted as it caused interference from the generator and had too great an effect on the other measurements.

Reliable measurements regarding electrical energy, tap water, solar panels and the evaporation plant were collected during the period when the station was occupied.

3.2 Satellite based data transmission

In the winter of 1991/92 a satellite based measuring system for transmission of outdoor climate data was installed in Wasa. In simple terms, two portable telex machines, one in Wasa and one in Lund, transmit data to each other via the satellite. The system at Wasa and possibilities to reprogramming from the home terminal worked extremely well.

The weak point of the system is power supply. The transceiver cannot withstand temperatures below 0°C. The intention was that batteries, charged by solar cells, in combination with a wind generator would supply the system with heat. The wind generator, however, was destroyed by a storm in winter 1991.

4 CONSUMPTION STATISTICS

4.1 Electricity for household and space and water heating

The electricity consumption was not measured in a sufficient number of items due to the design of the electrical installation. It was therefore necessary to estimate a breakdown of the energy consumption, see tables 4.1 and 4.2.

Table 4.1. Estimated breakdown of electrical energy of 3,562 kWh measured in January 1992.

Equipment	Energy (kWh)
Fans and pumps	1 928
Heating in extra container	535
Heating cables	223
Fans for solar panels	435
Household electricity	441
Total	**3 562**

Table 4.2. Estimated breakdown of electrical energy of 2,449 kWh measured in January 1992.

Equipment	Energy (kWh)
Sauna	550
Hot water	633
Heating in container	297
Electrical tools	150
Heating in building	819
Total	**2 449**

4.2 Measured water consumption

For Wasa 50 l was considered to be a reasonable target. The actual consumption during the expedition in 1991/92 was on average 60 l per person per day, with a variation between 40 and 80 l. 24 l of the 60 l was hot water.

5 THE HEATING REQUIREMENTS OF THE BUILDING

The calculated losses are broken down into fabric, ventilation and waste water losses, specific losses and heat gains from occupants and electricity.

5.1 Calculated fabric losses

Theoretical values of thermal transmittance have been calculated for the different parts of the building. The specific fabric losses were 59.9 W/K without corrections for workmanship (ΔUg), design details (ΔUk) and solar radiation. With corrections the losses increase to 70.1 W/K which is approximately 23% of the total heating requirement for January 1992.

Table 5.1. Calculated fabric losses

	UA (W/K)	Jan. 1992 (kWh)	Calculated annual consumption (kWh)
Fabric losses, windows, doors	16.10	276	4 838
Fabric losses, other	43.80	752	13 160
Total fabric losses	**59.90**	**1 028**	**17 998**

A = total enclosing area in contact with the indoor air (m^2)

5.2 Calculated ventilation losses

The ventilation losses have been calculated on the basis of the tracer gas measurements made at the station. Average infiltration represents 0.2 air change per hour (ach) and ventilation 0.6 ach. To the ventilation system there is a heat exchanger connected with an assumed efficiency of 60%. Opening of windows, among others due to the significant heat contribution during the summer months, is considered to represent in average 0.075 ach.

Table 5.2 Calculated ventilation losses without window opening

Specific losses through infiltration and window opening	25.6	(W/K)
Specific losses through ventilation (60% recovery)	22.4	(W/K)
January 1992 (60% recovery)	823	(kWh)
The whole year (60% recovery)	**14 422**	**(kWh)**

5.3 Waste water losses

The waste water losses have been calculated as the calculated electrical energy for hot water plus the electrical energy used by the dishwasher and washing machine, less losses in the water heater. This gives a total of 728 kWh for January 1992 and 8,569 kWh annually. This works out at 2.4 kWh per person per day.

5.4 Gains from occupants and electricity

The gains from occupants, assumed to be 1.2 kWh per person per day, have been calculated by estimating the time spent by the occupants in the different modules in the main building. Gains from occupants, household electricity etc. give the station a total increment of 606 kWh during January, and 7,135 kWh over the whole year.

5.5 Calculated annual consumption

In the calculation of annual consumption the contribution of solar radiation is not included. This is due to the fact that is not possible to estimate by simple manual calculations how much solar radiation can be utilised as a heat gain.

Table 5.3 Calculated annual consumption without solar contribution.

	Specific heat requirement (W/K)	Calculated annual consumption (kWh)
Fabric losses	59.9	17 998
Ventilation losses	48.0	14 422
Waste water losses		8 569
Total		40 982
Heat gains from occupants and electricity		-7 135
Grand total		**33 854**

6 ANALYSIS OF ENERGY BALANCES

6.1 Computer program

The computer program DEROB-LTH (Dynamic Energy Response of Buildings) has been used to simulate the energy balance in the main building (radio building). The program enable calculations of temperatures and energies to be performed for buildings of arbitrary shapes.

The program system comprises 7 modules, each and every one of which is executed as an independent program. Information between the different programs is exchanged by means of a number of files in which output data from one module constitute the input data for the next module.

The computation modules are as follows:

- translation of the user's geometrical information for the whole building into a representation in an orthogonal co-ordinate system
- computation factors for the radiant heat transfer between walls belonging to each volume in the whole building
- illumination factors are computed for all the wall surfaces in the building in view of the transmitted radiation
- generation of the required computational network through the elements of structure in the building
- computation, for every point of time during the 24 hour period (once an hour), the proportion of solar radiation on each surface in the building
- sets up and solves the energy balances for every hour for the whole building

The fundamental equilibrium equation is

$$C \frac{dT}{dt} = Q \qquad (6.1)$$

where

C = heat capacity
T = temperature
t = time
Q = energy input

Simulation of the building consists in computing energy inputs and solving Equation (6.1) simultaneously for all the nodes of the thermal computational network.

6.2 Comparisons with measurements

On the basis of the consumption statistics and the breakdown of electrical energy into appropriate items, an energy balance can be drawn up for January 1992 and is set out in Table 6.1.

Table 6.1. Energy balance for Jan. 1992 according to DEROB and measured heating requirement

	Energy balance according to DEROB (kWh)	Measured heating requirement (kWh)
Fabric losses	1 078	
Ventilation losses	1 425	
Heat gains from occupants	540	
Solar utilisation	1 174	
Total	**789**	**819**

6.3 Simulation with DEROB for the whole year

Simulation of the main building for the whole year is made under the same assumptions as above.

The theoretically calculated solar radiation and measured radiation differ due to the fact that the air in Antarctica is extremely pure. However, these differences cancel out over the month as a whole. If it is assumed that clear and cloudy days during the rest of the year cancel out in the same way as in January, the heating requirement for a year can be calculated in spite of the lack of direct measurements.

The calculation assumptions and calculation results are set out for each month in Table 6.2. It is seen that, November-February, Ventilation rate is higher during the warmest months because opening of windows is necessary to avoid very high indoor temperatures.

Table 6.2. Heating requirement and calculation assumptions for each month.

Month	Heat-ing (kWh)	Mean outdoor temp. (°C)	Mean indoor temp (°C)	Venti-lation (ach)	Solar utili-sation (kWh)	Fabric losses (kWh)	Venti-lation losses (kWh)
Jan.	789	-5.0	19.93	0.85	1 174	1 078	1 425
Feb.	945	-8.2	19.90	0.70	754	1 235	1 146
March	1 313	-11.9	19.90	0.44	450	1 383	944
April	1 912	-16.2	19.90	0.44	114	1 531	1 047
May	2 310	-19.1	19.90	0.44	0	1 706	1 167
June	2 338	-20.4	19.90	0.44	0	1 712	1 171
July	2 298	-18.9	19.90	0.44	0	1 701	1 163
Aug.	2 527	-22.4	19.90	0.44	38	1 856	1 270
Sept.	2 233	-22.5	19.90	0.44	253	1 798	1 230
Oct.	1 233	-13.4	19.90	0.44	654	1 459	997
Nov.	814	-9.0	19.95	0.60	1 016	1 229	1 146
Dec.	630	-4.3	19.93	0.85	1 270	1 055	1 394

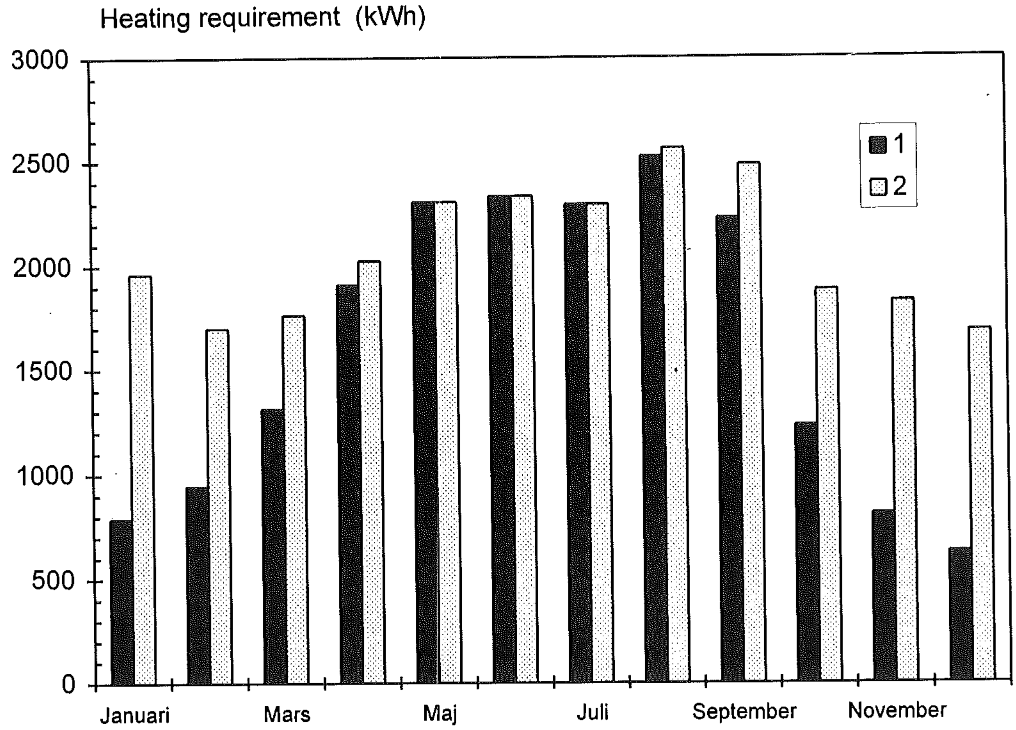

Fig. 6.1. *Heating requirement for each month during 1990.*
1 = solar radiation, occupied (10 persons); 2 = no solar radiation, occupied

6.4 Electrical energy requirement in terms of diesel oil requirement

The calculated efficiency of the generator set is 46%. Thus, approx. 22.2 l diesel oil is needed to produce 100 kWh. Based on all measured electricity consumption for the whole station in January 1992, the total diesel oil requirement has been calculated to 1 334 l.

6.5 Energy balance

Monthly energy balances have been produced for a whole year, based on measurements and calculations It shows that the energy supplied from the space heating system, household electricity etc. makes up for 21% of the total energy requirement. Of the losses of the building on an annual basis, ventilation accounts for 44%, the fabric losses are 37% and waste water losses 18%.

On the input side operation of pumps and fans accounts for 25% of the energy supplied and heating of the buildings accounts for 24. Producing cold water during the Antarctic winter by melting ice would use a significant quantity of energy, 15%, which almost corresponds to the energy needed to heat the main building over a whole year. Hot water production accounts for only 7%.

If we study the losses of the whole station and also include the losses of the diesel generator, the total energy requirement is 220 361 kWh at 46% efficiency. Of this, generator losses account for 50% of the station's energy losses. Over 20 m^3 of diesel oil is needed to run the station for a whole year.

7 DISCUSSION AND CONCLUSIONS

This analysis shows that in its present state the station needs approx. 94 MWh for its operation over a whole year. Production of this energy by the diesel driven generator requires just under 21 m^3 diesel oil. Heat losses from the generator set have not been utilised for the heating requirement which exists over the whole year. In the total energy balance for the station, generator losses account for 50%, i.e. 110 MWh. It therefore appears that by far the most important action that must be taken is to modify the energy supply installation so that some of its losses can be utilised.

The object of the following discussion is to quantify the different energy saving measures or other improvements. The result is set out in Table 7.1.

It was found during the measurements that the air change rate in the main building was somewhat low. An increase in this so that ventilation corresponds to 7 l/s per person raises the energy requirement by ca 1500 kWh.

Reduction of the indoor temperature from 20 to 18°C would on an annual basis produce a saving of ca 1800 kWh.

If the windows are replaced by windows with a U value of 0.9 W/m^2K, the annual saving is ca 2000 kWh or, with the lower indoor temperature, 1800 kWh.

Reduction of water consumption by 8% means that less energy is used in melting ice, and represents an annual saving of approx. 1400 kWh, as well as ca 600 kWh for water heating.

Utilisation of the 10 m^2 solar collectors which have been tested, if they are used during the months when the contribution of solar energy is higher than the energy needed to drive the necessary fans, means that ca 5000 kWh can be saved from October to March. In addition, stopping the fans from April to September saves ca 2500 kWh of electricity.

The wind generator tested would, if it could be given the required strength and on the assumption of a mean wind speed of 7 m/s over the year, produce a total of ca 2600 kWh.

Table 7.1. Summary of energy saving measures

Measure	Energy kWh
Original electricity requirement	93 975
Increased ventilation	+1 500
Lowering of indoor temperature (from 20 to 18°C)	-1 800
Replacement of windows	-1 800
Reduction of water consumption	-2 000
Solar collectors	-5 000
Stopping of solar collector fans, April-September	-2 500
Wind generator	-2 600
Remains	79 775
Saving	**14 200**

The total saving of over 14 MWh represents more than 3 m^3 of oil or 15% of the energy requirement of the station. The saving, exclusive of the wind generator, calculated on the electrical energy requirement of the main building is 31%.

With the proposed measures set out above, the generator losses decrease from ca 110 MWh to ca 94 MWh. This means that there are still large energy losses which can be used for the operation of the research station. If we assume that all heat for the main building and the container is supplied by utilising the generator losses, the total electricity requirement for the station is ca 68 MWh and the generator losses are 79 MWh. Together with the previous measures, this means that the energy consumption of the station has decreased from ca 94 MWh to 68 MWh, i.e. by 28% which represents about 5.8 m^3 diesel oil.

The remaining losses from the generator could be further utilised. The energy used in producing cold water is a remarkably high energy item. The total energy used in producing cold and hot water is more than 24 MWh. If the losses of the generator can be used for this purpose also, the total electrical energy requirement for the station is ca 44 MWh and the remaining generator losses are 50 MWh.

When all the above measures are taken, the total energy consumption of the station on an annual basis is reduced from 94 MWh to 44 MWh, i.e. a saving of 53%. In terms of diesel oil, this is a reduction from ca 21 m^3 to just under 10 m^3.

It is considered that all the measures can be carried out reasonably easily; the technique of utilising generator losses has also been studied in detail.

It is evident that by far the most important measure is to make use of the energy which is available by redesigning the heating system so that the generator losses can be utilised.

7.1 Satellite based data transmission

It would be interesting to continue the project by recommencing satellite transmissions. As mentioned before, data collection and satellite transmission worked perfectly, the problem was the power supply.

The part of the system which consumes most energy is heating of an insulated box. The temperature in the box must be above 0°C in order that the transceiver should work. Although the box is kept indoors, the temperature still drops to -30 - -35°C during the winter months.

An energy calculation for the box shows that the energy required to maintain a constant temperature of 0°C during August, which is the coldest month, is 2800 Wh. If the temperature in the box were put at -25°C, the energy requirement during the same period would be only 115 Wh.

Thrane & Thrane now have a model which withstands temperatures down to -25°C. With this model in place, only the already installed solar cells are needed to charge the batteries. Naturally, the batteries do not get charged during the winter months, but with a capacity of 250-300 Ah they should remain operational until the sun again rises.

If the old transceiver is to be used, a wind generator must be installed. The same battery capacity as above can be used, provided that the wind generator works without interruption throughout the winter. In view of the low degree of reliability of this system, this is hardly to be recommended.

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The PICO Hot Water Drill System

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Abstract

The Polar Ice Coring Office has developed a hot water drilling system that is capable of providing access holes in ice sheets up to 60 cm in diameter and greater than 2000 meters in depth. Four holes were drilled to depths of 1950 m, 1966 m, 2033 m, and 2180 m during the 1995/96 austral summer at Amundson-Scott South Pole Station, Antarctica, to place photomultiplier tubes in the ice sheet as part of the Antarctic Muon and Neutrino Detector Array (AMANDA). The drill system will support this project again during the 1996/97 field season, drilling up to seven more holes. Other uses in the future may include drilling holes to the ice sheet bed to provide access for geological sampling.

Introduction

The AMANDA detector is an experiment intended to look for neutrinos using clear glacial ice as the detecting medium. Light-sensitive photomultiplier tubes are lowered in strings 400 m long to a depth of 1900 m at the South Pole. AMANDA is an on-going experiment, expanding on the 1993/94 season in which four, 200 m strings of photomultiplier tubes were successfully deployed into the ice sheet. Each photomultiplier tube has an effective diameter of approximately 34 cm when encased in the protective bathysphere that protects it from the high pressure of the freezing process. Therefore, holes with a minimum diameter of 45 cm must be drilled to allow for freeze back that occurs as the detector string is being lowered. Hot water drilling of access holes in glaciers to depths of 1 km is now common. Freezing rates can be predicted using finite element computer models. Most hot water drills are used to drill smaller diameter holes quickly so small instrument packages can be inserted to monitor glacier progress. Drilling holes in excess of 45 cm in diameter into ice that is -50°C to the hole bottom requires much more heat and a slower drilling rate. However, the principles remain essentially the same.

The Polar Ice Coring Office (PICO) has developed a hot water drilling system that is capable of providing access holes in ice sheets up to 60 cm in diameter and greater than 2000 m deep. The drill system is capable of generating hot water at the drill output of approximately 85°C and 75 bars. This paper will describe the PICO hot water drill system and the logistical requirements for drilling at the South Pole, Antarctica. It begins with a general description of the entire drilling setup, and then goes into greater detail regarding the system components. In addition, a brief summary of the 1995/96 field season, and the recommended improvements to the drill system are presented.

System Description

The PICO hot water drill is a large system capable of supplying up to 1.8 MJ/sec of heat for the drilling process. To accomplish this, flow rates of up to 350 liters/minute are provided by three large triplex pumps. Twelve industrial grade, high pressure water heaters comprise the main heating plant. A smaller pre-heat system controls the temperature of the inlet water to the main system regulating the final water temperature. A Rodriguez[1] well is used to supply the make up water. These items are shown on the site plan and drill system schematic diagram given in Figures 1 and 2, respectively.

The high-tech hot water drill is suspended on an electromechanical telemetry cable which provides communication to and from the drill, as well as mechanical support for the drill and hose. Instrumentation on the drill provides data on hole diameter, temperature and pressure on the inside and outside of the drill, and tilt within the hole. Hole diameter is measured using mechanical spring calipers in addition to acoustical sonar, which can also track the relative position of the drill in the hole. Instrumentation on the surface provides information on flow, temperature and pressure at several inlet pre-heat locations. Hole depth and line tension are measured at the drill hole using two instrumented sheaves. Safety precaution features are built in so the system can be shut down in the event of potential problems such as low flow or excessively elevated temperatures in the water heaters. All of this information is displayed on the main computer control screen to keep track of drilling progress and the state of the equipment. An additional computer is networked to review, display, and analyze the data in real time.

Hot Water System Operation

The hot water generation system consists of three main components. The pre-heat stage, the main heat plant, and the use of a Rodriguez well for re-supply. The pre-heat stage centers around a large, 32,000 liter main supply holding tank, and several smaller re-supply holding tanks. The total supply of water available for drilling from these holding tanks can be 62,500 liters. This water is maintained at a temperature of approximately 34 °C by eight oil fired water heaters.

This water is pumped to the main heating plant by three high pressure triplex pumps, each pumping up to 150 liters/minute. The main heating plant comprises of twelve industrial grade, high volume, oil fired water heaters which heat the water to its final drilling temperature of approximately 85 °C. These twelve heater outputs are manifolded together and pumped into a single 3.81 cm (inside diameter), high pressure hose which is used as the primary drill hose. This hose is typically used in 150 meter lengths, and enough sections are used to total approximately 2300 meters. Sections of hose can be cut to custom lengths if needed. This enormous amount of hose is spooled onto three winches and used sequentially as the hole is drilled deeper. The hose is run over a roller guide crescent at the tower structure and is terminated at the drill. Due to heat and frictional losses over this amount of hose, the final drilling temperature and pressure of the water is approximately 75 °C and 70 bars.

Drill System Electronics

The drill system consists of uphole and downhole monitoring and control electronics which is all tied together and controlled from one computer in the drill command center.

Surface Electronics

The uphole electronics consist of pressure, temperature, and flow sensors on the main heat plant water heaters and output lines. Each of the twelve industrial grade, high pressure water heaters are equipped with platinum resistance temperature detectors (RTD) in order to track temperatures on an individual basis. Pressure sensors, flow meters, and additional resistance temperature detectors are put in line to monitor the drill water parameters prior to entering the heat plant and upon exiting as well. These sensors are labeled and shown in the drill system schematic in Fig. 2. Each of the eight water heaters in the pre-heat system are equipped with thermometers and pressure gauges and the output lines are equipped with flowmeters, all of which are monitored manually.

The uphole electronics also include payout systems for the telemetry cable and main water hose. The payout system for the telemetry cable attached to the drill is monitored by two instrumented sheaves, one at the tower base, the other located at the top of the tower. They utilize Hall effect sensing as the sheave rotates to determine drilling speed and how much cable is payed out for depth monitoring.

The hose winches are powered by high torque, precision direct current motor/tachometer combinations to allow accurate speed control with the electromechanical telemetry cable during drilling operations.

Downhole Electronics

The downhole subsystem consists of the electronics and communications package in the hot water drill. All information from sensors on and in the drill is sent to the surface computer by the microprocessor driven integration controller inside the main body of the drill. A diagram of the drill is shown in Fig. 3.

Temperature: The temperature of the hot water traveling through the drill is measured by a sealed probe that houses a thermistor that has a range of -30 to 100°C. The probe is a small protrusion that extends into the hot water tube which runs inside the length of the drill. The temperature of the hole water is measured by a sealed probe that houses another thermistor with a range between -30 and 100°C. This probe is angled along the side of the drill to avoid hanging it up on the cabling. The integration controller circuit board also has a temperature sensor onboard to measure the ambient temperature of the controller board electronics inside the drill. Its range is also -30 to 100°C.

Pressure: The drill is equipped with two pressure transducers with ranges from 0 to 690 bars. One is used to measure the pressure of the hot water flowing through the drill and the other is used to measure the external hole water pressure.

Load Cell: The coupling device which connects the drill to the telemetry cable is fitted with a load cell whose primary function is to work as a GO-NOGO signal that the drill is attached properly to the cable/hose support structure. It is a -70 to 207 bar strain gauge sensor used primarily in tension, but it may also be used for measuring compression loads as a warning indicator due to bottoming out of the drill.

Flow Meter: The flow meter consists of a sensor housing which contains a rotor which protrudes down into the hot water drill tube. Inside this sensor housing is a magnet surrounded by a coil creating a magnetic field. As the liquid flow causes the rotor to spin, it concentrates the lines of magnetic flux creating a repeatable AC sine wave output which is calibrated and converted to give flow in liters/min.

Navigation: An xyz coordinate system is fixed on the surface and defined as the z-axis being vertical and pointed downward, the x-axis points north along the Greenwich meridian and the y-axis points towards 90E. The drill coordinate x'y'z' defines z' along the drills axis, x' and y' are defined by two right angle flux gate magnetometer detectors. All coordinates form right-handed systems and the information provided should allow the drill operator to guide the drill down a hole that is always within 0.1 degree of vertical. In addition, there are two tilt pendulums that provide continuous x-tilt and y-tilt for bank and elevation information, respectively, which are accurate to +/- 0.1 degrees. The calculated combination of the magnetometer and tilt pendulum outputs are used to determine the drills attitude and heading relative to the Earth's magnetic field and should give accuracy's better than +/- 3.0 degrees absolute and +/- 1.0 degrees relative.

Spring Calipers: The drill is equipped with spring calipers which are used to measure the average hole diameter. This is accomplished by using the deformation action (squashing) of the calipers which moves a collar along a magnetic linear displacement transducer (MLDT). The repeatable linear displacement is then converted to give the average hole diameter in the range of 30 to 80 cm.

Acoustic Calipers (Sonar): The sonar capabilities of the drill consist of two rings, one at the head of the drill and the other at the tail, each containing 6 pressure compensated, piezoelectric crystal transducers which provide 360 degree coverage of the hole diameter. They are driven in turn by a voltage pulse which rings the element at a specific frequency, and the time between this ringing and the return echo is measured and converted to a distance with the average velocity.

Drill Control System: The drill's control system is configured of two IBM compatible computers connected in a local area network (LAN) configuration. The primary computer is used as a monitoring and control computer in a "cockpit" based format. This application, written under the Microsoft Visual Basic development environment, allows the operator to control the display of decoded information from the drill and surface equipment. A wide variety of graphic display mechanisms, such as gauges, histograms, etc., are used in order to display each piece of data in an intuitive manner. In addition to outright display and logging functions, the application also has the capability to monitor the incoming data for alarm conditions such as low flow or over-temperature. If an alarm condition is detected, it will be reported to the operator graphically through the display.

The secondary computer communicates with the primary computer and runs a "Stripchart Display" program. It receives drill data from the primary computer, stores this data in a file local to the secondary computer, which then gives a redundant archive of the hole data. Acquired data from each drilling session can be completely logged as a function of time to give valuable information such as depth, position, temperature, velocity, and other variables of interest.

Logistical Requirements

The AMANDA drill site located at Amundson-Scott South Pole Station, Antarctica, is an extremely remote, far away location in addition to having some of the world's most challenging and cold weather conditions. This combination of obstacles makes the logistical requirements just as important, if not more important than the workings of the drill system itself. All people, equipment, and supplies have to be flown to and from the South Pole. The remoteness of the location requires an enormous amount of time and fuel for the supply aircraft, typically the LC-130 Hercules, which are equipped with skis for landing on the ice sheet. The severe and unpredictable weather conditions require skilled pilots and up-to-date weather forecasting at all times. The success or failure of a drilling season depends on all of these potential logistical problems falling into place.

Much of the equipment used for the drilling operation was left in storage areas at Amundson-Scott South Pole Station at the end of the 1993/94 field season. In addition to this equipment, and due to an up scaling in size of the drilling operation, many new pieces of equipment were required for the 1995/96 drilling season, most of them being quite large and heavy. The equipment must fall within the dimensions of 213 x 264 x 244 cm in order to fit into the back of an LC-130. This is usually a design criteria. PICO's new equipment and supplies totaled approximately 41 tonnes, which is approximately half of the total equipment required.

Due to the complexity of the PICO drilling operation, many logistical obstacles had to be overcome at the drill site to make the season successful. Upon arriving at the South Pole on November 7, The PICO drill crew found the equipment left over from the 1993/94 season drifted in. Support was immediately needed and was provided by Antarctic Support Associates (ASA) in terms of digging out and moving equipment from storage areas to the drill site. Once the site was leveled, ASA began construction on the shelters, water supply holding tank, the fuel containment area, and the electrical distribution network. Once the drill site construction was completed, drilling was ready to begin on December 23. Logistical support from ASA was still required throughout the remainder of the drilling season in regards to continual transport of cargo, moving the drill towers with the station crane, fork support for relocating equipment, and hauling away debris caused by drilling, waste, and empty fuel barrels. In addition to support for the drilling operation, South Pole Station was considered home for the drill crew throughout the entire drill season of three months.

Field Season Results

Our initial goal was to drill six holes to depths of approximately 2200 m. The schedule called for drilling to begin during the second week of December. Due to an intense construction effort at the beginning of the field season which put us slightly behind schedule, and various problems with parts and equipment failures, drilling was not attempted until the 23rd of December. As the drill was lowered down the hole, water flooded onto the main connector on the telemetry cable and short-circuited the system. A second attempt was made on December 25 with similar results. A new connector was installed and a third attempt was made with the same results. Finally, the drill's main power requirement was lowered from 300 volts dc to approximately 60 volts dc. This eliminated the problem of the drill short circuiting in the melt water, but only part of the drill's electronic sensors were operational. This included the mechanical spring calipers, the navigation package and the temperature sensors. Sensors that did not work include the drill load cell, the flow meter, and the acoustical sonar. On the surface, the instrumented sheaves did not work properly, and the tachometers on the winch motors failed, possibly due to the extreme weather and damage during shipment. Even though many parts of the system were disabled, the system as a whole was operational. We were able to proceed with drilling on January 3rd, with the first hole requiring approximately 8 days to complete, which also includes repositioning the equipment. Once the crew became used to the requirements and procedures for drilling, the remainder of the field season went smoothly. We were able to complete three more holes, each requiring approximately seven days to complete. There were still a few minor incidences and equipment failures that resulted in frozen supply lines and ruptured heater hoses and coils, but these were repairable in the field. Due to the short field season at the South Pole, we ran out of time at the end of January and were required to break down the drill site in preparation for station closing. Once the drill site was broken down and the large equipment was packed and stored for winter, an inventory was taken of all remaining tools, replacement parts ans supplies, and all the smaller equipment. Equipment that was damaged or failed in the field was sent back to PICO for evaluation, repair or replacement.

Recommended Improvements

The use of the Rodriguez well for make-up water was inefficient and at times seemed more trouble than it was worth. This is due to the fact that the well was located approximately 80 m from its own heater units. This extra distance greatly contributed to heat loss in the system, made the pump work harder, and rendered the well system prone to freeze ups which happened on three occasions. For the upcoming drill season, the well will be moved much closer to its heaters and will be enclosed to help protect the system against the elements. In addition to the well, the remainder of the pre-heat system will also be enclosed to protect it from the elements. This will make repairs to the system easier and should reduce the risk of potential freeze ups.

The drill system will be permanently converted to a low voltage supply of approximately 60 volts dc. The internal circuitry of the drill will be modified and a new power regulator will be installed in the drill housing. The pressure transducers in the drill will be replaced and the failed units will be tested to determine why they failed. The drill load cell will be tested and replaced if necessary. An additional "S" bridge load cell will be used to hang the drill from the telemetry cable to compare readings to the existing load cell in the drill. This will be designed as a common mounting block for the drill cable and supply hose to allow the drill to hang more freely. This will improve navigation and allow a straighter hole to be drilled.

Acknowledgments

The Polar Ice Coring Office would like to thank the drill crew members for their contribution towards a successful drill season. The drill crew consisted of the following people. Tom Strauss, Kurt Wulser, Ketil Soyland, Walt Hancock, and Tim Makovicka from the University of Nebraska. Bill Barber from Kentucky and our consultant, Bruce Koci from the University of Alaska Fairbanks. In addition to the American crew, Hans Linderholm, Sven Lidstrom, and Pontus Stenstrum from the Swedish Polar Institute in Stockholm.

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Since the early 1980's the British Antarctic Survey (BAS) has been using a hot-water drill to create access holes first through George VI Ice Shelf and, since 1990, through Ronne Ice Shelf. BAS has successfully drilled three holes through Ronne Ice Shelf: Site 1 in 1990/91 (562 m of ice (Nicholls *et al*, 1991)), Site 2 in 1992/93 (541 m of ice (Robinson *et al*, 1994)), and Site 3 in 1995/96 (825 m of ice) (see Figure 1). The locations of the sites were selected such that the oceanographic measurements yielded the maximum information about the circulation beneath the ice shelf, while still remaining logistically feasible. The programme is supported entirely by Twin Otter aircraft operating out of Rothera, the BAS base on Adelaide Island on the west coast of the Antarctic Peninsula (Figure 1). This paper will focus on the logistical constraints, and how those constraints have modified the way in which the work has been undertaken.

Constraints

When considering the selection of the drillsite there are three concerns:

1. Scientific merits. Since the number of instrumented sites across the entire ice shelf is likely to be no more than a handful, the selection of a suitable site depends on the consensus of the models of the oceanographic conditions. An ideal site is one which tests the predictions of as many different types of models of the sub-ice shelf circulation as possible. The aim here is to attempt to disprove models as categorically as possible. Reasonable agreement between field data and model predictions might be fortuitous and is therefore more ambiguous than categoric disagreement.

2. Flying hours. From Rothera, the nearest point on the FRIS is about half as far (900 km) as the farthest point. When carrying a realistic payload a Twin Otter aircraft will need to be refuelled at least once, usually twice before arriving at the drillsite. If the site was on the other side of the ice shelf from Rothera, the aircraft would need at least two refuellings. Flying time is therefore required to deploy fuel to refuelling-depots. The total flying hours required to service a site therefore goes up very rapidly with distance from Rothera. The second predictor for the number of flying hours is the amount of fuel that will need to be supplied to power the drill; the fuel requirement increases approximately exponentially with the depth of ice to be penetrated. The total aircraft usage is therefore largely set by the total ice depth at the site, and its distance from Rothera.

3. Drill capability. The deeper and colder the ice at the selected site, the more problems are likely to arise during the drilling process, and the more spares and equipment will have to be carried. Initially, the constraint is simply the resources to purchase the necessary equipment. Even given the financial resources, however, a greater weight of equipment will generally result in more flying hours to get it to the drillsite.

To minimize the number of flying hours needed to service a site the work is generally carried out with only four personnel. This also reduces the amount of food, camping and safety equipment that has to be flown to the site, and it helps reduce the transport and victualling costs from the UK to Rothera. Four personnel is regarded as an absolute minimum required for the work, which continues 24 hours-a-day, typically for a few weeks.

The equipment has been designed and built so that it can be broken down to be transported in Twin Otter aircraft. Each element of the broken-down drill is light enough to be hand-manageable

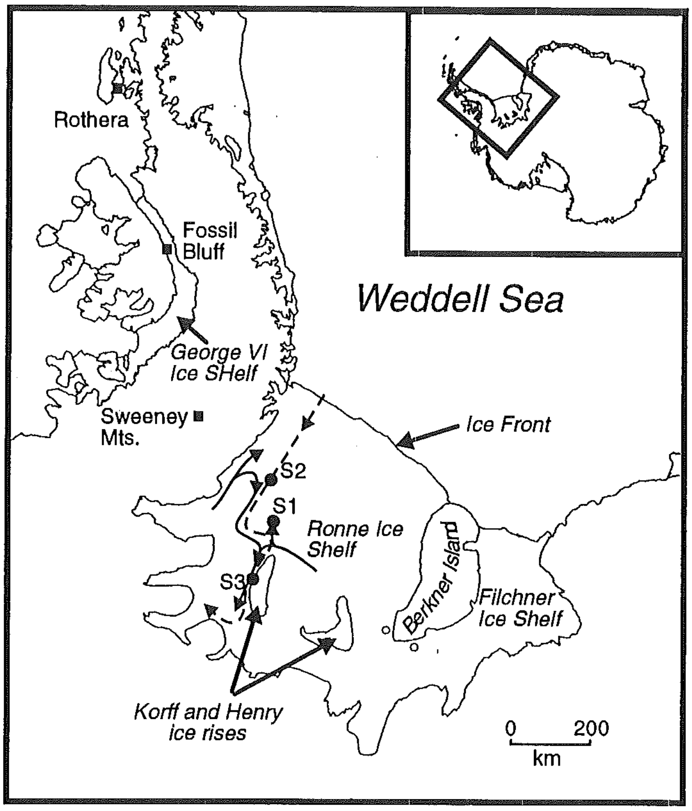

Figure 1. Location map. S1, S2 and S3 show locations of sites 1 to 3. Flows: Broken line shows inflowing warm water. Full arrows give flow and recirculation of Ice Shelf Water.

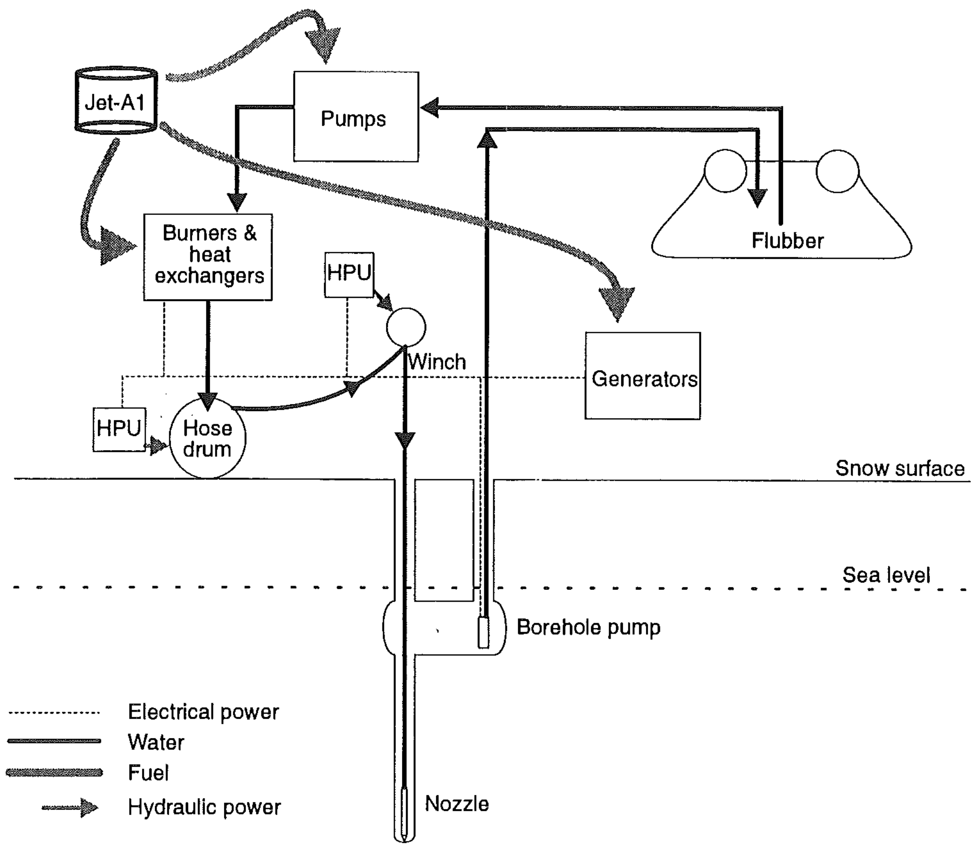

Figure 2. Simplified schematic of hot-water drilling system.

by four or fewer personnel, working in soft snow. The heavier pieces of equipment are furnished with a skid-style base that makes them relatively easy to move over a snow surface. Another requirement that is met by the small-element drill design is the need to be able to transport the system by Skidoo-towed sledges. During the 1990-91 field season, the drill as it existed then was moved 100 km between two drillsites using four Skidoos and six Nansen sledges, though one pair of Skidoos made the round trip three times, resulting in 14 sledge-loads in total.

The principal disadvantage of having a drill that is broken down into smaller components is the length of time taken for its assembly prior to starting work. That time period is of the order ten to fourteen days. However, as the scientific instruments must be fully checked out and prepared before the start of the drilling operation, the time is generally a busy one for everybody.

Logistics

BAS operates up to four Twin Otters out of Rothera Base. There are permanent fuel depots at Fossil Bluff on the east coast of Alexander Island, and in the Sweeney Mountains, southern Palmer Land (Figure 1). These refuelling points are maintained from Rothera and form the most common route for aircraft from Rothera to Ronne Ice Shelf, allowing a payload of between 1500 and 2000 lbs. It is occasionally possible for a BAS ship to enter the semi-permanent lead in front of Ronne Ice Shelf and to depot large amounts of fuel on the ice. The fuel to power the drill and refuel aircraft does then not need to be relayed from Rothera by air, resulting in much more efficient logistics.

As the programme of work on Ronne Ice Shelf has been largely uninterrupted by the need to have the drill elsewhere in the BAS area of operations, it has proved possible to depot the drill on the ice shelf after each season. In that way the only drilling equipment that needs to be flown to and from Rothera is new or modified equipment going in at the start of the season to enhance the drill's performance, or damaged equipment coming out for repair or disposal at the end of the season. This approach yields a considerable saving in flying hours.

Description of drilling equipment

The method of operation of the drill has remained unchanged over the course of the programme, but the drill itself has been considerably enhanced. The description here will be for the present drill configuration. A simplified schematic is given in Figure 2. At the heart of the system is a rank of up to eight oil-burners with horizontal, double-coiled heat exchangers. The nominal power for each burner is 80 kW. Based on the calorific value of the fuel (Jet A1 aviation fuel) and the snow-melting capacity of the system (4.5 tons per hour), we estimate the efficiency of the heating system to be about 60%.

A pair of diesel-driven, positive-displacement, high pressure water pumps, each rated at 38 litres per minute at a maximum pressure of 2000 psi, drive the water through the drilling system. Submersible borehole pumps retrieve water from the borehole and return it to a 12000 l reservoir flubber. A range of pumps are used, driven by single phase electric motors ranging from 1 to 3 hp. The flubber is made from a flexible material, and packs up to a manageable volume. Most of the drilling hose comprises several 350-m lengths of ¾″ polyester-braid reinforced plastic hose; the 120-m length nearest the nozzle is steel-braid reinforced rubber, helping to provide weight to keep the drill hose vertical. The drill hose is lowered and raised using a hydraulically-powered capstan, the hose being stored at low tension on the winch drum, again hydraulically-powered. Hydraulic power is supplied by a range of electrically-powered hydraulic-power-units (HPU). Electrical power comes from a pair of diesel-driven, 8 KVA, single-phase generators. Various smaller petrol-driven generators are available as partial back-ups.

The initial, cutting nozzle has a forward-pointing, full-cone jet; the reaming nozzle uses a backward pointing cone jet, washing over a larger-diameter nozzle body (0.13 m diameter). At the front of the reaming nozzle there is a long "nose" designed to follow the hole initially drilled by the cutting nozzle. Several drill parameters are monitored routinely: the water temperature and pressure at the surface, the tension in the hose, the speed at which the nozzle is being lowered, and the length of hose down the hole. In addition, a small datalogger fitted inside the larger, reaming nozzle records the temperature of the water at the nozzle itself.

The burners and the main engines are all fuelled by Jet-A1 aviation fuel. For an air-supported operation such as ours, this provides valuable flexibility: any unburned fuel can be used in the aircraft, and fuel at aircraft fuel depots can be used in the drill.

Site 3: A case study

To illustrate the way the drill is used we describe in this section the work at Site 3, including the problems that were encountered. During January 1996 a drillsite was established 17 km west of Korff Ice Rise (Figure 1). The location for the site had been determined after new seismics data gave the detailed geometry of the sub-ice cavity in that area. A depot containing the majority of the hot-water drill was located another 17 km to the west, where it had been left two years previously. Two personnel were input to the depot site with Skidoos and sledges, and spent two days ferrying the equipment to the drillsite. Two others were input to the drillsite with more hot-water drilling and scientific equipment, and were assembling the drill and testing the instruments.

The flubber was filled on 6th Jan, enabling the drilling system to be fully tested. The system comprised the two water pumps each supplying four heaters in parallel. A bleed valve with a flow meter was used to divert some of the drilling water to supply the submersible pump umbilicals. On 10th Jan. a test hole 35 m deep was drilled. This hole was used to determine and practice the best method of deployment for the oceanographic mooring that was to be deployed at the end of the drilling work.

Drilling started on 11th Jan. The first hole was drilled and reamed to 105 m, and a 2-HP submersible pump lowered on a plaited umbilical to a depth of approx 98 m. The umbilical consisted of a 1″ return hose, a ½″ hose supplying warm water to stop the pump from freezing, a cable supplying power to the pump, and the signal cable for a pressure sensor that gave the head of water above the pump. Initially there was a 64-m head of water. The water was pumped out at 60 l min^{-1} to refill the flubber and lower the head of water in the hole. Hot water was also pumped down the umbilical to form a cavity at the depth of the pump. Late on 11th Jan. a second hole, 0.6 m from the first, was drilled and reamed, again to 105 m depth. By early on the 12th Jan. a connection was achieved between the holes and a second 2-HP submersible pump was in position. The third hole, previously drilled to 35 m and used as the test hole, was 1.1 m from the nearest hole, and was drilled and reamed to 105 m during 12th Jan. A fan spray was lowered in that hole to the same depth as the submersible pumps in an attempt to connect it to the existing cavity. After six hours the spray had not connected the holes, and a fourth hole was drilled, in the centre of the 1.1 m gap, to help make the connection. During this period, the engine on one of the pumps stopped working. It was later found to have a broken crank shaft. Over the night of 12th to 13th Jan. the drill system was reconfigured for use with only one pump. Drilling of the main hole was underway by the morning of 13th Jan.

The system configuration now consisted of five heat exchangers heating the water used to drill the main hole. A separate recirculation system used one of the submersible pumps to feed one heat exchanger, the water then being returned to the cavity via both the umbilicals. The second submersible pump lifted water from the cavity directly into the flubber with a valve regulating the rate at which water was recovered, which therefore regulated the water level in the hole. The drilling side of the system was operating at 450-550 psi, 85 to 90°C, with a flow of 38 l min^{-1}, or about half the original power and pressure.

The process of recovering water from the hole means that constant snow-melting is not necessary. Once the flubber has been filled the first time, no more snow melting is required. As melting the snow takes as much heating power as heating the water to 85°C, recirculating the water saves on the number of necessary burners, and also reduces the fuel requirement by a factor of about 2. Clearly though, the pump must be deployed below sea level, otherwise no water can be returned once the base of the ice shelf has been penetrated.

For the drilling of the main hole it was decided to attempt to drill straight through with a drilling speed profile that should have resulted in a hole of near-constant diameter. The profile was calculated using a model based on the work of Humphrey and Echelmeyer (1990). It is important to maintain, as far as possible, a hole of uniform diameter: the effective diameter of the hole is its smallest diameter, and that is the diameter determining how long the hole can be used for oceanographic measurements before it needs to be re-widened.

At 1225Z on 14th Jan. the ice shelf was penetrated. The water level in the cavity rose from about 93 m to 84 m and the load on the hose was reduced by up to 10 kg for a period of 30-40 s. A problem often encountered is "necking" in the hole at the ice-shelf base. This results from the loss of hot water into the ocean as soon as the base is penetrated, and before the hole has been fully widened. In an attempt to reduce the necking, the section in the vicinity of the base was re-drilled twice more. The drill was withdrawn and the first oceanographic profiles were obtained. A constriction at a depth of about 200 m prevented further CTD work after only one dip. Reaming of the hole started late on 14th Jan. but the nozzle became stuck at 200 m. It was finally pulled free after a 30-minute struggle. The smaller nozzle was then used to re-drill the hole but almost immediately one of the generators failed. As both generators were needed to run two submersible pumps drilling was suspended while the system was reconfigured for use with only one. One submersible pump and umbilical was antifreezed and left in place. The other pump was just capable of providing sufficient water to the flubber and one heat exchanger, without reducing the flow required for drilling, and a 2 kW petrol generator used to supply power to the burners. The drilling performance remained as before.

Re-drilling of the hole was resumed at 16:00Z 15th Jan., but early on the 17th the hole was abandoned. The re-drilling had been very difficult. Some regions, where the hole had presumably not closed entirely, were drilled with ease, but others were very difficult to penetrate. We assume that in the difficult areas the hole was not entirely closed, and that most of the water from the drill was being lost into voids beyond the immediate constriction. With about 300 m left to drill, and fuel stocks getting low, it was decided to recover the nozzle. In the event this was a time-consuming process as the hole had closed above the nozzle for some hundreds of metres. The cause of the constriction at 200 m is unclear. A borehole caliper is usually used to give a diameter profile, which would have given forewarning of the constriction. That tool had unfortunately failed during testing prior to the drilling work.

An additional 22 drums of fuel were flown to the site on the 17th and 18th Jan. The recirculation system to the cavity was maintained during this hiatus, and the drilling winch moved ready for a new hole, on the other side of the submersible pumps. Drilling of the second hole was underway by 18:20Z on the 18th Jan. Instead of drilling continuously to the base of the ice shelf, this hole was drilled and then reamed in stages. Drilling in stages means that the upper reaches of the hole, which are in the coldest section of ice column and which will therefore be refreezing the fastest, are reamed-out several times. The hole was drilled and reamed, first to the depth of the cavity (105 m), then to 350 m, then to 600 m, and finally to the base at 825 m. Connection with the sea was achieved at 07:30Z 21st Jan, and reaming of the last section was completed by 22:00Z. Oceanographic profiling was carried out for about 5 hours. The hole was again reamed from 03:30 to 20:50Z on 22nd Jan, followed by a further two hours of profiling work. Final reaming lasted from 23:30Z on 22nd Jan to 17:40Z on the 23rd. The oceanographic mooring was then deployed. The graph in Figure 3 shows the position of the drill nozzle as a function of time during the drilling of the second hole, giving an idea of the drill speeds used and the total time taken to drill and ream, compared with the time available for science work. Clearly, the deeper the hole, the worse the ratio.

Throughout the drilling of the second hole the total aviation fuel consumed had been approximately 4.5 drums per day to power six heaters, the water pump and the generator. The system had been operating at 38 l min^{-1}, 85-88°C and 450-550 psi. During the reaming of the hole the nozzle temperature logger was used to measure the water temperature at the nozzle. This allowed the thermal resistance of the hoses to be determined: 0.37°C m W^{-1} for 3/4" thermoplastic hose and 0.17°C m W^{-1} for the 3/4" steel-braided hose. The total weight of all the drilling equipment was about 11000 lbs. A further 800 lbs of anti-freeze, engine oil and two-stroke oil (for mixing with the aviation fuel prior to use in the burners) were either depoted or input by aircraft. The total amount of fuel burned in the heat exchangers and diesel engines was about 10000 litres.

Results

Figure 4 shows the average profile of temperature and salinity recorded during the profiling work at Site 3. The base of the ice shelf is about 730 m below sea level, which is about 95 m below the snow surface. The sea floor was found at about 1215 m below sea level, giving a water column about 485 m deep. Near the base of the ice shelf the water is at -2.44°C, with a salinity of about 34.51, whereas deeper in the water column there is a 150-m deep layer of water at -1.96°C and at a salinity of 34.7. One of the current meters on the mooring is monitoring the currents in the lower layer, and a sample of the record is shown in Figure 5. It shows a tidal signal with a range of about ±0.12 m s^{-1} superimposed on a steady flow of about 0.04 m s^{-1}. Coupled with the temperature and salinity profiles, this suggests an inflowing, relatively warm current of about 300,000 $m^3 s^{-1}$. It is this current that is powering the basal melting at the west side of the Ronne Ice Shelf.

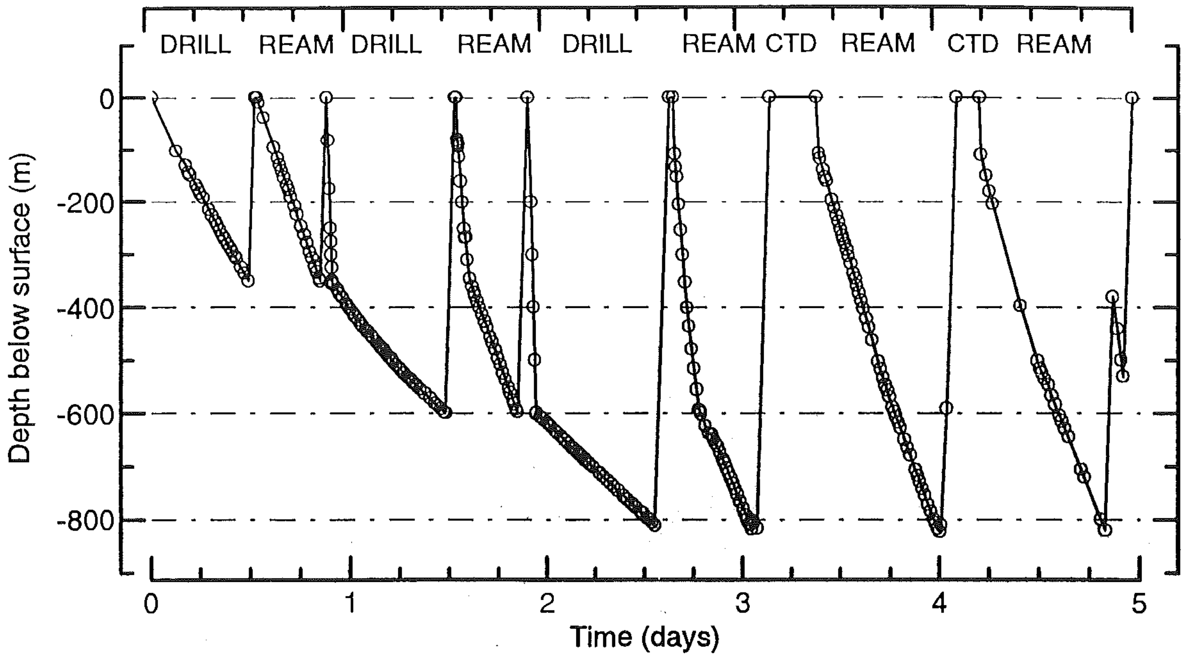

Figure 3. Position of drill nozzle below snow surface

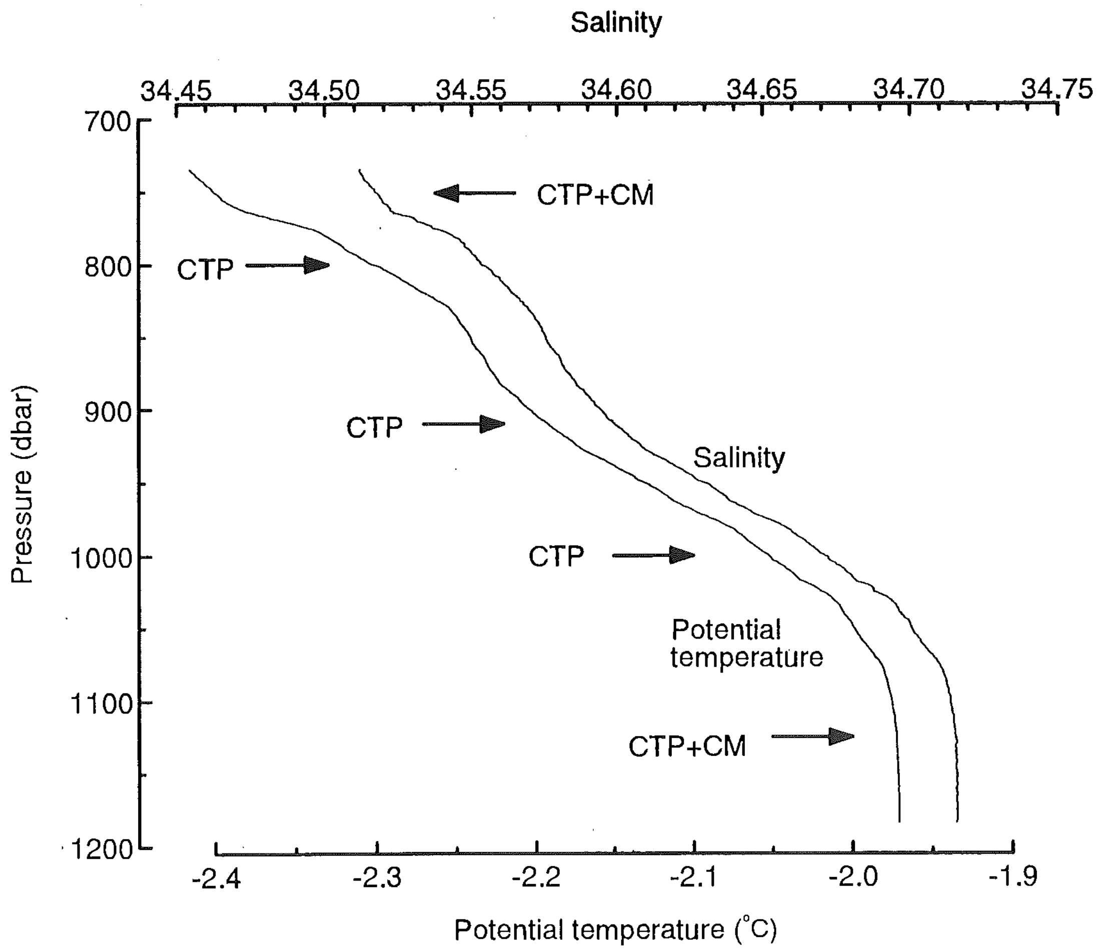

Figure 4. Average temperature and salinity profile from Site 3. CTP and CM indicate depths of conductivity-temperature-depth units and current meters on instrument mooring.

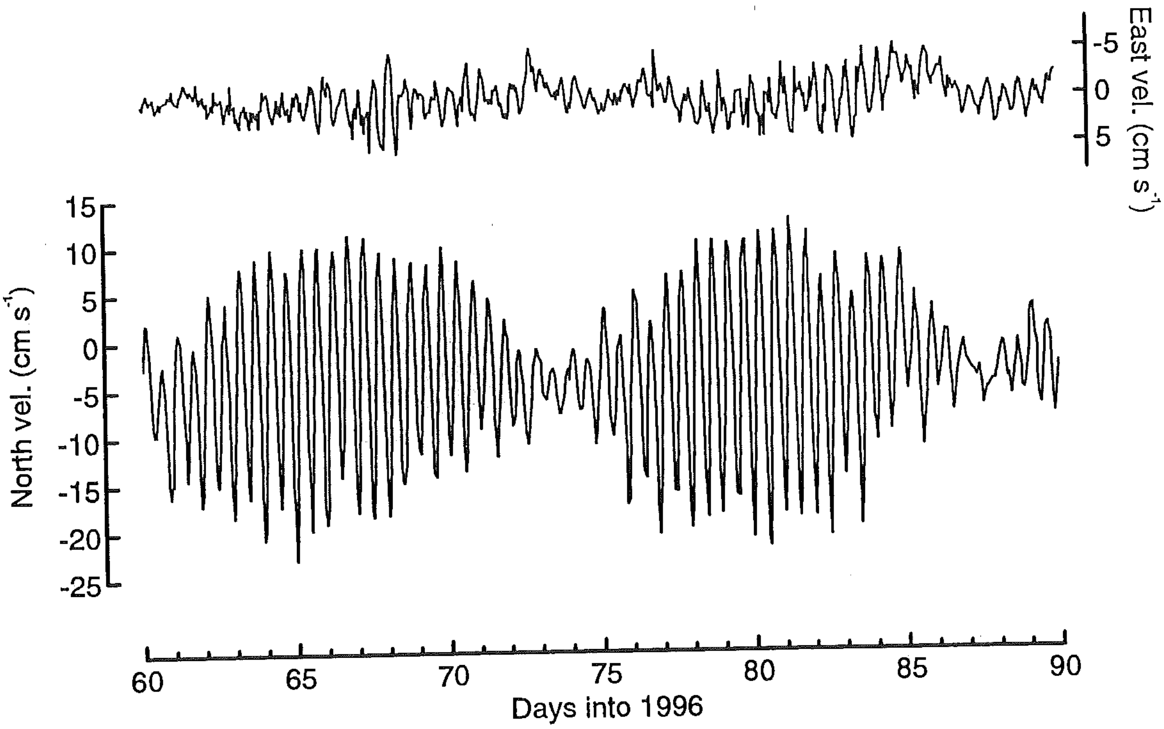

Figure 5. Excerpt from time series obtained from lower current meter. Upper trace is component perpendicular to Korff coast (magnetic easterly component)

Based both on the data from Site 3 and the two earlier drillsites, and on the geometry of the sub-ice shelf cavity, and bearing in mind the results of three-dimensional simulations of the sub-ice shelf oceanographic conditions (Determann et al, in preparation), it has been possible to construct a probable circulation pattern for this part of the ocean cavity. The pattern is shown in Figure 1. Relatively warm water flows in from the ice front at a rate of about 300,000 m s^{-1}, and is directed by the bathymetry past sites 2 and 3 before reaching the deep grounding lines where rapid melting takes place. The plume of less dense, but cold water that results from the melting travels along the western boundary before splitting into a recirculating component, and one that escapes from the cavity at the ice front. The recirculating component mixes with a recirculation that takes place around the Henry and Korff ice rise complex, before it is observed at Site 3.

Such an overall pattern of flows is consistent with the data from the three sites, broadly consistent with data from ice front oceanographic cruises, and consistent with many aspects of a three-dimensional numerical model. Clearly much can be learned from a small number of carefully selected drillsites. In collaborative projects with German and Norwegian agencies, the programme will continue with holes drilled through nearly 1 km of ice south of Berkner Island in the 1997/98 season, and at a site near the west coast of Berkner Island, opposite Henry Ice Rise.

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ABSTRACT NR B4

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ABSTRACT. **(Category B.)**

The Hot-Water Drilling System of the Alfred Wegener Intstitut fur Polar und Meeresforschung (AWI)

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A hot-water drilling system was developed at AWI and since 1990 used several times on Filchner-Ronne Schelfeis and on Ekstroem Ice Shelf.
With this system a 420m deep hole with a diameter of more that 20cm could be drilled in 16 hours. At the moment the system can be used to drill to a depth of 550 meters, but can easily be adopted to depths of 1000 meters.

The system consists of six 125kw heat exchangers, a motor driven winch, a high-pressure hose with inner diameter of 3/4 inch, a 5000 lt water tank, several nozzles and a submersible pump. A monitoring system allows the control of drill depth and speed and shows the actual weight of hose and nozzle in the hole. Moreover it was planned to control the dip of the nozzle during drilling with a two axes inclinometer. The inclinometer worked very well for the first two hours of drilling and then failed.

The normal drill operation would start with drilling a cavern below the firn-ice-boundary into which the submersible pump is lowered. The main hole is then drilled through the cavern and the used drill-water that is collected in the cavern is pumped back to the tank on the snow surface. Thus melt energy can be saved.

We use nozzles with different diameters : with a nozzle of 5cm diameter we normally drill a pilot hole, this is reamed with a nozzle of 13cm diameter. The 13cm nozzle has a mechanically driven valve on its upper end that opens a back cone spray in case the hole has closed during drilling . This then enables the nozzle to drill backwards.

In the paper the system will be shown as well as some data that could be collected by different instruments lowered through the hot-water-drilled holes.

ENDS

The deep bore-hole drilling is possible only when it is filled by the non-freezing fluid in order to create the hydrostatic pressure on the walls and at the bottom of the bore-hole and prevent the hole closure. For this purpose we have used a mixture of kerosene of TS-1 type and of freon-11 as a densifier. At present the freon-141B type is used which is harmless for the ozone layer of the Earth.

For filled bore-holes a thermal drill of TBZS-152M type was developed (Fig.2). The drill head (1)- ring copper or aluminium casting - contains an electric heater inside the tube with a power of 2.5 kW. The outer/inner diameter of the drill head is 152/114 mm.

The corebreaker (2) with fixed water-lifting pipes (5) and the core pipe (3) fixed to the water accumulating tank (8) by means of the adapter (4), are mounted above. The water tank (8) has a volume of about 35 liters.

The pump (11) for water removing from the bottom is mounted in the adapter (10). The voltage of the electric type DC motor of the pump (11) can be changed from 15 to 27 V with the maximum current of 8 A.

The total length of the TBZS-152M drill is 7.5 m and its weight is 180 kg.

During drilling the pump (11) provides circulation of the fluid from the bottom through the water lifting pipes (5) to the water accumulating tank (8). The fluid in the tank (8) is separated into components: water is collected at the tank bottom and the non-freezing fluid is evacuated to the bore-hole.

The main difference between the thermal drill TBZS-132 and the TBZS-152M is in the size of the drill head, the core pipe and the tank. The outer/inner diameter of the drill TBZS-132 head is 132/93 mm.

The KEMS-112 electromechanical ice core drill (Kudryashov et al., 1994) is designed for core drilling in glaciers and subglacial rocks to a depth of 4000 m. The drill (Fig.3) consists of the core chamber, a driving electric motor with a gear reducer, a pump, an antitorque system,a hammer block, an electric chamber, and cable termination. The total drill length, depending on the length of the core barrel, is 7-12 m, the drill weight is 120-180 kg.

The core chamber consists of a drill head (1) with three bits and three core catchers, a core barrel (2), a nipple (3), a barrel (4), and a chips filter (5). The outer/inner drill head diameters in different modifications are 112-116/85-89 or 132-135/107 mm. The corresponding outer/inner core barrel diameters are 108/99 or 127/117 mm, the core barrel length is 1.5-3.0 m.

The power of the driving electric type three-phase AC motor (7) with a nominal voltage of 220 V and the rotation speed of 2800 rpm is 2.2 kW. A two-step gear reducer (6) reduces the core chamber rotation speed to 230 rpm.

The voltage of the electric type DC motor of the rotary type pump (8) can be changed from 15 to 27 V with the maximum current of 12 A. An independent electric drive of the pump provides continuous circulation of the hole fluid during drilling, as well as other technological operations (bore-hole cleaning, for example).

The antitorque system for balancing the torsion torque consists of a lever system (10), a spring (11) and three skates (9). The force of each skate at the bore-hole walls, depending on the outer diameter of the antitorque system, varies from 540 to 980 N.

The hammer block (12) is used for breaking the core if it is necessary to extract a stuck drill. The weight of the hammer block with the travelling upper part of the drill is about 40 kg. A free run of the hammer block is 300 mm.

The electric chamber (13) acts as a rotary current collector and is intended for preventing cable twisting in case of failure of the antitorque system.

In termination the cable armor is clutched between the travelling plug (15) and the copper cone (14). The drill weight is taken up during penetration by the spring (16). The chips collector (17) is fastened on top the drill for bore-hole cleaning during recovery.

A special drilling complex (Fig.4) for deep coring was built at the Vostok station. The drilling complex consists of two huts mounted on sledges and measures 4.5x18.0x2.5 m.

In one hut the winch with the electric drive (the power is 15 kW), a unit for regular drill transfer, the control desk and other auxiliary equipment are installed. In the other hut a tower with a height of 15 m is mounted.

There are about 4000 m of the cable of KG7-95-180 type reeled on the winch. The cable diameter is 16.5 mm, the breaking strength is 95 kN, and the weight in the air is 865 kg/m. The cable has six teflon-insulated conductors with an area of the cross-section of 2.5 mm^2 each and the central coaxial conductor of the same cross-section.

The electric DC power for drilling operations is provided by diesel electric generators at the electric power station. The total power consumption of the drilling complex including heating and lighting, is about 40 kW.

3. Drilling Operations

In January 1990, the drilling complex which was located at Vostok at the deep bore-hole 4G (the bore-hole 4G was completed at the 2546.4 m depth) was moved to the west over the distance of 25 m. After assembling and adjusting all auxiliary devices (a system of heating, the power line, the control desk, etc.) the drilling of the bore-hole 5G was started on February 20, 1990.

The upper permeable interval was drilled without the hole fluid filling by the TELGA-14M type thermal drill. Then the bore-hole was filled with the hole fluid, and the core drilling was continued by the TBZS-152M type thermal drill. During the 35th and the 36th Russian Antarctic Expeditions (1990 and 1991) the bore-hole was deepened up to 2502.7 m.

This interval was drilled without serious complications. All systems of the thermal drill functioned in the normal operation mode. There were made 398 runs by the TBZS-152M in 1990 and 408 runs in 1991. The total time of the drilling run increased: 3.4 h for the 400 m depth, 4.4 h for 800 m, 5.2 h for 1200 m, 5.9 h for 1600 m, 6.6 h for 2000 m and 7.3 h for 2500 m. At the 2500 m depth the time of lowering the drill down to the bottom was 2.6 h and the time for its recovery was 1.8 h.

Inclinometric measurements showed the inclination angle of the bore-hole up to 2000 m to be almost constant, it varied within the range of 0.2-0.6°. Below 2000 m the inclination angle increased gradually from 0.4° to 1.8° at a depth of 2250 m.

At the end of December 1991 during the recovery of the drill the drill was suddenly stuck at the 2259 m depth. All attempts of moving the drill have failed, and the cable was broken from the cable termination. This accident was caused by insufficient compensation of the confining pressure: the average density of the hole fluid was only 860 kg/m3 and its level was at a depth of 207 m. This means that at a depth of 2260 m the difference between the pressure of ice and that of the hole fluid was about 2.8-3.0 MPa.

In 1992 a necessary quantity of the densifier was added into the bore-hole, and the average density of the hole fluid was increased up to 900 kg/m^3. Then pieces of the artificial ice core with a diameter of 93-95 mm and a length of 1.0-1.1 m were lowered on top of the damaged drill. About 35 m of the ice core was lowered and a new bottom of the bore-hole was raised up to the depth of 2232 m.

The deviation of the bore-hole was made by the TBZS-132 type thermal drill with a shortened length of 6 m. After drilling 14 m (the interval 2232-2246 m) a new bore-hole was created, and the ice core of a complete diameter was recovered to the surface. From the 2249.5 m depth the drilling was continued with the TBZS-132 which had a normal length of 8 m.

During the last months of 1992 and wintering of 1993 the bottom of the bore-hole (it was named 5G-1) reached a depth of 2755.3 m. But from September 18, 1993 the drilling operations were interrupted for more than one year due to shortage of fuel and temporary closing down of the Vostok station.

In the summer season of 1993/94 at the upper segment of the bore-hole a plastic casing was installed from the surface down to the 120 m depth. The inner diameter of the plastic tubes was 165 mm.

The main aim of the casing was to close the upper permeable interval and raise the level of the hole fluid. Testing has shown the casing to have a leak in one of the tube joints. It was possible to maintain the level of the hole fluid at the 70 m depth.

The drilling operations were resumed in the summer season of 1994/95. First, about 6.2 t of the densifier was added to the bore-hole, but, unfortunately, mixing by lowering and raising the drill was ineffective, and the main portion of the densifier was located in the upper part of the hole fluid. This situation caused the fluid leaking, probably, at the 400-420 m depth and the loss of about 1.7 m^3 of the drilling fluid. In our opinion, this drilling fluid drained to the 4G bore-hole.

During the next drilling operations a special device for adding the densifier to the needed depth was used. It allowed the concentration of the densifier in the bore-hole to be made uniform.

Then the diameter of the bore-hole within the interval 2200-2755 was enlarged from 134 mm to 139 mm by an electromechanical enlarger aiming to provide for reliable lowering and recovery of the drill.

Deep ice core drilling was continued by means of the electromechanical drill of KEMS-112 type on February 20, 1995. The interval 2755-3000 m was drilled using a drill head of 132 mm in the outer diameter. The technology of drilling included enlarging of the bore-hole every three runs with a drill head of 137 mm in the outer diameter.

The interval of 3000-3350 m was drilled using a drill head with the 135 mm outer diameter. Every 25-30 m the bore-hole was enlarged to 137 mm.

The entire lower segment of the bore-hole 5G-1 was drilled without serious complications. The average core production rate during the summer season of 1995/96 was about 10 m/day.

4. Conclusions

The deepest bore-hole in Antarctica was drilled using the thermal and electromechanical drills designed at the St.Petersburg State Mining Institute. After several years of intensive work the optimal drilling modes were achieved.

The drilling of the deepest bore-hole is considered important not only from the technical point of view, but it opens a new stage in climate reconstruction of the Earth.

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Table 1. Technological characteristics of ice core collection from the deep bore-hole 5G at the Vostok station

Intervals, m	Drill type	Average penetration rate, m/h	Average length of the run, m	Core diameter, mm
0-119.7	TELGA-14M	1.8	1.95	122
119.7-1279.8	TBZS-152M	2.1	2.9	109
1279.8-2502.7	TBZS-152M	2.3	3.2	110
2232.0-2249.5	TBZS-132	2.0	1.0	90
2249.5-2270.7	TBZS-132	2.0	2.0	90
2270.7-2755.3	TBZS-132	1.8	2.5	86
2755.3-3000.0	KEMS-112	8.0	2.4	100
3000.0-3350.0	KEMS-112	8.0	2.4	106

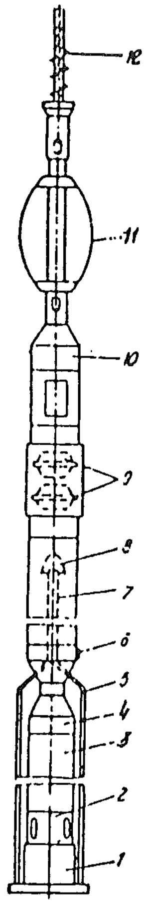


Fig.1. The "dry" boreholes TELGA-14M type thermoelectric drill principle layout:
1 - ring heater; 2 - adapter with a wedge corebreaker; 3 - corereceiving pipe; 4 - erection adapter; 5 - water lifting pipes; 6 - water output cock; 7 - central water lifting pipe; 8 - waterreceiving tank; 9 - turbocompressors; 10 - adapter with the cable; 11 - spring lantern for drilling tool aligning; 12 - armoured carrying cable

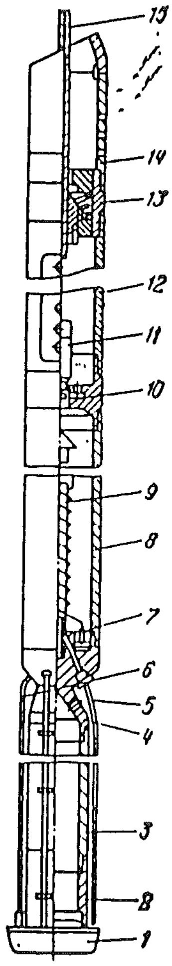


Fig.2. The TBZS-152Mtype filled borehole thermodrilling tool layout:
1 - ring heater; 2 - adapter with a wedge corebreaker; 3 - corereceiving pipe; 4 - erection adapter; 5 - water lifting pipes; 6 - feeding electric drive; 7 - water output cock; 8 - waterreceiving tank; 9 - central water lifting pipe with heating element; 10 - adapter with a pump; 11 - power-driven pump; 12 - electric compartment; 13 - adapter with a cable disconnector; 14 - slime collector; 15 - armoured carrying cable

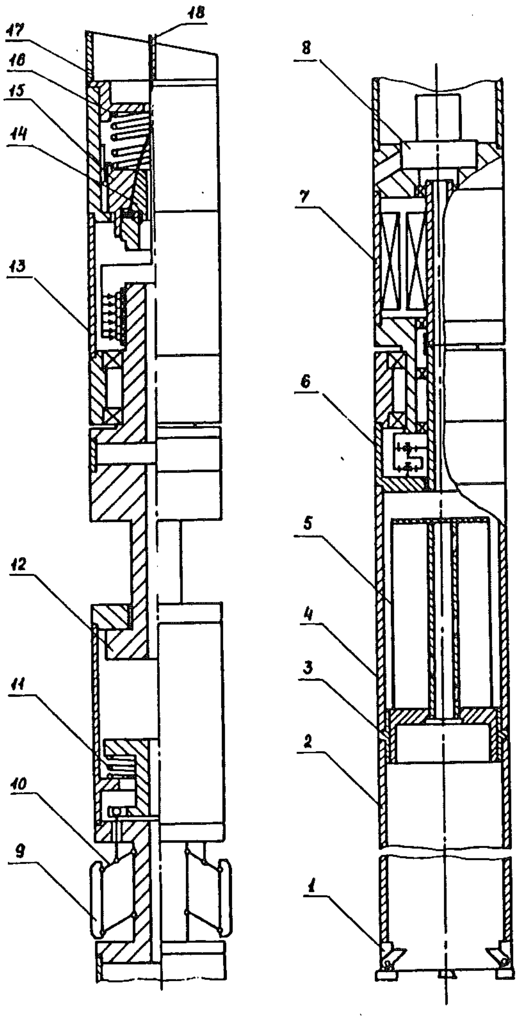
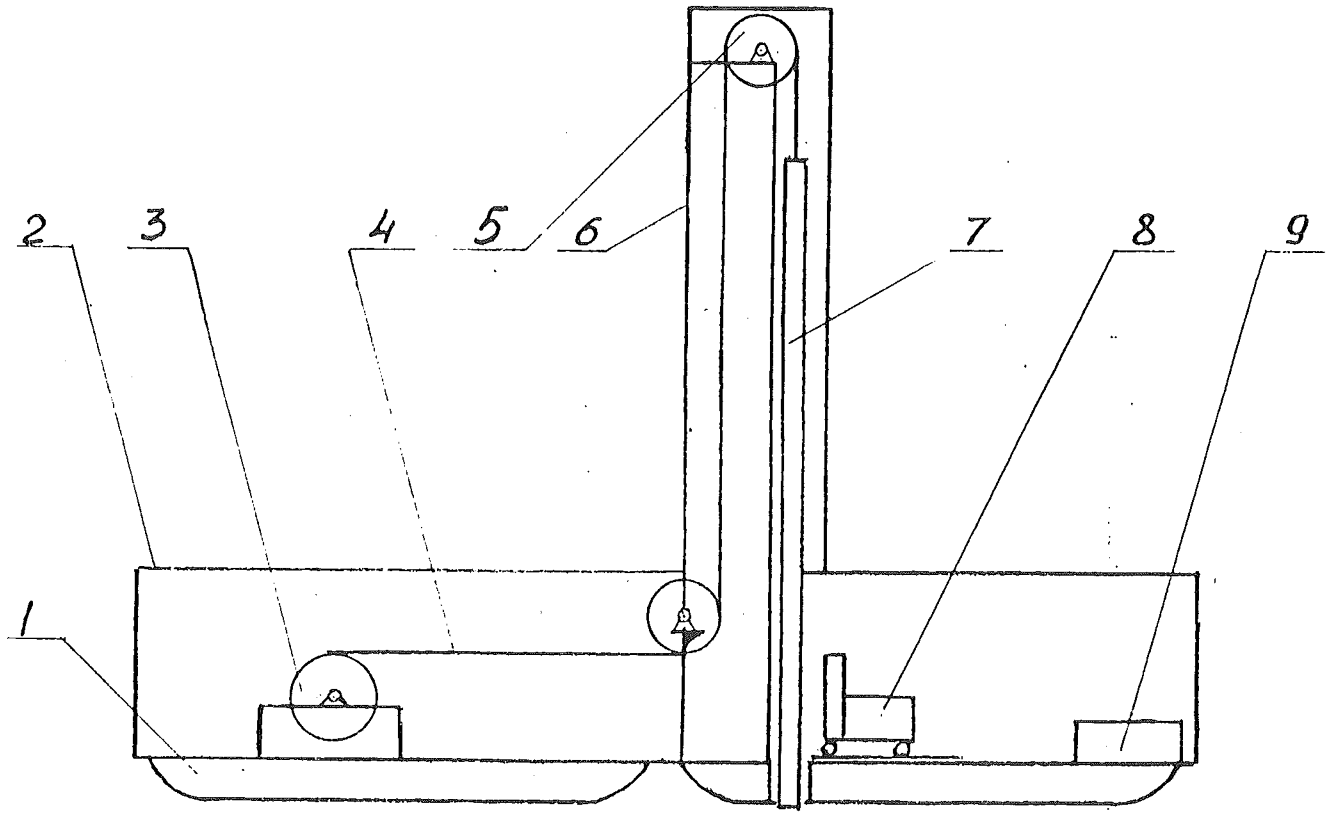


Fig. 3. Scheme of the KEMS-112 electromechanical ice core drill: 1-drill head, 2-core barrel, 3-nipple, 4-barrel, 5-chips filter, 6-gear reducer, 7-driving electric motor, 8-pump, 9-skates, 10-levers system, 11-spring, 12-hammer block, 13-electric chamber, 14-copper cone, 15-plug, 16-spring, 17-chips collector, 18-cable.



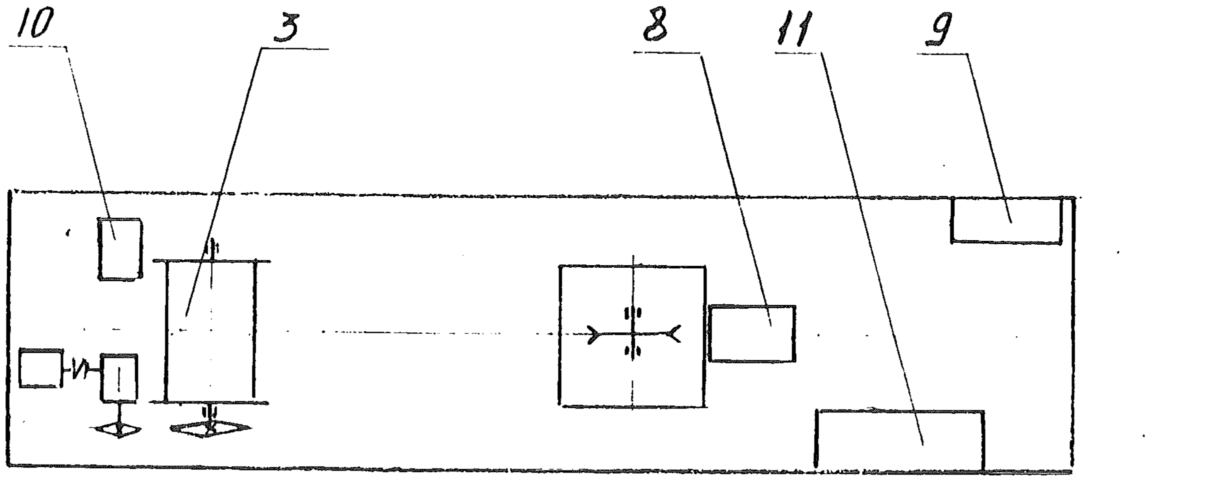


Fig.4. Plan of the drilling complex at Vostok station: 1-sledge, 2-hut, 3-winch, 4-cable, 5-top wheel, 6-tower, 7-drill, 8-assembling/disassembling device, 9-motor-generator system, 10-control desk, 11-joiner's bench.

The 13.2 Centimeter PICO Deep Coring Drill
Current Capabilities and Future Developments

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Abstract

The Polar Ice Coring Office has developed and deployed an electromechanical drill that is capable of recovering a 13 cm diameter ice core from ice that is as thick as 4,500 meters. This drill is also capable of taking a 3 cm diameter rock core after coring through an ice sheet. The limits on this drill are caused more by the logistical burden placed upon the support staff and aircraft transportation than on any inherent limitations of the drill itself.

Introduction.

The 13 cm deep coring drill has been deployed twice, to date. The first deployment was at Summit Camp in central Greenland from 1989 thru 1993 where the GISP2 ice core of 3,050 meters length was recovered. The second deployment was at Taylor Dome (McMurdo Dome), Antarctica during the 1993-94 Austral summer where an ice core of 550 meters was recovered. A third deployment is scheduled for the 1996-97 Austral summer when we will set up the drill system in preparation for recovering a 1,000 meter core at Siple Dome, Antarctica.

The more times that the deep drill system is set up and used in the field, the more reliable become the predictions of support requirements, cargo weights, and set up and drilling times. Since the effort put into the support and aircraft transportation requirements exceed those of recovering the core itself, it becomes essential to be able to accurately predict what support will be required and when drilling equipment will be required at the drill site.

Description of Drill System

The drill itself is a 27 meter long string that separates into 5 pieces varying in length from 3 to 6 meters. Starting from the bottom of the drill, the removable parts of the drill are: the 6 meter long core barrel with the coring head, the 3 meter long pump section, and two six meter long filter screen sections. On the top of the drill is the 6 meter long motor, instrument package, and antitorque section which are fixed to the drill cable and not removed during normal drilling activities.

The drill rig consists of a 34 meter tower built upon a one meter high berm of snow, a control room that is 6 meters above the snow surface, a drill handling carousel system for disassembling and holding the drill sections, an ice chip and drilling fluid handling system, a core handling system, and two cable winches. One winch is capable of holding 1200 meters of drill cable, the other is capable of holding 5,000 meters of drill cable.

Logistics

The following logistics model is based upon an airlift to a camp that requires 2-1/2 LC-130 flight hours from the logistical support base. It assumes that there is a prepared skiway at the remote field camp.

Camp and Camp Supplies

The science/drilling contingent in a camp as described above should be 8 drillers, one drilling manager, 4 core handlers, one or two physical properties scientists, and a chief scientist, for a total of 16 people. There would also be 6 to 8 camp staff. Additionally, any time a camp of this type is set up in Antarctica, other scientists have a reason to go there to "do science". Add 4 to 6 other scientists for a total of 30 people. Prior to the science/drilling contingent arriving at the camp, and during their first two weeks in the camp, 4 to 8 construction workers (in addition to camp staff) will be setting up or constructing the following:

one 16 section Jamesway, Galley
one 8 section Jamesway, Bath & Laundry
one 10 section Jamesway, Science
two 8 section Jamesway, Berthing
two 10 section Jamesway, Berthing
one 8 section Jamesway, Mechanic Shop
Camp water melter
Camp generator
two 9 section Jamesway, Drilling
Drilling generator
Core Storage Trench
Fuel Storage

The camp would take an estimated 10 LC-130 flights to be fully supplied.

There is a difference in science support between Antarctica and Greenland. In Antarctica, there is a large base at McMurdo Station that can supply construction workers to assist in setting up a remote field camp. In Greenland, this is not the case and the drillers normally arrive at the remote field camp one week prior to beginning their drilling duties in order to assist the camp personnel in setting up the camp.

Drilling Equipment

The drilling equipment mass is 25 tonne, which is 3 LC-130 flights. The drilling fluid mass is 40 tonne per 1,000 meters of drilling, which is 4.5 aircraft per 1,000 meters. The core boxes and core tubes mass 5 tonne (empty) per 1,000 meters of drilling, which is two aircraft per 1,000 meters. An additional half of an aircraft would be filled with items requested from Science Support. The drilling equipment for a project such as Siple Dome would take 10 LC-130 flights to be fully supplied.

Total Camp Supplies

For 1,000 meters of core in one season, 20 LC-130 flights would be needed to supply the camp and drill, and 18 flights would be needed to retrograde the camp, drilling equipment, and the ice core for a total of 38 aircraft flights. A two season project of 1,000 meters would probably take an additional four LC-130 flights to shuttle personnel and equipment at the end of the first season and the beginning of the second. This brings the total aircraft flights for the project to 42.

For 3,200 meters of core in two seasons in Greenland, 65 LC-130 flights would be needed to supply and retrograde the camp and drilling equipment.

Future Developments

Most proposed modifications to the deep drill system are incremental, in that they are minor modifications that make the drill system easier to assemble or easier to use. For example, at Taylor Dome, assembly of the crown block and sheave to the top of the 34 meter tower took 1.5 days. Enlarging four holes by 1.5 mm is expected to reduce that time to 0.5 days. Although this is a small improvement in the assembly time, such improvements are cumulative.

Other improvements to the drill system are major departures from the way things have been done in the past. Some of those will be discussed below.

30 cm Core Barrel

Prior to putting drilling fluid down the hole, the hole is normally cased past the firn-ice transition to prevent the drilling fluid from soaking into the firn. In order to install the casing, a core is first taken with a 13 cm dry drill, the hole is then reamed in four steps to 36 cm diameter, and a 26 cm I.D. casing is lowered into the hole. Drilling the hole and recovering the core takes 1.5 days, and reaming takes 4.5 days for a total time of 6 days or one drilling week.

PICO is presently having a core barrel built that would take a 30 cm diameter firn core, and leave a hole of 36 cm diameter ready to take the casing. Assuming that recovering the core would still take 1.5 days, this is a savings of 4.5 drilling days. Most scientists are quite pleased with the prospect of having so much firn core to examine.

Brittle Ice

One of the problem areas of ice core drilling is the brittle ice region. This ice is not strong enough to be supported on the core catchers or core dogs as it is retrieved from the borehole. PICO uses a six meter core barrel with the deep drill. However, when drilling brittle ice we only attempt to recover three to four meters of ice at a time. Even when attempting to recover as little as 2.5 meters of core, sometimes the core will avalanche out of the core barrel and we will get only one meter of core. The rest is shards and pieces floating in the drilling fluid that, although recovered, is of little or no use to the science community.

PICO is examining different ways of closing off the bottom of the core barrel when retrieving core from the brittle ice region. Although this would not prevent the brittle ice from cracking because of the highly pressurized bubbles, it would keep the pieces in the shape of an ice core and should make the core more useful to the science community.

Acknowledgments.

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ENVIRONMENTAL AUDITING

The Antarctica New Zealand Experience

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1.0 Introduction

1.1 Background to the Audit

Operating in Antarctica and within the framework of the Antarctic Treaty system (ATS) requires a commitment to a level of environmental awareness and practice which seeks to minimise the impacts of human activities. In 1991, Antarctic Treaty Consultative Parties agreed to the Protocol on Environmental Protection to the Antarctic Treaty (the protocol). The protocol builds on and strengthens existing environmental measures and guidelines under the ATS and while not yet legally in force parties agreed to conduct their activities as if it was.

In September 1993 the New Zealand Antarctic Programme (NZAP) (now Antarctica New Zealand) commissioned an independent environmental audit of its activities. The audit was completed in March 1994 and assessed the level of compliance of procedures and activities with the requirements of the protocol. The audit was the first of its kind for a national Antarctic operator and represents one tool that managers can use to review and build on current environmental practice.

The final audit report contained over 190 recommendations. Review and implementation of the recommendations is still continuing two and a half years later. The environmental audit process and subsequent action on recommendations was seen as a means by which NZAP could improve its environmental management and determine independently, its level of compliance with the protocol. The benefits and value to the organisation of the audit were considerable.

The process by which the audit was conducted and managed, the audit results and process for implementation of audit recommendations are discussed below. The value of the audit process is considered and key components important to the success of the audit and to attaining maximum benefit from audit results are identified.

1.2 Antarctica New Zealand

On 1 July 1996 Antarctica New Zealand was created under the New Zealand Antarctic Institute Act 1996. Antarctica New Zealand has its origins in the Ministry of Foreign Affairs and Trade's operational division known as the New Zealand Antarctic Programme and the government science advisory body the Ross Dependency Research Committee.

Antarctica New Zealand's mission is to provide leadership in developing, promoting and realising opportunities for New Zealand from international involvement in Antarctica and the Southern Ocean. To achieve the mission, Antarctica New Zealand has identified six strategic goals. Environmental Stewardship features as one of the goals and states that Antarctica New Zealand will:

(iv) Provision of recommendations for ensuring compliance where this was lacking; and

(v) Provision of recommendations to improve compliance, where protocol requirements are non prescriptive.

3.3 Background investigations, interviews and the Antarctic visit

Christchurch facilities were examined and detailed discussions held with Christchurch based staff. The purpose of interviews was to gain an up-to-date understanding of current operations. Plans staff had for implementing the protocol requirements were also discussed. Files, documentation and other information requested by the auditors was also made available.

Two auditors visited Scott Base and nearby field facilities for 10 days during January 1994. Scott Base activities were examined and involved a thorough investigation of all facilities and storage areas and detailed discussions and interviews with Scott Base staff. A cross section of NZAP field facilities was also visited and discussions held with over 30 science staff about their research and support requirements.

3.4 Evaluation and recommendations

Throughout the review process, the current level of, or potential for, environmental impact was evaluated in a qualitative manner as sampling and monitoring were not part of the audit process. This evaluation was incorporated into the assessment of compliance and identification of appropriate recommendations.

Recommendations were categorised according to whether they related to procedures or operations. Recommendations for compliance with protocol requirements were made where there was non compliance, partial compliance or where the degree or method of compliance could be improved. In a number of cases, recommendations were made regarding operations and/or procedures that although affecting NZAP activities were not necessarily the responsibility of NZAP to implement.

4.0 The Audit Report

4.1 Report format

Early on in the audit process it was decided to separate the audit of protocol compliance from that of New Zealand legislative compliance. Consequently, two reports were prepared although considerable cross reference was provided where appropriate. Both reports followed the same format and resulted in documents that although large, were easy to follow and reference.

The main audit report (for protocol compliance) was 148 pages long. The bulk of the document, the compliance assessment section, was split into procedures, operations and "common matters" sections. Procedures and operations are described, evaluated for protocol compliance and recommendations put forward. The format provides an excellent summary of nearly every aspect of NZAP operations and a clear evaluation of compliance. Recommendations follow logically from the discussion and are easily referenced and accessed by readers. Each subsection also includes a summary table that allows quick reference to relevant articles of the protocol, with a summary of the requirements of the article and a comment on NZAP compliance with each article.

The procedural section includes matters such as permitting, training, exchange of information, purchasing, environmental impacts assessment and policy. Operational items include waste management, fuel storage, use and transport, water systems, contingencies and energy efficiency.

4.2 The recommendations

The final audit report on protocol compliance contained 193 recommendations. A further 27 recommendations were made in the second audit report which dealt with compliance with New Zealand resource management and health and safety legislation. For the remainder of this paper, the discussion will be confined to consideration of the main audit report for protocol compliance.

The 193 recommendations in the protocol report were grouped into two categories, those where action was required for compliance with the protocol directly (50) and those where the action would improve compliance (143). The audit concluded that:

> *"...the New Zealand Antarctic Programme (NZAP)....has achieved a high level of compliance with the Madrid Protocol to date."*
>
> (Royds Consulting, 1994)

However major areas of non compliance were identified and included:

(i) Lack of detail in preliminary environmental impact assessment;

(ii) An inadequate level of monitoring;

(iii) Some poor field camp management activities;

(iv) Inadequate training of some Scott Base personnel;

(v) Uncertain impacts of sewage discharges;

(vi) Some fuel handling/storage practices; and

(vii) Some materials handling/storage practices

4.3 Important elements of the audit report

The format of the audit report meant that the document was user friendly and enabled both in depth use as well as providing a quick overview of compliance. Key elements of the report include the following:

(i) An executive summary - the summary includes a two page compliance overview which was the most widely read and distributed part of the report. Summary compliance tables were cross referenced to specific protocol articles;

(ii) Separation of procedural and operational areas of NZAP activities;

(iii) A logical easy reference format for specific activity areas - description of activity, evaluation of compliance and recommendations; and

(iv) A clear method of direct and detailed cross reference to protocol articles:

5.0 Implementing the Audit Recommendations

5.1 Implementation approach

The approach to implementation of audit recommendations took two main directions. Firstly, an organisational commitment to the protocol and an environmental stewardship ethic was incorporated into business and operational planning, and secondly, a comprehensive internal review of audit recommendations was carried out.

The Business Plan and Operational Plans for the years immediately following the completion of the audit identified a number of environmental obligations and environmental initiatives which would require additional resources. A strong planning base and clear organisational commitment to the protocol through implementation of audit recommendations was therefore established at an early stage after completion of the audit. A commitment at this level provided the necessary impetus to allow a comprehensive review of recommendations and ensured support from management staff.

Recommendations were reviewed in April and May 1994 by the NZAP Environmental Officer. Recommendations were grouped according to where responsibility for implementation lay within the organisation. Recommendations were assigned to five responsibility areas; operations (78), facilities (77), information (10), administration (5) and management/policy (23). Specific individuals within the groups were then assigned responsibility for implementation and each recommendation assigned a priority (low, medium, high).

Priorities were assessed primarily according to whether the action was required for compliance with the protocol (or just for improving compliance) and taking into account the perceived level of environmental risk associated with not carrying out the proposed action. The review identified 35 high priority recommendations which formed the core for the development of timetables and strategies for achieving protocol compliance.

Recommendations were then reviewed by the relevant manager with comment sought on proposed priorities and timing. Input and agreement on key initiatives arising from the audit was also sought from other New Zealand agencies and individuals with a role and interest in the Antarctic. A workshop was convened in November 1994, to discuss the recommendations and provide NZAP with feedback on the implementation strategy. Workshop participants represented a wide range of organisations with Antarctic interests, from government departments and ministries to scientists and non government organisations.

The workshop reached general agreement on the priorities (as identified by NZAP) although there was debate about which Antarctic agency should be implementing some recommendations ie agencies external to NZAP. The workshop also identified the need for an independent review and monitoring of the implementation of recommendations although this was not seen as an immediate task. Areas where the workshop saw potential problems arising in implementation were also identified (Waterhouse, 1994).

The results of the workshop were formally written up, reviewed by NZAP and suggestions and comments incorporated into the review process where appropriate. Following the workshop, agreement was reached with managers on the implementation strategy. The timing for implementation of recommendations was set out and individual managers tasked with implementing recommendations in their areas. Oversight, advice and regular review was provided by the Environmental Officer.

5.2 Progress with implementation

A regular six monthly review and reporting timetable was set up after the workshop and final agreement on priorities and timing for implementation. The last review report was completed in July 1996. The review reports ensure that there is regular information available to staff and other Antarctic agencies on progress with implementation. Maintaining the momentum for implementation and review of progress was seen as a major challenge after the audit was completed. The review reports are an essential element of the overall implementation strategy and clearly identify progress with implementation and identify achievements in the last six month period.

Since March 1994 (when the final report was completed), 140 recommendations have been implemented by NZAP. Overall approximately 80% of audit recommendations (where it was identified that NZAP action was required) are either under immediate action or have been implemented. Major initiatives completed since the audit was completed include the following:

(i) Draft environmental policy for NZAP;

(ii) Review of all NZAP policy and procedures to more fully reflect protocol requirements;

(iii) Environmental code of conduct distributed to all Antarctic personnel;

(iv) Detailed preliminary environmental assessment procedures for non science activities;

(v) Post season environmental review of all activities to assess level of compliance with pre season EIAs;

(vi) Staff training with increased environmental components;

(vii) Monitoring programmes for incinerator emissions, landform change around Scott Base and the sewage discharge;

(viii) Completion of a comprehensive waste management handbook;

(ix) Continuing implementation of the NZAP oil spill contingency plan;

(x) Improvements to fuel handling, storage and transport arrangements; and

(xi) Development of a waste inventory system at Scott Base.

Implementation of the remaining recommendations is planned over the next 12-18 months.

5.3 Key elements for successful implementation

The final audit report was completed two and a half years ago. Since that time considerable progress has been made by Antarctica New Zealand to systematically review and implement the recommendations. Key actions which enabled successful implementation of approximately 80% of recommendations are listed below:

(i) The commitment to sound environmental management practice and consequently implementation of the audit recommendations at the highest level of the organisation. Implementation goals were built into organisational and operational planning documents;

(ii) An internal review of recommendations was commissioned with a single point of contact with responsibility for coordination of the audit process;

(iii) Management and staff were informed of progress and educated about the audit implementation process/strategy;

(iv) Recommendations were prioritised according to specified criteria;

(v) Realistic time frames and appropriate resources were allocated;

(vi) Clear individual responsibility was allocated against every recommendation; and

(vii) A clear process with provision for regular reporting on implementation progress was established early on in the process in order to maintain the momentum and incentive for implementation.

6.0 Value and Benefits of the NZAP Environmental Audit

6.1 A compliance assessment tool

As a signatory to the protocol, New Zealand agreed to operate as if it was already in force. In 1993, legislation for implementing the protocol in New Zealand law was being drafted. As New Zealand's national operator in Antarctica, NZAP would be required to comply with the requirements of the Act. Identification of actions required to achieve compliance with the protocol and New Zealand's implementing legislation was therefore required.

The audit provided a systematic approach to assessing compliance and established a baseline from which improvements in environmental performance could be planned and measured. Implementation of audit recommendations would ensure that NZAP was operating within the boundaries of the protocol and New Zealand legislation (once enacted).

6.2 Providing direction to environmental initiatives

While the audit identified recommendations required for compliance with the protocol, implementation was required in an effective manner which minimised immediate environmental risks and impacts. The approach to implementation of recommendations was efficient, comprehensive and transparent and had as its basis a clear direction based on previously agreed priorities and deadlines.

The implementation strategy has been used as the basis for determining major environmental initiatives in particular in the development of environmental policy and management systems for the organisation. The audit itself provided the first significant step towards the development of this comprehensive environmental framework.

6.3 An awareness and educational tool

The audit was the first of its kind for a national Antarctic operator. NZAP recognised the value of the report (in particular its positive findings) as an excellent opportunity to illustrate NZAPs commitment to implementation of the protocol as well as a report on existing environmental performance.

Within New Zealand the audit results served to provide detailed information about NZAP activities to non governmental agencies, environmental groups and organisations with Antarctic policy interests. For these groups, the independent nature of the audit was of particular importance and contributed significantly to the credibility of the findings and the new environmental initiatives that were subsequently proposed.

The audit report was officially released, a press conference held and press releases distributed. The audit contents and executive summary were placed on the World Wide Web site "Gateway to Antarctica" and the report made available for purchase. To date over 50 copies of the audit report have been sold. The audit was also tabled as an Information Paper at the XVIII Antarctic Treaty Consultative Meeting in 1994.

Although the report found significant areas of non compliance, the overall positive tone of the report, the transparency and willingness with which the audit was distributed ensured that the outcome in terms of public and stakeholder perception was beneficial to NZAP. This process also assisted in raising the level of awareness among policy makers and funders about the implications of protocol compliance.

6.4 Providing back up for environmental staff

The audit report was an independent assessment of the current status of NZAP compliance with the protocol. Subsequent review of the audit recommendations confirmed the findings and provided the basis for the development of environmental management initiatives within NZAP. The audit provided useful back up and verification of new initiatives especially where additional funding was required or significant changes in procedures and practices were advocated by environmental staff.

6.5 Definitive statement on organisational operations and procedures

An unanticipated additional benefit of the audit process was the value of the audit report as a reference document. The report provided a readily accessible statement of current procedures, facilities, activities and operations in Christchurch and Antarctica. In many cases staff were unaware of some practices and procedures within the organisation.

Sections of the audit report has since been used as background information for other reports and publications, as educational material, for staff training and provision of information to the public.

7.0 The NZAP Environmental Audit - key conclusions.

7.1 Operating in the Antarctic environment - the need for balance

The auditors were the first to acknowledge that "in assessing the level of compliance with the protocol it is necessary to bear in find the often difficult practicalities of performing tasks and operations within the often harsh and changeable Antarctic climate and physical environment". The auditors went on to state that a balance was required between environmental protection and what is practically achievable and that this need for balance was a key factor in determining recommended action for NZAP..."

The previous Antarctic experience of the audit team leader, the extensive briefing and contact with staff and scientists, and in particular the Antarctic visit, ensured that the auditors formed realistic expectations of what was achievable under Antarctic conditions while remaining independent in their assessment.

7.2 Important components of a successful audit in the Antarctic

The audit was completed two and a half years ago. Since completion of the audit important elements needed for a successful outcome to the audit and to implementation and follow up have been identified. Key components which contributed to NZAP implementing approximately 80% of audit recommendations are detailed below:

(i) The scope, objectives and expectations of the audit must be clearly identified before any work commences;

(ii) Reporting outcomes and follow up support should be agreed with the auditors before work commences;

(iii) One person should be designated as the single point of contact for the auditors in the organisation. This person can also be responsible for education of staff and provision of information on the audit process as required. A similar person should be designated for the Antarctic visit;

(iv) The auditors must be given free and unimpeded access to files and documents and be free to interview all staff;

(v) An Antarctic visit is essential. A full range of full range of activities should be included in the itinerary ie visit to the main base(s), field site and field camps and other infrastructure;

(vi) Auditors should be appropriately qualified and/or be able to demonstrate and prove their experience in auditing in a wide range of environments. Previous Antarctic experience or involvement in Antarctic projects is also highly desirable;

(vii) Auditing procedures should be carried out in accordance with approved international standards and guidelines;

(viii) The difficulties inherent in interpreting some aspects of the protocol need to be acknowledged and dealt with eg prescriptive vs non prescriptive requirements;

(ix) To fully capitalise on the investment in the audit, the audit process and implementation strategies must be successfully "sold" to staff, Antarctic stakeholders and interested parties outside the organisation. The availability of the audit report is a key element in this process;

(x) The audit does not "stop" when the final report is produced. The majority of benefits of going through the audit process accrue from the subsequent review and implementation of recommendations. A clear mandate and responsibility should be assigned within the organisation for carrying audit findings further;

(xi) Prioritisation of actions and identification of systems and procedures to improve the management of environmental aspects of the organisation is required to allow effective identification of both the framework, and detailed requirements necessary to ensure sound practice;

(xii) A clearly defined implementation strategy should be developed and appropriate resources assigned. This approach does not necessarily mean that all recommendations will be implemented. Some recommendations may be discarded through the review process as being unpractical or unachievable or not responsibility of the organisation; and

(xiii) Consideration should be given to how implementation of recommendations is to be monitored. A follow up audit (after a specified time) is one option.

7.3 The environmental audit as a valuable management tool

The environmental audit of NZAP activities collated and documented compliance with legal and cooperate requirements. It also provided verification, by inspection, of the establishment and operation of mechanisms and procedures in place to protect the environment and personnel from harm.

In commissioning the audit the primary focus was on determining independently the level of compliance with the protocol and impending legislation. While this was the main objective of the audit, it became clear throughout the process and in the follow up to the audit that numerous other benefits have accrued to the organisation.

The use of environmental auditing is becoming more widespread as standard practice in environmental management. Examination of any literature on environmental auditing illustrates the range of audits that can be completed. Environmental auditing in whatever form should be viewed as a useful management tool that can be used by Antarctic operators to provide the organisation with valuable information about their environmental performance and possible future initiatives.

Acknowledgments

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USAP Spill Response Summary

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INTRODUCTION

As part of the Safety, Environment and Health (SEH) initiative in the late 1980's, the National Science Foundation (NSF) developed a comprehensive spill response program for the United States Antarctic Program (USAP). The program has two basic philosophies:

> **Prevention** of spills through community awareness, operational procedures designed to prevent spills, and engineering controls.
>
> **Preparedness** through strategic prestaging of response equipment, training and organization of spill teams, and procedures that decrease response time.

Initial program development involved a comprehensive review of all USAP fuel handling operations to determined the most likely "worst case" scenario—the largest spill that could reasonably be responded to with resources available on station. The resulting program integrated recommendations of the Standing Committee on Antarctic Logistics and Operations (SCALOP) sub-group on Oil Spill Prevention and Response, as well as U.S. regulatory requirements enacted as part of the Oil Pollution Control Act of 1990 (OPA-90). OPA-90 is similar to the SCALOP recommendations in that it requires a more comprehensive approach to oil spill planning than in the past. OPA-90 regulations identify specific types of facilities subject to regulation in the U.S. and details the required components of facility response plans. Both SCALOP and OPA-90 use a tiered approach to contingency planning as well as defined formats. The tiered approach includes development of contingency plans for facilities and geographic areas where coordinated response by two or more operators is feasible.

Historic analysis of spill data indicates that the USAP Spill Response Program has been remarkably effective in reducing the total number of spills as well as average spill size over the last 3 years. The bulk of these improvements stems from increased community awareness, both in preventing spills as well as reducing environmental impact through alert observation and reporting. Improvements in engineering controls have also had significant impact in reducing the total number of spills that occur in a given period.

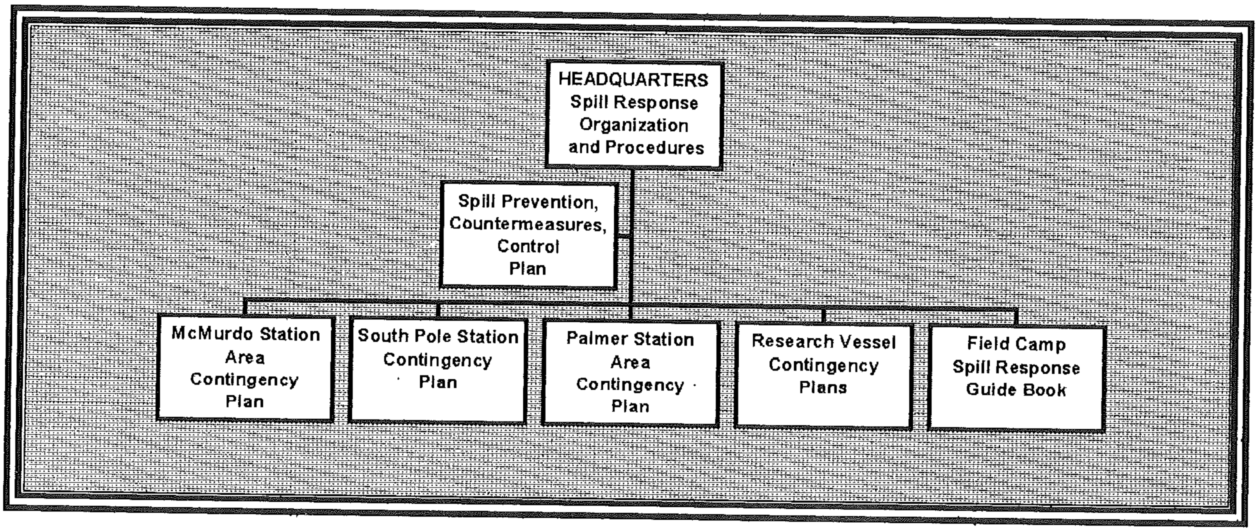
CONTINGENCY PLANS

USAP Spill Response Plans consist of several inter-related documents that basically follow the tiered approach recommend by the SCALOP sub-group. These documents include:

Headquarters Contingency Plan (HQCP)
Area/Facility Contingency Plans (ACP)
Spill Prevention, Countermeasures and Control Plan (SPCC)

These documents are both policy and practical guidance documents that are used as a technical resource. The plans are reviewed and updated every 3 years, as recommended under OPA-90. Significant changes in operational procedures also trigger review of the plans to assure that they accurately reflect response capabilities, available resources, and changes in station operations. Figure 1 shows the organization of USAP Contingency Plans.

FIGURE 1
USAP Contingency Plan Organization



The HQCP describes procedures and responsibilities for National Science Foundation and subcontract management personnel at headquarters offices. Support procedures for formal spill reporting to pertinent governmental agencies of a spill, coordinating outside assistance and resources, and public relations can become critical to effective spill response.

Original USAP Spill Response Program development included separate facility and area plans as recommended by SCALOP. However, these plans proved to be somewhat redundant in the information and procedures they detailed when compared to the facility plans. Multi-national cooperation is feasible at several US Antarctic Stations. However, coordination and pre-planning have not been formalized making the information in the original area plans limited and rather generic. As a result, USAP area and facility contingency plans have been consolidated into a single document. The consolidated plans each describe in detail:

Facilities

Potential risks
Response Strategy
Response methods and procedures
Response organization
Communications
Equipment
Cleanup and decontamination
Safety
Documentation and reporting

Figure 2 shows the basic USAP Contingency Plan format.

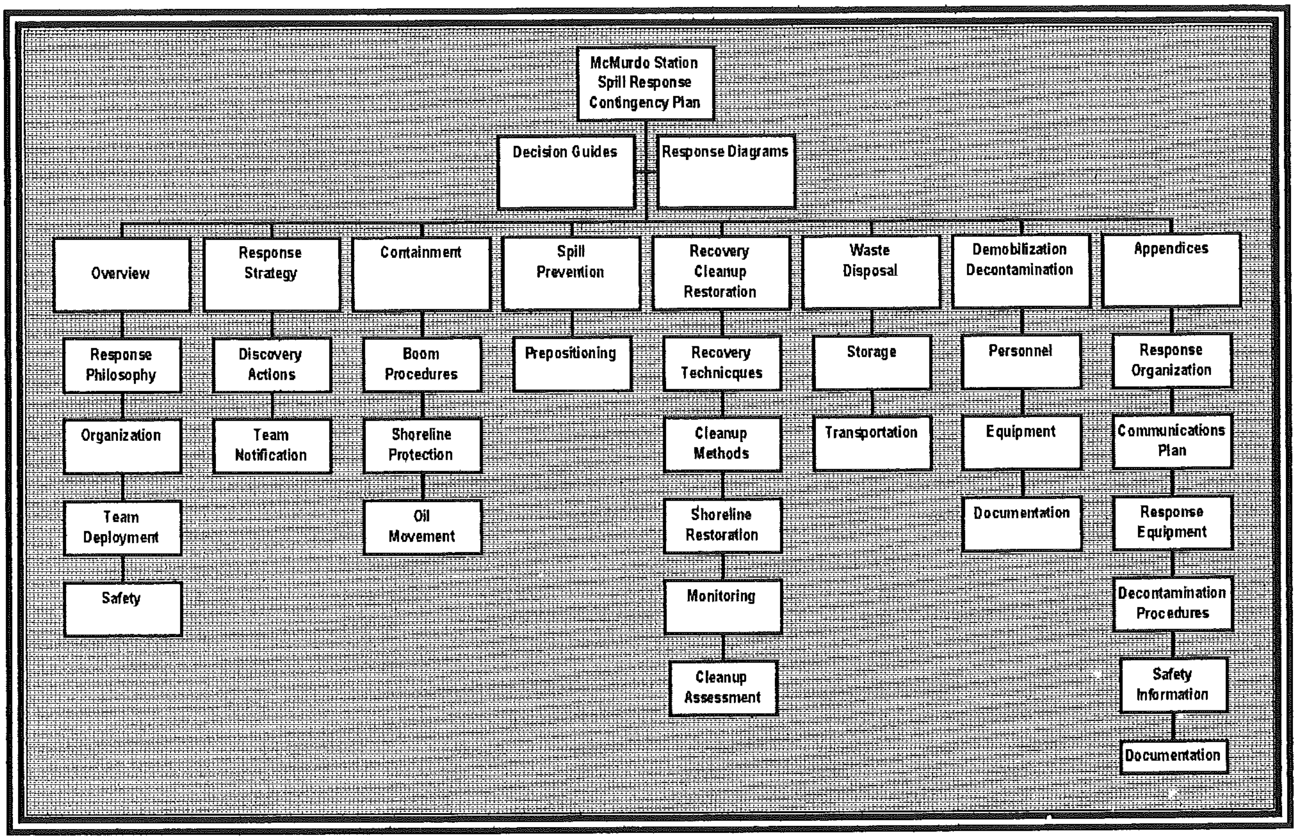
Future coordination with other national programs may warrant separate documents. However, the level of coordination and mutual aid will dictate the complexity of these plans.

USAP contingency plans also contain decision guides and response diagrams that are used during an actual spill event. The decision guides consist of step-by-step flow charts for a variety of potential spill scenarios and function as an operational checklist ensuring all measures required by the contingency plan are implemented. Graphical response diagrams showing equipment staging locations, inventories, and equipment deployment recommendations complement the decision guides and assist response teams in determining optimal response measures for a given location under a variety of environmental conditions. These are key elements in making the contingency plans a practical resource for response personnel.

The SPCC Plan describes the engineering controls and operational procedures that are in place and designed to prevent, control, and minimize both the incidence and size of any potential spill. The plan includes a comprehensive listing and description of:

All oil storage and handling facilities such as tanks, pipelines, transfer facilities, and sites of use.
All engineering controls in use and designed to prevent, contain, and/or control any potential spill. These include items such as secondary containment (berms, drip pans, etc.), tank

FIGURE 2
USAP Contingency Plan Format



construction (double walled), equipment design ("dry-break" hose), physical barriers, etc.
All operational procedures used in the handling of oil including safety and spill prevention steps and/or requirements.

The SPCC ensures that appropriate measures are taken to prevent potential spills from either equipment failure or operator error during normal operations. It also identifies all oil handling facilities, equipment, and tanks. Cross referencing of this information with spill contingency plans is extremely valuable for response planning.

PREVENTION AND PREPAREDNESS

In the U.S., spill prevention programs are normally described in a separate document, the SPCC. Most industrial complexes also have awareness programs directed at employees and/or the community. These programs enlist the support of personnel to conduct their jobs in a manner that prevents spills from occurring and reporting spills more quickly. The USAP has developed both an SPCC and community awareness program as integral parts of the overall Spill Response Program. A Spill Prevention, Countermeasures, and Control plan identifies all fuel storage and handling sites and equipment, engineering controls, and specific operational procedures designed to prevent spills. This provides a valuable resource for determining spill volumes during actual incidents, making the SPCC a companion document for the contingency plan.

All personnel involved in the USAP receive orientation that includes spill prevention, awareness, and reporting. Spill response personnel often work with spillers on procedural modifications or engineering controls to prevent a spill happening again. This public relations effort results in personnel actively participating in spill prevention and response making the entire community an "adjunct member" of the spill response organization.

Preparedness ensures that an organization has the equipment and appropriately trained personnel to respond to a theoretical "worst case" spill with the resources available under the facility's limiting conditions. Using algorithms developed by the U.S. Environmental Protection Agency and Coast Guard, worst case scenarios for the USAP are fuel transfer operations during station refueling. A variety of spill response equipment is staged at both shoreside transfer and bulk fuel storage locations. Equipment at shoreside locations includes containment and sorbent booms, gas powered skimmers for removal of fuel from water, and spill response boats. Response equipment staged at bulk fuel storage areas consists primarily of sorbent and containment media. In addition to this dedicated equipment, heavy equipment, such as forklifts, bulldozers, backhoes, and loaders are identified for priority use, should a spill occur. Field camps are provided with transportable spill kits sized appropriately for the camp.

Training is a critical element in spill response and preparedness. Spill response personnel receive initial and annual refresher training equivalent to U.S. standards for spill response personnel. Reviews.and "hands-on" exercises are also conducted in Antarctica to ensure familiarity with procedures and methods specific to each station.

SPILL TEAM ORGANIZATION AND TRAINING

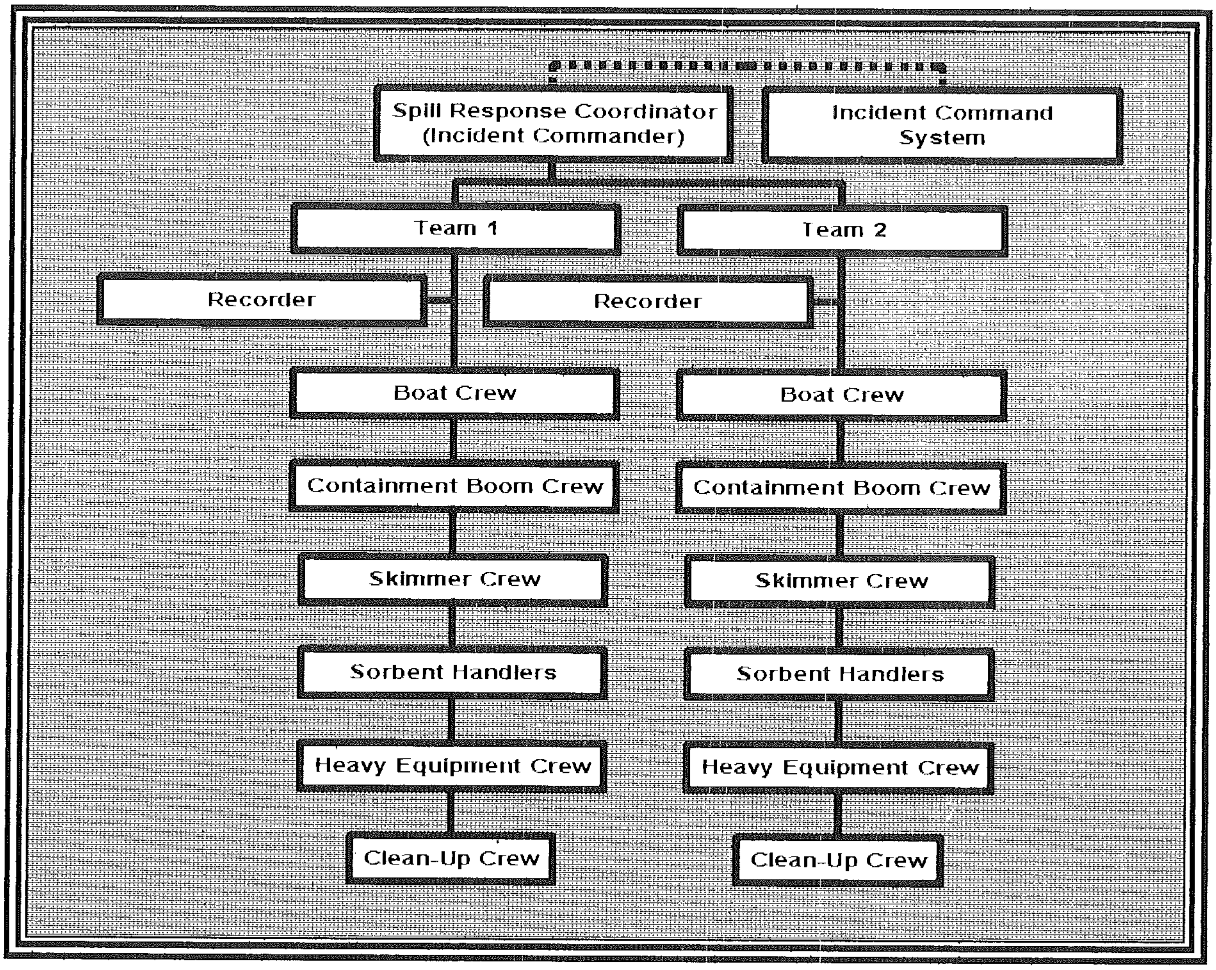
The USAP Spill Response organization utilizes the Incident Command System (ICS) to respond to spills. The ICS uses a "matrix management" approach for responding to spills in which key operational and support elements are coordinated through a central management group (i.e., command post). During an actual response operation, the on-scene incident commander coordinates and requests support from other operational elements (heavy equipment, aircraft support, additional personnel, supplies, outside assistance, etc.) through the "command post." The command post is staffed by key managers that have the authority to assign assets to the incident. For example, if an on-scene spill commander requires helicopter support for aerial reconnaissance, he requests that support through the Command Post who coordinates that support with the manager for helicopter support. The key to an effective ICS is both communications and adherence to the proper chain of command.

Spill response teams at USAP stations vary in size based on the size of the station and the spill risks present. The spill response team at McMurdo Station consists of two 23-member response teams. The "core team" consists of 18 personnel who also function as the Hazardous Materials Spill Response Team. The remaining 28 personnel are drawn from the station population as volunteers during high risk evolutions. Volunteers receive first responder training and are assigned to a specific sub-team. At Palmer and South Pole Stations the spill response teams consists of 6-10 member teams because of the reduced volume of materials and risk.

Spill response teams are subdivided into "sub-teams" with specific duties. Sub-teams include boat crews for containment boom deployment, sorbent teams for placing sorbent materials on shore areas, skimmer teams that operate oil skimming equipment, clean-up workers for equipment decontamination, heavy equipment operators, and recorders for maintaining incident logs (see Figure 3). Each spill team also has a Team Leader and On-Scene Commander that manage the incident and coordinate with the ICS.

The USAP has adopted U.S. spill response training requirements as a guideline for USAP spill team training. Regulations require that spill response personnel receive a minimum of 24-hours initial training and 8 hours of annual refresher training. Team leaders and on-scene commanders must receive and additional 8 hours training in incident management and control. USAP spill response personnel are certified for both oil spill and hazardous materials response. Integrated training provides certification in both areas by attending a customized 40-hour training course. Community volunteers used for the McMurdo Station oil spill team receive 8-hours of classroom training at McMurdo, followed by 4 hours of practical training on response equipment. This training is scheduled shortly before high risk evolutions and uses the practical training to conduct equipment checks and final staging of key equipment such as containment boom, skimmers, and the response boat. Management and headquarters personnel assigned to the ICS also attend an8-hour training session that reviews incident command procedures and uses "table top" demonstration exercises to simulate spill scenarios.

FIGURE 3.
USAP Spill Response Team Organization



RESPONSE PROCEDURES

USAP spill response procedures are based on 5 basic steps:

Stop the source of the spill
Contain the product spilled
Recover the spilled product
Prepare the recovered and contaminated material for disposal
Restore the areas affected by the spill

Activation of the spill response system is the same as other emergency situations and occurs on a graduated step-by-step basis. Fire department or on-duty Spill Team personnel function as first responders when a spill is reported. Additional elements of the contingency are implemented by the first responders depending on the size of the spill and the assets needed to control and contain the spill. Activation of additional contingency plan elements occurs through a centralized communications center with access to all station operational and management groups. The order of activation is as follows:

Spill reported by discoverer to communications center
First Responders (Fire Department or Duty Spill Team Leader) respond and

assess spill scene.

First Responders activate duty spill team(s) and Spill Response Coordinator.

Spill Response Coordinator assumes on-scene command and determine if ICS activation is required.

On-Scene Commander activates the ICS.

ICS provides support and resources as requested by the On-Scene Commander and activates the Headquarters Contingency Plan.

On-Scene Commander deploys assets as required to control, contain, and clean up the spilled material utilizing dedicated spill response assets and support from other station operations, as necessary.

Environmental conditions in the Antarctic often limit response and cleanup capabilities. For landborne spills, cleanup often entails excavation of the contaminated soil which is then either staged for treatment or packaged for disposal. Waterborne spill response and recovery are significantly more difficult, particularly with respect to sea and brash ice. Basic response procedures for waterborne spills consist of containing the spill using containment and sorbent boom and recovering as much product as possible using skimmers and various types of sorbent. However, the presence of sea and brash ice make these operations extremely difficult because of equipment damage, reductions in recovery efficiency, and personnel safety.

Demobilization and decontamination procedures identify specific locations and methods for cleaning spill response equipment following an incident. These procedures include precautions to avoid secondary contamination during the transport of contaminated equipment. The decontamination area is in an enclosed area with secondary containment for collection of contaminated water generated by steam cleaners.

The contingency plans also contain information on a variety of methods and technologies for spill cleanup and remediation. Once the actual spill response and initial cleanup are completed, site remediation is turned over to the Environmental Department. Once the parameters of the remediation have been determined, operational departments, in cooperation with both the Environmental Department and the Spill Response Coordinator, conduct the final site remediation.

SPILL RESPONSE GOALS AND HISTORY

USAP spill prevention goals are to prevent all spills. To accomplish this efforts have concentrated on the two primary causes:

Operator Error
Equipment Failure.

Operator error caused spills are the most easily controlled through awareness, training, and procedural review. Equipment failures can also be controlled to a great extent through effective preventive maintenance programs. The effectiveness of these measures in the USAP is demonstrated by downward trend in total spills, average spill size, operator error spills, and equipment failure spills, as shown in Figure 4.

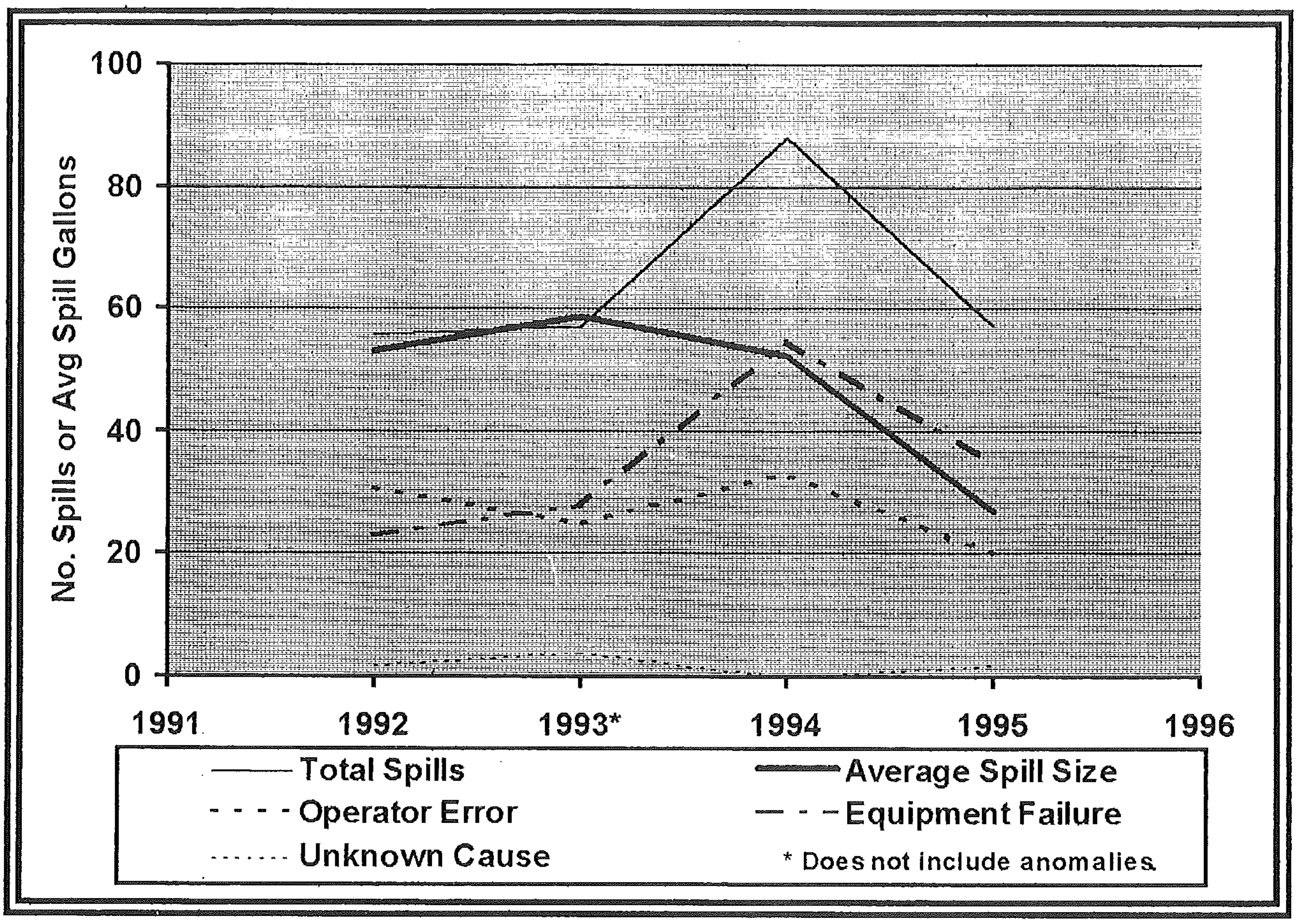
Overall, USAP spill response statistics indicate downward trends in all areas. During 1992 and 1993, when full implementation of the spill response awareness and prevention program began, spill statistics remained relatively consistent. Although 1994 data indicates significant increases in the total number, operator error, and equipment failure spills, this is attributed to better reporting by the community and substantiated by a corresponding decrease in average spill size. Spills as small as 200 milliliters, as well as spills that occurred in-doors were regularly reported, indicating significant improvements in community awareness.

In addition to reductions in the total number of operator error caused spills, the relative percentages of operator error and equipment failure spills, on an annual basis, indicate that the USAP is actively working toward its goal of preventing all spills. Of the two primary spill causes, operator error is more easily controlled through training and awareness. Between 1992 and 1995 the percentage of operator error spills has steadily decreased while the percentage of equipment failure spills has increased indicating that annually there are more spills resulting from equipment failure than operator error. This trend, along with a decreasing trend in total spills, indicates that the USAP Spill Response Program is having a positive effect in preventing and controlling spills in the Antarctic.

FUTURE SPILL RESPONSE ACTIVITIES

The USAP is researching and implementing a wide variety of improvements for

FIGURE 4.
USAP Spill Response Statistics, 1992-1995



both spill prevention and response. Significant upgrades to fuel storage and handling facilities are currently being engineered and implemented, including:

Replacement of dated bulk fuel storage and transfer facilities.
Installation of secondary containment around fuel storage and handling facilities.

The National Science Foundation, and it's contractor, Antarctic Support Associates, continuously research new and innovative spill response technologies and methods for potential application in the Antarctic environment. One technology currently under evaluation and applicable to spill clean up is soil washing which would allow soil contaminated with fuel and oil to be cleaned and returned or used as fill material.

Facility upgrades and implementation of new technologies will be included in the next review and update of USAP contingency plans, scheduled for 1997.

REMEDIATION OF FUEL CONTAMINATED SOILS IN ANTARCTICA WITH EMPHASIS ON MCMURDO STATION

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Environments contaminated with hydrocarbons pose unique containment and restoration challenges. The ultimate fate of contaminants is a complex process that includes weathering, evaporation, degradation by indigenous microbial populations, and potentially chemical and mechanical removal. Technologies available to address the type of contamination present at McMurdo Station, Antarctica can generally be classified into in-situ (processes not requiring excavation) and ex-situ (processes requiring excavation) technologies. Ex-situ technologies include thermal, soil washing (using detergents or surfactants), solvent extraction, solidification/stabilization, and biological treatment (including landfarming or slurry-phase bioreactors). In-situ technologies include flushing the contaminated soil with water containing surface active agents such as surfactants (surfactant flooding), steam stripping, and containment. Environmental conditions such as those found in Antarctica can limit technologies such as vapor vacuum extraction, landfarming, composting, and in-situ bioremediation. We present an overview of technologies offering potential application to sites such as McMurdo Station and report comparative data for two promising technologies; soil washing based on surfactants, and a soil treatment process based on a combination of aqueous treatment and solvent extraction. Experimentation was performed on porous, red, volcanic soils from McMurdo Station contaminated with up to 8,600 mg/Kg extractable petroleum hydrocarbons (EPH) of organic residues. Solids were analyzed for EPH, volatile petroleum hydrocarbons (VPH), and particle size distribution.

INTRODUCTION: McMurdo Station is the largest research station in Antarctica, with a population that ranges each year from 250 to 1,200 people. Because of its size and 40-year history of use, a number of locations around the station have been contaminated with petroleum-related products, PCBs, other organics, and metals. The "soils" at McMurdo Station are derived by physical weathering and comminution of the local volcanic material and also as loess. Hut Point Peninsula consists of basaltic volcanic cones and a phonolite dome which are composed of lava flows and scoriaceous pyroclastic material. Crushed, red oxidized scoria (here called "red" soil - but in reality it is not a true soil) is used for fill and is obtained by blasting and scraping the soft rock from the sides of small cones. The "red" soil is very porous and coarse with only minor amounts of fine material.[1]

Contaminated "red" soil was evaluated for treatability using a patented[2] combination of aqueous treatment (soil washing) and solvent extraction in a materials classification/separation system. The process is designed to recycle fluids to minimize waste streams and reduce costs. The resulting contaminant stream is concentrated and may be used as a fuel, or recovered for sale, destruction, or approved disposal. Cleaned solids are not sterilized. The technology is based on biochemical solvation, liquid/liquid and liquid/solid extractions, materials classification, mechanical

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1 "Background Levels of Metals in Soils, McMurdo Station, Antarctica," A.B. Crockett, 1996, Submitted to Environmental Monitoring and Assessment

2 U.S. Patents 5,454,878 and 5,490,531.

and hydraulic scrubbing, and separation of organic and aqueous phases. Solvation is accomplished with controlled and defined mixtures of terpene products.

Terpenes (biosolvents) are best known as primary components of essential oils, which are mixtures of fragrance and flavor substances that originate in higher plants. Many high purity terpenes are used by the food, beverage, cosmetic, and household market industries. As a biochemical botanical product, terpenes represent a naturally occurring product derived from a renewable resource that alleviates problems typically associated with chemical solvents such as high toxicity, recalcitrance, adverse environmental impact, and negative public acceptance. Terpenes have relatively low toxicity profiles, are easily biodegraded, and in many instances are generally recognized as safe (GRAS).

APPLICABLE TREATMENT TECHNOLOGIES: Soil, like any porous medium, is capable of trapping fluid compounds in its pore spaces or on its surfaces. Trapping of organic constituents in interstitial pore space does not preclude the movement of other fluids through the same pore space without displacement of the organic phase. Depending on the physical and chemical properties of the organic compounds and the soil, fluids or their dissolved constituents may be deposited at the soil/fluid interface or incorporated into the soil matrix. The type and amount of compounds retained in and on the soil influences technology selection. The essence of fluid/solid interactions with respect to organically contaminated soils has been described in recent literature.[3,4]

Technologies to be discussed here include ex-situ and in-situ applications. Ex-situ technologies are thermal, soil washing (using detergents or surfactants), solvent extraction, solidification/stabilization, and biological treatment (including landfarming or slurry-phase bioreactors). In-situ technologies include flushing with surface active agents such as surfactants, steam stripping, and containment.

Thermal: Thermal processes rely on thermal energies to volatilize contaminants for removal. Examples of technologies are well known and include processes such as incineration, reverse-burn gasification and liquid volatilization. Technologies are frequently assisted by vacuum or air sparging. Thermal technologies have long been recognized as useful and the most recognized application is incineration. There is typically a definitive size requirement for feed materials. Incinerator systems are attractive from a contaminant removal standpoint, but are difficult to construct and operate. Solid materials exiting the plant are sterilized and often highly friable. These characteristics greatly limit the reuse/recycle opportunities for incinerator discharge. Recent advances in incinerator technology have resulted in the use of plasma arcs (suitable for liquid streams only) and infrared incinerators. Operation in frontier arctic environments is difficult because thermal masses must be generated and maintained. Fugitive gas emissions can be problematic.

Soil Washing: Soil washing is usually based on the use of aqueous fluids in a materials handling system. Soil washing strengths are treatment of metal or radioactively contaminated media. Processes rely heavily on materials classification and froth flotation and less on extraction. Soil washing has been applied for extractive purposes by using surfactants, alkalis, acids, or

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[3] *Impact of Oil-Rock Adhesion on Reservoir Mechanics*, 1993, D.N. Rao and B.B. Maini, *Petroleum Society of CIM*, Paper No. CIM 93-65.

[4] "Adsorption of Polycyclic Aromatic Hydrocarbons (PAHs) by Soil Particles: Influence on Biodegradability and Biotoxicity," 1992, W.D. Weissenfels, H. Klewer, and J. Langhoff. *Appl Microbiol. Biotechnol.* 36:689-696.

temperature to increase the removal efficiencies of contaminants. For optimal success, precise control over pH, temperature, salinity and surfactant concentration are required but not attainable. Contaminants are frequently transferred from the solid material to the liquid phase resulting in extensive water treatment requirements. Further, intractable emulsions are frequently formed that are difficult to separate. Recycle or disposal of the aqueous phase can be problematic.

Solvent Extraction: Solvent extraction makes use of preferential solubility of the contaminant in a solvent. Potential chemical and matrix interferences depend on the specific solvent used. Solvents reported for use include Varsol (a mid-range naphtha), toluene, heptane, and liquid propane or butane.

Success of solvent extraction technologies depend on the appropriate selection of solvent material. Appropriately designed technologies are usually successful and considered versatile. Solvent selection is a key factor with respect to both process effectiveness and public acceptance. Additionally, most solvent extraction technologies rely heavily on solvent removal by vacuum or heated gas streams. Although effective, direct sublimation of solvents can leave elevated levels of organic compounds on the cleaned material.

Solidification/Stabilization: Solidification/stabilization is a treatment process that immobilizes wastes or contaminated products in a solid matrix to mitigate leachability. Once stabilized, the material is typically deposited at a landfill. An elaborate form of stabilization is in-situ vitrification (ISV). ISV melts inorganic soil for the purpose of thermal destruction of the organic component. Solidification/stabilization processes are applicable to toxic inorganic, organic, and radioactive materials. Although wastes are solidified, they are not, and frequently cannot, be destroyed. With the exception of ISV, the volume of waste product typically increases. Many binding and solidification agents are incompatible with organic wastes.

Biological Treatment: Bioremediation is the application of either native or non-native microorganisms to degrade contaminants and includes composting and landfarming. Native organisms can be stimulated by the addition of selected nutrients. Non-native organisms can be added to solids and maintained by nutrient addition. Bioremediation is generally viewed as versatile and cost effective. However, bioremediation can be time consuming and site conditions must be held within predetermined limits for successful application. Limitations of bioremediation are any factors detrimental to the selected organisms or microbial population such as bioavailability of contaminants or substrates, or wide variance in pH, temperature, salt concentration, oxygen tension, etc. Although most studies of bioremediation have been conducted in aerobic environments, anaerobic and anoxic studies have been reported.[5]

Remediation strategies using a biological system enjoy public acceptance (provided genetically engineered organisms are not utilized) and result in destruction of contaminants. Many of the limiting factors for bioremediation can be mitigated through the application of bioreactors to control contaminant loading, temperature fluctuations and optimization, and nutrient feed.

In-Situ Flushing: In-situ flushing is a process similar to those employed for secondary and tertiary oil recovery activities. Flushing agents include water, surfactants, chelators, gasses, and acids. The technology relies on displacement of contaminants through and over the soil matrix. Displacement efficiency is influenced by heterogeneities in the soil matrix and transportation and partitioning efficacies of the flushing agents in relationship to the contaminant and soil matrix.

Steam Stripping: Steam stripping is analogous to other "washing" technologies except steam is used as the extractant. Steam stripping can be performed in materials

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Biodegradation of Toxic Organics: Status and Potential, Grady, Jr. and C.P. Leslie, *Journal of Environmental Engineering*, 1990. Vol 116 No. 5, 805-828.

handling systems or in-situ. Generation of steam, separation of contaminants from the aqueous phase, mass transfer, and contact can be problematic.

Containment: Containment technologies include simple measures such as berming, capping, or burial in lined impoundments. Although simple and often cost effective, the wastes require continued monitoring and assessment which can be logistically difficult and expensive.

METHODS, ANALYSIS, AND RESULTS OF TREATABILITY STUDIES: Samples received for study consisted of two drums of contaminated "red" soil, and approximately 1 gallon of clean soil. The contaminated samples consisted of a very heterogeneous size mixture ranging upwards to greater than 15 cm in diameter. The solids had the visual appearance of a porous, red volcanic material. Clean soils were more homogeneous with particles no larger than 0.64 cm. Contaminated samples were sieved and split into three fractions: less than 0.64 cm, 0.64 cm to 2.54 cm, and greater than 2.54 cm.

Composite samples of materials < 0.64 cm were collected for chemical analysis in accordance with the established procedures of "Composite Sampling and Field Subsampling for Environmental Waste Management Activities."[6] Compound sampling errors were mitigated by submitting the minimum volume required for analysis. Particles greater than 0.64 cm were sampled using a grab technique. For particles greater than 2.54 cm, single, 30 g particles were crushed and submitted for analysis. Solids were analyzed for EPH, VPH, and for particle size distribution.

Organic Analysis of Soils: Organic analyses were conducted by Analytica, Inc. (Broomfield, Colorado). Samples were prepared and analyzed according to accepted methods. Samples were evaluated for EPH using protocols established by the Colorado Department of Highways for underground storage tanks.[7] VPHs were analyzed according to EPA method 8015M/API (5 g samples are sparged per method 5030A and analyzed by gas chromatography with flame ionization detection using conditions outlined in the American Petroleum Institute method for gasoline and SW846 8015 modified for gasoline).[8] Quality control samples included true matrix and method blank spike recoveries, and method blanks. Surrogate recoveries were within acceptable limits.

EPH and VPH were below detection limits in clean soils (20 mg/Kg for EPH and 100 μg/Kg for VPH). Analyses of three contaminated samples (<0.64 cm) indicated 6,300 mg/Kg EPH± 200 mg/Kg. A chromatograph of the contaminated material is presented as **Figure 1**. Data for all size fractions analyzed are listed as **Table 1**. Analyses for VPH

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6. "Standard guide for: Composite Sampling and Field Subsampling for Environmental Waste Management Activities," June, 1995. D34.01.14, Version 1.4.

7. "Storage Tank Facility Owner/Operator <u>Guidance Documents</u>," Colorado Department of Health, Hazardous Materials and Waste Management Division, April 15, 1994.

8. "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," EPA. Publication SW-846, Third Edition (September, 1986), amended by Update I (September 1994).

are not reported for solids due to surrogate recoveries in excess of acceptable limits. The high surrogate recoveries are interpreted to result from matrix interferences.

Geotechnical analysis was conducted by Terracon Western Consultants, Inc. (Boise, Idaho) using ASTM Standard Method D422. Solids are described as a silty sand; quantitative data are reported in **Figure 2.** The sample was sieved to exclude particles greater than 0.64 cm.

Treatability Evaluations at the Bench Scale: Contaminated solids were evaluated for treatability utilizing terpene and surfactant chemistries in a set of time variable experiments. All evaluations were conducted on aliquots of contaminated solids screened to <0.64 cm. All mixing was performed with a mechanized mixer. For all terpene evaluations, Limonene 145 (SCM Glidco Organics, Jacksonville, FL) was used. Limonene 145 is clear, has a flash point of 43.3 X , σπεχιφιχ γραϖιτψ οφ 0.849 (ατ 15.5 C), and boils at 177.8 C (760 mm Hg).

The five surfactants used were obtained from Witco Chemical (Oilfield Products Division, Houston, TX). Surfactants were applied at or above the suppliers recommendations for diesel/jet fuel compounds (**Table 2**). All surfactants were prepared by making a 2% (w/w) stock of the material as received before application. Controls included a ground sample that would pass a 20 mesh (841μm) screen but not a 40 mesh (420 μm) screen. Terpenes were evaluated for times of 2.5, 5, 10, and 20 minutes. Surfactants were screened at time equal 5 and 20 minutes.

Results of Bench Scale Evaluation of Terpene Chemistries: Data are summarized in **Table 3.** "Water Control" and "Air Dry" controls are included since they occur during all treatments except during operation of the engineering-scale prototype. The "Water Control" consisted of only performing the water rinse step in the absence of any other treatment. During this step, it was observed that fine soil particles were immediately suspended into the water and were slow to settle. Therefore, the fine particles were removed during decanting. Fines removal can effectively lower the analyzed contaminant concentration by an unknown amount and appear to improve extraction efficiency.

Results of Bench Scale Evaluation of Surfactant Chemistries: Surfactants were screened at time equal 5 minutes and were compared with each other and terpenes to select surfactants for further testing. Witcomul 3235 was selected for further evaluation for remediation efficacy using a treatment time of 20 minutes at the same concentration used previously. Data are summarized in **Table 4.**

Treatability Evaluations with an Engineering-Scale Prototype Plant: Materials handling and classification were conducted with a rotating screen deck (trommel) configured so that retention time, size fractionation, wetting, and fluid flow were controlled. Contaminated solids were loaded from a feed hopper into the trommel by a rotating screw. Contact time in the feed hopper was controlled by balancing feed and removal rates. Fluid volume was held constant in the feed hopper and excess overflow entered the trommel with the solid material. In the trommel, hydraulic, mechanical, and chemical energies were used to increase contaminant removal. The trommel was configured with a series of internal flights, lifters, high pressure spray nozzles, and screens. The flights were designed so that solid, wetted material moved through the trommel at a predefined rate controlled by trommel rotation. The first third of the trommel was "blind" and contained only flights, lifters, baffles, and spray nozzles. The second third of the trommel included removable screens (300 µm) in addition to the flights, lifters, baffles and spray nozzles. The last third of the trommel was a repeat of the preceding section. A positive displacement pump supplied fluids to the nozzles at 827 KPa.

Solvated organic contaminants were removed from the solids by displacement with water. Large (defined by screen size as greater than 300µm) cleaned solids exit the end of the trommel and receive no additional treatment. Fine solids (solids of a lesser diameter than the screen size), water, and terpenes containing the solvated contaminants passed through the screens into drainage sumps. The sumps were connected through a mixing "T" that received solids, organics, and water from the sumps and clean water from a recycle water tank. The resulting slurry (fine solids, water, and organics) was fed to a hydroseparator for primary liquid/solid separation.

A concentrated slurry of solids greater than 20 µm accumulated in a grit chamber in the hydroseparator and was discharged into a holding tank. The hydroseparator overflow (water, organics, and fine solids less than 20 µm) was fed to a 5 µm bag filter for secondary liquid/solid separation. Liquid/liquid separations were accomplished with a depth coalescer that cleaned the water to the solubility level of the terpene/contaminant mixture. Clean water was returned to the recycle tank and the terpene/contaminant fraction flowed to a holding tank.

Previous samples processed using the technology have been evaluated for toxicity and sterility using the Microtox[9,10] Polytox[11] and Community Level Physiological Profiling [12] (CLPP) techniques. These data demonstrate that the toxicity level

9 Microbics Corporation. 1992. Microtox manual: toxicity testing handbook, Vol. 1-5. Carlsbad CA.

10 "*Photobacterium phosphoreum* toxicity bioassay: test procedures and applications (1)," Ribo, J.M., and K.L.E. Kaiser. 1987. Toxicity Assessment: An International Quarterly. **2**:305-323

11 EPA document **440/4-87-005**, 1987.

12 "Classification and characterization of heterotrophic microbial communities on the basis of patterns of community-level sole-carbon-source utilization," Garland, J.L. and A.L. Mills, 1991. Appl. Environ. Microbiol. **57**:2351-2359

associated with all materials is extremely low (¡100% EC50).[13] It was concluded that the treatment technology decontaminated the samples without making them sterile.

System capacities and flows used are delineated in **Table 5.** A generic flow schematic is given as **Figure 3** and photo-reproduction of the system is presented as **Plate 1.** A 5 Kg aliquot of screened (to less than 2.54 cm) soil was mixed with 1.47 L of terpene hydrocarbons (4:1 use ratio by weight) and agitated for 3 minutes prior to introduction into the trommel. Specifications used for the treatability evaluation are defined in **Table 6.** The material was handled at a rate of 1 Kg/min.

Results of Engineering-Scale Evaluation of Terpene Chemistries: Solids were collected from the end of the trommel and from the hydrocyclone effluent. Clean water samples were taken at the beginning of the process. Additional water samples were taken from the end of the trommel, from the dirty water recycle tank, and after the recycle loop. Water was also analyzed before and during the treatment for pH, conductivity, salinity, turbidity, and temperature using a Grant/YSI water quality sonde. Liquid samples were collected as grab samples in glass containers provided by the analytical laboratory. Samples submitted for EPH were preserved by temperature (4°C) and samples submitted for VPH were preserved with hydrochloric acid. All liquid sample containers were filled to the maximum volume to minimize head space. Data for solids are summarized in **Table 7.** Water quality data are summarized in **Table 8.** Water analysis for organics is summarized as **Table 9.** Data are reported for EPH and VPH content of the water. Chromatographs of the engineering-scale application are presented for the starting material (**Figure 4**), and the hydrocyclone effluent (**Figure 5**). Chromatographs of water analysis are presented for samples taken before recycle (**Figure 6**), and at the end of the process (**Figure 7**).

Mass Balance: Mass of solid materials entering the system equaled 5,000 g. The system is closed and only those solids suspended in the water column are lost. At a contamination load of 8,600 mg/Kg solids there was 43 g of contaminant present. Of the contaminant present, 37.8 g was removed at an efficiency of 88%.

Flocculation Tests: Flocculation tests were preformed on recycled water from the engineering-scale prototype to evaluate the applicability of standard water treatment flocculants for process improvement. Prior to flocculation experimentation, fines content of the recycle liquid from the engineering-scale prototype application was evaluated using filtration. Filters used for evaluation and turbidimetric results are delineated in **Table 10.** Flocculation experiments were performed by preparing a 0.25% stock and titrating a 100 mL aliquot of liquid to a final concentration of 125 mg/Kg. Results were judged visually. Non ionic and medium anionic flocculants (Allied Colloids, Inc. Percol 720 and 727, respectively) were equally effective.

CONCLUSIONS AND DISCUSSION: All experiments were performed on material that had been collected and stored at an unknown point in time, shipped to the continental United States, and held before treatment. Data may not be representative of site specific operations because of differences in climate, weathering, and site heterogeneities. Analysis indicates that, as expected, the contaminant is a light fuel product which can be determined by EPH analysis. VPH analysis was not suitable for application due to the presence of matrix interference and the inability to distinguish the surrogate (p-bromofluorobenzene) from contamination.

The contamination level observed for samples ranged between 6100 and 8600 mg/Kg EPH. An appropriate internal control was included in each Individual suite of experiments to eliminate the impact of such variations as much as possible. Variations in contaminant concentrations are common and expected to occur as a function of sample origin, collection technique, storage time, and sampling and

[13] "EC_{50}" is the effective concentration of a toxic substance at which light output by *P. Phosphoreum* is diminished by 50%.

compositing procedures. Homogeneous analytical data would only be possible if the entire sample (drum) was homogenized for grain size and contaminant distribution.

Contaminant concentration appears highest on particles less than 0.64 cm and lowest on particles over 2.54 cm. Analysis performed on whole and crushed material indicate a substantial degree of internal porosity, independent of particle size. The soil appearance is clearly consistent with the presence of internal porosity as confirmed by the analytical data. The internal porosity affects all technologies required to extract the contaminants from the internal pore space as well as remove the contaminants from the exterior surface.

The data from the water control sample (1100 mg/Kg) as compared to the crushed control sample (2300 mg/Kg) and the observation that cleaned, uncrushed material (1700 mg/Kg) has lower concentrations of contaminants than cleaned crushed material (4000 mg/Kg) from the trommel effluent, indicate that laboratory extraction and analysis methods may also be influenced by the presence of internal porosity.

Data indicate that application of water alone appears to be fairly effective at removing hydrocarbon contamination. However, it has also been demonstrated that the finer the particles, the higher the concentration of hydrocarbons. An important observation noted during the treatment of McMurdo soils with water during flask testing was that the material was immediately suspended into the water column. This was not observed when the solids were placed into terpenes. As a consequence of this, the finer material was slow to settle in water and was removed during decanting. Fines removal effectively lowers the analyzed contaminant concentration by an unknown amount.

The effects of air drying on the samples illustrate that a significant fraction of the contamination can be removed through this process (e.g., about 75% under laboratory conditions with low humidity (30%) and temperatures of 22 C); however, this may be logistically difficult and unacceptable for application at the scale required for operations at McMurdo.

Time variation experiments strongly indicate that exposures of 2.5 minutes or less to terpenes have little or no effect in direct comparison to water treatment alone. Exposure times of 3 minutes used in the trommel resulted in a lower contaminant residual than bench scale treatments. This observation coupled with the observation that a reduction in particle size greatly increases removal efficiencies argues strongly that implementation of size reduction and longer exposure times in the engineering-scale prototype would result in even higher process efficiencies.

Application of surfactant chemistries resulted in significant removal of hydrocarbon contamination. However, it is well recognized that the function of surfactants and detergents is to emulsify/solubilize non-aqueous phase liquids resulting in a hydrocarbon-rich aqueous phase that must be further treated before discharge. Removal of contaminants from a solid to a liquid phase is commonly referred to as contaminant shift, not contaminant removal. In direct comparisons, terpenes removed more contamination than the most effective surfactant (Witcomul 3235) evaluated.

Application of the engineering-scale prototype resulted in an average removal of 88% of the contamination using a contact time of 3 minutes, a feed rate of 1 Kg/min, and a terpene use factor of 0.25 Kg/Kg with full water recycle, and complete recovery of the solids. Water recycled during the application of the engineering-scale prototype contained 17 mg/Kg EPH and 0.24 mg/Kg VPH and fine solids < 20µm that can be removed with the addition of standard water treatment flocculants. Collectively, these data indicate that the process is effective and can be operated at a rate meaningful for applications at McMurdo Station. Additionally, terpene chemistries are more effective than the surfactant chemistries evaluated and do not create a water contamination problem as would be expected to occur with surfactants. Process enhancements to increase contact time and reduce particle size by crushing and grinding could potentially allow the technology to reach the proposed 100 mg/Kg TKPH closure level.

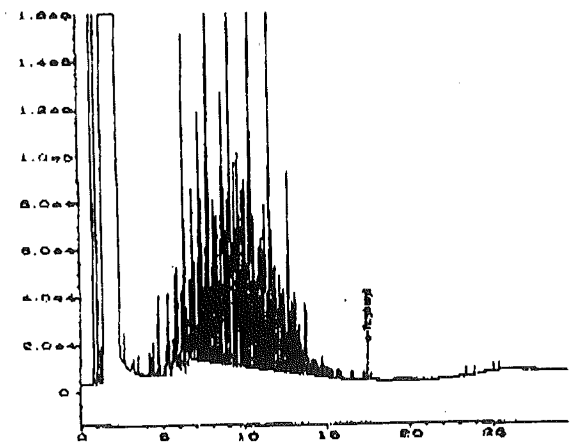

Figure 1. EPH chromatograph of contaminated soils, dilution factor = 20, hydrocarbon concentration = 6,300 mg/Kg.

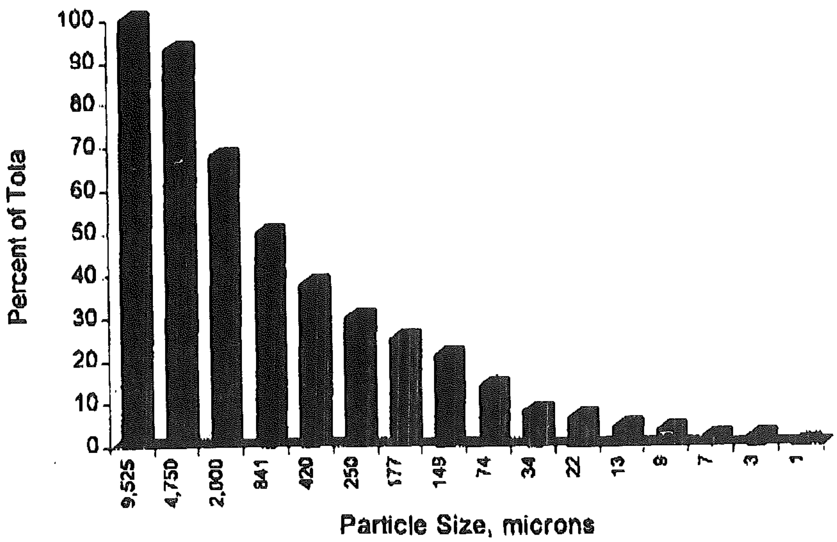

Figure 2. Sieve analysis of McMurdo Station solids below 0.25 in.

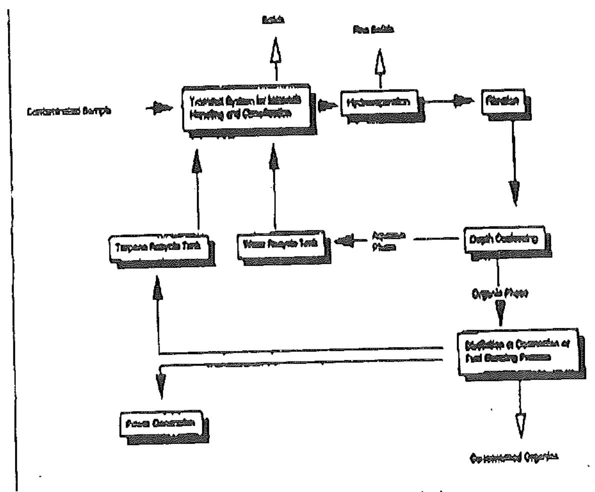

Figure 3. Generalized schematic of the remediation process.

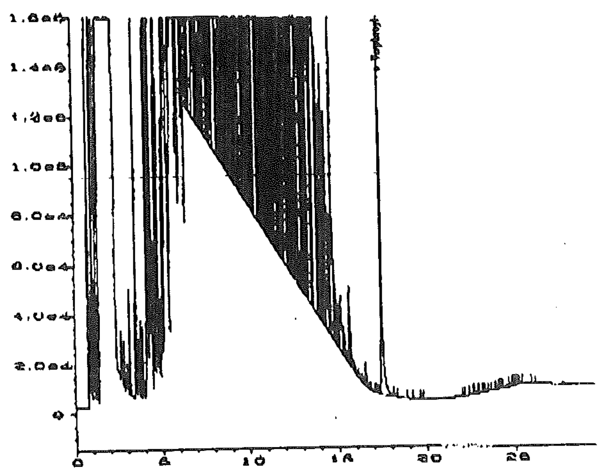

Figure 4. EPH chromatograph of starting material for the engineering-scale treatability, dilution factor = 1, hydrocarbon concentration = 8600 mg/Kg.

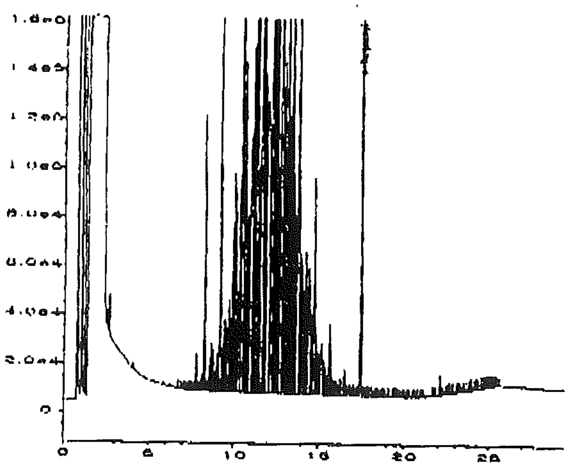

Figure 5. EPH chromatograph of treated solids (hydrocyclone effluent) from the engineering-scale prototype, dilution factor = 1, hydrocarbon concentration = 940 mg/Kg.

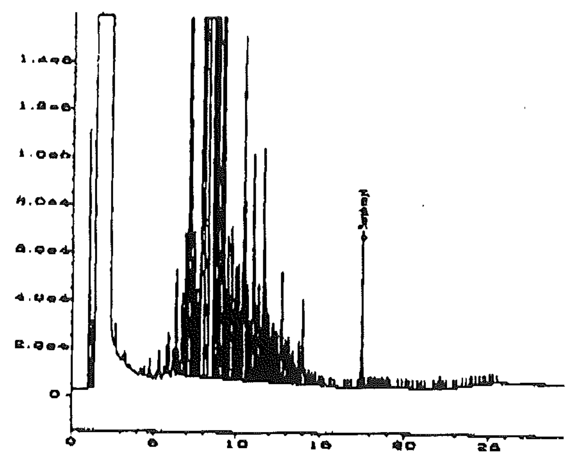

Figure 6. EPH chromatograph of water before recycle, dilution factor = 5, hydrocarbon concentration = 200 mg/Kg.

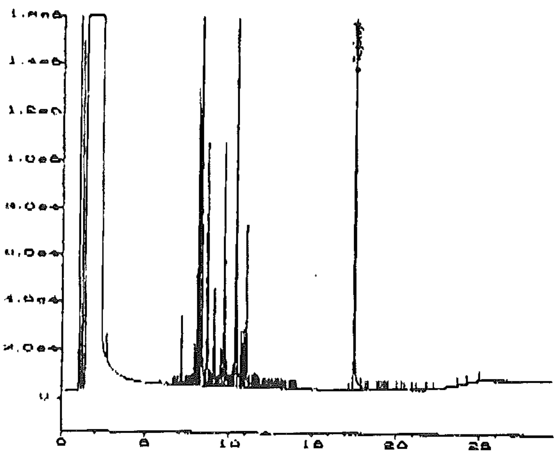

Figure 7. EPH chromatograph of recycled water, dilution factor = 1, hydrocarbon concentration = 17 mg/Kg.

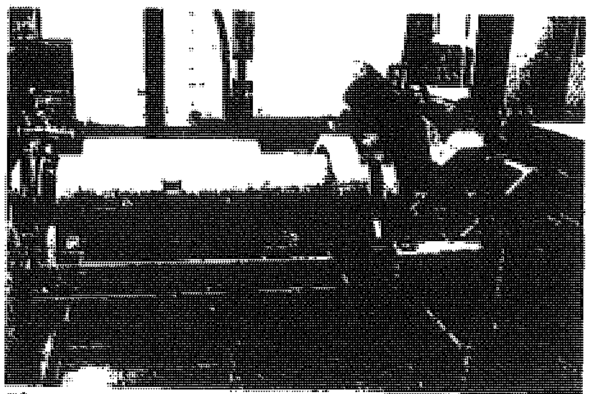

Plate 1. Photo-reproduction of the engineering prototype equipment.

Table 1. Analytical results (EPH) of contaminated soils from McMurdo Station Antarctica.

Sample	Size (cm)	Concentration (mg/Kg)	Detection Limit	Surrogate Recovery (%)
Clean Red	<0.64	ND	20 mg/Kg	92[b]
Clean Grey	<0.64	ND	20 mg/Kg	92[b]
Contaminated A	<0.64	6100	20 mg/Kg	84[b]
Contaminated B	<0.64	6500	20 mg/Kg	80[b]
Contaminated C	<0.64	6300	20 mg/Kg	80[b]
Contaminated[a]	0.64 - 2.54	5100	20 mg/Kg	80[b]
Contaminated[a]	>2.54	1900	20 mg/Kg	80[b]

a. Crushed prior to analysis to approximately the same consistency of <0.64 cm material.
b. Acceptable limits for surrogate (o-terphenyl) recoveries are between 50 and 150%.

Table 2. Surfactants, recommended concentrations, and applied concentrations used.

Surfactant	% Active	Recommended Use Concentration	Applied Concentration
Witconol SN70	100	252 mg/Kg Active	20,000 mg/Kg Active
Witcomul 3234	13.5	252 mg/Kg Active	2,700 mg/Kg Active
Witcomul 3235	53	252 mg/Kg Active	10,600 mg/Kg Active
Witcomul 3236	53	252 mg/Kg Active	10,600 mg/Kg Active
Witcomul 4078	100	252 mg/Kg Active	20,000 mg/Kg Active

Table 3. Results of bench scale evaluations using terpene chemistries (single repetition, EPH analysis).

Treatment	Time	Concentration (mg/Kg)	Percent Reduction
None	0	8600	
Air dry	0	2100	**
Water Control	0	1100	**
Terpene	2.5	1100	87
Terpene	5.0	960	89
Terpene	10.0	690	92
Terpene	20.0	540	94
Grind[a]/Water	0	2300	73
Grind[a]/Terpene	5.0	300	97

a. Sample crushed to a particle size between 20 and 40 mesh.

Table 4. Results of bench scale evaluations using surfactant chemistries (EPH analysis).

Treatment	Time (Minutes)	Concentration (mg/Kg)	Percent Reduction
None	0	8600	**
Air dry	0	2100	**
Water Control	0	1100	**
Witcomul 3235 (10,600 mg/Kg)	20	870	89
Terpene	20	540	93

Table 5. Engineering-scale capacities and flows.

Parameter	Specification
Aqueous Capacity (clean)	960 liters
Operating Volume	385 liters[a]
Clean Water Flow	to 75 liters/min[b]
Clean Water Pressure	to 1,380 KPa[c]
Water Recycle	to 75 liters/min
Terpene Flow	Variable[b]
Terpene Pressure	to 138 KPa[c]
Solids Feed	Variable[b]
Distillation Rate	to 35 liters/hr
Solids Retention	Variable[b]
Screen Size	Variable

a. Defined by position of take-out on tank.
b. Pump/motor speed dependant.
c. Flow and spray head dependent.

Table 6. Parameters and flows used for evaluation

Parameter	Specification
Contaminated Solids	5 Kg
Terpene Use	1.47 L (1:4 w/w)
Water	675 liters
Clean Water Pressure	827 KPa
Water Recycle	39 liters/min
Solids Feed	1 Kg/min
Screen Size	300 μm

Table 7. Results of engineering-scale treatability application; all data from EPH analysis.

Sample[a]	Terpene Contact Time	Concentration (mg/Kg)	Percent Reduction
Beginning Solids	0 minutes	8600	**
Cleaned Solids >25,400 μm	3 minutes	2000	77
Cleaned Solids >300μm	3 minutes	1700	80
Cleaned Solids >300μm crushed[b]	3 minutes	4000	53
Cleaned Solids <300 μm	3 minutes	940	89
Calculated Average[c]	3 minutes	1047	88

a. All samples taken by composite, particles over 2.54 cm were crushed prior to analysis.
b. Samples crushed prior to analysis to approximately the same consistency of the <300 μm material.
C. Weighted average based on sieve analysis, not including result of crushed material.

Table 8. Water quality during engineering-scale treatability evaluation.

Parameter	Start	Mid-Run	End-Run
pH	7.55	8.01	8.09
Conductivity	0.502 mS/cm²	0.51 mS/cm²	0.52 mS/cm²
Salinity	0.2 %	0.2 %	0.3 %
Turbidity	5 NTU	30 NTU	62 NTU
Temperature	13.6°C	16.1°C	16.5°C

Table 9. Analysis of process water for organics.

Sample	Concentration EPH (mg/Kg)	Concentration VPH (mg/Kg)
Beginning Water	ND	ND
Water Before Recycle[a]	200	2.2
End Water	17	0.240

a. Sample taken as a grab sample from approximately 8 cm below the water surface at a tank volume of 285 liters.

Table 10. Filters used for fines evaluation of recycle liquids and resulting NTU.

Manufacturer	Filter Designation	Particle Retention (μm)	NTU
Whatman	GF/F	> 0.7	1
Fisher	P2	1 - 3	10
Whatman	2	> 8	16
Whatman	1	> 11	18
Fisher	P8	> 20	24
None	**	None	38

THE CONSTRUCTION OF SANAE IV:

LESSONS LEARNED IN ENVIRONMENTAL MANAGEMENT

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***Abstract*:**
The construction of the new South African base in Antarctica, SANAE IV, required a new management approach. SANAE IV is being built on an inland nunatak, in contrast to the old SANAE III base which is located on the ice shelf. It was realised early in the planning stages that the major environmental threat to the nunatak would be the cumulative effect of small impacts. An Environmental, Health and Safety Management System (EHSMS) was adopted as a strategy to reduce the negative impacts of the construction operations. Health and safety aspects were included to deal with the complexity of impacts. The EHSMS principles follow a model of continual improvement. A waste management plan was introduced to deal with the abnormally large quantity of waste which is being generated during the construction phase. SANAP's approach to waste management comprises the reduction of waste, the simplification of procedures and the training of personnel. The lessons learned during construction so far might be of value to countries planning similar operations. The EHSMS proved to be a valuable internal management tool. Dedicated personnel, resilience to failure, and effective backup systems are essential to successful waste management. Along with waste reduction, more attention should be given to reuse and control of packaging materials. Creating environmental awareness through education and training of construction personnel demands a repetitive approach. The realities of the physical environment require special consideration during planning of operational schedules. Commitment from management is the key to a successful EMS.

**"Man, like an earthworm, burrows into the earth and turns over its surface;
like a bird he brings material from elsewhere to build his nest;
and like the pack rat he accumulates quantities of trash." - Anon.**

INTRODUCTION

The construction of the new South African base in Antarctica, SANAE IV, is the latest operational challenge to the South African National Antarctic Programme (SANAP).

SANAE IV is to replace the old SANAE III facility, which has become unsafe due to structural collapse. SANAE III is located 15 km from the permanent Fimbul ice shelf edge and is now 25 m below the snow surface after 18 years' snow build up. In contrast to the old SANAE III base the new base is being built on an inland nunatak, Vesleskarvet, 200 km from the coast.

A temporary base (Figure 1), consisting of container units on stilts, was constructed 500 metres from the building site to house the construction personnel; ±80 people during summer construction periods. This facility is to be removed once the base is completed.

The SANAE IV base (Figure 2) consists of three interlinked double storey units of approximately 14 m x 44 m each. They are joined at the lower level by interleading passageways, which also serve as the access points. The frame is constructed from steel and the cladding consists of rigid preconstructed glass-fibre resin panels. Rounded corners and smooth surfaces minimise the effect of wind. All three units are raised 3.5 m above the rock surface of the nunatak to allow for free wind flow underneath the base, resulting in a limited snow buildup on the lee side of the base.

The base will be able to accommodate 20 overwintering team members and 60 summer take over personnel. Provisions and vehicles will be raised to the helipad by two screw drive lifts from where they will be moved into the base through the hanger doors.

Figure 1 The temporary construction base

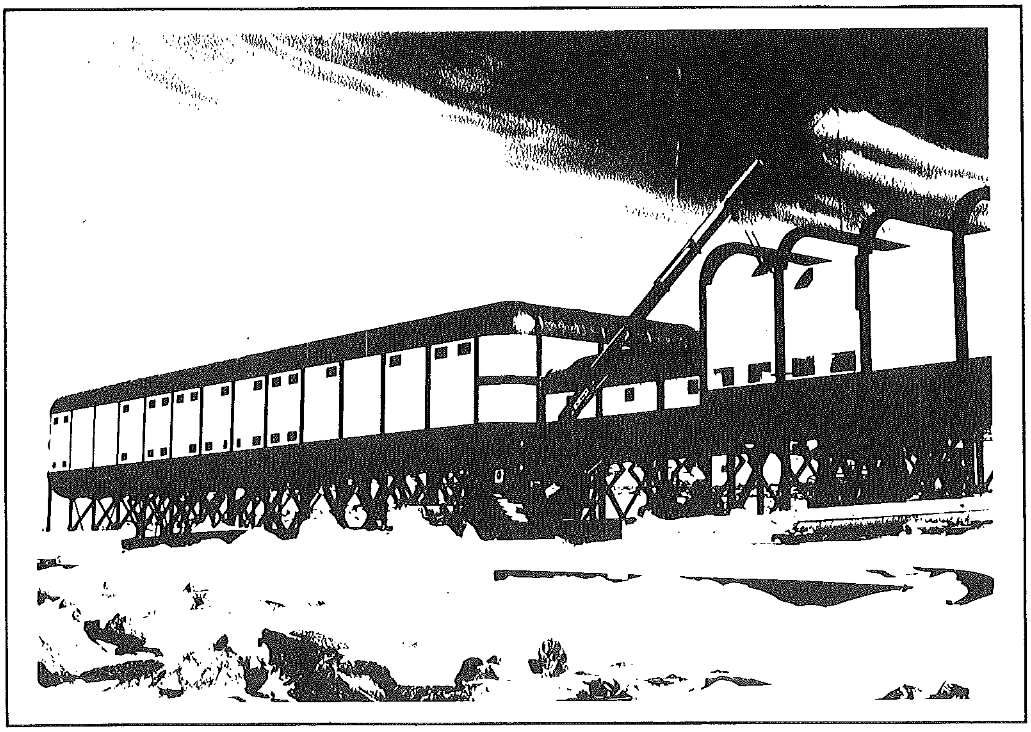

Figure 2 SANAE IV in construction

Interior base temperature will be thermostatically controlled. In addition, waste heat from the diesel electricity generators will be used for heating fresh air on intake using a special heat exchange system. Fresh water will be obtained from a remote, manually operated snow melter.

A sealed effluent treatment plant will be located in the structure, and all sewage will be pumped through the plant to be treated. The discharge effluent will conform to standards for release into rivers in South Africa. The concentrated sewage sludge and all other waste will be containerised and removed to South Africa during summer take overs.

A computer monitoring system will also be installed to relay system performances back to South Africa. This will enable fault diagnoses and maintenance to be directed by experts in South Africa.

The following scientific programmes will commence once the base is completed:

- HF Radar project: A joint venture with APL (Applied Physics Lab of Maryland University) and BAS (British Antarctic Survey) to measure irregularities in the atmosphere.
- Imaging Riometer Experiment: It consists of 64 cross dipole matrix ray antennae connected to a very sensitive receiver measuring cosmic radio wave noise to determine changes in the ionosphere.
- Two Neutron Monitor projects: The neutron monitors record the secondary nucleons and nuons which are produced by primary cosmic rays in the atmosphere.
- Pulsations and 3-axial magnetometers measuring changes of the magnetic fields.
- Aurora project
- VLF (Very Low Frequency) project to measure whistlers.
- UV-B project
- Omnipol receiver to record amplitude and phase variations in the sub-ionospheric region.
- Automatic weather station

MANAGEMENT STRATEGY

The SANAE IV Comprehensive Environmental Evaluation (CEE) strongly recommended the use of an Environmental, Health and Safety Management System (EHSMS) to reduce negative impacts derived from the construction of the base and its occupancy. This recommendation was made in the light of ever more stringent Antarctic Treaty obligations and the notion that the major threat to the environment at Vesleskarvet would be the cumulative effect of small impacts. A clean environment at Vesleskarvet is not seen as a luxury but a necessity in order to compete with international standards. It was realized that the management of human behaviour and activities would be crucial in this exercise.

INTRODUCING THE ENVIRONMENTAL, HEALTH AND SAFETY MANAGEMENT SYSTEM

It was believed that the most encompassing Environmental Management System (EMS) model at the time when South Africa was compiling its environmental management system, was that of the British Standards Organization (BS 7750:1992). Other standards consulted were that of the International Standards Organization (drafts of the ISO 14000 series). The South African

Bureau of Standards (SABS) was also in the process of developing EMS specifications. These standards were applied as far as practical, and extended to include Health and Safety aspects. It was felt that Environmental, Health and Safety aspects cannot be separated in this type of project. All organizational activities, facilities and equipment interact, and have some impact upon the environment as well as on health and safety aspects. An effective EHSMS needs to be capable of dealing with these complexities. The EHSMS components are inextricably interwoven or infused with the overall management of the project. Table 1 shows a breakdown of medical consultations over the past two summer construction periods.

Tabel 1 Breakdown of medical consultations for the 1995/1996 construction period in relation to the 1994/1995 construction period.*

Discipline	Non emergencies		Emergencies		Surgical intervention	
	94/95	95/96	94/95	95/96	94/95	95/96
Dental	-	4	10	17	-	-
Orthopaedic	13	65	4	50	5	4
Surgical	5	20	1	26	-	14
Medical	40	194	2	5	2	-
Ear, nose & throat	25	38	-	2	-	-
Ophthalmo-logical	5	11	-	14	-	-
Urological	-	12	-	-	-	-
Psychiatric	3	33	3	2	-	-
Total	**91**	**377**	**17**	**116**	**7**	**18**

* The figures show the number of consultations. Different consultations might involve the same patient. The number of personnel at Vesleskarvet increased from 50 during the 1994/1995 period to 83 during the 1995/1996 period.

The EHSMS model (Figure 3), follows the basic view of the principles to which SANAP subscribes. These principles are defined below:

Principle 1 Commitment and policy

SANAP defined its environmental policy and declared its commitment to its EHSMS with the release of the Final Comments and Responses on the CEE report.

Principle 2 Planning

SANAP has formulated a preliminary programme to fulfil its EHS policy for the construction phase. A Code of Conduct was drawn up which forms the basis for the manner in which all construction activities should be conducted. This was found a very important part of the EHSMS, as it required the participation of all personnel working on the project. A waste management plan was devised and special procedures were implemented for the construction phase, which is revised after each summer. The latest update to the programme is a comprehensive safety plan. An operational EHSMS programme is currently in the development process and will draw extensively on the experience gained during the construction phase.

Principle 3 Implementation

SANAP has developed most of the capabilities and support mechanisms to achieve its environmental policy, objectives and targets. Deficiencies in the system are attended to as the logistic and financial means of the Antarctic programme develop.

Principle 4 Measurement and evaluation

To measure is to know. EHS monitoring and auditing of on site activities take place annually, using a fixed set of environmental criteria, and an EHS Auditor external to SANAP. On site corrective action is encouraged. The audit process is rigid and cannot change much during the operational phase in order to obtain comparitive results. For the operational phase of the base however, the auditing programme will be updated and continued, drawing on the results of the past audit reports. South Africa further intends to invite environmental auditors from other treaty countries for official inspections on SANAE IV.

Principle 5 Review and Improvement

After the release of every Audit Report, the results are evaluated and mechanisms introduced to follow up on the recommendations made. Audit Reports are afforded high priority and are submitted to the Director General of the Department: Environmental Affairs and Tourism for his attention.

For an environmental management system to be successful, a cyclic feed back mechanism is necessary to ensure that the system operates in a self-regulatory fashion. The EHSMS is thus an organising framework to provide effective direction in response to changing internal and external factors. Every individual should accept responsibility for environmental improvements.

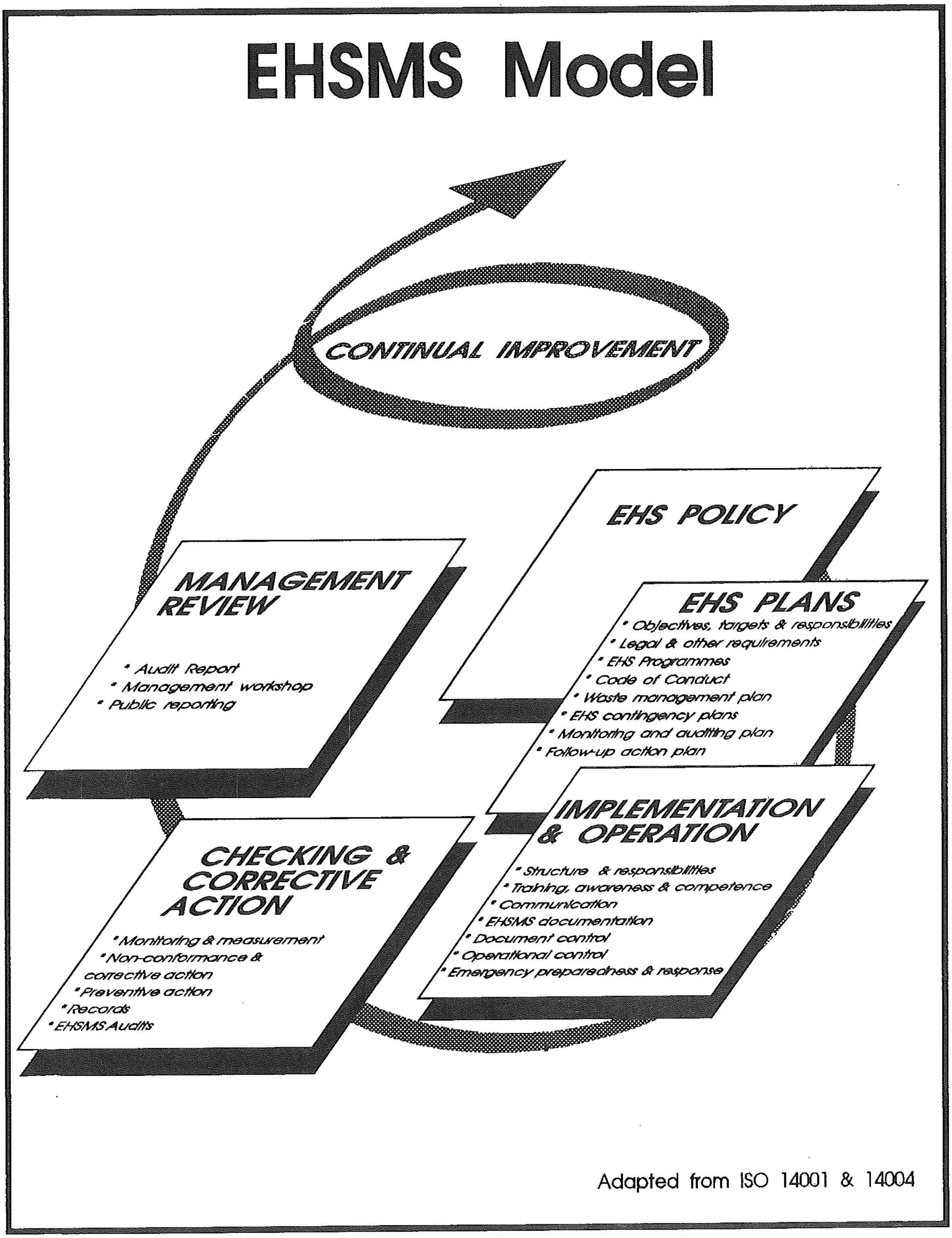

Figure 3 Model of the SANAE IV Environmental, Health and Safety Management System

SANAP has moved through this cycle for three consecutive summers, with the construction of the new base. An overall improvement of environmental performance has been evident during the second and the last construction periods, due to management becomming more committed. Success can therefore be achieved if management is fully committed to improvement of environmental performance.

ISO 14001 discloses the following advantages in using an Environmental Management System:

- Improvement of environmental performance;
- assurance of conformance with the stated environmental policy;
- demonstration of conformance;
- certification/registration of the environmental management system by external organisations;
- self determination and declaration of conformance with standards, and
- emphasis is placed on prevention rather than cure.

A further advantage of using an EMS is its built in correspondence to Quality Control Systems (ISO 9000 series). This provides the basis for the development of an integrated facility and environmental management programme.

The EMS is also a valuable instrument should the results of scientific monitoring programmes suggest particular management inputs. It was stated as one of the conclusions of the recent workshops on 'Monitoring of Environmental Impacts From Science and Operations in Antarctica' that "Environmental monitoring of human activities and impacts is only useful when it is firmly tied to an environmental management strategy." (SCAR & COMNAP, p vii)

MAKING THE EHSMS WORK FOR WASTE MANAGEMENT

The EHSMS provides the order and consistency to address the environmental concerns surrounding waste generation through the allocation of resources, assignment of responsibilities, and ongoing evaluation of practises, procedures and processes.

Biosensitivity was not an immediate concern at SANAE III owing to its location on the ice shelf. The sensitivity of the nunatak to prolonged construction activities and occupancy was taken into account as Vesleskarvet nunatak is a habitat to several lichen species, various arthropods and micro biota. Damage in a pristine area is proportionally greater than in already polluted areas.

The construction phase of SANAE IV would also generate large quantities of waste, needing processing and containerisation for the long journey to the ship by means of heavy duty Challenger hauled sledges. The bumpy 200 km ride required a more rugged packaging and container system than used for SANAE III. Nearing the completion of the base, we appreciate this fact much more than when the Comprehensive Environmental Evaluation (CEE) was conducted.

The Waste Management Approach

SANAP's approach to waste management is threefold and comprises the reduction of waste, simplification of handling procedures, and training of personnel.

Waste Reduction

Although the range of waste generated by construction operations is generally of a narrower assortment range than that normally generated during the operational phase of a base, the quantities are significantly larger. Reduction of waste, which is a fundamental principle in waste management, seems to be one of the greatest challenges. The largest sources of waste generated during the construction are the packaging materials, construction debris, domestic sewage and wet waste. Table 2 is a brief account of waste generated during the 1995/1996 construction period.

Table 2 Waste generated during the 1995/1996 construction period

Waste type	Colour code	Container type	Quantity	Quantity recycled
General waste	Orange	210 L drums Steel containers (±4 m^3) Timber crates (±4 m^3)	222 43 48	-
Sewage & Waste food	Black	210 L drums	237	-
Metals	Blue	210 L drums	49	2.74 tonnes
Glass	Green	210 L drums	15	1.2 tonnes
Chemical waste	Brown	210 L drums	8	-
Oil	White	210 L drums	6	-
Medical waste	Red	100 L drum	1	-

For the safe handling of cargo between the suppliers and the eventual destination on the ice, extensive packaging is needed, thus shifting the real problem to **material types** and **reuse** of packaging.

Whatever packaging is used, should be large and easy to control. Using large pieces of bubble plastic wrapping is much easier to control than polystyrene beads, shredded paper or polyutherane foam in windy conditions. Bubble plastic also has the further advantage of reuse for packing equipment to be shipped back home.

Prepacked meals for construction workers during the first summer of construction resulted in so much paper and plastic waste generated that the practise was stopped.

The same principle can also be applied to the type of containers used. Unfortunately a large quantity of timber crates we used for transporting construction material were not robust enough for repetitive handling and broke during handling and transport, consequently landing in the waste stream, instead of being reused as waste containers. Currently, only high quality reusable timber crates and steel containers are used for transporting construction material and provisions.

Simplifying Handling Procedures

To ensure that the waste management system is resilient to failures, procedures were kept as simple and flexible as possible. This resulted in a robust but not disorderly waste management procedure, which is especially useful in a construction environment.

This applies to procedures as much as to containers. The special plastic containers we used at first for wet waste soon proved to be impractical. The old 210 L Aftur drums proved themselves as robust enough, always available, easy to handle and reusable. A simple visual colour coding system, on containers also paid off.

Waste managers appointed at respective areas of the total operation, ensure the use of the same procedures throughout.Monitoring of the procedures is of cardinal importance to ensure that efficiency and effectiveness are maintained.

Training of Personnel

The past three austral summers showed us the importance of environmental training especially with such large groups of construction personnel on a site. The sheer number of people complicates educational responsibilities substantially. New personnel are unaccustomed to the varying conditions which occur in Antarctica, for which a training programme in South African conditions cannot prepare them completely. Training should however still take place before departure to Antarctica because of the changing of priorities once the ship arrives. The fact that construction personnel are technical experts and not scientists or people with a particular interest in environmental matters, demands a repetitive approach in environmental training. For overwintering team members, the emphasis is on living in Antarctica for a year. For Summer construction team members, the emphasis is on getting a job done.

CONCLUSION

Although ample material on guidelines, measures and procedures for the disposal of waste in the Antarctic exists, a great deal can still be learned about the managerial side of waste management from projects like the SANAE IV base construction. Managers who feel their programmes suffer from limited means, funds, personnel or an ineffective Environmental Management System might find some value in the lessons we learned with SANAE IV:

- Waste management will not improve if it is not monitored and evaluated constantly.
- Waste handling was inefficient when specific personnel were not dedicated to waste management. Making waste management the responsibility of a senior management person, and not a junior officer, is essential.
- The waste management system must be kept simple, robust and flexible to increase resilience to failures.
- Having backup systems in place could prevent pollution in case of accidents and failures. (Eg. Over drums for leaking 210 l drums.)
- Substantial waste reduction can be achieved through choice of packaging materials and reuse of packaging and containers.
- Environmental friendly behaviour in large construction teams cannot be fully achieved through moral suasion. Other incentives should therefore be sought and used in addition.
- The practicalities of Antarctica as a working environment should be kept in mind during planning. Since the construction of SANAE IV started, we have been generating more waste than anticipated, we had to increase our personnel component and we had to expand our logistic support system. Most activities usually take longer than expected. A tendency towards pessimistic planning is advisable.

- Managing small operations in the Antarctic requires the integration of line functions, programme management and project management, unlike the separation of management functions in large organisations. As the SANAE IV project developed over time, these complexities increased while management resources remained unchanged.

It should be emphasised that an EMS shouldn't be seen as a strict command and control mechanism, but rather as a tool to gradual self improvement. An EMS is no guarantee to instant rectification of unsound environmental impacts, but rather a processed change. Commitment from the entire management component to improve environmental performance is the key to a successful EMS.

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A New Waste Water Treatment Plant Installed at the Italian Antarctic Station of Terra Nova Bay.

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ABSTRACT

This paper describes the characteristics of a new waste water treatment plant that has been installed and put into service at the Italian Antarctic Station of Terra Nova Bay, during the 95-96 Expedition. (Fig.1 Station top view)
The plant's main characteristics are:
-treatable organic loading: 10 kg BOD_5/day (sufficient to serve a population of 100 people)
-flexibility: very high (three different treatments of the effluent)
-transient periods: none
-residual sludge: thick
-installation global volume: compact (five containers ISO 20").

INTRODUCTION

During the 1995-96 Antarctic Season a new waste water treatment plant has been completed and put into service at the Italian station of Terra Nova Bay. The new plant, based on a combined treatment, Physical-Chemical and Biological, replaces the previous waste water biological treatment plant that was installed during the 1987-88 Antarctic season. In that period the base could house only 40 people while now it can house 80 people making the biological plant undersized.

When it was first planned to use a biological plant for waste water treatment at the Italian base, was assumed an average value of organic load for person equal to 60 g BOD_5/day. This is the amount normally published on waste water treatment handbooks as medium pollution load for person in urban waste water. Therefore, assuming a maximum population of 50 people, a biological plant capable to treat 3 kg per day of BOD_5 was installed.

During operations in Antarctica, the organic load per person was often measured equal to 100-120 g BOD_5/day, amount normally found into waste water produced in rich areas of the world.

This very high organic load made the previous biological plant able to serve only 30 people.

Afterwards, the increased scientists population working at TNB imposed the enlargement of the base to a total capacity of 80 people. Consequently also an increase of the waste water treatment plant capability became essential.

For this reason it was designed a new treatment plant , reusing every part of the old system, consisting of the following sections:

- <u>pretreatment section</u> with a selfcleaning screen, a primary homogenization tank with preaeration;
- <u>treatment section</u> with a combined biological and physical-chemical process;
- <u>post treatment</u> with a settling tank, an active-carbon filter and a UV lamp.

The target capacity of the plant was fixed to 10 Kg/ day BOD_5 in 20 m^3/day

-DESCRIPTION OF THE TREATMENT PLANT

Fig. 2 shows the treatment plant flow chart.

-PRE-TREATMENT SECTION

The old treatment plant was equipped with a pulping pump to mix and homogenize every solid part contained in the sewage. In the resulting waste water was normally measured a biological load of around 1200 mg/ liter of COD. In order to decrease the biological load in the treatment plant inlet, the new treatment plant has been equipped with a self-cleaning screen (Fig. 3). Considering the very short path length to go from the main building to the waste water system, where the solid parts do not have enough time to dissolve themselves, it is understandable that the contribution of the screen to lower the pollution load is very important.
Since the quantity and characteristics of the sewage change with time, in order to feed the treatment system uniformly with an homogenous waste water it is necessary to accumulate the sewage in a primary tank. The tank installed has a volume of 14 m^3 and is equipped with four air sprinklers to perform preaeration.

-TREATMENT SECTION

This section is composed with two main parts: a *Physical-Chemical* part and a *biological* part.

- *Physical-Chemical reactor*

A *Physical-Chemical* reactor (Fig.4) has been included into the water treatment system in order to obtain the following capabilities:

1)treat up to 10 kg BOD_5/day with an hydraulic load of 20 m^3/day;
2)good efficiency also during transient periods;
3)very compact installation compared with the depuration system capability.

Generally this method of treatment realizes its task by cleaning the water from suspension particles, colloids and partially of diluted organic substances through a double step process.
During the first step (flocculation) the pollutants cake into bigger particles by the effect of specific reactants opportunately added to the sewage. During the second step (separation) the flocky mass separates and can be taken away from the clarified water.
With respect to the third Point (compact installation) the Physical-Chemical plant installed at Terra Nova Bay has been realized replacing a series of tanks where the reactants are added and the sludge is separate, with an hydraulic circuit for the coagulation and with a dissolved air flotation tank for the separation. The two parts are composed to give form to a system with a really small global volume. This system's trade mark is ULTRASLIM-2.
ULTRASLIM-2 is capable to treat 2 m^3 / h of sewage, well above the Italian Base needs. It is clear that with this flow of waste water per hour it is not expectable any kind of contribution to the depuration process coming from the RBC system. Anyway in normal condition the waste flow is not more then 12 m^3 of sewage per day.

The ULTRASLIM-2 simplified flow chart is shown in Fig. 5 and is described in the following steps:

a) Chemical reactants preparation and proportioning

A normal urban sewage flocculation requests three different kind of reactants: a pH corrector (base), a primary coagulant (salt), a binder (polyelettrolite). At the beginning all the reactants are stored as a water solution in different tanks and continuously stirred. The different solutions are injected sequentially into the flocculation part of the system by proportioning pumps.

b) Flocculation

Flocculation is accomplished inside the tubular reactor (hydraulic circuit made of stainless steel pipe installed on the outer side of the flocculation tank's walls) where the sewage is pumped after being pumped from the storage tank. The turbulent flow in the pipe mixes the reactants and the sewage intimately, inducing the flocculation that occurs in two subsequent steps. In the first part of the circuit (after the salt injection) the pollutants coagulate and precipitate as micro flocks. In the final part of the circuit (after the polyelectrolite injection) the micro flocks become macro flocks.

c) Dissolved air flotation

the sludge separates from the clarified water inside the dissolved air flotation tank. this tank is made of stainless steel and equipped with a recycling pipe provided with appropriate apparatus (air injector, pump and valve) to supersaturate the clarified water with air, a bladed skimmer to remove the sludge, and an overflow with base intake of water to remove the clarified effluent. At the end of the recycling pipe, the fluffy mass is mixed with clarified water supersaturated with air which generates micro air bubbles. The micro air bubbles stick to the micro flocks lowering their density. In this way, while the recycled mixture is injected into the flotation tank, the lighter flocks migrate towards the surface, where the skimmer blades remove them. The clarified water in the bottom of the tank is drawn off through the overflow pipe and discharged into the final section.

d) Sludge drying process

The sludge produced into the flotation tank and removed by a surface collector system contains 95 to 98 % of water. To facilitate the solid waste disposal the sludge is treated with a filter press that dewater from98% of water to 85 %, reducing the sludge volume almost 7 times. (Fig.6)

-Biological reactor

The *biological reactor* (Fig7) has been the main part of the old treatment plant. Now it is installed in the new system in order to complete the treatment capacity of our chemical-physical reactor It is known that this last system is incapable to streep dissolved particles from polluted water with an high efficiency, while a biological treatment easily accomplishes this task.

The rotating biological contactor (RBC) system installed at Terra Nova Bay is capable of treating 3 kg BOD_5/day with an hydraulic load of around 10 m^3; placed to work in a combined system, like that installed at Terra Nova Bay, it becomes not only well dimensioned, considering the residual pollution load contained into the sewage after the chemical-physical treatment, but also essential to improve the purifying action efficiency of the above mentioned plant

POST TREATMENT SECTION

This section is formed by three main components:
- a settling tank;
- an active-carbon filter;
- a UV lamp.

After the treatment section the effluent is pumped in a 7 m^3 settling tank where the retention time is not less than 3,5 hours. The settled sludge is periodically pumped into the storage tank because its separation is performed only in the flotation tank.
A 290 liter tank contains almost 100 kg of active-carbon which can streep a total of 30.000 g COD from the effluent.
The last component of the purification system is represented by a ultraviolet germicidal device.

RESULTS AND DISCUSSION

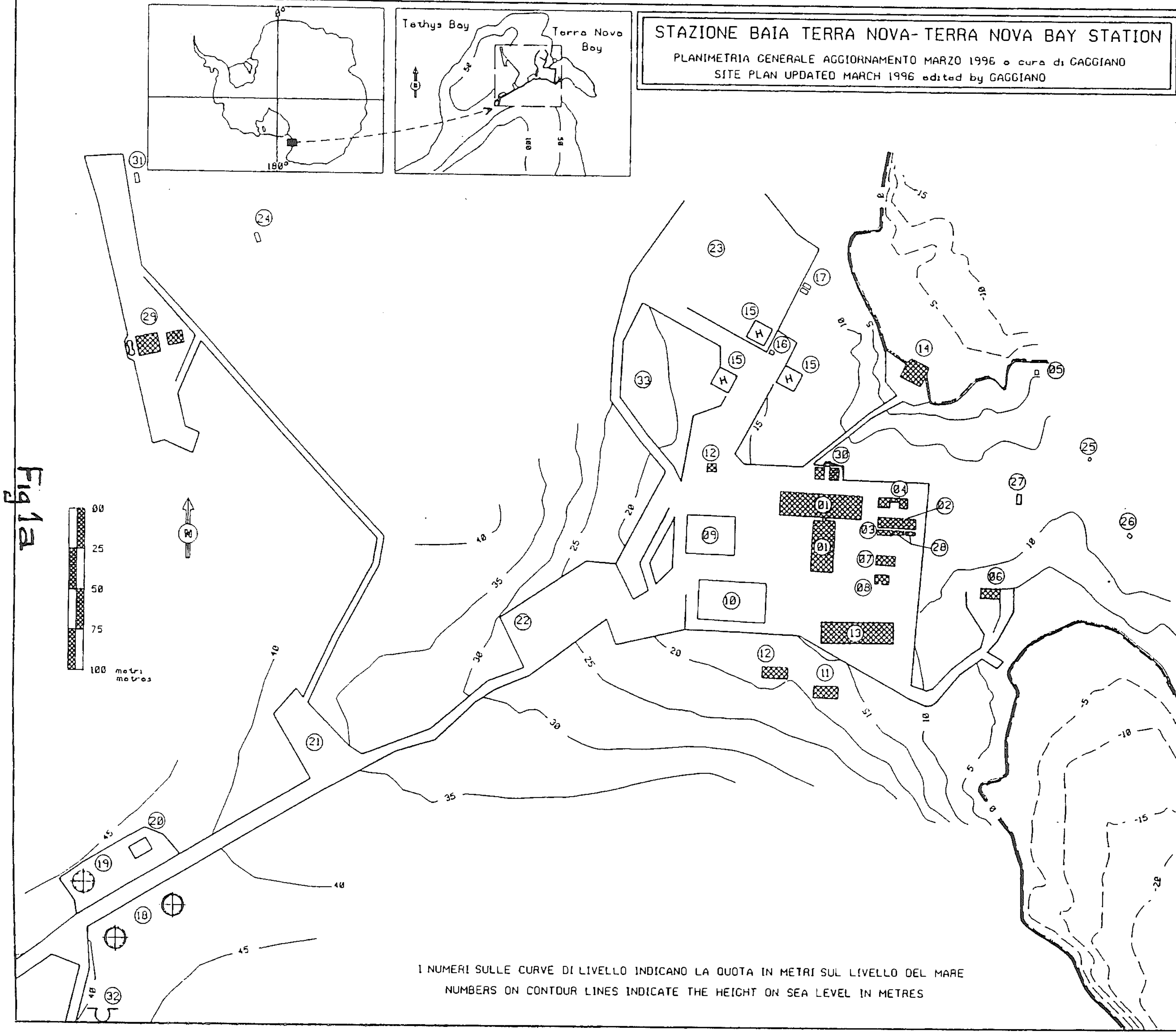
The new waste water treatment plant has been run between the fifth of December 95 and the sixth of February 96. Part of the time has been used to test and improve some components, so that the operating period during which were collected data goes from December the 19^{th} 1995 to January the 30^{th} 1996., for a total of almost 40 days.
In Fig. 8 are reported the values of the analysis on the inlet and outlet effluent (PC0, PC1 and PC4 on the flow chart -Fig. 2-).
The large peaks on PC0 are related to accidental spilling of soluble organic compounds in the kitchen.
In the ***pre-treatment section*** it was not possible to have a direct measurement of the inlet COD level during the past expedition. An indirect measurement has been performed, comparing the COD level between two different plant configuration: the first one using the new selfcleaning screen, the second one using the old pulping pump. The average value was 800 mg/liter in the first case and 1200 mg/liter in the second case. Consequently it was possible to estimate that the pre-treatment section is responsible of a removal of about 30% of the pollution load.
Considering the pollution load reduction, the pretreatment section is evaluated positively, but from the waste handling point of view this section generates two important problems, both of them related to the sanitary level of the closed space in which the treatment plant is installed.
Meanly to solve the two above problems, it is necessary to perform the two following actions:
-install a conveyor to transfer the untreated and smelly solid waste produced here to the filter-press. In order to make the above material inert the solid waste must be mixed with lime added during the transfer.
-install a foam destroyer to reduce the huge quantity of foam produced by the air sprinklers into the homogenization tank.

In the **treatment section** the chemical-physical reactor has worked as designed with an average efficiency on COD removal of 70%. The main problem was related to the RBC performance. In fact, according to design, the RBC system placed after the physical-chemical plant, has treated 10 m^3 per day of sewage with an average pollution load of 280 g COD/ m^3 for a total of 2800 g COD / day (1700 g BOD_5/day).
Unexpectedly even if it worked in tag conditions, its efficiency was close to zero and some time even negative.
The analysis of this phenomena is not completed; further and more accurate investigations will be performed during next expedition. The most probable reason of this bad result is related to the unsteady characteristics of the urban sewage after a chemical-physical system combined to a higher daily flow of waste water. Since growth and multiplication of the bacterial cultures is very dependable on the chemical stability of the sewage, can be explained the very low efficiency noticed during our waste water system operation. Next year it is planned to perform a working test placing the RBC system before the chemical-physical plant (Fig.9 flow chart)
In the world many Companies are using combined treatment plant to purify their waste water. Performing the above method, sewage is before pumped on top of a biofilter and than sent through a chemical-physical plant.
Initially, while the sewage drips over the huge biofilter surfaces, selected and highly active micro-organisms rapidly degrade accumulation of organic solids. (During this step into the sewage mass there is a production of micro flocks that can be separated in two different way: deposition and floatation).
Subsequently, since separation is performed by flotation, a chemical-physical plant is used to transform micro-flock into macro-flocks ready to be removed by a surface collector system. This last transformation is obtained by adding only a binder liquid (polyelectrolite) and a pH corrector if needed, saving the all amount of metallic salt.
Our plan is to repeat the above process at the Italian base of Terra Nova Bay using the RBC system (in place of a biofilter) before the chemical-physical one. In this way, we think to obtain a stronger depuration action with lower cost and less material to transport to Antarctica.
The COD measurement data collection of the ***post-treatment section*** reveals an average contribution to the depuration process of 52 g COD/m^3 (detention time 15 minutes, COD reduction 20 %). In presence of the above working conditions the active.carbon filter could be usable for 40-50 days. Some problems on the carbon bed packaging reduced this expectation. In the future plant configurations a re-sizing of the active-carbon filter could solve definitively the problem to reduce the COD level on the effluent coming from the treatment section. In fact our installation is in very different conditions from a conventional plant where economical considerations restrain the use of this kind of filter.
Microbiological analyses detected zero biological pollution after UV devices.

CONCLUSION

The combined waste water treatment plant installed in Terra Nova Bay demonstrated during preliminary service in 95-96 good performance. In particular the core of the new plant, the chemical-physical reactor, has behaved with the expected characteristics of efficiency, versatility, rapid response to transients. There are the possibilities to improve different aspects relating to: lower maintenance cost, lower reactants use, higher reliability and stability of the process. During the following expeditions this modifications will be realized.

Fig. 1a



LEGGENDA (LEGEND)

01 CORPO PRINCIPALE (MAIN BUILDING)
02 GRUPPI ELETTROGENI (ELECTRIC GENERATORS)
03 SERBATOI CARBURANTE PER GRUPPI ELETTROG. (FUEL TANKS FOR ELECTRIC GENERATORS)
04 DISSALATORE/LIQUEFATTORI AZOTO ED ELIO/ LABORATORIO GEOLOGIA (DESALINATOR/LIQUID NITROGEN AND HELIUM PRODUCTION PLANTS/GEOLOGY LABORATORY)
05 POMPA ACQUA MARE (SEA WATER SUCTION PUMP)
06 DEPURATORE (SEWAGE TREATMENT PLANT)
07 INCENERITORE (WASTE INCINERATOR)
08 DISTRIBUTORE CARBURANTI/STAZIONE RICARICA BATTERIE/CAMERA IPERBARICA (VEHICLE REFUELLING AND BATTERY RE-CHARGING STATIONS/HYPERBARIC CHAMBER)
09 HANGAR MAGAZZINO (WAREHOUSE)
10 HANGAR OFFICINE E RICOVERO MEZZI (WORKSHOP/VEHICLE STOREHOUSE)
11 FORESTERIA (GUEST HOUSE)
12 PINGUINATTOLO (HUT FOR SOCIAL ACTIVITIES)
13 CONTAINERS MAGAZZINO (WAREHOUSE CONTAINERS)
14 MOLO (PIER)
15 PIAZZOLA PER ELICOTTERO (HELIPAD)
16 STAZIONE POMPAGGIO CARBURANTE ELICOTTERI (HELICOPTER FUEL PUMPING STATION)
17 SERBATOI CARBURANTE ELICOTTERI (HELICOPTER FUEL TANKS)
18 SERBATOI CARBURANTE 600 m^3 (MAIN FUEL TANKS 600 m^3)
19 FONDAZIONE PER SERBATOIO FUTURO (FOUNDATION FOR FUTURE FUEL TANK)
20 TUBAZIONI FLESSIBILI PER REFUELLING (LONG LENGTH COLLAPSIBLE HOSE FOR REFUELLING)
21 DEPOSITO FUSTI CARBURANTE (FUEL DRUMS STORAGE AREA)
22 MAGAZZINO ALL'APERTO (OPEN STORAGE AREA)
23 AREA ESPANSIONE FUTURA (FUTURE EXPANSION AREA)
24 LABORATORIO GRAVIMETRIA (GRAVIMETRY LABORATORY)
25 LABORATORIO GEOFISICA (GEOPHYSICS LABORATORY)
26 OSSERVATORIO GEOMAGNETISMO (GEOMAGNETISM OBSERVATORY)
27 LABORATORIO GEOMAGNETISMO (GEOMAGNETISM LABORATORY)
28 MODULO AUTOMATICO INTEGRATO (AUTOMATIC INTEGRATED MODULE, AIM)
29 LABORATORIO OASI (ASTRONOMY OBSERVATORY)
30 ACQUARIO/LABORATORI SCIENTIFICI (AQUARIUM/SCIENTIFIC LABORATORIES)
31 OSSERVATORIO ELIOSISMOLOGIA (HELIOSEISMOLOGY LABORATORY)
32 OSSERVATORIO SISMOLOGIA (SEISMOLOGY OBSERVATORY)
33 MANICA A VENTO (WIND SLEEVE)

Fig 1a

Fig 1b

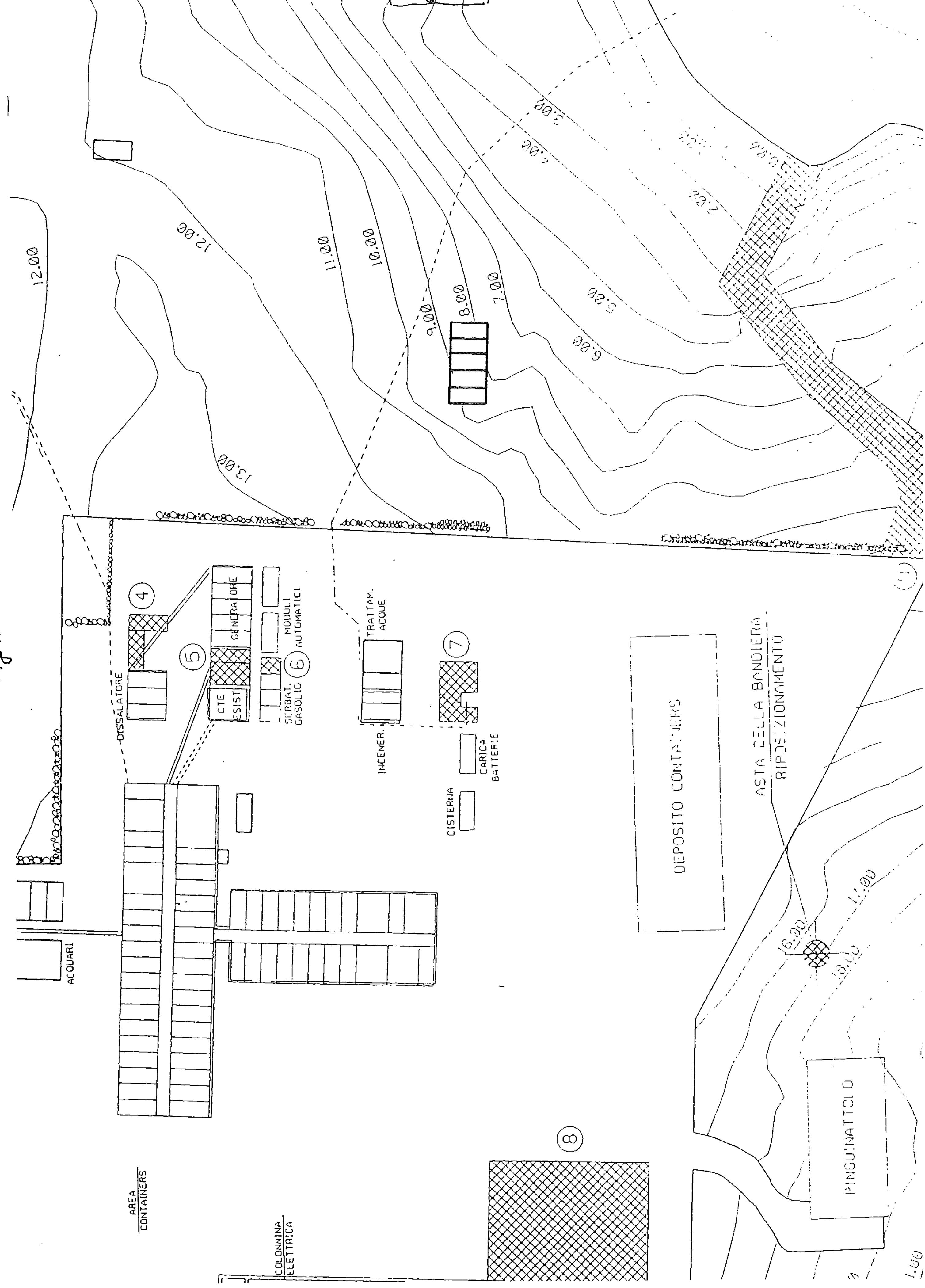


Fig 1b
12.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
13.00
4
5
6
7
8
DISSALATORE
GENERATORE
MODULI AUTOMATICI
SERBAT. GASOLIO
TRATTAM. ACQUE
INCENER.
CARICA BATTERIE
CISTERNA
DEPOSITO CONTAINERS
ASTA DELLA BANDIERA
ACQUARI
AREA CONTAINERS
COLONNINA ELETTRICA
PINGUINATTOLO
16.00
18.00

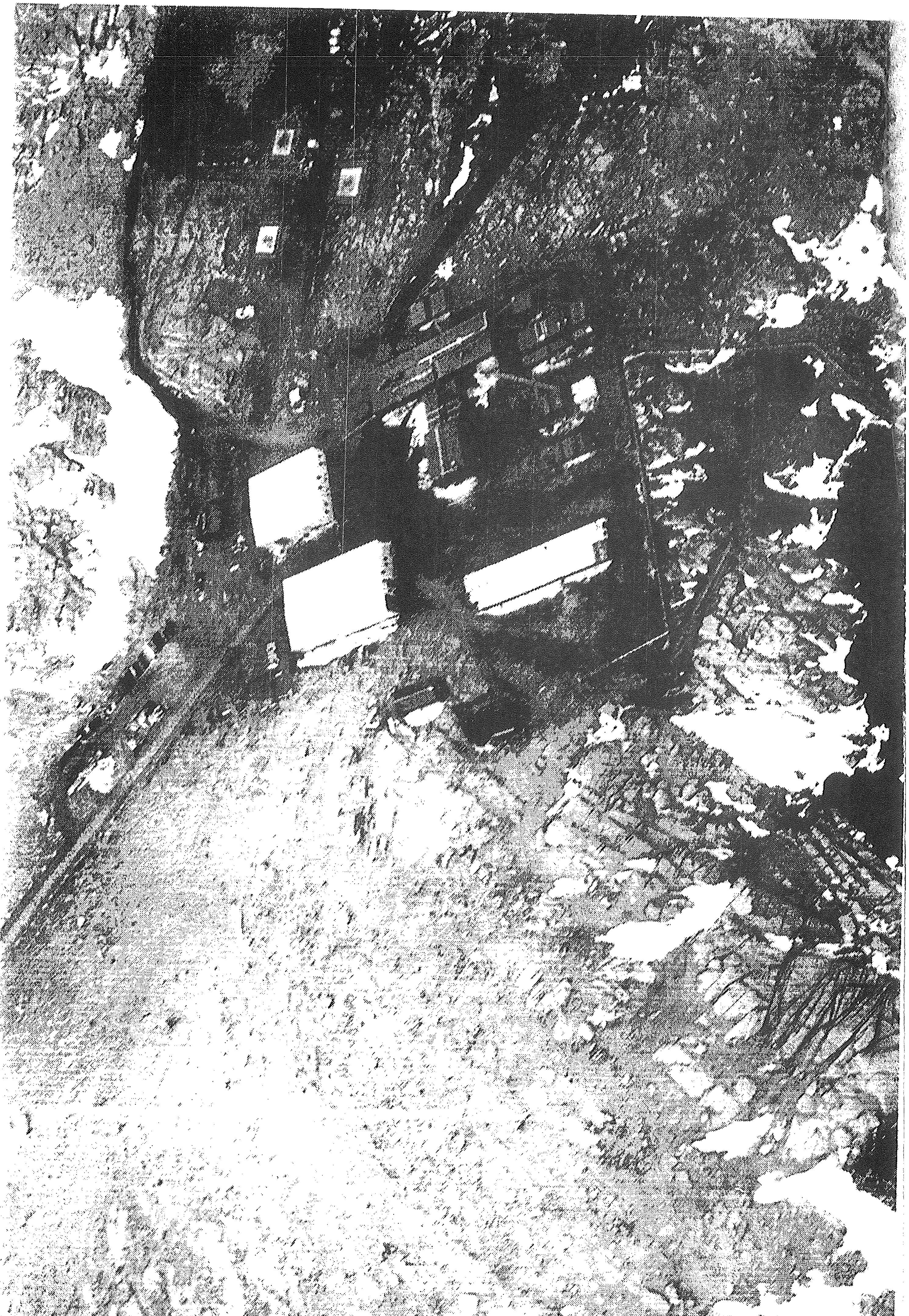


Fig 1 c

Fig 1c

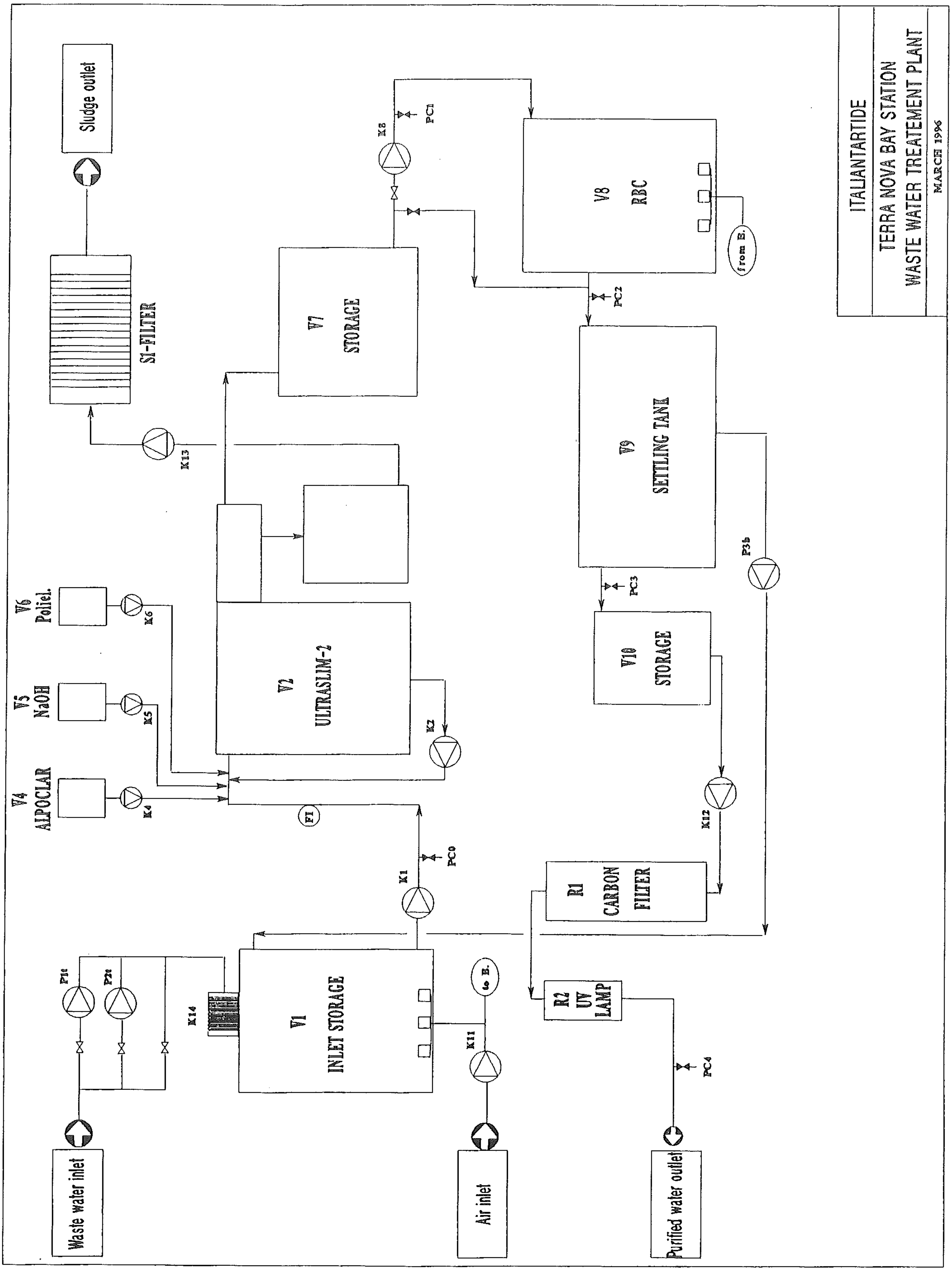

ITALIANTARTIDE
TERRA NOVA BAY STATION
WASTE WATER TREATEMENT PLANT
MARCH 1996
Sludge outlet
S1-FILTER
K13
V7
STORAGE
K8
PC1
V8
RBC
from B.
PC2
V9
SETTLING TANK
P3b
PC3
V10
STORAGE
K12
R1
CARBON
FILTER
R2
UV
LAMP
PC4
Purified water outlet
V6
Poliel.
K6
V5
NaOH
K5
V4
ALPOCLAR
K4
V2
ULTRASLIM-2
K2
FI
PC0
K1
V1
INLET STORAGE
K14
P1t
P2t
to B.
K11
Waste water inlet
Air inlet

Fig 2

POCKET

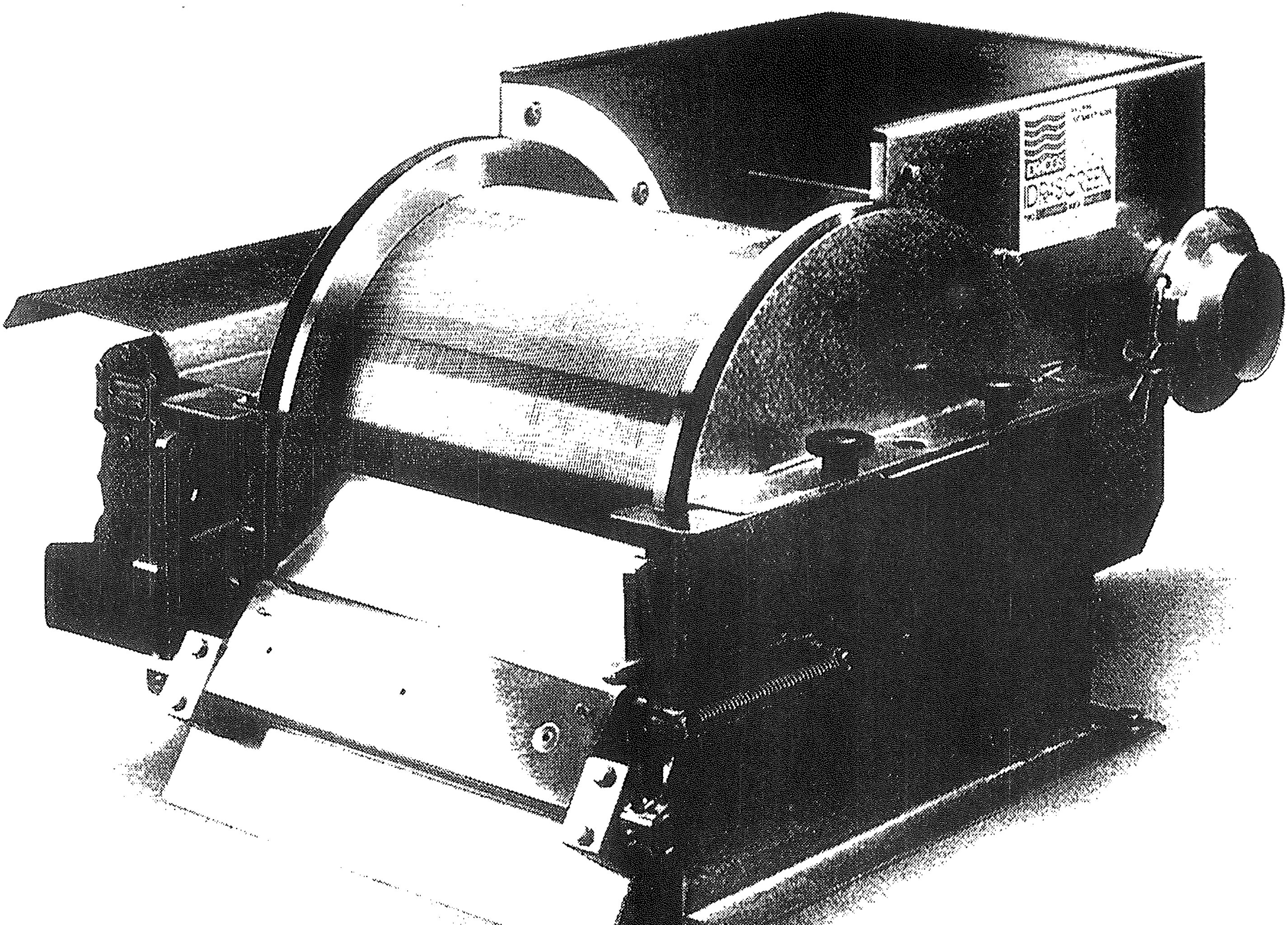


Fig 3

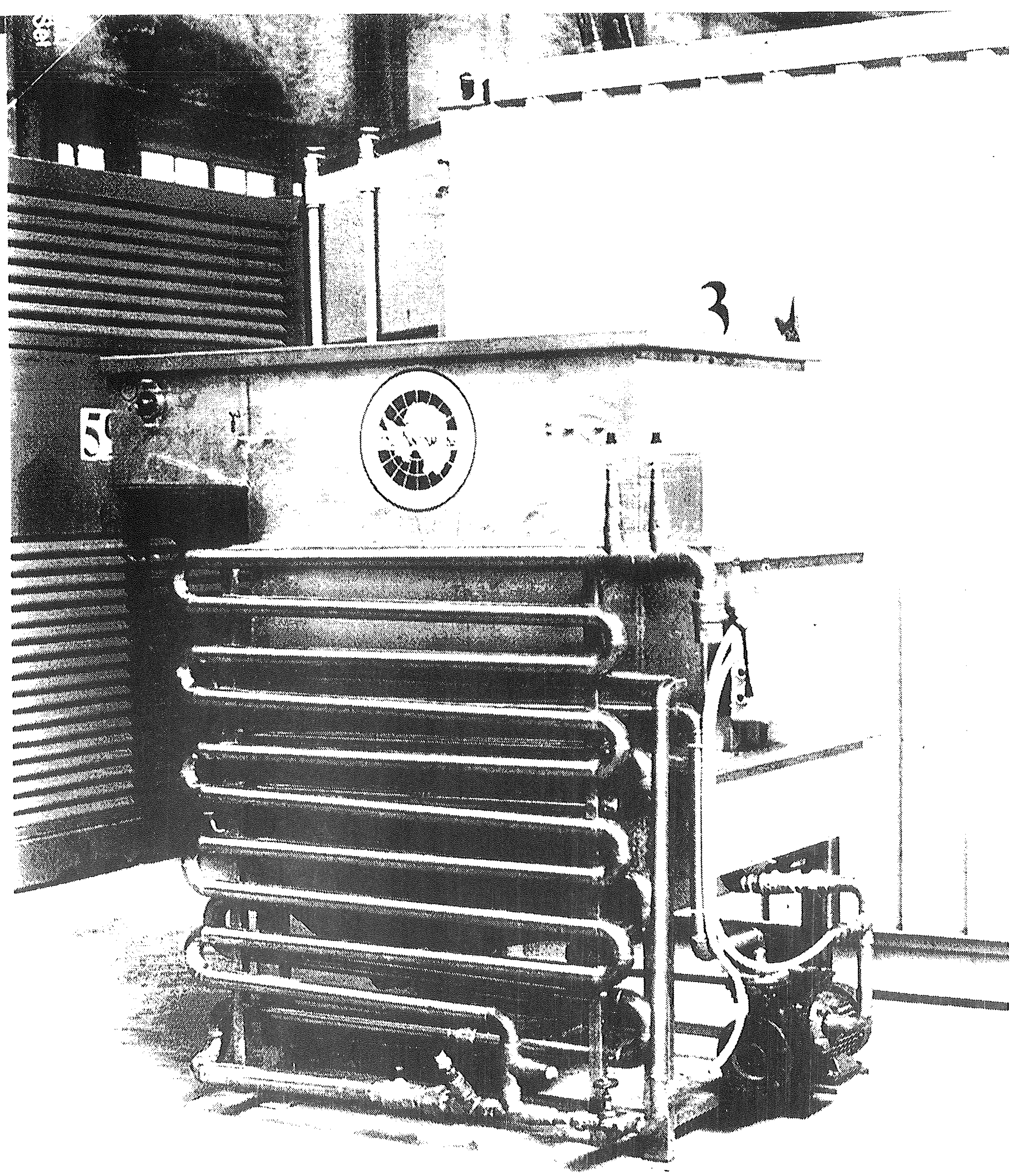


Fig 4

Fig 5

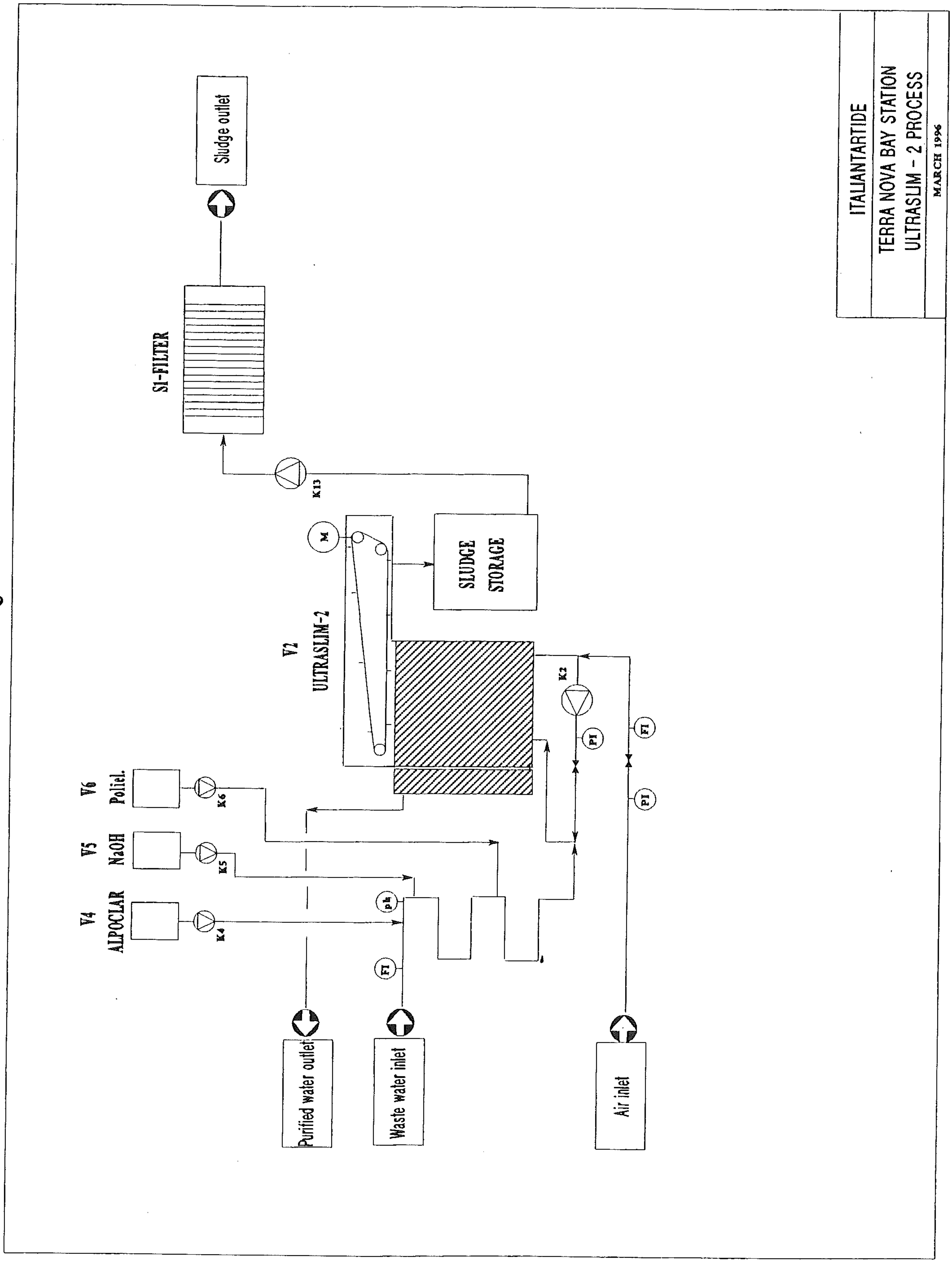

ITALIANTARTIDE
TERRA NOVA BAY STATION
ULTRASLIM - 2 PROCESS
MARCH 1996
Sludge outlet
S1-FILTER
K13
M
SLUDGE
STORAGE
V2
ULTRASLIM-2
K2
PI
FI
V6
Poliel.
K6
V5
NaOH
K5
V4
ALPOCLAR
K4
ph
Purified water outlet
Waste water inlet
Air inlet

Fig 5

Assonometria

Fig 6

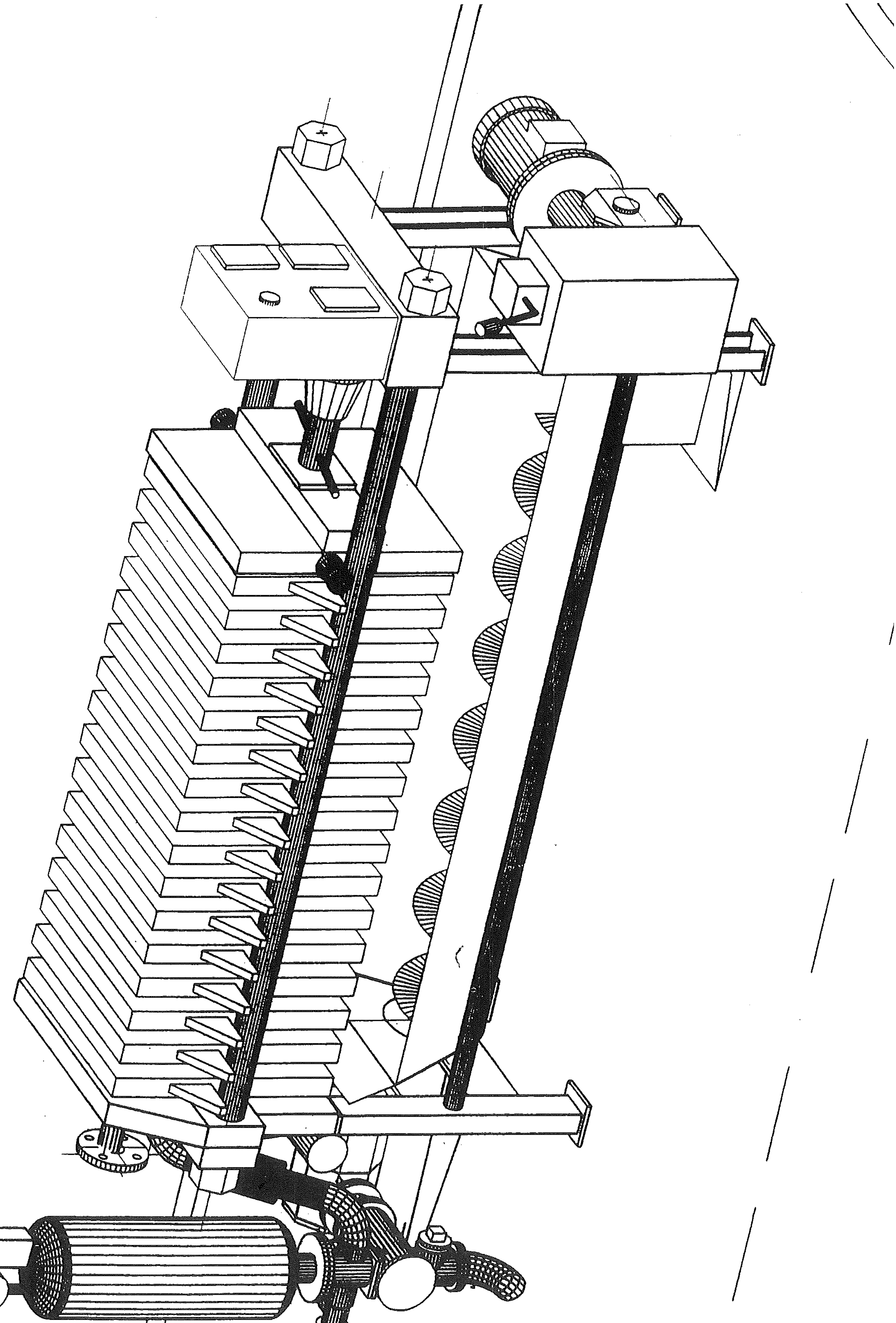


Fig 6

Fig 7

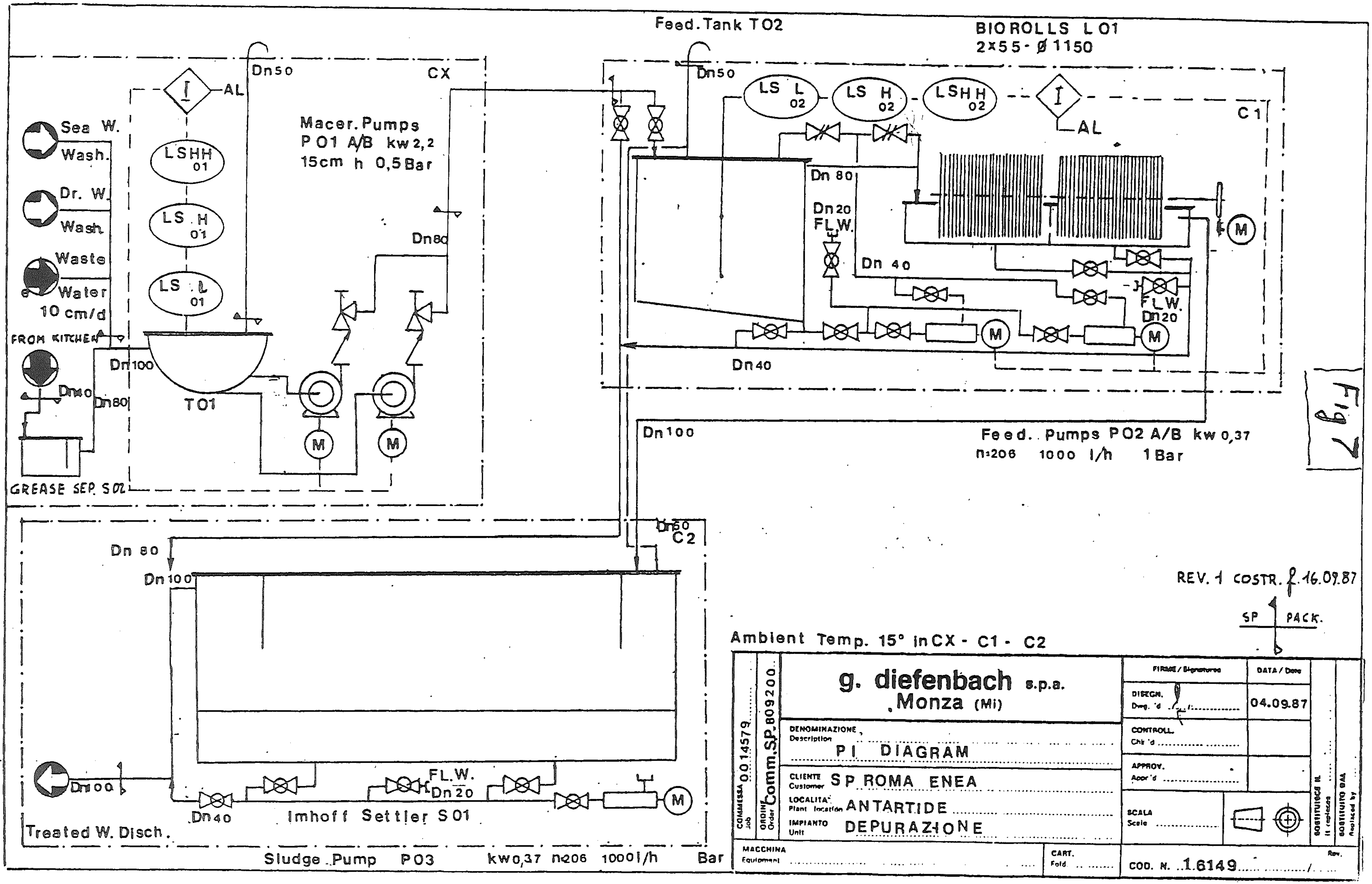

Feed. Tank T02
BIOROLLS L 01
2x55 - Ø 1150
Dn50
CX
AL
Sea W. Wash.
Dr. W. Wash.
Waste Water 10 cm/d
FROM KITCHEN
LSHH 01
LS H 01
LS L 01
Macer. Pumps
P 01 A/B kw 2,2
15cm h 0,5 Bar
Dn80
Dn100
Dn40
T01
GREASE SEP. S02
LS L 02
LS H 02
LSHH 02
C1
Dn 80
Dn20 FLW.
Dn 40
Dn40
Dn100
Feed. Pumps P02 A/B kw 0,37
n:206 1000 l/h 1 Bar
Fig 7
Dn 80
Dn100
C2
REV. 1 COSTR. 16.09.87
SP PACK.
Ambient Temp. 15° in CX - C1 - C2
FL.W. Dn20
Dn40
Imhoff Settler S01
Treated W. Disch.
Sludge Pump P03 kw0,37 n206 1000 l/h Bar
g. diefenbach s.p.a.
Monza (Mi)
COMMESSA Job 0014579
ORDINE Order Comm. SP. 809200.
DENOMINAZIONE Description PI DIAGRAM
CLIENTE Customer SP ROMA ENEA
LOCALITA' Plant location ANTARTIDE
IMPIANTO Unit DEPURAZIONE
MACCHINA Equipment
CART. Fold
FIRME / Signatures
DATA / Date
DISEGN. Drw'd 04.09.87
CONTROLL. Chk'd
APPROV. Appr'd
SCALA Scale
COD. N. 16149
Rev.

Fig 8

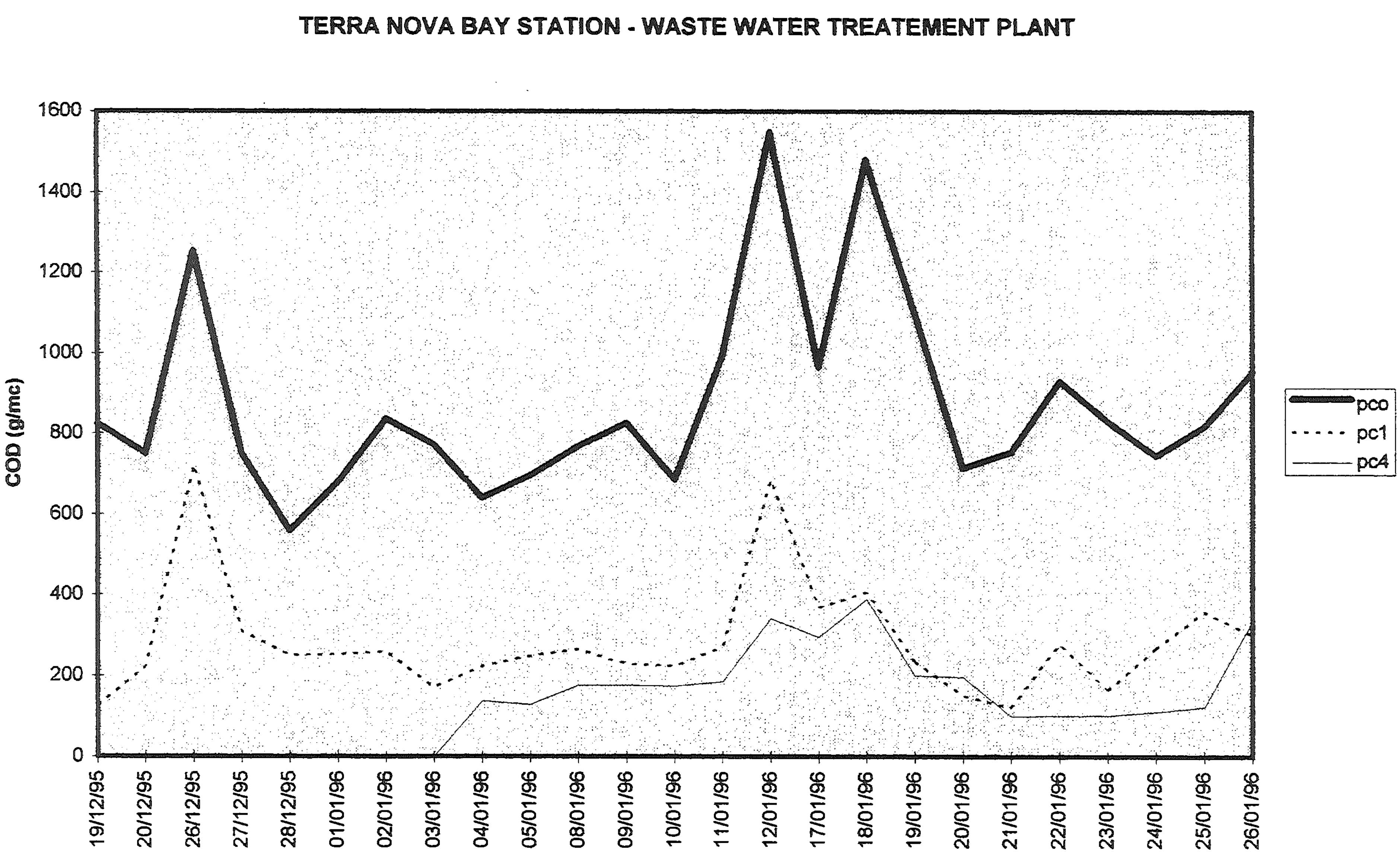

TERRA NOVA BAY STATION - WASTE WATER TREATEMENT PLANT
COD (g/mc)
1600
1400
1200
1000
800
600
400
200
0
19/12/95
20/12/95
26/12/95
27/12/95
28/12/95
01/01/96
02/01/96
03/01/96
04/01/96
05/01/96
08/01/96
09/01/96
10/01/96
11/01/96
12/01/96
17/01/96
18/01/96
19/01/96
20/01/96
21/01/96
22/01/96
23/01/96
24/01/96
25/01/96
26/01/96
pco
pc1
pc4

Fig 8

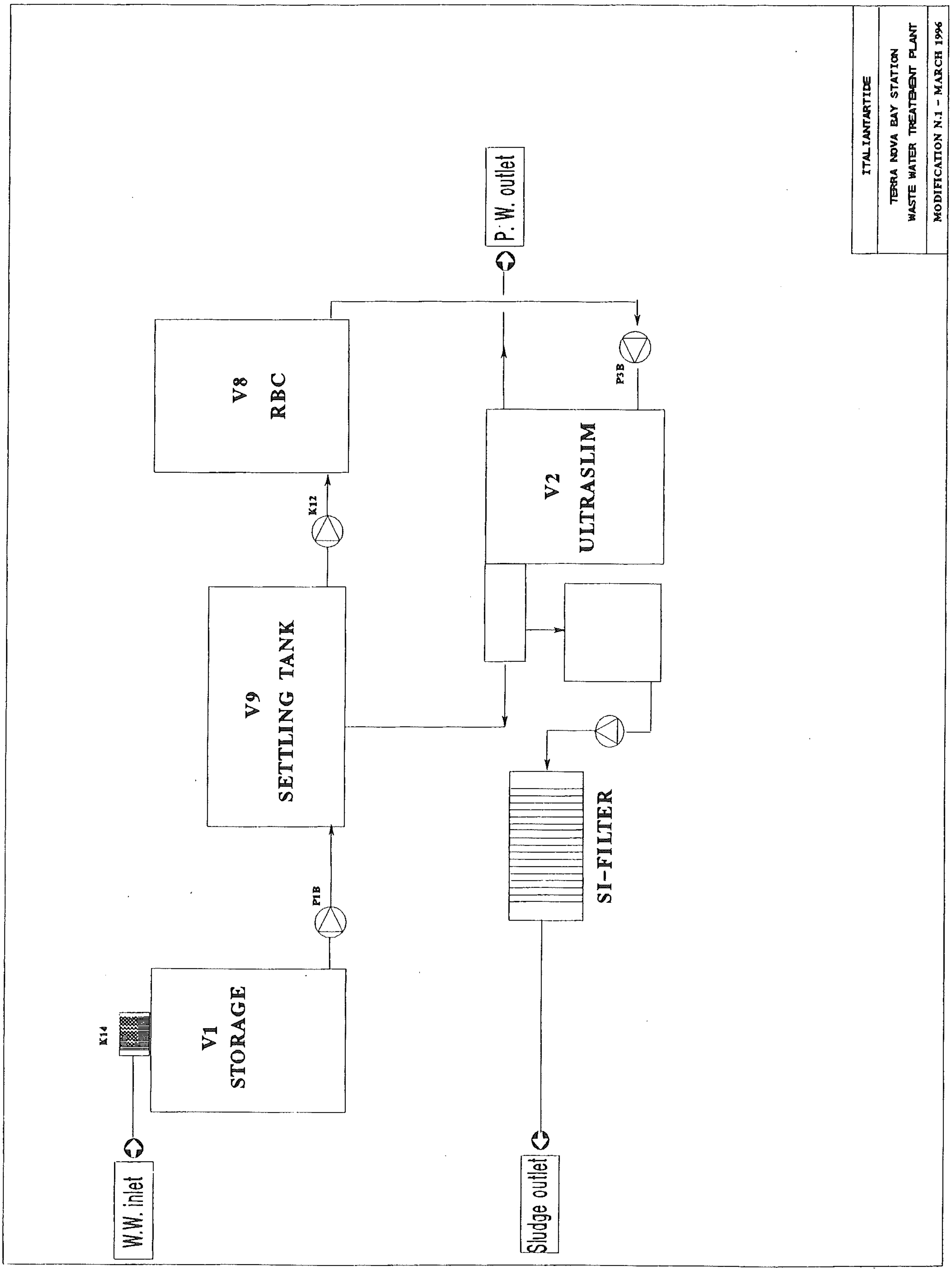

ITALIANTARTIDE
TERRA NOVA BAY STATION
WASTE WATER TREATEMENT PLANT
MODIFICATION N.1 - MARCH 1996
W.W. inlet
K14
V1
STORAGE
P1B
V9
SETTLING TANK
K12
V8
RBC
P: W. outlet
P3B
V2
ULTRASLIM
SI-FILTER
Sludge outlet

Fig 9

Development of Environment Protective Technologies for Snow Tractors

by

H. Kohnen, N. Müller, Bremerhaven
G. Strähle, W. Deininger, Ulm

I.

Lubrication oils and hydraulic fluids in vehicle operations represent potential hazards to the Antarctic environment. However, oils and greases exist which are naturally degradable and which are environmentally safer with regard to the water quality standards.

One of AWI's Pisten Bully tractors has been adapted to such oils and greases and has been tested during the summer 1995/1996 in Antarctica. This outline gives an overview of different types of oils and greases and presents results of tests already completed.

Our basic question in regard to protective technologies of snow tractors is, how to meet the „protocol of environmental protection to antarctic treaty".

II.

Kässbohrer Geländefahrzeug GmbH has done research for 10 years on how our Kässbohrer Pisten Bullys will meet higher standards in environmental protection, especially in the case of hydraulic oil, engine oil, gear-box oil and grease. The reason we started these tests was the demand from customers with ski areas in glacier areas as well as an increased awareness for environmental protection.

The problems facing us with alternative oils have been the lifetime of components, including high pressure hoses, the mixing ability of oils and last, but not least, the lack of standardization of these oils worldwide or even in Europe. Today we can say that most of the problems listed above have been solved with the exception of standardization. Until some type of standardization is in place we can only recommend specific oils which we have tested and rated as satisfactory.

III. What hydraulic oils are available?

Film 1 shows the alternative oils: polyglycol, vegetable ester, synthetic ester

Polyglycol

Polyglycol based hydraulic oils have been on the market the longest. Ten years ago we started testing synthetically produced oils. In a five year period the composition of these synthetics has changed four times in order to achieve test results which are useful. While thinking about a wider use for this medium, vegetable and synthetic ester based oils came on the market and we stopped further tests with polyglycol. However, when dropped on the ground, the danger exists that the taste of the drinking water could be affected.

Vegetable oils

The rape, which is a yellow blooming spring flower, is a base medium for the production of vegetable based hydraulic oils. The seed corns are minced and cold pressed. After further complicated procedures a base medium is achieved that hydraulic fluids can be produced from. There have been great problems concerning the viscosity during bench tests. Therefore, it was necessary to bring the standard viscosity of these hydraulic oils from 46 to 22 in order to achieve reasonable results regarding the lifetime and performance in general.

Synthetic Ester

This alternative hydraulic oil is made from synthetic basic oils. Therefore, it is possible to use certain additives in a specific way to increase high temperature performance and oxidation stability. But oils made in this manner must be used carefully, especially as far as mixing ability with mineral oils or vegetable oils are concerned.

IV. Water endangering class of the hydraulic oils (Film 2)

An important subject in rating the impact of these alternative oils on the environment is the so called water endangering class.

On this film two words appear: Water Endangering Figure and Water Endangering Class. The base for the water endangering class is established by using the water endangering figure which can be determined with the help of the following four rating criteria:

1. Determining the acute bacteria toxicity
2. Determining the acute fish toxicity
3. Naturally degradable behaviour (this is rated only to some extent)
4. Determining the acute oral mammal toxicity

Our main goal is to reach water dangering class 0 and to use adequate mediums.

Biological decomposition (Film 3)

In general mineral oils will also decompose biologically. But decomposition needs a longer time when compared with products which are naturally degradable. From this film you can see the behaviour of mineral oil based hydraulic oil fluids in relation to environmentally friendly hydraulic oil fluids:

Mineral oil	approx. 36 %
Polyglycol	approx. 60 %
Synthetic ester	approx. 92 %
Vegetable ester	approx. 93 %

Mixing Ability (Film 4)

There are two different things to consider when talking about the mixing ability of alternative oils. First, how well they blend together, and second, how stable they are chemically. For example, we have done a test between vegetable ester and synthetic ester where we learned the chemical stability was good, but they would not blend well together. The result of this test was all hydraulic units were defective after approximately 300 hours of operation.

Standardization

One of the greatest problems currently is lack of standardization. There exists no standardization for alternative hydraulic oils, and it will surely take years until this is accomplished. Until there is a standard developed, only oils having achieved positive results after years of testing can be used.

Experiences up to now (Film 5)

Kässbohrer Geländefahrzeug GmbH has chosen ski areas with extreme conditions for testing of the alternative mediums. There are a lot of operationg hours per season and their consent that all vehicles in the area can be equipped with alternative oils. We have chosen the German Ski Area „Nebelhorn“ in Oberstdorf and an Austrian Glacier Ski Area named Kaprun („Zell am See“).

If polyglycol is used, 1,550 operating hours can be achieved. We also have 132 vehicles operating with vegetable ester based oils. The operating hours on these vehicles range between 300 and 5,600. In another 41 vehicles synthetic ester based oils are used; these vehicles have between 500 and 5,000 operating hours.

Austria is the first country that has decided to use biodegradable hydraulic oils as standard. This decision could only be made after testing proved that 5,000 hours of component life was possible. Generally this lifetime in the Antarctic is acceptable. We have had problems with the high pressure hoses in the hydrostatic system. It has taken several years to find a special company which will produce hoses for us that will not be affected by the alternative oils and have a sufficient lifetime.

Engine oils

An alternative is the use of synthetic engine oils. Until now we have reached water endangering class 2, further tests are planned. We did our tests with Avia Turbosynth 10W-40.

Gear box oils

AWI uses the same oil in the planetary geax boxes and splitter boxes that are used in the diesel engines. Logistically this is beneficial. The following alternative gear box oils are offered:

- synthetic engine oils (e. g. Avia Turbosynth 10W-40)

- vegetable gear box oils (e. g. Castrol Biotec UTTFR) - WEC 1

Greases

Synthetic greases, as well as vegetable greases have been approved with good success. It is important that the greases are in accordance with the 00-penetration, which means there is no danger to the water.

We have done our tests with the following oils:

DEA - Delon E2 (synthetic)

OMV - ECODUR EP00 (synthetic)

CASTROL - BIOTEC ARCTIC

From all of these tests we can make the following conclusion:

Today, we are in a position to offer our customers who would like to use biodegradable oils and greases, a solution without restriction in lifetime of components.

Development of Environment Protective Technologies for Snow Tractors

Until now:

Mineral based hydraulic oil

alternatively:

Naturally degradable hydraulic oils
are based on the following basis liquids:

Polyglycol

Vegetable ester

Synthetic ester

PistenBully

Film 1

Water endangering classes (WEC)

1. Determining the acute bacteria toxicity
2. Determining the acute fish toxicity
3. Naturally degradable behaviour (this is rated only to some extent)
4. Determining the acute oral mammal toxicity

In order to determine the water endangering classes the results of the tests have to be calculated arithmetically. Then you will get an average valuation number (WEF) which can be related to the water endangering classes:

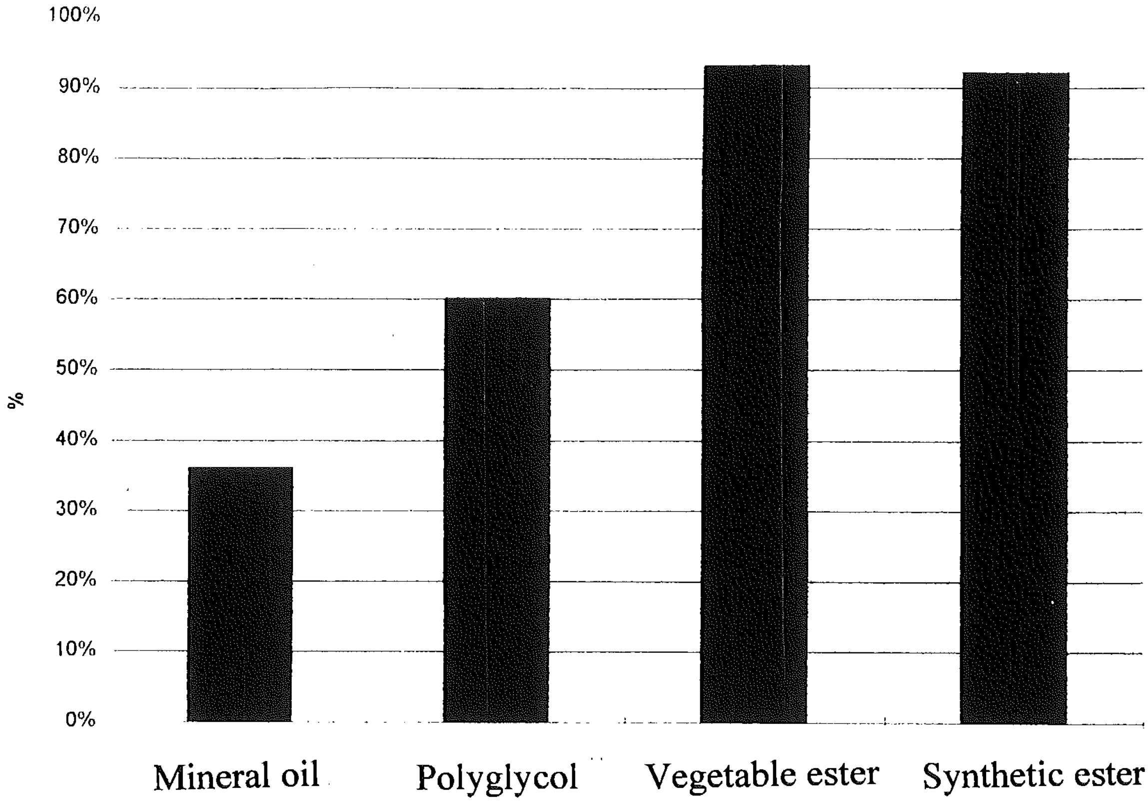
WEF	WEC	Indication
0 - 1,0	0	„generally not water endangering“
1,1 - 3,9	1	„slightly water endangering“
4 - 5,9	2	„medium water endangering“
6	3	„strongly water endangering“

PistenBully

Film 2

Biological decomposition

due to CEC-L-33-T-82



PistenBully

Film 3

Mixing ability

Blending ⇓

Chemical stability ⇒	Mineral oils	Vegetable oils	Synthetic ester	Polyglycol
Mineral oils	1	2	3	4
Vegetable oils	2	1	2	5
Synthetic ester	4	4	1	4
Polyglycol	2	5	5	1

Example: - If you mix the vegetable oils with synthetic ester they will **not blend** together good.

- Concerning the **chemical stability** between vegetable oils and synthetic ester you have a good result.
- That means, both mediums are not mixable, even though they were chemically stable in the technical values!

Film 4

Achieved operating hours in practice

1. Polyglycol

1 PB (no further tests)	1.550 h

2. Vegetable oils

132 PBs	300 - 5.600 h

PB 150 D, PB 170 D, PB 200 D, PB 220 D, PB 240 D, PB 240 DW, PB 260 D, PB 260 DW, PB 270 D, PB 320 D, PB 330 D

3. Synthetic ester oils

41 PBs	500 - 5.000 h

PB 150 D, PB 170 D, PB 200 D, PB 220 D, PB 240 D, PB 260 D, PB 270 D, PB 320 D, PB 330 D

The Dismantling of Georg Forster Station and the Clean-up of the Eastern Schirmacher Oasis

H. Kohnen, Bremerhaven and Valery Lukin, St. Petersburg

In the Schirmacher Oasis in East Antarctica three winter stations have been operated, namely the Russian station Novolazarevskaya since 1961, the station Georg Forster of the German Democratic Republic since 1976 and the Indian station Maitri since 1989. The oasis is an ice free area of approx. 31 km^2 at a maximum length of 20 km and a maximum width of 4 km. Surrounded by glacier ice the oasis contains many fresh water lakes covering an area of approx. 5 km^2 totally. The Russian station Novolazarevskaya was reconstructed at a different place during the 1977/78 Austral summer. The old station was given up, but may sporadically still be used as a summer quarter (Fig. 1).

Because of the close vicinity of Novolazarevskaya and "Georg Forster" of 1.5 km and because of the long distance of more than 100 km between the oasis and the ice shelf barrier, the transport logistics as well as the general logistical activities of both stations were tied together since the beginning. The annual logistical operations exerted a considerable impact on the ice free territory which is consequently not to discern according to its source.

After the reunification of both German states Georg Forster Station fell under the responsibility of the Alfred Wegener Institute for Polar and Marine Research (AWI) in Bremerhaven. Because major investments would have been required to bring the environmental and technical standard of the station up to date, the AWI decided to terminate the winter operations by the end of 1992. Important observatory programmes like the ozone programme were transferred to AWI's winter station Neumayer and have been continued there since.

Georg Forster Station was still used as a base for summer activities until 1996. However, because of its environmental and technical standard the AWI had also to decide to dismantle the station and to clean up the area by the mid nineties and to remove all material and wastes from the Treaty Area according to the requirements of the Protocol to the Antarctic Treaty.

Because of the close connections between the logistics of the two stations it was logical and consequent to develop a joint project between the Russian Antarctic Expedition (RAE) and the

AWI for the dismantling and clean up. A relevant "Agreement" was set up and signed in November 1993, in which the duties and responsibilities of both sides were defined.
The responsibility of the Russian partner was to provide the sea transportation for personnel and material, the overland transport between the ice shelf barrier and the oasis, helicopter support, energy as well as the man power required to dismantle the buildings and to collect, separate and containerize the wastes. The man power, i.e. labour should be given from the winter crew of Novolazarevskaya Station. The German side was responsible to provide special machinery and tools. Furthermore, the Alfred Wegener Institute financially supported the Russian partner through a special grant of the German Ministry of Science and Technology for transport and labour services. The project was coordinated by AWI and RAE (H. Kohnen, V. Lukin).

In spring 1993 a joint inspection team visited the Oasis to estimate the amount of material to be removed. The evaluation, which was carefully mapped, comprised the station (Fig. 2) consisting of the containerized main building, 15 partly remote huts, heavy vehicles, sledges and tanks as well as 17 waste deposit sites (Fig. 3) of various contents totalling to about 800 to 1000 tons equivalent to 4000 to 5000 cbm. The waste disposal sites contained the wastes of both stations accumulated during the past decades.

The clean-up work started during the 1993/94 season. In this season the priority was laid on the removal of hazardous goods like batteries, fuel, noxious goods. At the end of the 93/94 summer twenty 20'containers had been filled with hazardous and non-hazardous goods and had been transported to the ice shelf barrier. Because of severe sea ice conditions the wastes could unfortunately not be removed from the treaty area.

During the following summer (94/95) the clean-up work focussed on collecting and separating wastes and on the dismantling of huts and laboratories. Some 3,000 empty drums were compressed and containerized. After this season about 580 tons of wastes, hazardous goods and old vehicles had been removed from the Antarctic Treaty area on board the Russian expedition ship "Akademik Fedorov".
The last season (95/96) was devoted to the dismantling of all buildings and to the final clean-up of all waste disposal sites and polluted areas. Another 420 tons of wastes left the Antarctic on the Norwegian icebreaker "Polar Queen" on 16 February 1996.

By this time the project was successfully brought to an end after three summer seasons and two winters. Approximately 1000 tons of building materials, old vehicles and other hazardous and non-hazardous goods, most of it loaded in about 100 20'containers, were removed from the Treaty Area; the region is now thoroughly cleaned (Fig 4).

The field work was performed by the winter team of Novolazaveskaya Station as well as by joint summer teams of AWI and RAE. The first season had already shown the necessity of having a summer team in the oasis exclusively devoted to the clean-up work.

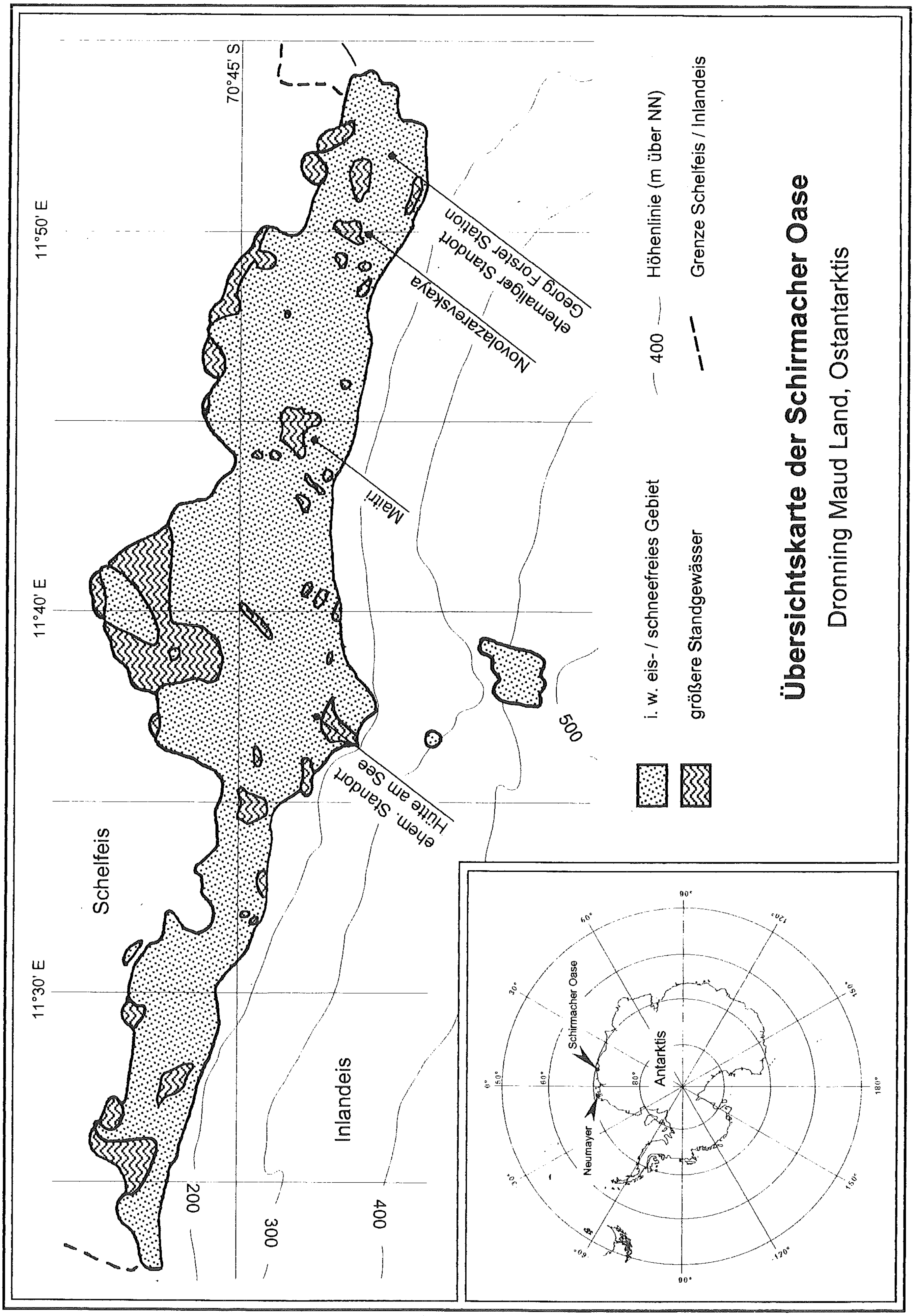
The non-hazardous goods were properly disposed of in South Africa for which a special permit was given by the South African Department of Environmental Affairs. All hazardous goods were brought back to Germany and Russia according to the Basel Convention of 1989.

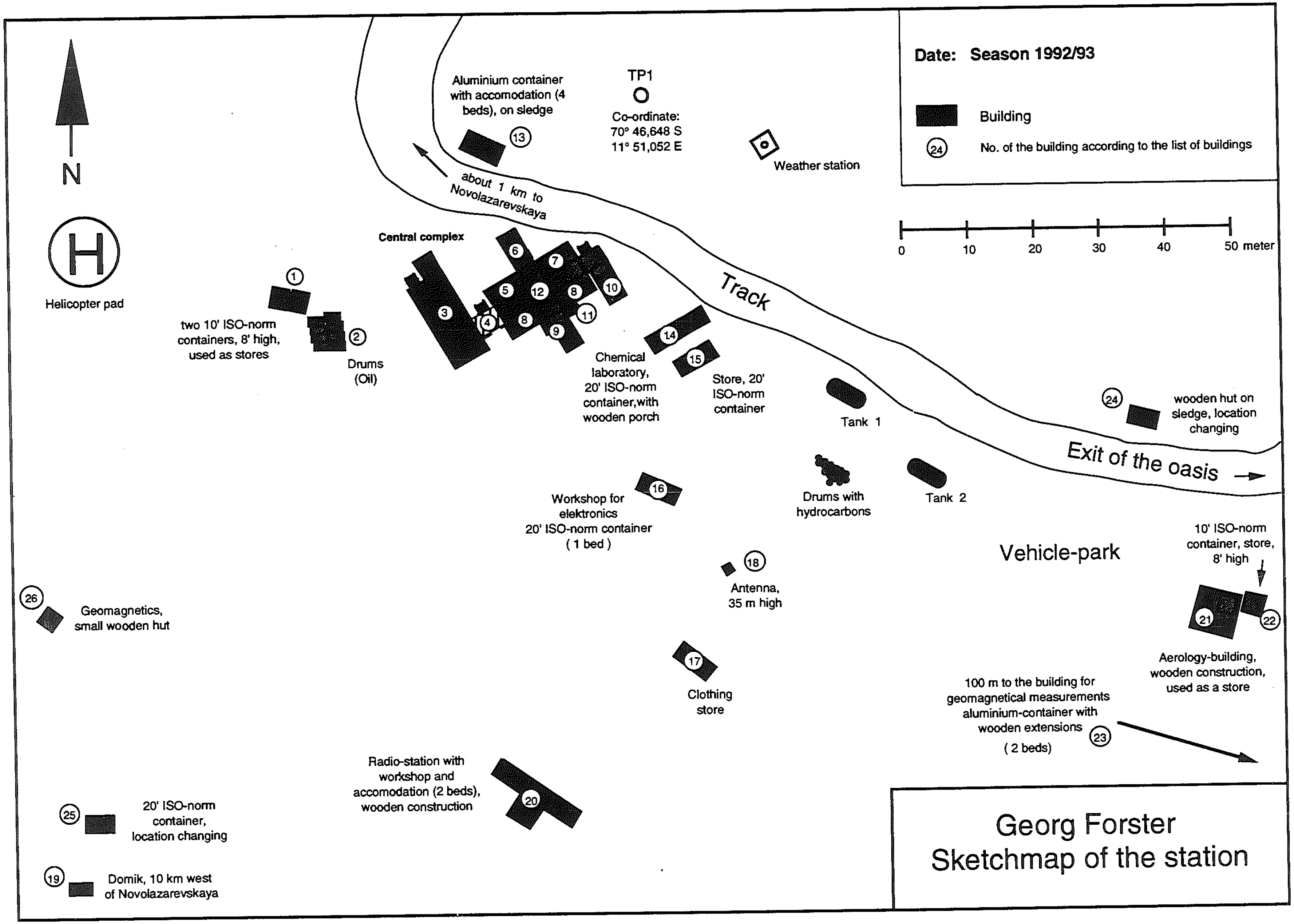
The costs of the project totals to 2.6 Million Deutsch Mark equivalent to about 1.7 Million US-$. The costs of the total job if delivered by a private company can be estimated to about 15 Million US-$.

As a consequence of the success of the fruitful cooperation, Novolazarevskaya Station has taken all necessary steps to keep the area free of wastes by retrograding all wastes after each season. AARI started a monitoring programme to observe the recovery of the area, particularly also the recovery of the lakes.

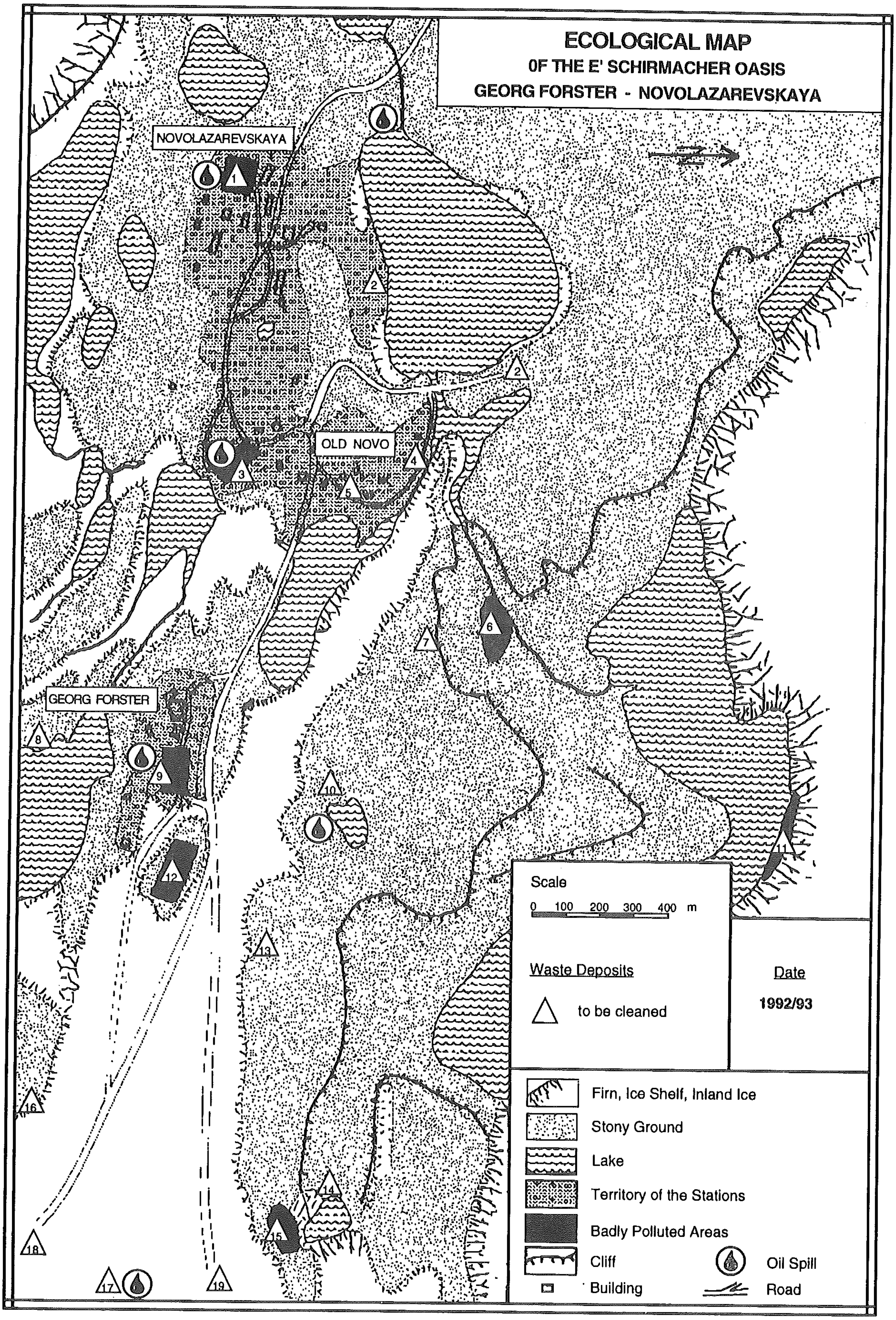
Figures:

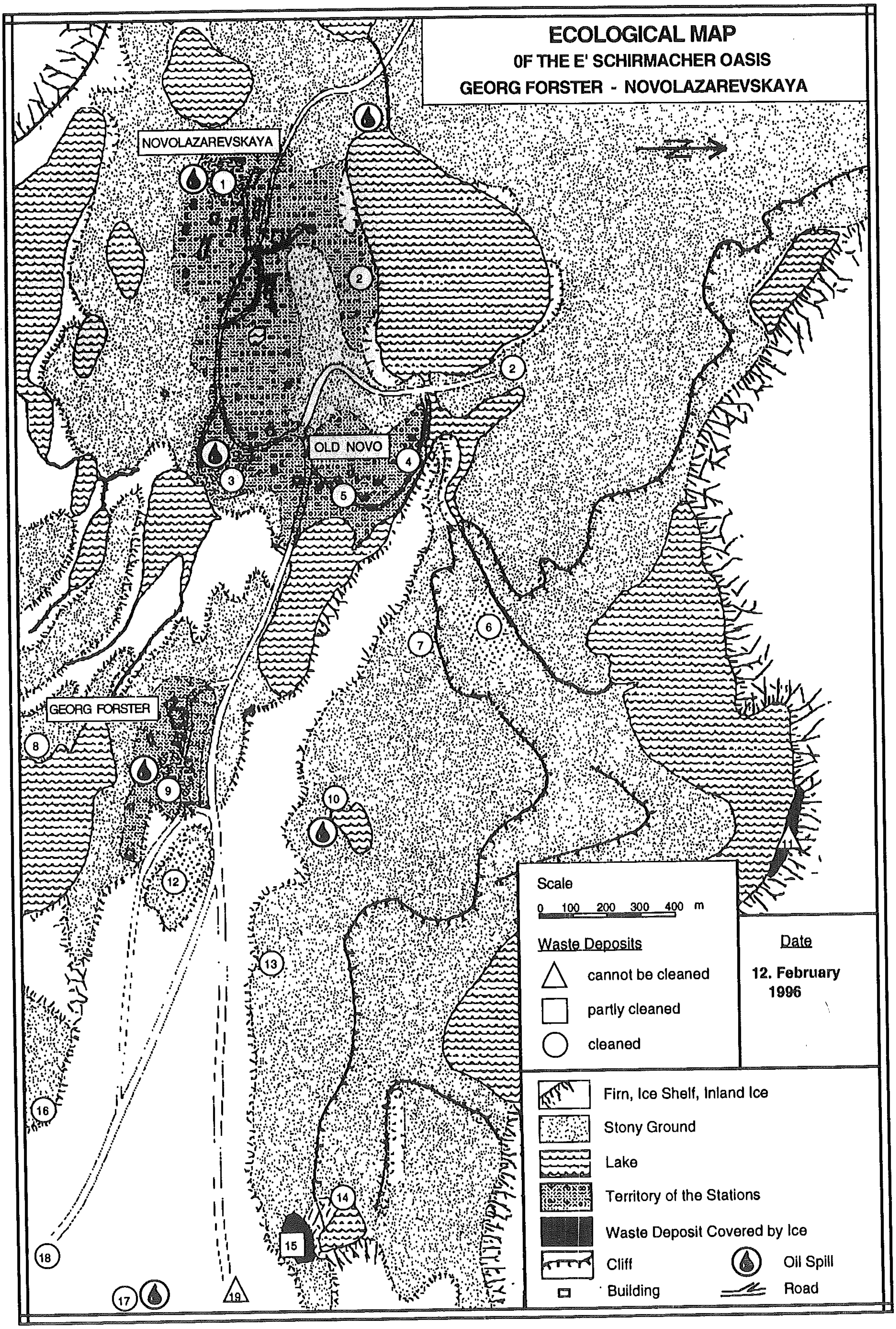
1. Map of the Schirmacher Oasis
2. Map of the station assembly of "Georg-Forster"
3. Ecological map of the Schirmacher Oasis at the beginning of the project
4. Ecological map of the Eastern Schirmacher Oasis, February 1996


Übersichtskarte der Schirmacher Oase
Dronning Maud Land, Ostantarktis
i. w. eis- / schneefreies Gebiet
größere Standgewässer
400 Höhenlinie (m über NN)
Grenze Schelfeis / Inlandeis
Schelfeis
Inlandeis
11°30' E
11°40' E
11°50' E
70°45' S
200
300
400
500
ehem. Standort Hütte am See
Maitri
Novolazarevskaya
ehemaliger Standort
Georg Forster Station
Schirmacher Oase
Antarktis
Neumayer



Date: Season 1992/93
Building
No. of the building according to the list of buildings
0
10
20
30
40
50 meter
N
Helicopter pad
Aluminium container with accomodation (4 beds), on sledge
TP1
Co-ordinate: 70° 46,648 S 11° 51,052 E
Weather station
about 1 km to Novolazarevskaya
Central complex
Track
two 10' ISO-norm containers, 8' high, used as stores
Drums (Oil)
Chemical laboratory, 20' ISO-norm container,with wooden porch
Store, 20' ISO-norm container
Tank 1
Tank 2
wooden hut on sledge, location changing
Exit of the oasis
Workshop for elektronics 20' ISO-norm container (1 bed)
Drums with hydrocarbons
Vehicle-park
10' ISO-norm container, store, 8' high
Antenna, 35 m high
Geomagnetics, small wooden hut
Clothing store
Aerology-building, wooden construction, used as a store
100 m to the building for geomagnetical measurements aluminium-container with wooden extensions (2 beds)
Radio-station with workshop and accomodation (2 beds), wooden construction
20' ISO-norm container, location changing
Domik, 10 km west of Novolazarevskaya
Georg Forster
Sketchmap of the station


ECOLOGICAL MAP
OF THE E' SCHIRMACHER OASIS
GEORG FORSTER - NOVOLAZAREVSKAYA
NOVOLAZAREVSKAYA
OLD NOVO
GEORG FORSTER
Scale
0 100 200 300 400 m
Waste Deposits
to be cleaned
Date
1992/93
Firn, Ice Shelf, Inland Ice
Stony Ground
Lake
Territory of the Stations
Badly Polluted Areas
Cliff
Oil Spill
Building
Road


ECOLOGICAL MAP
OF THE E' SCHIRMACHER OASIS
GEORG FORSTER - NOVOLAZAREVSKAYA
NOVOLAZAREVSKAYA
OLD NOVO
GEORG FORSTER
Scale
0 100 200 300 400 m
Waste Deposits
cannot be cleaned
partly cleaned
cleaned
Date
12. February
1996
Firn, Ice Shelf, Inland Ice
Stony Ground
Lake
Territory of the Stations
Waste Deposit Covered by Ice
Cliff
Oil Spill
Building
Road

Results of the Monitoring of Sea Ice Formation and Break-Up Signy Island - Antarctica.

Vsevolod AFANASYEV
British Antarctic Survey

Background

Sea ice covers over half of the ocean around Antarctica during the southern winter, but retreats to cover less than 10% in summer. It plays a major role in regulating the marine environment around the Antarctic continent, and it might provide an early indication of climatic change. The ocean around Antarctica plays a major role in determining the properties of the World Ocean. Sea ice plays a major role in generating the cold saline water which occupies the lowest layers of the ocean and intrudes far into the Northern Hemisphere. Ice cover also determines the character of the local ocean circulation and also interacts with weather patterns. Because many biological systems in the Antarctic involve sea ice, an understanding of long-term changes in ice extent is also important for an understanding of marine living resources. Antarctica already supports several major fisheries.

Scientists at the British Antarctic Survey have completed an initial assessment of the data from Signy Island. They have also combined their own records with those from another station in the same island group, which has made similar observations more-or-less continuously between 1903 and 1976. The combined dataset provides a unique record of year-to-year variation in ice cover, and is one of very few such detailed series and is unique for the Antarctic.

An important conclusion of the study is the demonstration that the recent sea-ice duration observations correspond exactly to changes in ice extent around the whole of Antarctica, as demonstrated by satellite imagery. Thus the view of sea ice changes shown by the long-term data series for the South Orkney Islands is likely to provide an indicator of major changes in the Southern Ocean. However, it is important to assess the correspondence with satellite data over as long a time as possible. With the change of the BAS station to summer-only operations as part of a reorganization, we are looking for means of continuing the local sea ice measurements.

Our problem has been to decide on the best means of providing an automated substitute for human observation. We have decided to install an automated camera system on the island to record sea ice throughout the Antarctic winter. This will be the most cost-effective means of continuing a series of environmental data which are unique in the region and may prove to be of importance for the entire planet.

The project is a continuation of an important environmental data series which records the duration of sea ice. These measurements have been carried out at Signy Island since the British Antarctic Survey research station was established in 1947, but will end in 1995/96 when the base will transfer to summer-only operations.

The camera system will need to function unattended through an Antarctic winter. This will be approximately six-eight months. On Signy Island, winter temperatures may drop below -35°C, so we are looking for a camera system of high technical specification, reliable and capable of withstanding the rigorous environment of Antarctica.

THE SYSTEM

ROBOT MOTOR-RECORDER 36 CE fitted with Schneider-Xenar 38mm f/2.8 lens and gear drive, second optical system for data recording, Automatic Exposure Control Unit and 30m magazine (800 frames).

POWER SUPPLY, Two 12V, 100AH lead acid batteries "top up charged" by two 42W solar panel modules (880mm X 445mm) with temperature compensated shunt regulator.

CONTROL UNIT for timing of the ROBOT, thermal cut out (whenever the temperature of the camera is under -20 C, the camera is disabled), non-volatile record of frames/day taken from reset and diagnostic.
If the system is started at 13-00 GMT (10-00 local time), frames are taken at 12-00, 13-00, 14-00 and 15-00 local time.

TWO INDEPENDENT SOLAR PANEL MODULES for heating the glass window with conducting coating at daylight to protect it from rime ice.

INDEPENDENT COUNTER OF HOURS FROM RESET for the second optical system.

CASE IP-67 protection class with the glass window and waterproof connectors.

PURPOSE-BUILT HAND-HELD DIAGNOSTIC COMPUTER.

The system was tested from 22 MAR 1995 to 12 NOV 1995, 234 days.

MECHANICALLY the system functioned perfectly.

ROBOT MOTOR-RECORDER, AUTOMATIC EXPOSURE CONTROL UNIT and 30m MAGAZINE functioned perfectly.

POWER SUPPLY functioned perfectly.

TIME-STAMP SYSTEM functioned perfectly. It is not temperature compensated and the total drift was 20 minutes.

CONTROL UNIT

1. TIMING of the ROBOT functioned perfectly. It is temperature compensated in software and the total drift was only one minute.
2. THERMAL CUT OUT functioned perfectly. The maximum gap in the data set is only three days, total 9 full days between 01 JUL and 13 AUG. Minimum recorded temperature is 29.5C, 13 AUG 1995.
3. DIAGNOSTIC SYSTEM functioned perfectly.
4. ELECTRONIC DATA BACK-UP functioned perfectly for 202 days, but on 10 OCT 1995 the data in one of the registers of the embedded microcontroller was corrupted. There is no electronic data back-up for the last 32 days. The software is modified.

A high quality PCB was developed and the test unit is replaced.

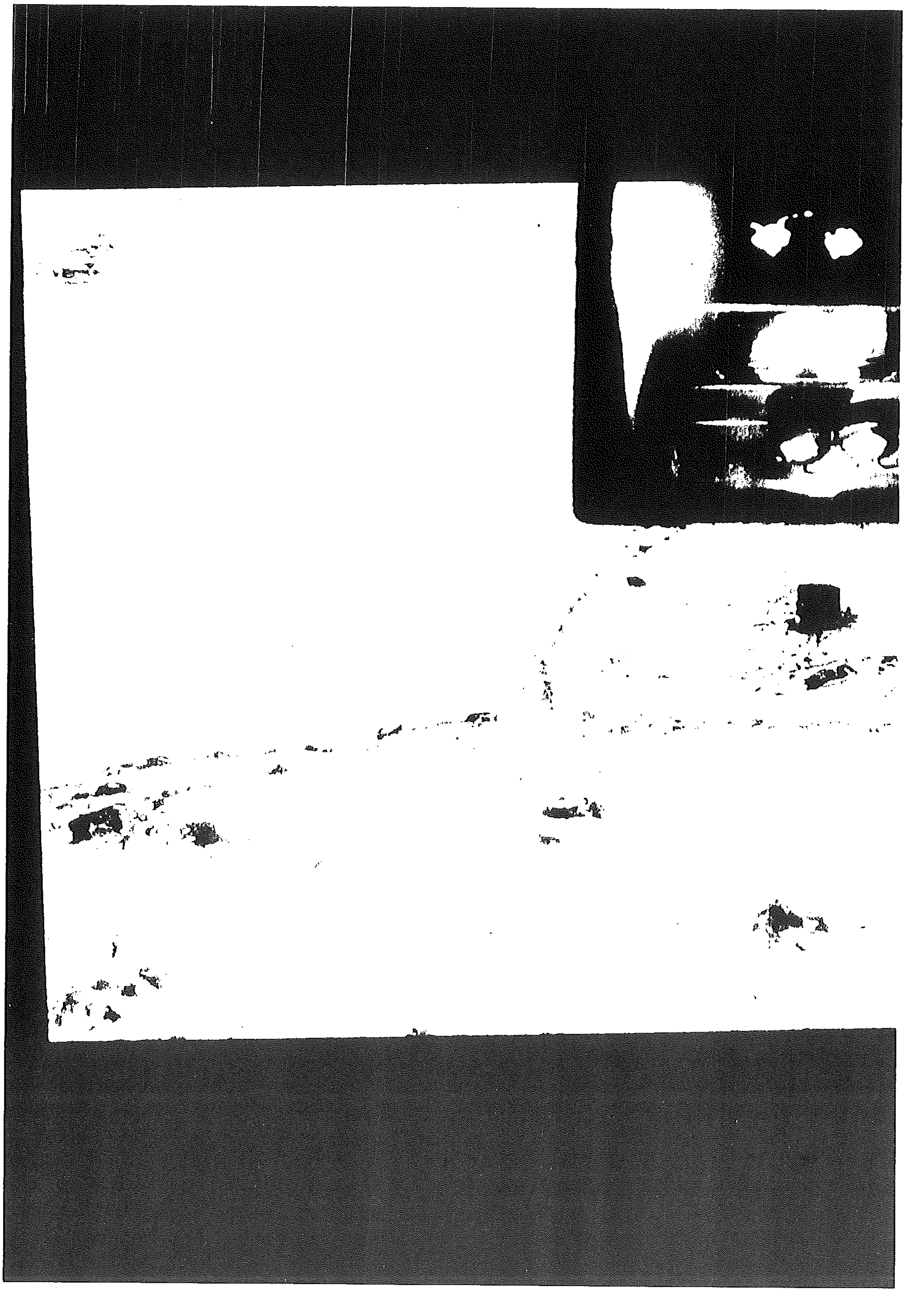
MONITORING PROCEDURE functioned perfectly.

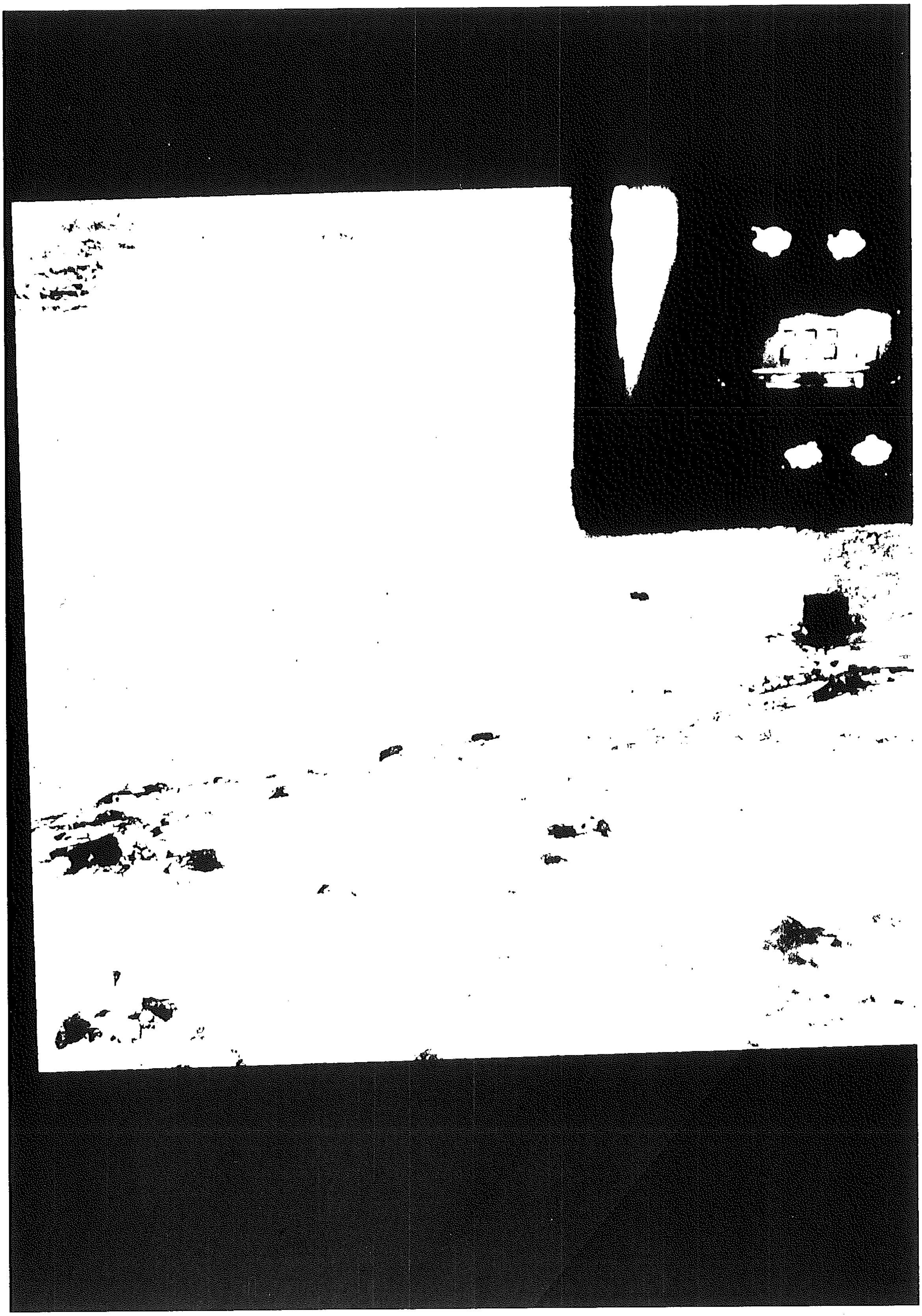
TWO INDEPENDENT SOLAR PANEL MODULES for heating the glass window with conducting coating at daylight to protect it from rime ice functioned. The window was frozen for only 8 days. Solar panel modules are replaced with larger units.

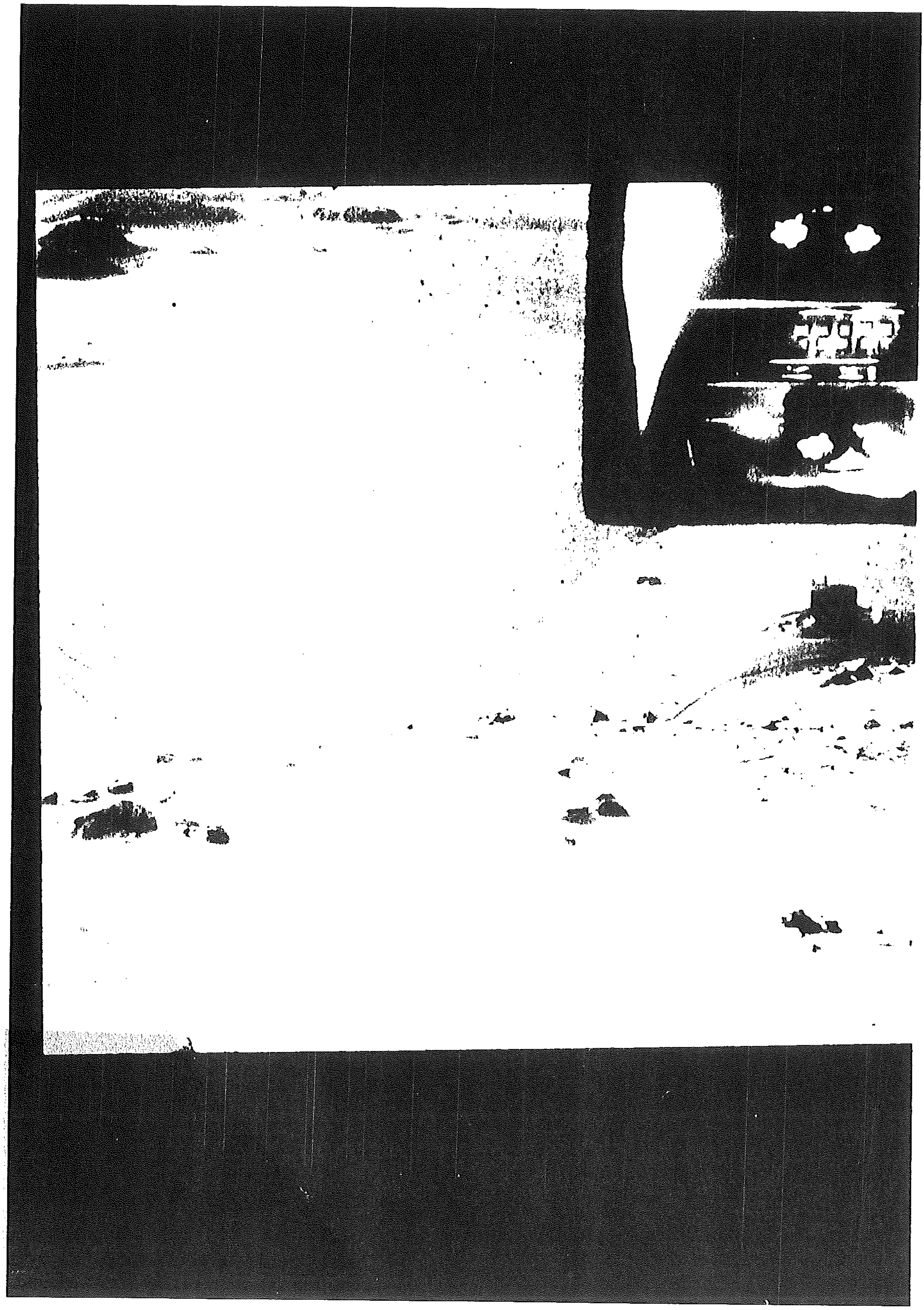
PICTURES:

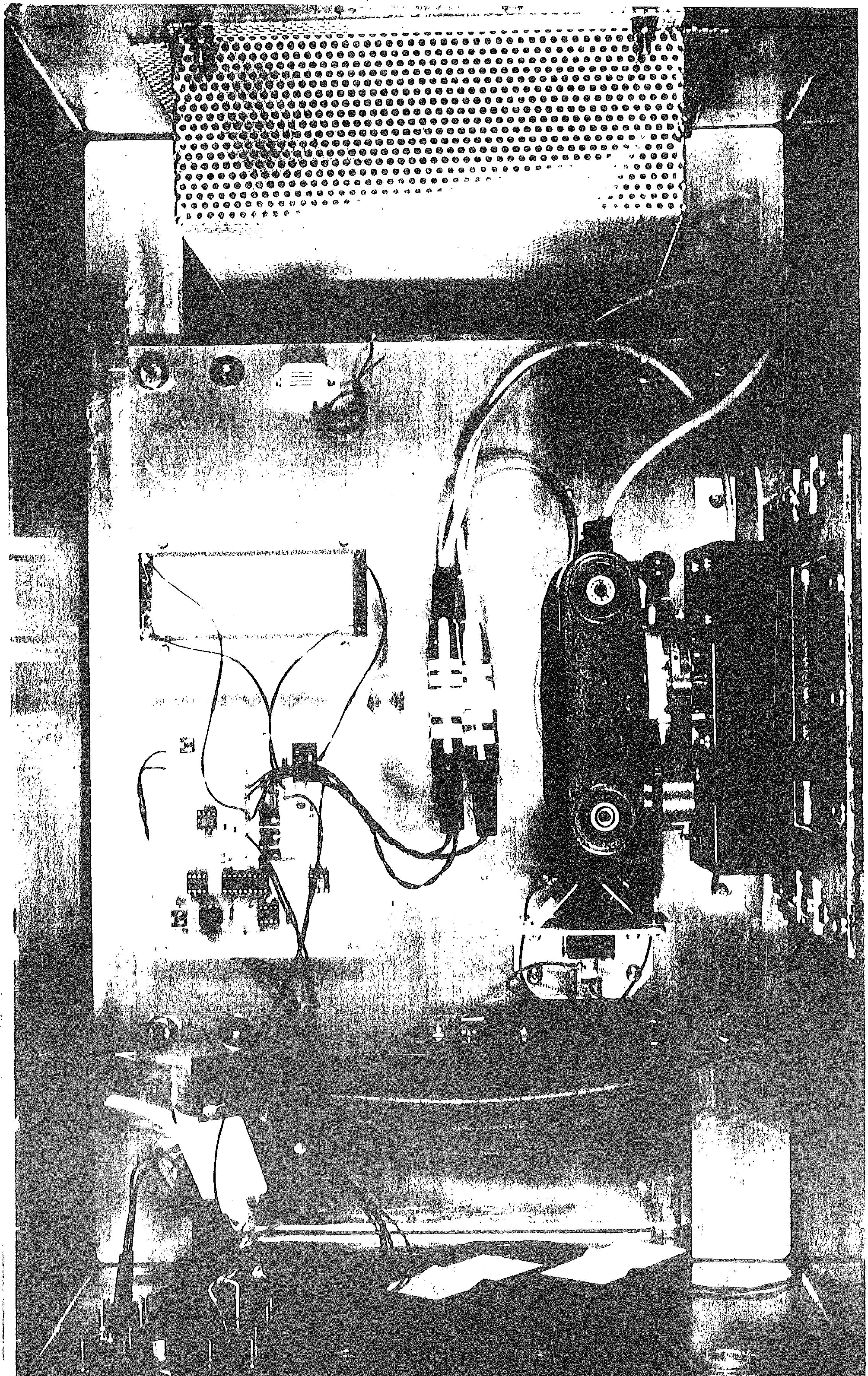
1780 HOURS, DAY 74, 04 JUN 95, 14-00 Local time
2237 HOURS, DAY 93, 23 JUN 95, 15-00 Local time
3292 HOURS, DAY 137, 06 AUG 95, 14-00 Local time

Vsevolod AFANASYEV 01.04.96









Procurement Requirements in Support of the United States Antarctic Program

by

Reginald P. Thomas
Manager, Contracts
Antarctic Support Associates

Introduction

Procurement requirements in support of the United States Antarctic Program (USAP) for supplies, equipment, materials, and services total about $55,000,000 per year. This represents about 40,000 line items to be identified, purchased, and shipped to Antarctica each year. In addition to the inherent logistics challenges of weather and limited transportation - other obstacles must be overcome. The fiscal budget year begins in October and the appropriations by the Congress may not be made until November or later. In addition, the annual re-supply vessel sails early in January. These fixed schedules for funding and transportation result in a short 60-90 day period in which to acquire most of the annual material requirements. In tandem, all procurements must be in compliance with the Federal Acquisition Regulations which require that several vendors are given the opportunity to "bid" on the materials. To accommodate the tight schedule, availability of funding, changing requirements, and the enormous volume of materials that must be procured, Antarctic Support Associates (ASA) has developed and implemented automated material management systems to support the requirements of the Antarctic Program.

In the 1995-1996 season, the USAP supported over 600 participants involved in over 130 science projects and completed several support related projects. All of this required coordinating the availability of a variety of supplies and materials.

ASA, the National Science Foundation's logistics and operations support contractor, has created three integrated systems that help ensure the early identification, effective purchasing, movement and delivery of USAP supplies, services, and scientific equipment to Antarctica. These three systems are Maintenance and Planning Control (MAPCON), Power 1000, and Cargo Tracking System (CTS).

Antarctic Cargo History

The first Americans to work in the Antarctic in the 1800s were sealers and whalers who discovered many sub-Antarctic islands and were first to explore parts of the peninsula jutting out of the Antarctic mainland toward South America. All of the required supplies to sustain the crew were procured and stored on the vessel prior to such journeys. Various sea mammals were also caught during these voyages to supplement the vessel supplies.

The United States' Operation Highjump in 1946-1947 was the largest single expedition ever to explore Antarctica. It involved 13 ships, numerous aircraft, and more than 4,700 men. Again, all supplies required for the expedition were procured and stored on the vessels for this expedition.

The 1957-1958 International Geophysical Year (IGY) emphasized Antarctic exploration and included research by 12 nations at 67 stations in Antarctica. For the first time, year-round stations were maintained in the continental interior. The United States established seven IGY Antarctic wintering stations: four on the coast (Little America, Hallett, Wilkes, and Ellsworth), two inland (Byrd, South Pole), and a logistics base (McMurdo). During the IGY, 6,000 kilometers of traverses were made, 10 to 12 ships were used each season, and 23 Navy and 8 Air Force aircraft were utilized. The Navy and the Air Force supported these efforts logistically.

The success of the IGY resulted in the tasking of the National Science Foundation (NSF) with the responsibility for the U.S. research effort in Antarctica, and in the establishment of the United States Antarctic Program (USAP). The Naval Support Force Antarctica, identified as Operation Deep Freeze, was tasked to support the scientific effort.

After 1971 the NSF was assigned overall responsibility for U.S. activities in Antarctica. Several U.S. agencies cooperate to accomplish objectives established by NSF. Some of these are the Department of Defense, U.S. Coast Guard, U. S. Navy, and a commercial firm, currently ASA, for operations of Antarctic stations, research ships and related services. All of this is done in support of scientific research.

In 1976, the responsibility for construction projects and the procurement of materials and supplies began to transition from the U.S. Navy to commercial contractors. Currently the U.S. Navy is progressively phasing out of the USAP, and the commercial contractor is responsible for procuring virtually all required materials and supplies to support all U.S. operations in Antarctica.

Antarctic Support Associates

ASA, a joint venture of Holmes & Narver Services, Inc. (HNSI), and EG&G, Inc., was established in 1989 to provide logistical support to the USAP. ASA is headquartered just outside of Denver, Colorado. ASA's required tasks are established by an annual Program Plan and budget submitted in June. During Contract Year Six (1 April 1995 - 31 March 1996) ASA had a full time professional staff of approximately 270 employees (principally at ASA Headquarters), and approximately 700 contract personnel of all disciplines working in Antarctica.

ASA is the single point manager for the shipment of all cargo to Antarctica. This encompasses construction activities at all U.S. Antarctic stations, construction and operations of temporary field camps during the Antarctic field season, operations and maintenance of facilities, vehicles, and equipment at all U.S. Antarctic stations. Additionally, direct support to NSF-sponsored research projects, operations and maintenance of the research vessels R/V NATHANIEL B. PALMER and R/V POLAR DUKE, and other specialized tasks such as Research & Development projects and studies as directed by the NSF.

Software Systems

ASA has designed a comprehensive integrated software system that is used to plan, manage and control the acquisition, shipping and receiving of supplies necessary for continuous USAP operations. The integrated software solution combines three software programs that provide efficient data management to produce automated purchasing, receiving and shipping documentation. The three integrated software programs are Maintenance and Planning Control (MAPCON), Power 1000 (used for purchasing), and the Cargo Tracking System (CTS).

a. Maintenance and Planning Control (MAPCON)

MAPCON is comprised of five integrated modules: 1) Inventory, 2) Purchasing, 3) Equipment, 4) Maintenance, and 5) Human Resources. This discussion will be limited to the Inventory and Purchasing Modules because they relate directly to the procurement process (Modules 3, 4 and 5 are described in Appendix I). These MAPCON modules provide the user a tool to either replenish stocks using existing stock record information or to purchase new stock items, or to purchase services. In addition, these modules provide the user an efficient tool for inventory management and control, determining resupply quantities and initiating requisitions.

1. Inventory

The Inventory Module contains the standard stock record information which includes last receipt, price, stock location, quantities available, quantities currently reserved for maintenance actions, quantities on order, manufacturers, vendors, and usage history. The usage history is a summation of the issues by stock item for a specific period and is the primary element used to forecast future resupply needs. The Inventory Module is programatically linked to the Purchasing, Maintenance, and Equipment Modules and is functional at all three U.S. Antarctic stations.

2. Purchasing

The Purchasing Module is used to create and track the status of purchase requisitions (see below) at all U.S. Antarctic stations and at ASA Headquarters. In addition to creating purchase requisitions on-site, a requester at a remote station can use the module to determine the status of a particular order. The integration with Power 1000 permits purchase requisitions to be updated with purchase order information, expected vendor ship date, quantities shipped, shipment identification, date of receipt at Port Hueneme, California, etc.

2a. Purchase Requisition to Shipment

A Purchase Requisition is the initial electronic request for goods or services and can be initiated from any Antarctic station in addition to ASA Headquarters. A typical requisition originates in the Antarctic and is transmitted to Denver for funding approval and Logistics review before it is passed to the Purchasing Branch or Contracts Branch at ASA Headquarters. The integrated system allows the reviewer to automatically convert the MAPCON requisition into a Power 1000 requisition. Purchasing solicits vendor response, negotiates the prices and terms, issues the order to the selected vendor and expedites shipment to Port Hueneme, California. Only the Buyers or Subcontract Administrators of the Procurement Division are authorized to create a purchase order or to otherwise make a financial commitment on behalf of ASA.

2b. Purchase Requisition Preparation

Requisitions are prepared by a variety of people at a variety of locations. The requisition can be prepared any time a new requirement or a resupply need becomes apparent. MAPCON has the capability to automatically generate requisitions by comparing inventory balances with user-defined minimum and maximum stock levels. Currently the ordering decision is based on past usage history, on-hand stock levels and knowledge of future events or projects.

The lead-time required from submitting a request to receipt differs between the Continental area (McMurdo and South Pole Stations) and Peninsula area (Palmer Station) due to the various transportation modes available at these locations. Requisition schedules are maintained for the Antarctic stations and research vessels which list standard procurement and transportation lead-times for each required-on-site date. Adherence to these schedules enables ASA to take advantage of the least expensive mode of transportation, which is commercial surface.

b. Power 1000

Power 1000 is the actual purchasing software that supports all purchasing related activities. It allows receipt documentation at several locations. the vast majority of materials are shipped by vendors directly to Port Hueneme, California, which is the staging point and transportation hub for worldwide shipment of supplies by commercial air, land and sea transportation modes and military airlift and sealift. Additionally, a stand alone Power 1000 system is maintained in Christchurch, New Zealand specifically for New Zealand procurements. Power 1000 is not used at the Antarctic stations because purchase orders are not placed from Antarctica.

When the material is received into Power 1000 at Port Hueneme, a dynamic link creates a shipping document, a bar coded label, and updates both the CTS and MAPCON with purchase order and receiving information. The vendor's invoice is certified for payment at the time of material receipt at Port Hueneme. Purchase order information is linked to the accounting software when the purchase is made, which provides the justification for vendor payment. The MAPCON inventory module is not updated until the material is received on station.

Power 1000 updates MAPCON and CTS with current requisition or procurement information. These updates are passed to the Antarctic stations so the remote users also have current real-time status of their requisitions. This module is functional at all three Antarctic stations, and at the ASA Headquarters.

c. Cargo Tracking System (CTS)

CTS is the software package to track cargo. A "smart" shipping number known as a transportation control number (TCN) is assigned in CTS and marked on each piece of cargo to ensure 100% traceability. This TCN works within the military cargo system and communicates the mode of transportation, the project for which it was purchased, and individual package serialization. Requisitioned materials are considered to be cargo from the time they are received and packed for shipment at Port Hueneme until they are turned over to USAP employees for receipt into inventory system. Shipment status information is available at all Antarctic stations. The bar coded label affords fast and efficient tracking of cargo as it passes through the transportation hubs at Christchurch, New Zealand and McMurdo Station, and Palmer Station on the Peninsula.

The Integrated Functionality of MAPCON, Power 1000, and CTS

Each software package plays a distinct role in the processing of information. A brief illustration of the process follows. An initial purchase requisition is created in the MAPCON Purchasing Module. It is converted into a Power 1000 purchase requisition and becomes a purchase order when an agreement is reached with a vendor. When the goods are received in Port Hueneme, the information is entered into Power 1000, the goods are packed and a transportation control number is assigned. A dynamic link between Power 1000 and CTS creates a shipping record, a bar coded label and a shipping document. The package is tracked by the TCN from its entry into the transportation system until it is delivered to USAP employees who enter the material into the inventory module. Its progress across the 12,000 mile pipeline to Antarctica is recorded at each USAP transportation hub.

Figure 1 (below) illustrates the interfaces between the programs. The drawing traces an inventory item from the discovery of need and requisition to its receipt on station. The numbers provide the order for each step in the process and emphasize the interrelational aspects of this integrated procurement system. For example, a worker sees that the on-hand quantity of cable at South Pole Station is low, and asks the staff to reorder (1). After confirming the quantity is not on site or available at another site, a MAPCON requisition is created and approved by the work center. (2) The requisition is placed in an electronic file and sent to ASA Headquarters where it is loaded into MAPCON and distributed to the work centers where budget approval resides. (3) After budgetary approval and Logistics review, the MAPCON requisition is converted to a Power 1000 requisition and electronically passed to the Purchasing or Contracts Branch. The Power 1000 purchase requisition becomes a purchase order when a vendor is selected. (4). The purchase order information is fed back to MAPCON (4) and (5).

(6). Upon receipt from the vendor, Port Hueneme personnel receive the cable into Power 1000 where a shipping record, bar coded label, and shipping document are created. The cable is packed into a box with the TCN marked on the exterior for South Pole Station. (7). Power 1000 feeds the TCN into both CTS and back into MAPCON in Denver. (8). MAPCON in Denver, in turn, updates the station MAPCON with the TCN. (9). The station receives real-time status and a tracking number.

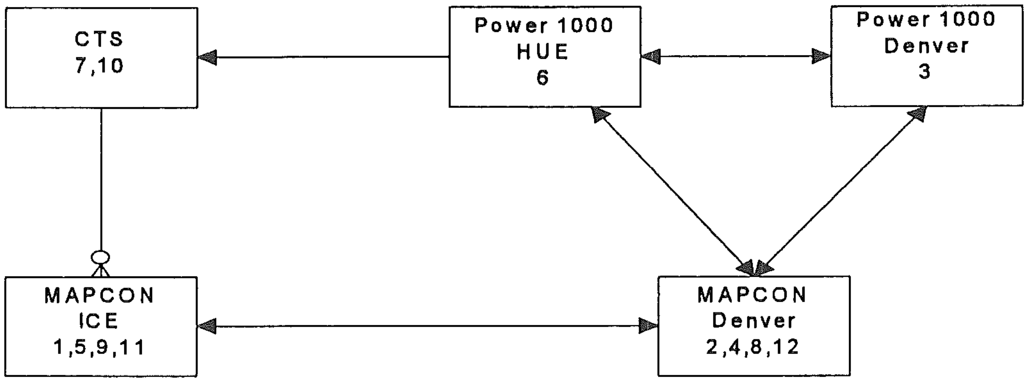


Figure 1

As the cable passes through Christchurch and McMurdo Station, the record in CTS is updated with receipt and location information. This information remains in CTS only. When the cable is entered as 'received' at its final destination, CTS is updated (10) and the item is turned over to designated personnel. In MAPCON, the individual item is received and the open purchase requisition in the MAPCON Inventory Module is closed out. This updates the inventory on station (11) which then updates MAPCON at ASA Headquarters (12).

The USAP provides the inter and intracontinental transportation. For the Peninsula Area the Research Vessel POLAR DUKE doubles as a cargo and passenger vessel by providing regularly scheduled trips between Punta Arenas, Chile and Palmer Station. The R/V POLAR DUKE can carry nine sea containers and other loose load cargo. For the Continental Area, aircraft are used to move material to McMurdo Station and onward to field camps and South Pole. LC-130 aircraft are used to resupply South Pole Station from McMurdo Station during the austral summer season. McMurdo Station is re-supplied via LC-130, C-141, and C-5 aircraft throughout the austral summer. These military flights are provided by the United States Air Force, Navy, and New York Air National Guard and are supplemented by New Zealand and Italian LC-130 aircraft. Near the end of the summer season the annual resupply vessel, M/V GREEN WAVE, delivers the majority of the material requirements.

Port Hueneme Operations is the transportation hub for the receipt and onward shipment of all USAP cargo for Antarctic Stations. In addition to transportation management, Port Hueneme packs and crates 90% of the cargo being shipped, manages the USAP sea container pool, handles container stuffing and certifies vendor invoices for payment. Port Hueneme transports cargo by commercial air and surface modes. For the Continental area, military airlift and sealift provide additional transportation modes in the form of regularly scheduled flights or aircraft charter flights known as Special Assigned Airlift Missons (SAAMs) and a chartered container vessel, the M/V GREEN WAVE. The M/V GREEN WAVE is also referred to as the annual resupply vessel. The operation in Port Hueneme also develops a cargo load plan which is coordinated with the vessel's master to maximize space utilization. The vessel can carry 600 containers and up to 30 million pounds of cargo. The lead times for non-hazardous cargo shipments from Port Hueneme to the Continental area is 30 days for commercial surface shipments and 60 days for the Peninsula area.

Cargo System Overview

ASA handles four main kinds of cargo:

1.- ASA procured material purchased commercially,
2.- Research equipment purchased by scientists and shipped through ASA,
3.- Department of Defense procured material,
4.- Equipment owned by the United States Government and shipped through ASA.

Most cargo is transported to Antarctica by ship. The place of embarkation is Port Hueneme, California (see figures 2 & 3).

There are several types of departures each year:

1) *McMurdo cargo via Navy contract ship..* A contract ship (normally the M/V GREENWAVE) goes from Port Hueneme to McMurdo Station, arriving in late January. Cargo for this ship should be delivered to Port Hueneme, California by 8 November but receipt and loading will continue until the vessel sails. This ship is the preferred transport for delivering materials to McMurdo Station for subsequent delivery to the inland stations because it is the least expensive mode and it has the capacity to deliver annual resupply volume, special project materials, and is the most secure means of transportation.

The vessel GREENWAVE is a container and break-bulk vessel chartered from the United States Military Sealift Command. It has a capacity of 600 twenty-foot sea containers. During Contract Year Six (1 April 1995-31 March 1996), the 72-day charter started with the on-load of supplies at Port Hueneme, California on 2 January, followed by an intermediate stop at Port Lyttelton, New Zealand to off-load and on-load additional supplies and ended its southbound voyage at McMurdo Station on 2 February. At McMurdo, it off-loaded 8 million pounds and on-loaded 10 million pounds of retrograde cargo and waste for delivery at Port Lyttelton, Indian Island (Washington State) and Port Hueneme. The vessel transported the equivalent of 2,190 twenty-foot sea containers and 184 pieces of breakbulk cargo (not in containers) with a total weight of 36.8 million pounds. The average cost per pound was $.06 which is one-third the cost of commercial surface transportation at $.18 and significantly less than the cost of commercial air transportation at $2.40 per pound.

2) *McMurdo cargo via "Kilo-air".* This transportation method is used for material that cannot be sent to McMurdo Station on the resupply ship the year before. The term Kilo-air refers to both the mode of transport and the time frame for shipment. The time frame is the first Tuesday in October until mid-December. Kilo-air cargo is sent by commercial ship from Port Hueneme, California, and arrives in Lyttelton (near Christchurch, New Zealand). Two major Kilo-air shipments are planned from Port Hueneme to take advantage of the improved freight rates for full sea container shipments. Cargo is then flown from Christchurch to McMurdo Station. Kilo-air cargo must arrive in Port Hueneme by 30 August and 30 September coinciding with the planning for the two major container shipments.

3) *Commercial Air Cargo:* If circumstances prohibit the shipment by surface, authorization can be received to send materials via commercial air. This is the most expensive way to ship and is used only for essential material whose delivery cannot be delayed by the slower surface transportation mode.

4) *Antarctic Peninsula cargo via commercial ship:* Cargo must reach Port Hueneme, California, at least 60 days before it is to be loaded aboard the vessels R/V POLAR DUKE or R/V NATHANIEL B. PALMER in Punta Arenas, Chile, Hobart, Tasmania, Cape Town, South Africa, or Lyttelton, New Zealand for forwarding to U.S. Antarctica.

5) *WINFLY:* WINFLY means "Winter Fly-in" and occurs approximately six weeks before the start of the austral summer season. Additional employees and materials required to re-open the station are delivered to McMurdo Station to prepare the station for a population increase from about 230 to 1,200 inhabitants. Cargo is shipped by commercial vessel to New Zealand then airlifted to McMurdo Station, like Kilo-air cargo but only during a one-week period around the 20th of August.

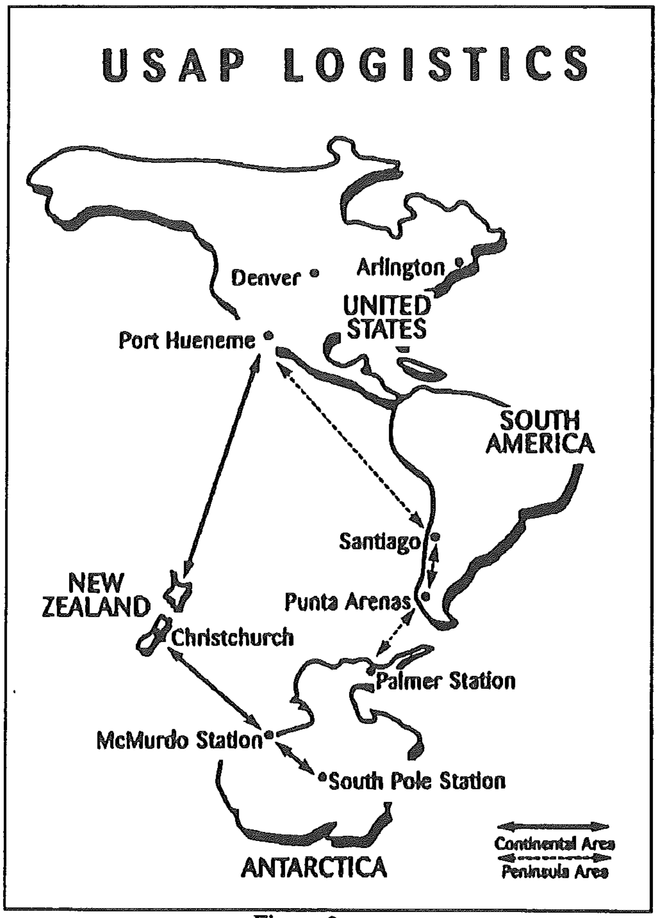


Figure 2

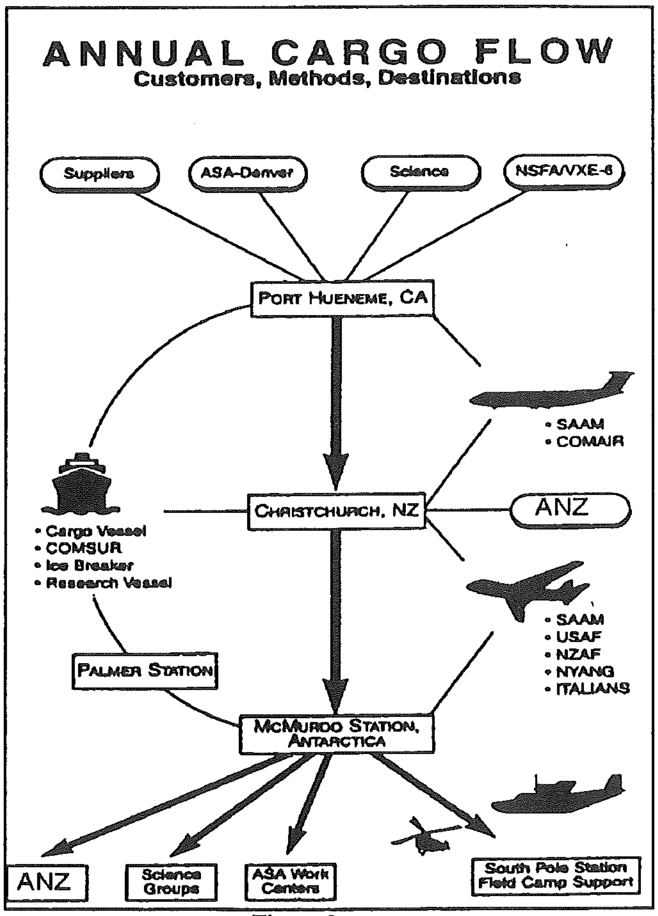


Figure 3

The graph below (Figure 4) illustrates the estimated amount of cargo delivered to McMurdo Station by contract year. The implementation of CTS in 1992 allowed for more accurate tracking of this data and has resulted in significantly more accurate projections of cargo to be moved and airlift required to move it.

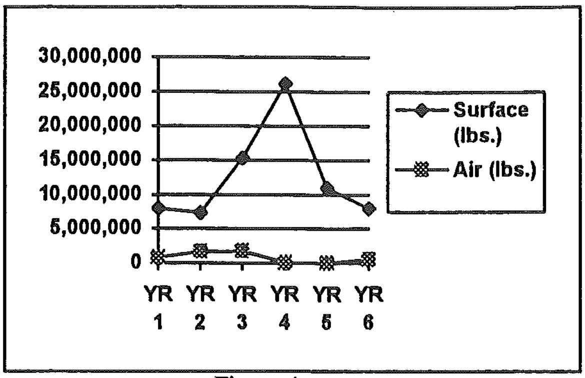


Figure 4

Cargo figures (Figure 4) increased significantly in Contract Year Four (1 April 1993 - 31 March 1994) due to the double shuttle of the M/V GREENWAVE. A double shuttle refers to two deliveries back to back coincident with the delivery of the annual resupply cargo. The vessel was off-loaded in McMurdo and returned to Port Lyttelton, New Zealand to on-load ten newly constructed berthing modules which had to be delivered before the start of winter in March 1994. These modules were then delivered to McMurdo completing the second shuttle.

Summary of First Six Years

The following charts illustrate the support provided from 1990 . Figure 5 shows the number of purchase orders awarded.

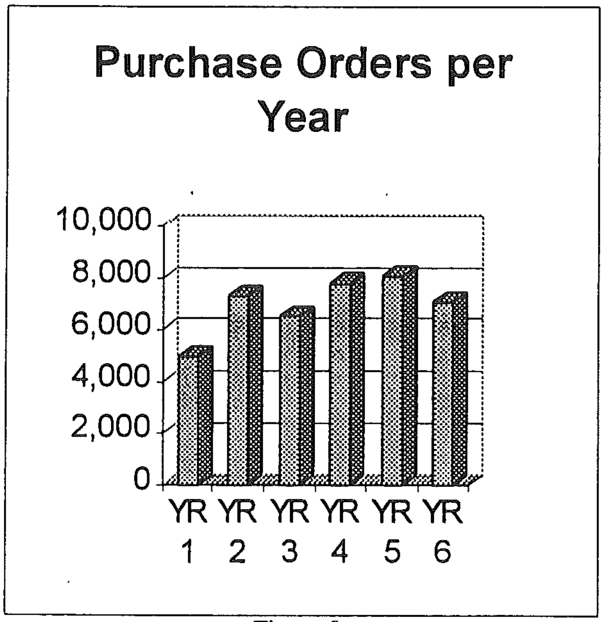


Figure 5

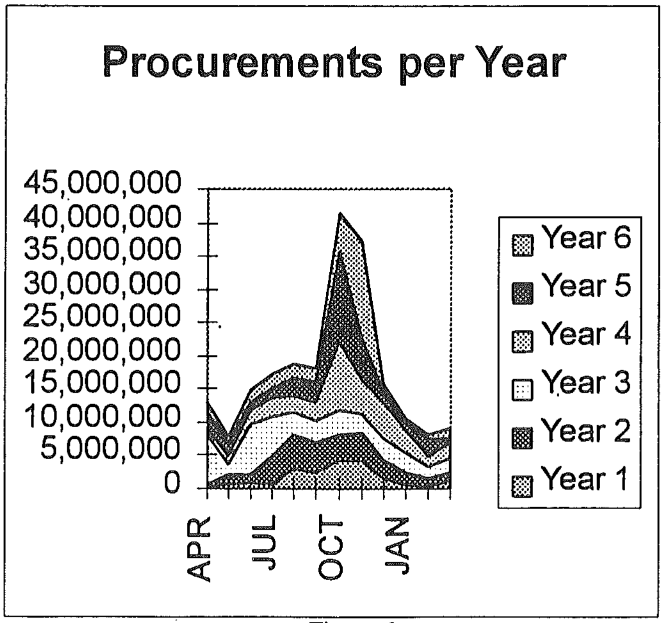


Figure 6

The number of purchase orders released in contract Year One was relatively low due to a number of purchase orders already committed by the previous contractor, and contract Year Two saw a sharp increase due to the purchasing of construction and scientific material and supplies. Contract Year Three was the first year MAPCON was implemented, and a slight reduction in purchase orders resulted from depleting current inventory as a part of a detailed inventory review of materials and supplies at the three USAP stations. With the start of the U.S. Navy withdrawal from most of the operations and support of the USAP, ASA was tasked with additional responsibilities such as food services, and fuel resupply, resulting in an increase in the number of purchase orders. Contract Years Four, Five and Six show an almost constant number of purchase orders. Budgets became tighter and ASA gained experience in management of the material and supply requirements with the help of its electronic Logistics systems. Refer to Figure 6 for dollar values of procurements per contract year.

Additional examples of USAP expenditures includes the estimated amount of scientific and engineering material and supplies procured by U.S. government fiscal year in Figure 7 for these two ASA divisions. Figure 8 shows the expenditure for food and related materials. The drop in FY 95 is the result of a planned reduction in its inventory.

Typically buying is slow during the quarter April through June since the USAP stations are in the winter season mode, but has increased due to the need to buy and deliver long-lead special construction material and supplies, and to start buying for the coming summer season. A high level of buying occurs in the fourth quarter and first quarter of a U.S. government fiscal year when requirements are made known. Science requirements are identified in the May-June time frame and station needs are identified after receipt of vessel cargo in the March through May time frame. Construction requirements continue to be identified across fiscal years as fast-track construction projects are designed and procured for resupply vessel delivery. The quarter, July through September, shows a sharp increase which reflects the active buying for the coming summer season. October

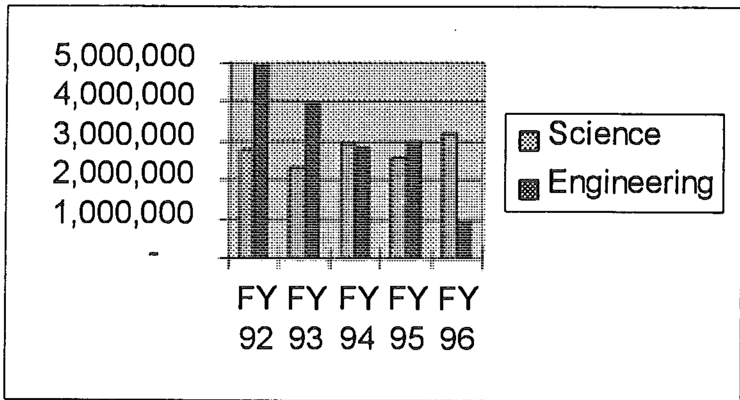


Figure 7 - Science & Engineering

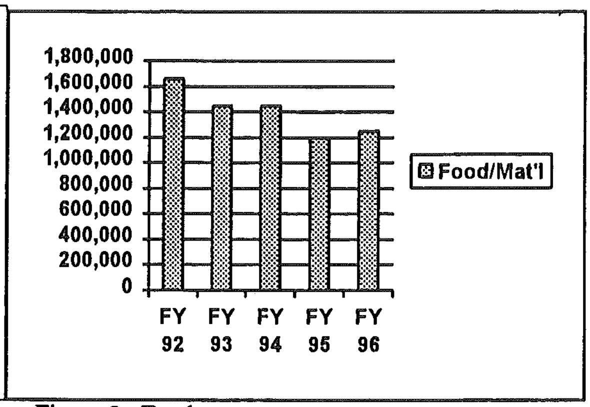


Figure 8 - Food

through December is the peak buying time and also reflects the impact of a new U.S. government fiscal year which provides new funds for the USAP. The final quarter shows continued buying activity at a slower pace but activity can be high in order deliver as much material and supplies prior to the closing of two of the three USAP stations.

Construction projects can be long-duration evolutions that include project design the first year, procurement and delivery to the stations the second year and construction the third year. The radio telescope project (Viper Tower) procurement for South Pole typifies a construction project. In Fiscal Year 1995 design Phase I and II were completed and materials for Phase I were procured and delivered to McMurdo Station. In Fiscal Year 1996 Phase I was constructed and materials for Phase II will be procured and shipped to McMurdo. In Fiscal Year 1997, Phase II will be constructed.

Fast-track procurements can occur in response to unforeseen events such as the wind damage to the Black Island Radome in the Austral Summer 1994. The decision was made to repair the damage before station close which meant the material had to be procured and shipped to McMurdo by mid-December before the ice runway closed. The ice runway is used to land wheeled aircraft such as the C-141 aircraft required to transport the large volume of panels. Additionally, a short-notice C-141 mission request had to be scheduled with the U.S. Air

Force to depart Hanscom Air Force Base in Massachusetts where the radomes were manufactured, and then flown to McMurdo in the same aircraft. This evolution was completed in a three-week window.

Conclusion

The specialized software has been developed to support the challenging USAP procurement requirements. Planning for the research program and its support, procuring of materials and supplies, and selecting and assigning field personnel generally involves 18 months of lead-time before material and personnel arrive in Antarctica. The overriding factor in the logistics planning is that transportation in and out of most of Antarctica is possible only during the austral summer months (October to March). Logistics and Procurement, two distinct and different organizations that utilize MAPCON, Power 1000 and CTS team together to ensure the continued scientific research and safe operation in Antarctica.

Acknowledgments

The development of this discussion of MAPCON, Power 1000 and CTS required many hours of dedicated effort on the part of several ASA employees but a few in particular are deserving of special recognition. Special thanks goes to Linda Harber and Ed Sargent for direct information on the software discussed in this article,. Also, thanks to Deb Erickson, Shawn Hill, Val Carroll, and Bill Daly for their computer assistance.

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1. Cargo Tracking System Manual, ASA, 1993.
2. United States Antarctic Program Personnel Edition, (NSF 94-113).
3. MAPCON Manual, ASA, 1995.
4. After-Operations Report, ASA, 1992-1996.

APPENDIX I

A brief description of non-procurement related MAPCON modules is provided to complete the functional description of MAPCON.

1. Equipment

The Equipment Module stores information concerning equipment which must be physically tracked (individually checked in and out), or for which a maintenance history must be maintained. It interfaces with the Inventory and Maintenance Modules. Data stored for each individual piece of equipment includes:

- required future preventive maintenance (PM) actions,
- historical PM data,
- repairs made to the equipment,
- lists of materials required to maintain the equipment,
- location of the equipment,
- component equipment items associated to the primary piece of equipment,
- check in and out data.

This module is functional at all three Antarctic stations.

2. Maintenance

The Maintenance Module is where maintenance actions can be initiated, planned, scheduled and tracked. A large part of this is preventive maintenance (PM). It allows repetitive work order information to be defined and entered into MAPCON once. Work orders to accomplish these repetitive, periodic tasks can then be automatically generated by MAPCON, based on the elapse of time or on meter readings. Proper preparation of this module requires significant time and effort, as specific tasks to be accomplished and detailed human and material resources required must be defined and inputted.

The utility of this module is highly dependent upon the availability of complete and accurate data in the Inventory and Equipment Modules. It is being used to varying degrees at McMurdo, Palmer, and South Pole Stations.

3. Human Resources

This module provides a means of tracking labor, to a project or facility, which is the key to determining maintenance costs and work order planning. It is primarily an adjunct of the Maintenance Module, but, because it must be used as part of authorizing users access to certain functions within the system, it is fully operational at all locations.

V11 SCALOP SYMPOSIUM
CAMBRIDGE, UK, AUGUST 1966

SCIENCE OPERATION PLANNING AND RESOURCE ALLOCATION THE BAS APPROACH TO MANAGEMENT

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British Antarctic Survey

ABSTRACT.

It has become increasingly apparent in recent years that, in response to changing economic circumstances and attitudes to scientific research, that many national Antarctic operators are coming under increasing pressure, both to curtail elements of their programme and to increase efficiency.

Following a period of rapid expansion in the 1980s' the British Antarctic Survey (BAS) has encountered such pressures. These arise from the increasing cost of sustaining technically advanced equipment in a demanding environment, environmental prescriptions themselves, the need to improve safety and other standards and growing reluctance from funding bodies to finance continuing growth.

The paper will address the importance of facing these pressures realistically, the construction of a coherent strategy to overcome them and for developing planning and resource allocation mechanisms to underpin the strategy.

The paper will describe the evolution of complex and efficient field season planning and implementation involving input and recovery, ship and aircraft programming and field support.

Opportunities to develop and exploit logistic co-operation with other national operators form an essential element in improving relative efficiency. The progress that BAS has made in this area will be described.

1. INTRODUCTION

1.1 After a decade during the 1980s of rapid expansion in a number of national Antarctic programmes, including the British, the more difficult global economic climate and political changes of the 1990s is having its impact on scientific research in polar regions. While each country involved in Antarctic research has specific problems resulting from its own financial, political and geographical circumstances, there is a common objective in how to conduct a quality scientific programme in a very hostile environment at a time when resources are becoming progressively squeezed.

1.2 The British Antarctic Survey (BAS) is certainly experiencing these problems and this paper aims to describe how it is approaching them in the spirit of sharing experience and stimulating debate among national operators. It is fully recognized that there is no panacea nor that approaches and solutions that suit one operation may not necessarily suit another. The BAS has traditionally maintained wintering stations widely dispersed over a large geographical area and its difficulties vary significantly from a single summer only operator, for example.

1.3 The paper will describe the pressures on BAS during the 1990s to sustain its science programme within a climate of severe pressure on resources and the development of strategies to address them.

2. THE PRESSURES ON BAS

2.1 The pressures on BAS during the early 1990s at least in part derived from its success or good fortune in attracting considerable investment during the previous decade. This investment, in particular, its new research vessel, the RRS James Clark Ross, the new airstrip and associated facilities at Rothera, the new highly technical jackable platforms at Halley and the acquisition of a four engine pressurised DHC-7 aircraft. The DHC-7 (Dash-7), while delivering the potential to enhance the programme, also imposed severe running cost pressures. In each case, the move to a higher technical level posed problems of availability and maintainability and hence resource constraints.

2.2 At the same time BAS possessed elsewhere at Faraday and Signy, 40 year old stations, an ageing infrastructure. New UK and EC safety regulations bearing on building and personnel standards meant that the problems of re-investment had to addressed sooner rather than later. Significant sums of money were required at both stations.

2.3 The 1991 Madrid Environmental Protocol is familiar to all Antarctic logistic managers. In the case of BAS, the short term and long term obligations were heavy given the Survey's long history in the Peninsula and Weddell areas. Resources were required both at existing stations to improve waste management and at abandoned stations to effect immediate clean up measures.
An Environmental Officer was appointed.

2.4 An area which perhaps can be overlooked in polar discussions is investment in computing. The BAS is a major user of computing power for scientific analysis and data handling and transmission, for Messaging and for administrative purposes. Developments in the computer industry to the distributed environment have pushed the Survey into major architectural changes over the past few years and pressures for continuous modernisation show no signs of easing.

2.5 Finally inflationary pressures in the UK in the late 1980s had severely eroded the purchasing power of the BAS's baseline budget which along with public expenditure generally was cash limited. The UK was entering a severe recession during which real GDP fell in 1991/92 and 1992/93 and pressure on government social expenditure was heavy.

3. THE SCIENCE PROGRAMME

3.1 At the same time, the Survey had developed its first quinquennial science programme, "Antarctica 2000", an ambitious inter disciplinary portfolio of projects requiring significant logistic support. This programme was succeeded in 1994/95 by a second quinquennial, "Antarctica into the 21st Century", which was equally demanding in research station and field support as well as on ship and aircraft time.

3.2 The problem for the Survey's senior management was, therefore, how to support these programmes and deliver the scientific objectives without serious over commitment.

4. PLANNING MECHANISMS

4.1 Clearly the acquisition of a more technically advanced infrastructure along with serious cost drift required better screening, analysis and forecasting techniques. A broader strategic overview was needed to judge where the balance of investment was needed, which cost pressures were most severe, where efficiencies were best introduced and how to produce greater choice and flexibility.

4.2 Project planning forms (Project Documentation) were introduced to provide a detailed picture of the resource requirement coming from science managers and similar mechanisms captured forward requirements for maintaining and developing Antarctic and UK infrastructure. These mechanisms fed into both field season planning and financial planning over a five year period. A Management Plan was produced in 1992/93 covering the period up to 1998/99. This, inter alia, produced a better means of analysing the programme and isolating the problems. Efficiency targets were set and flexibility margins produced with the specific aim of producing more available funds for the direct support of science.

4.3 On the technical side ways of stabilising major costs were examined involving longer term arrangements with contractors building a partnership approach. In particular, BAS now has 5 year maintenance and refit contracts for its 5 aircraft and for its 2 ships. These arrangements allow greater continuity and stability and more assurance on costs. Similar arrangements provide for facilities maintenance and management at BAS HQ in Cambridge.

4.4 A Balance of Investment Working Group was set up to consider how the more serious problems of under investment in the older stations and the cost pressures of the new infrastructure could be resolved. These deliberations led to discussions with government and proposals for restructuring emerged, known as "the Way Forward Programme". This will be described in more detail in Section 5.

4.5 Field Planning.

*** Project Documentation & Annual Summary Sheets.**
The Project Documentation provides a five year forward look.
This comprises eight sections of information for each individual project covering each of the five years. Sections:

1. Overall Objectives & Targets.
2. Staffing Requirement.
3. Financial Requirements.
4. Logistic Requirements - includes subsections on
   - Ship - Transportation - Pax & Cargo
   - Ship - Scientific Research Platform
   - Air & Field support.
   - Station Support - power, space, storage etc.
   - UK HQ Requirements - space, storage etc.
5. Instrumentation & Computing Requirements.
6. Health & Safety Hazards & Special Requirements.
7. Environmental Issues.
8. Waste Management.

Created from this five year project information pool a summary overview is produced to show an Antarctic season as a single entity. This is in order to identify in one set of spread sheets the overall resource demands for a given Antarctic season.
These summary sheets provide a fine tuned closer to time frame planning tool and are produced with a two year forward look.

*** Field Operations Working Group (FOWG).**
The Project Documentation & Summary sheets are assessed by a Field Operations Working Group (FOWG) in order to judge the feasibility of new projects and to appraise the overall demand on BAS Logistic resources and operational requirements. The FOWG identifies over-commitments & conflicting demands on resources such that the scientific and logistic demands can be sensitively married to the overall BAS operational capability.
Any unresolved conflicting demands are taken to the Directors Committee for final resolution & the overall seasons programme is thus sanctioned by the BAS Senior Management body.

The Field Operations Working Group which meets twice per year comprises representatives of all the Science Divisions, logistic Sections , ships & air unit.

It is this closely woven and integrated nature of the BAS system that thus allows percolation in both directions through the complex interface between science & logistics.

*   **Planning Timetable.**

Year 1.

May   FOWG reviews Summary Sheets for Yr 1 (coming season) & Yr 2.
June   Directors Committee sanctions coming seasons programme.
Nov   FOWG reviews Summary Sheets for Yr 2 & Yr 3.

Year 2.

May   FOWG reviews Summary Sheets for Yr 2 (coming season) & Yr 3.
June   Directors Committee sanctions coming seasons programme.
Nov   Review Summary Sheets for Yr 3 & Yr 4.

*   **Detailed Planning.**

Working alongside & in harmony with the above process is the more detailed planning required to execute the Antarctic programme.
This includes the "organic" development of Ship Itineraries, Cargo, Air movements & Passenger movements both internal to Antarctica & commercial worldwide connections.

Closely meshed into this planning process are the bids from agencies external to BAS for support & mutual collaboration :-

External University collaboration.
CASE Students/ Antarctic Special Topics
Media/Film
Distinguished Visitors (DVs)

Briefing, Instruction & Training prior to deployment for the Antarctic season.

e.g.   Briefing Conference - all new recruits.
First Aid
Field Introductory Training
Sailing Orders.
Flying Orders.

*   **Monitoring & Feedback.**

Internal Annual/Seasonal Reports - Admin, logistics & Science.
Post Season De-Briefings as supplement to the above reports.
Identify areas of concern - attention by Various Working Groups

Air Operations Working Group
Ships Masters Working Group
Individual Station Working Groups
Health & Safety Committee
Environmental Conservation & Waste Management Working Group

Implementation of measures to resolve problems.

5. THE WAY FORWARD PROGRAMME

5.1 Given the reluctance of government in the difficult recessionary period of the early 1990s to fund spiralling running costs or to reinvest heavily in ageing stations, some form of realignment was inescapable. Discussions with government produced modest funds to carry out what became a major restructuring programme known as "Way Forward". The programme was announced in 1993 and commenced in 1994/95. It will be in place by the end of the 1996/97 austral summer. Most major work has already been completed. The programme has involved a major commitment in planning and implementation by the Survey and its contractors.

5.2 The main elements of the programme comprised:

a. Conversion of Signy Research Station to a small summer only facility for mainly terrestrial ecology. Construction of modern purpose built laboratories and accommodation.

b. Migration of near shore marine biology and terrestrial ecology to Rothera Research Station. Construction of major additional accommodation on site and modern laboratory, aquarium, diving and boating facilities. Major upgrade of power generation and water production utilities at Rothera.

c. Transfer of Faraday Research Station to another national operator.

d. Development of automated instruments at Signy Station for unmanned winter use.

e. Commitment of effort to clean up at abandoned stations at Deception, Horeshoe Island, Admiralty Bay and Portal Point. Conservation project at Port Lockroy.

5.3 The programme is being completed to time and budget. The construction projects at Signy and Rothera were committed to a major UK construction company, Tilbury Douglas, on a fixed price design and build basis with BAS providing shipping and logistics. This work has largely been completed though some finishing off tasks are necessary in the coming 96/97 season. Scientific work on the new biological programmes at Rothera and Signy will commence during the season.

5.4 As other national operators are aware, Faraday Station was transferred to the Ukraine in February 1996 and our Ukrainian colleagues are successfully continuing the long meteorological, ionospheric and magnetic measurements at their new "Vernadsky Station".

5.5 A sea ice camera has been successfully tested at Signy and will record these measurements in winter thus continuing another important long data set.

5.6 Finally the clean up programme has been successfully started with much already accomplished at the bases mentioned (5.2e above). A considerable future programme, however remains. The conservation work at Lockroy has been impressive and will be repeated in future years at Horseshoe and Stonington Stations.

6. LOGISTIC CO-OPERATION WITH OTHER NATIONS

6.1 Logistic co-operation between national operators is not, of course, a new concept. Indeed the idea lies at the heart of the existence of the COMNAP and SCALOP. This section of the paper serves only to illustrate the range of BAS experience over the past few years and the major contribution co-operation has made to the Survey's work.

6.2 One should note the differentiation between scientific collaboration; shared science/logistic collaboration and purely logistic collaborative support.

The BAS has had many collaborative projects with numerous other national programmes over recent years. The following table shows just some **examples** :-

Country	**Science Collaboration**	**Shared Science & Logistic Collaboration**	**Purely Logistic Collaboration**
Argentina	✓	✓	✓
Australia	✓		
Chile	✓		✓
France	✓		
Germany	✓	✓	✓
Italy	✓		✓
Netherlands	✓	✓	✓
New Zealand	✓		
Ukraine	✓		✓
United States	✓	✓	✓

In order to provide a more effective and efficient foundation for such collaboration the BAS is now moving towards establishing mutually agreed Memoranda of Understanding (MOUs) wherever possible.

7. CONCLUSION

Thus far, through the use of planning mechanisms, it has been possible for the BAS to sustain and even enhance a high quality science programme and to stabilise running costs. At the same time the BAS has managed to implement modernisation of the Antarctic infrastructure available to its biological programmes. Restructuring has been the main building block in this process allied to the development of improved forecasting and management techniques.

Logistic collaboration with other national operators has also contributed greatly to the efficiency of the BAS's programme and must remain at the heart of future developments. Longer term relationships with key contractors and suppliers are also of much value in stabilising costs, improving quality and maintaining availability.

Summary:-

- Achieved restructuring.
- Improved the science/support staffing ratio.
- Stabilised running costs.
- Improved technical & contractual standards.
- Sustained the science programme.

Call for Titles and Abstracts

for the

Seventh SCALOP Symposium on Antarctic Logistics and Operations

Standing Committee on Antarctic Logistics and Operations (SCALOP)

Cambridge
United Kingdom

6-7 August 1996

Circular - December 1995

The Standing Committee on Antarctic Logistics and Operations (SCALOP) of the Council of Managers of National Antarctic Programmes (COMNAP) will hold a symposium on Antarctic Logistics and Operations in conjunction with the XXIV SCAR General Meeting in Cambridge, England, UK.

SCALOP Symposia have been held for a number of years to provide a forum for exchange of information, discussion and presentations of new ideas and achievements in a wide range of antarctic activities.

Topics

This Seventh Symposium will address the following topics:

* **Remote Sensing and the Use of Satellites for Science Support.**
* **Deep Drilling Technologies.**
* **Significant and Proven Developments in Operations, Logistics and Science Support.**
* **Energy Conservation.**
* **Best Available Technologies for Waste Management and the Protection of the Antarctic Environment.**
* **Science Operation Planning and Resource Allocation.**

Titles, Abstracts and Papers

You are invited to attend the symposium and to present papers relevant to the aforementioned topics. Papers are requested from the staff of national Antarctic operating agencies and from other government funded organizations directly involved in Antarctic operations and logistics. The papers proposed should be generated by or through National Programmes SCALOP members and their staff colleagues.

Each speaker will have a maximum of 30 minutes including questions and discussion. Papers should be presented in English with slides and/or overhead projection and be a maximum of 10 pages.

An abstract of approximately 250 words shall be submitted to the Steering Committee by no later than 31 March 1996. The papers will be reviewed by the steering committee in late April and contributors will be informed in May 1996 when the symposium programme will be established.

(See address for Abstracts on final page)

Publication

The Proceedings of the symposium will be published, therefore contributors are kindly requested to bring the manuscript to the Symposium with relevant pictures and charts in ready-to-print originals. Manuscripts should be no longer than 10 A4 sheets (including illustrations).

Trade Exhibition

There will be a trade exhibition in association with the Symposium. A number of stands are available. Many companies have been contacted to participate but SCALOP members are invited to refer relevant companies/agencies within their respective countries to the XXIV SCAR and COMNAP VIII Organising Committee (address below).

Accommodation, Tours and General Organization

The Symposium will be held in the Moller Centre and Churchill College, Cambridge, UK on Tuesday 06 and Wednesday 07 August 1996.

Accommodation, Tours and General Organisation is being administered by a company nominated by the Organising Committee - any correspondence or inquiries should be sent to:

XXIV SCAR and COMNAP VIII
Meetings Secretariat
42 Devonshire Road
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email: cc@confcon.demon.co.uk

Symposium Steering Committee and Address for Abstracts

The Seventh SCALOP Symposium Steering Committee members are:
E Chiang (USA), L Fontana (Argentina), P Guiliani (Italy), J Hall (UK- Chairman), O Melander (Sweden), J Sayers (Australia), R Schorno (Netherlands).

Abstracts from potential participants should be sent to Mr J Hall by 31 March 1996 at the latest please:

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44 1223 251400 (Switchboard)
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Seventh SCALOP Symposium on Antarctic Logistics and Operations

Standing Committee on Antarctic
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Cambridge
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6-7 August 1996

Information for those papers selected for presentation.

Each speaker has a maximum of 25 minutes (20 minutes for presentation & approx 5 minutes for questions). Papers should be presented in English with slides and/or overhead projection as required.

The normal range of audio visual aids will be available :-

35 mm Slide Projection
OverHead Projection
VHS Video
White Boards
(If you require anything different please get in contact.)

A Proceedings of the Symposium will be published as soon as possible following the event. In order to progress this publication in a timely manner I ask that you prepare your paper as detailed below :

and despatch a Top Copy (& Diskette) to myself by Monday 29 July 1996.

In this way I can also ensure that photocopies of your paper are available for Symposium participants on the day of your presentation.

* **Maximum of 10 pages (A4 size) camera ready top copy quality.**
  (The 10 pages includes illustrations & diagrams)

* **Diskette of the text .**
  (Word Perfect or Word is preferable but please specify what format is used.)

* Please identify any 'References' at the end of your paper - if applicable.

If you have any questions about the above or the Symposium generally please contact me at the following address:-

Mr John Hall,
British Antarctic Survey,
High Cross, Madingley Road,
Cambridge CB3 0ET United Kingdom.

Phone: #44 1223 251457
Fax: #44 1223 362616
email: jhal@bas.ac.uk
jhal@pcmail.nerc-bas.ac.uk

(Note: Queries about accommodation should be directed to the Conference Organiser)

Seventh SCALOP Symposium on Antarctic Logistics and Operations

Cambridge United Kingdom 6-7 August 1996

PROGRAMME - *REVISED 05 AUGUST 96*

TUESDAY 06 August (0830-1730)

0830 -0845	WELCOME & INTRODUCTION TO THE SEVENTH SCALOP SYMPOSIUM
0845-0920	**The Use of Modern Remote Methods in Determining the Feasibility of a Long Antarctic Traverse Route.** Blaisdell,Alger,Evans,Arcone & Bresnahan.
0920-0945	**Organisation & Operations of Logistic Traverses.** Godon & Cucinotta.
0945-1010	**G.I.S. for Logistic Applications at Terra Nova Bay Station.** Della Rocca, Manco & Rossi.
1010-1035	**Feasibility of Establishing a Snow/Ice Runway in the 60E-120E Antarctic Coast Sector.** Klokov, Lukin & Sayers.
1035-1105	MORNING COFFEE BREAK
1105-1130	**Continuous Observations of Surface Strain Changes for Safe Working on Sea-Ice.** Goodman, Bateman & Blake.
1130-1155	**Satellite Communication at Dome Fuji Station : Operations at High Latitude & Extreme Low Temperature Environment in the Antarctic Interior.** Otsuka & Sano.
1155-1220	**CAD for Logistic Applications at Terra Nova Bay Station.** Gaggiano & Manco.
1220-1420	LUNCH BREAK
1425-1450	**Automatic Geophysical Observatories.** Ditchl & Rainbow.
1450-1515	**A Down-Wire Control & Monitoring System for Scientific Nets.** Woodroffe.
1515-1540	**The Use of Remote Sensing & Satellites in the Italian Antarctic Programme.** Della Rocca, Frezzotti & Giuliani.
1540-1610	AFTERNOON TEA BREAK
1610-1635	**The Use of High Resolution Weather Satellite Imagery for the Support of Science.** Lachlan-Cope.
1635-1700	**Potential for Significant Wind Energy Utilisation in Antarctic Stations Energy Supply Systems.** Guichard, Magill, Godon, Lyons & Brown.
1700-1725	**Wasa Research Station. An Analysis of Energy Requirements.** Thormack & Olsrud.

(Edition 2 - JH - 05/08/96 Page 1 of 2) ...PTO...

WEDNESDAY 07 August (0830 - 1730)

0830-0855	**The AMANDA Hot Water Drill.**	Collins, Koci & Makovicka.
0855-0920	**A 'Light Weight' Hot Water Drill as Used by BAS on the Ronne Ice Shelf.**	Nicholls & Makinson.
0920-0945	**The Hot Water Drilling System of the Alfred Wegener Institute.**	Nixdorf, Oerter & Miller.
0945-1010	**Russian Drilling Equipment and Technology for Deep Ice Coring.**	Kudryashov, Krasilev, Talalay, Tchistyakov, Vassiliev, Zubkov & Lukin.
1010-1035	**The 5.2" PICO Drill - Current Capabilities & Future Developments.**	Collins & Giles.
1035-1105	MORNING COFFEE BREAK	
1105-1130	**Environmental Auditing - the New Zealand Antarctic Programme Experience.**	Waterhouse.
1130-1155	**USAP Oil Spill Response Summary.**	Hatcher.
1155-1220	**Remediation of Fuel Contaminated Soil in Antarctica - with Emphasis on McMurdo Station.**	Brown, Bala, Thomas & Crockett.
1220-1420	LUNCH BREAK	
1420-1445	**Waste Management for the Construction Phase of Sanae IV Station.**	Gildenhuys.
1445-1510	**A New Waste Water Treatment Plant Installed at Terra Nova Bay Station.**	Lori, Ponzo, Indulti & Stefanoni.
1510-1535	**Development of Environmental Protective Technologies in Snow Tractors.**	Knab, Deininger, Ulm, Muller & Kohnen.
1535-1605	AFTERNOON TEA BREAK	
1605-1620 (Short Paper)	**The Dismantling of Georg Forster Station & the Clean-Up of Eastern Schirmacher Oasis.**	Kohnen
1620-1635 (Short Paper)	**The Monitoring of Sea Ice Formation & Break-up at Signy Island - Using an Automated Camera System.**	Afanasyev
1635-1700	**Procurement Requirements of the United States Antarctic Programme.**	Koger.
1700-1725	**Science Operation Planning & Resource Allocation - the BAS Approach to Management.**	Curry & Hall.
1725-1730	CLOSING REMARKS.	

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Moller Centre/Churchill College
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14	Wärtsillä Diesel Service Ltd
15)	Tasmanian Polar Network
16)	Tasmanian Polar Network
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20	A & P Tyne
21	Tilbury Douglas Construction Ltd
22	Mann Aviation/Blackwell Science Ltd
23	Falkland Islands Co Ltd
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Outside space	Hägglunds Vehicle AB

6 June 1996

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