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BENTHIC FORAMINIFERA AND TRACE METALS IN SEDIMENTS OFF THE SCOTT BASE SEWER OUTFALL, ANTARCTICA

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Cover Photograph: *Aerial view of Scott Base.* **Image:** *Tim Higham*

TABLE OF CONTENTS

page

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

A preliminary survey was conducted in November-December 1994 in order to ascertain possible effects of effluent discharge from Scott Base on the benthic fauna. Scott Base is the New Zealand Antarctic Programme's only permanently staffed base in Antarctica located on Pram Point, Ross Island. Base occupancy rates were between 12-48 people during November-December 1994. Macerated sewage and wastewater from Scott Base are discharged into McMurdo Sound.

Sediment, sewage and wastewater samples were collected and analysed for trace metals. Spatial distribution and assemblage composition of benthic foraminifera in the region centred on the sewage outfall were examined. Current velocities and directions were recorded at selected sites.

Elevated levels of contaminants are reported in the effluent (1379 ppb Cu, 24 ppb Pb, 3693 ppb Zn, 20 ppb Ni) and in the sediment at the sewage outfall outlet (2754000 ppb (0.275%) Cu, 91200 ppb Pb, 462200 ppb Zn). Sediment contamination is mainly restricted to the area at closest proximity to the sewage outlet. Cu and Zn concentrations exceed and Pb concentrations nearly reach the levels above which toxic effects on marine biota occur frequently.

Twenty-eight benthic foraminifera species were identified in sediment off Pram Point. The populations were dominated by the five species *Ehrenbergina glabra, Cribrostomoides jeffreysii, Trifarina earlandi, Cassidulinoides porrectus and Rosalina globularis.* This association of five species forms between 79 - 92% of total specimens. At sites close to the sewer outfall foraminifera assemblages varied considerably. The site closest to the outfall contained no foraminifera in 34 g of sediment but contained high numbers of ostracoda. At the next closest sites different assemblages were recorded, with a reduction in numbers of *E. glabra.* This altered assemblage is interpreted as resulting from effluent discharge. Distant sites showed only minor variations in assemblage composition. A second near barren sample was collected from the area of the reverse osmosis water intake / brine return. Spatial variations in foraminifera assemblages off Pram Point are likely to be caused by changes in environmental conditions related to effluent discharge.

KEYWORDS

Scott Base, sewer outfall, trace metals, copper, zinc, lead, foraminifera, contamination, Antarctica

INTRODUCTION

Scott Base (77°51'S; 166°46'E), located at Pram Point on Hut Point Peninsula, Ross Island, Antarctica (Figure 1), has been continuously occupied by New Zealand since its establishment for the Trans-Antarctic Expedition of 1957-58. The base is the New Zealand Antarctic Programme's only permanently staffed facility in Antarctica and it provides base and logistical support to Antarctic science events. Responsibility for management of Scott Base lies with a division of the Ministry of Foreign Affairs and Trade, the New Zealand Antarctic Programme (NZAP) (now "Antarctica/New Zealand").

Effluent from Scott Base has been discharged into McMurdo Sound since the establishment of the base. The objective of this study was to determine the effects of sewage and wastewater effluent discharges from the base on the marine benthic environment at Pram Point. Data collection was carried

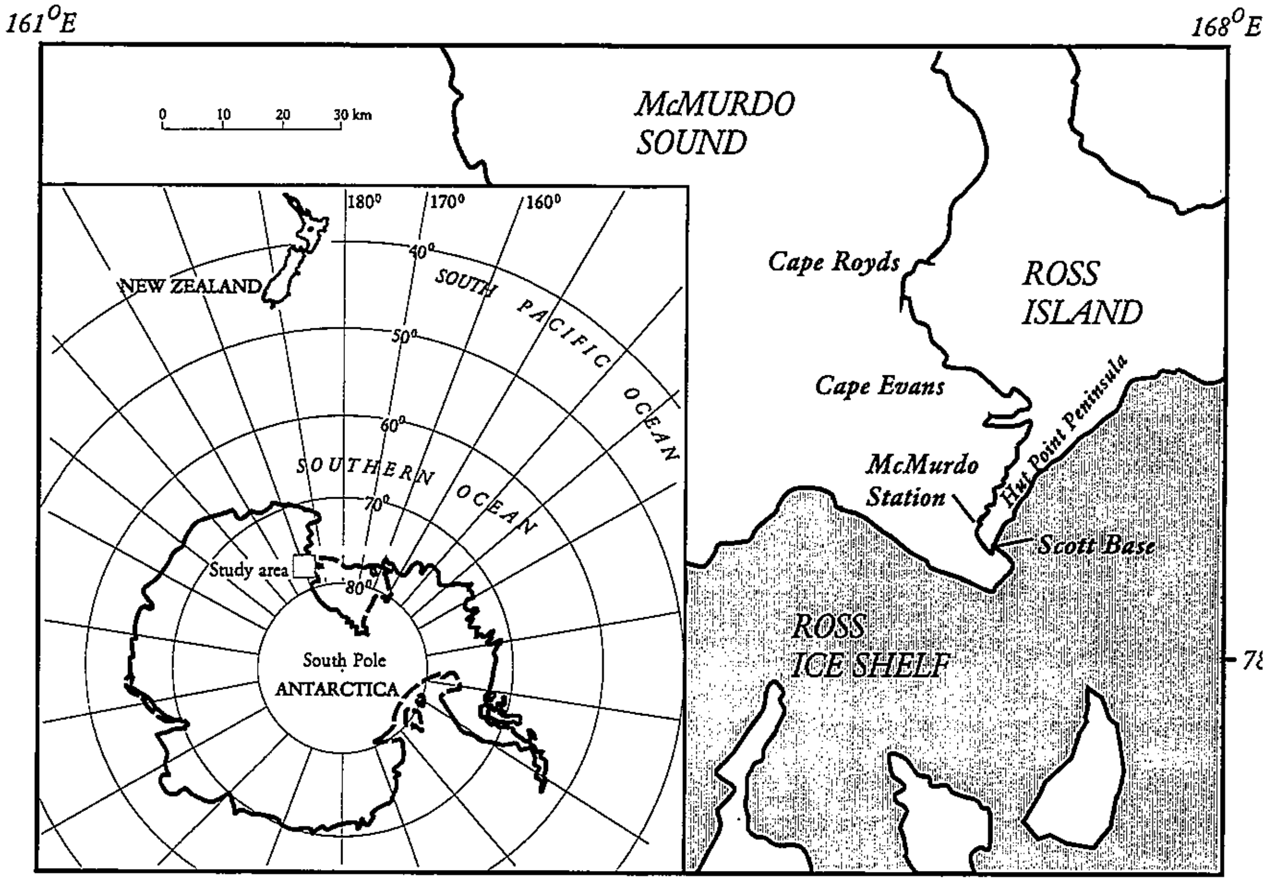

Figure 1: Location of study area

out in November and December 1994. Data on currents and bathymetry were collected and sediment, seawater and effluent samples were taken. The benthic environment was also filmed at several sites using an underwater video camera. Spatial distribution of foraminifera populations was analysed and concentrations of selected major and trace elements in sea-floor sediment were determined. Field work, preparation of samples for chemical analysis and paleontological analyses were carried out by the first author.

This study should be considered a preliminary investigation and it did not include the analysis of possible pollutants such as polyaromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB) or mercury, in outfall discharges, marine sediment or sea water.

ENVIRONMENTAL SETTING

Topography and Geology

Scott Base is located at Pram Point, at the southern end of Hut Point Peninsula (Figure 1). Hut Point Peninsula is formed by a 20 km long, and 2 to 4 km wide *en échelon* line of volcanic cones that extend in a south-west direction from Mt. Erebus. At the southern end of the peninsula, there are numerous small, well-exposed basaltic scoria cones with thin flows and associated pyroclastic rocks (Kyle, 1981).

The base was built on a lava flow (olivine-pyroxene basanite) which originated from Crater Hill (1.5 km north-west of Scott Base). From the summit, a steep boulder slope extends downward terminating to the east and south in cliffs of 6 to 20 metres height. Between the two sets of cliffs the Pram Point lava flow forms a low flat area on which the NZAP base was built. The flow to the northeast continues to form a shore platform that slopes gently beneath the waters of McMurdo Sound. K/Ar dating of stratigraphically similar rocks at Twin Crater indicates an age of between 600,000 and 400,000 years (Kyle, 1981).

Climate

A continuous record of climatological data has been gathered at Scott Base since 1957. Monthly readings averaged over 1957-1996 are shown in Table 1, along with extreme maximum and minimum values.

Temp (°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	-4.7	-11.1	-20.4	-23.9	-26.5	-26.2	-29.0	-30.3	-28.3	-22.0	-11.8	-5.0
max	+6.8	+5.0	-0.5	-4.3	+0.2	-4.2	-4.2	-2.7	-3.3	-0.2	+4.9	+6.5
min	-19.7	-31.4	-44.6	-50.4	-53.2	-52.2	-54.2	-56.6	-57.0	-52.0	-37.2	-22.8

Table 1: Monthly temperature readings from Scott Base averaged over 1957-1996 obtained from National Institute of Water and Atmospheric Research, Wellington. (max, min = extreme maximum, minimum values for survey period).

Sea Ice Behaviour
Ice up to 3 m thick covers the sea in front of Scott Base for most of the year. Usually, the ice breaks out in late summer and reforms during the winter, but in 1994, the sea ice did not break out. Sea ice grounds on a shallow marine platform to the east of Pram Point, causing pressure ridges to form at an oblique angle to the shore. Although the actual location of individual pressure ridges changes from year to year, the direction of formation remains constant. Figure 2 shows pressure ridges in the region of Pram Point and Scott Base during December 1994.

Bathymetry
The bathymetry in front of Scott Base is shown in Figure 3. From the shore, the sea-floor deepens rapidly to a platform at 30 m depth which extends 100 m offshore, from where the bottom drops below 100 m water depth. A small bay to the west of Pram Point, called Back Bay, has a relatively constant depth of between 30 and 40 m. The seafloor off Scott Base is made up of isolated basalt boulders and thick sponge spicule mats. At depths greater than 40 m, sponge mats are replaced by large bryozoan colonies.

Biota
Crockett (1994) divided the benthic environment along the front of nearby McMurdo Station into three zones depending on levels of ice disturbance:

> *Zone 1 (0 - 6 m water depth) is heavily disturbed by the scouring action of the sea ice in the shallowest depths and the formation of anchor ice throughout. The resident invertebrate species in Zone One are mobile scavengers (seastars, nemertean worms, and sea urchins) and opportunistic polychaete worms that invade during the spring and summer months.*
>
> *Zone 2 begins at about 6 m and contains increasing densities of invertebrates with increasing water depth. Dense assemblages of benthic infauna begin at about 20 m where the influence of anchor ice begins to diminish.*
>
> *Zone 3 begins sharply at 25 m where a thick carpet of sponges, sponge spicule mat, begins and extends into deep water. This habitat is relatively unaffected by physical disturbances and is a community extremely high in diversity and biomass.*

Currents
Currents off Pram Point are largely tidal and cycle between once and twice a day (DOSLI, pers. comm., 1994). The maximum tidal amplitude in front of Scott Base from October to December 1994 was 1.2 m and occurred on 5 December 1994 (DOSLI, pers. comm., 1994).

Current velocity and direction (Table 2, Figure 3) were measured at 5 sites using an S4 Interocean current meter. The current meter was lowered to 1 m above the sea-floor and collected data every 0.5 seconds over a 5 minute block every 15 minutes. The meter remained in position for periods ranging from 22 hours to 93 hours. Table 2 shows the average speed and direction of currents and also the duration that the current meter operated (as a date/time group).

Average current measurements over 22 hours at site 1 show a net direction of transport to the north toward the sewage outfall at an average velocity of 0.32 cm/s. At site 2, close to the reverse osmosis (RO) intake, the current flows south away from the shore at 0.37 cm/s. At sites 6 and 7, data collected over 3 days at each site show that the average current flows parallel to the shore with mean velocities of 0.29 cm/s and 0.28 cm/s respectively. The longest record of 4 days was collected at site 14 at 110 m water depth, where the current flows at 0.34 cm/s toward the shore in a NNW direction.

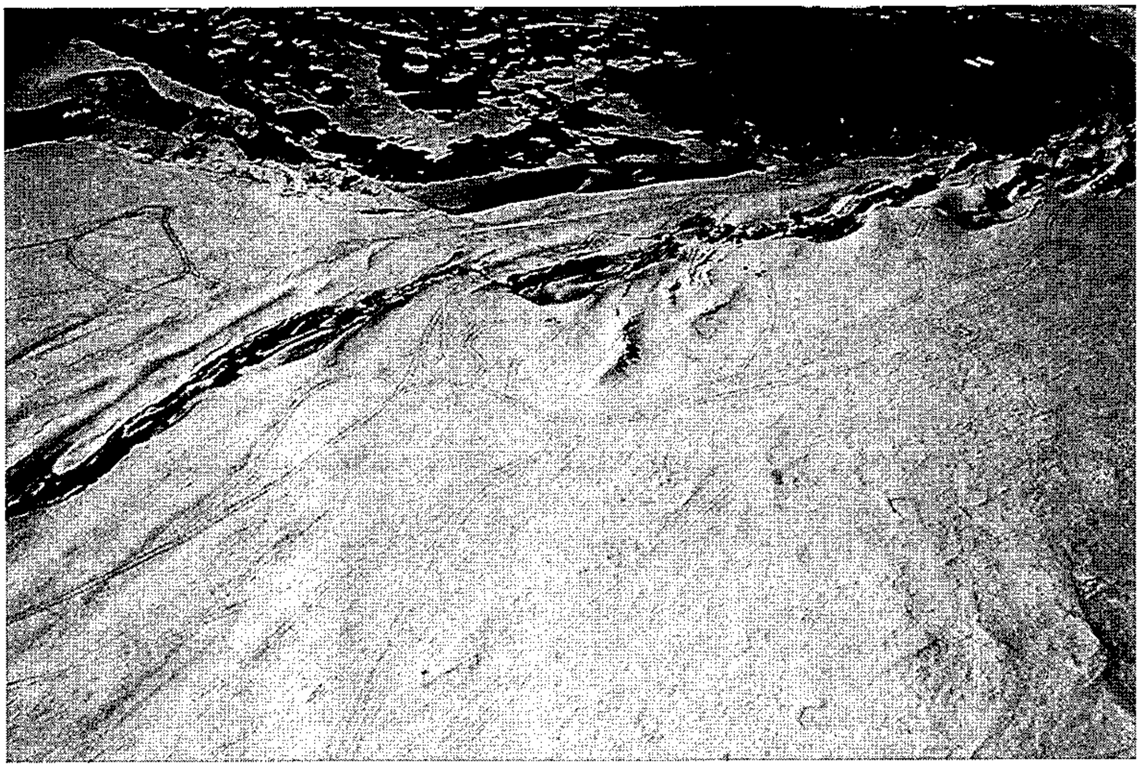

Figure 2: Oblique aerial photograph showing pressure ridges forming off Pram Point during December 1994.

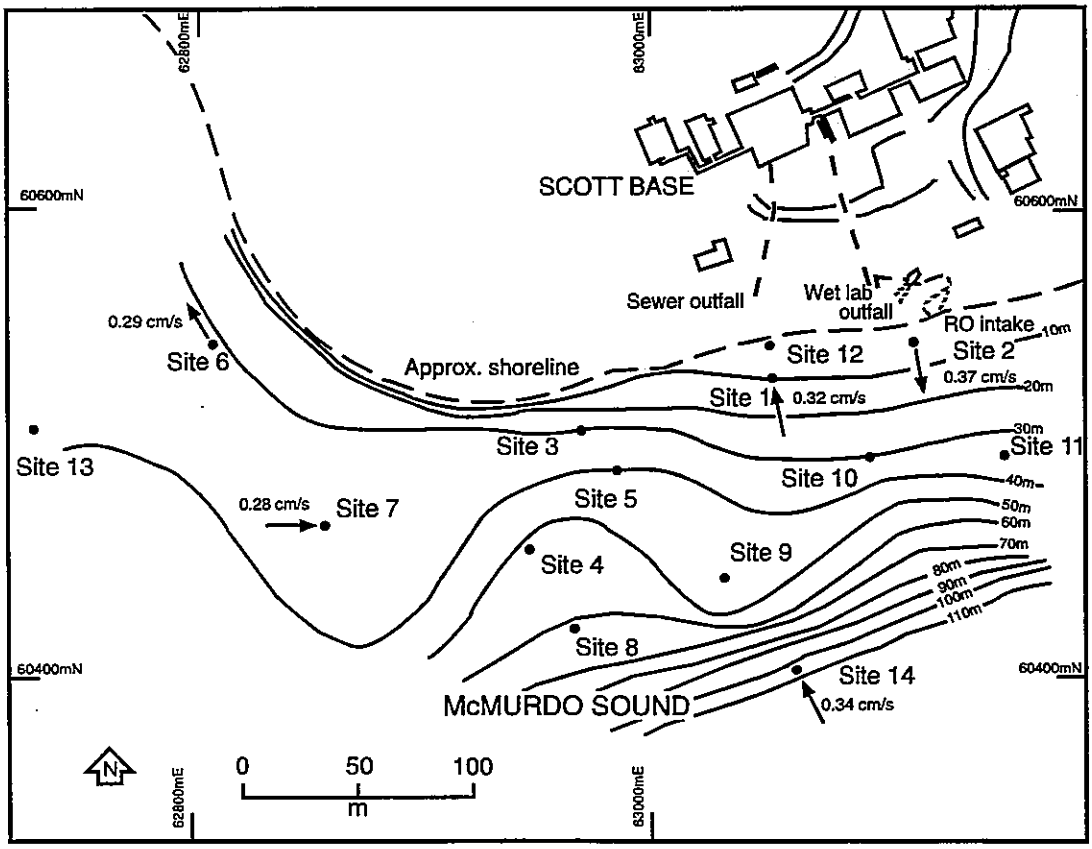

Figure 3: Location map showing sampling sites, bathymetry, current directions and velocities in front of Scott Base (Grid markers taken from the local Scott Base survey grid).

Site	Water depth (m)	Start	Finish	Average velocity (cm/sec)	Direction (grid)
1	10	22/11 13:09	23/11 11:39	0.32	354
2	5	23/11 14:04	24/11 15:37	0.37	167
6	32	26/11 10:46	28/11 09:16	0.29	331
7	32	28/11 12:26	01/12 18:29	0.28	089
14	110	02/12 17:36	06/12 14:24	0.34	331

Table 2: Average current direction and velocity at five sites in the region off Pram Point, Scott Base. Date/time groups of the start and finish of data collection are included.

A weakness of the set of measurements is that only one current meter was used and thus the meter had to be moved from site to site. For this reason, the record is incomplete and does not show the average flow patterns over the month. From the data available, currents show a complex pattern with net transport at low velocities toward the sewage outfall. At shallow depth the current is deflected by the shore and splits into two flows. The western stream travels west then north following the shore, while the eastern current is diverted offshore by a shallow platform. Average current velocity offshore from Scott Base ranges from 0.28 cm/s to 0.37 cm/s. In comparison, the current flows at 1.6 to 2.7 cm/s offshore from the McMurdo Station outfall, and at 2.6 to 9.8 cm/s west of Hut Point.

Sewage and wastewater effluent discharged into the marine environment should be dispersed by currents. If the current flow velocity is low, then accumulations of contaminants can occur. Article 5 (1b) of Annex II to the Protocol on Environmental Protection to the Antarctic Treaty has a requirement that *such discharge* [sewage and liquid waste] *is located, wherever practicable, where conditions exist for initial dilution and rapid dispersal.*

Human Occupation

For most of the year (late February to early October) the base is staffed by 12 people. In early October staff numbers increase; in 1994 during the months of October, November and December, the population averaged 43, 52, and 44, respectively (NZAP, pers. comm., 1994). A maximum occupancy of 64 base staff and event personnel occurred in late November. The 1994 levels of occupancy are considered normal for recent years (NZAP, pers. comm., 1994).

Pollution Sources

There are four likely point-sources of marine pollution in the Scott Base area: the domestic sewage and wastewater effluent outfall, the reverse osmosis plant, the wet laboratory outfall and drainage from the laboratory and other sources (Sheppard *et al.*, in review). Other possible sources of contamination are wind blown aerosols and terrestrial run-off containing contaminants from vehicle and helicopter operations, incineration of solid waste, or soil disturbance. Additional point-sources such as McMurdo Station and the Ice Runway are possible, but unlikely because of intervening distance. Cape Armitage has been used as a control site for American pollution studies (Lenihan, 1992; Kennicutt *et al.*, 1995) and no measurable impact has been recorded there.

Sewage Effluent Outfall
Effluent from activities at the base is discharged onto land at least 20 m from the edge of the sea-ice. Frozen sewage has accumulated at the outfall and in the surrounding area (Figures 4, 5 & 6). Warm effluent and waste water have melted the inside of the ice mound (Figure 4), in which quantities of food scraps, toilet paper and human excrement have collected. During November-December 1994, warm temperatures allowed effluent to flow down slope under snow and ice into the sea. The effluent and wastewater stream enters the seawater at a depth of about 1 m at high tide (Figure 6).

In this study it is assumed that Scott Base is essentially a closed system as far as sewage and domestic effluent are concerned. This means that all water produced by the reverse osmosis plant is discharged through the Scott Base sewage outfall and that there are no significant additions from, or losses to, external sources. In addition, each person contributes an unknown amount in domestic waste such as food scraps, detergents and human effluent. If the closed system assumption holds true, between 3,601 and 11,179 litres of domestic waste were discharged through the outfall per day from October to December 1994 (Table 3).

Reverse Osmosis Plant Intake and Brine Return
Water for the base is made using a reverse osmosis desalination (RO) plant. The location of the desalination plant intake is shown in Figure 3, and the intake and brine return are shown in Figure 7. Daily records of the water produced and used are summarised in Table 3.

Excess water and brine are discharged at the site of the desalination plant intake, but no data are available on either the volume of brine returned nor its salinity. NZAP (pers. comm., 1994) suggest a 10:1 ratio of production water to potable water (10 litres of seawater used to make 1 litre of potable water). Applying this ratio to the daily usage figures in Table 3, it is estimated that between 36,000 and 111,800 litres of brine are returned daily to McMurdo Sound. When returned to McMurdo Sound the brine is at 12-14°C.

Wet Laboratory Outfall
Figure 8 shows the Scott Base wet laboratory and outfall. Discharges from this laboratory were not collected as part of this study. The composition of the effluent is expected to vary, depending on the activities being conducted in the laboratory. In November-December 1994 the wet laboratory was used for fish physiology experiments and the main discharges were of seawater from the fish holding tank overflows. Wet laboratory outfall flows are minimal and thus are unlikely to contribute to the trace metal signature in front of Pram Point. However, further study is required to verify this assumption.

Laboratory Drainage
In the past, the laboratory drainages from the geophysical laboratory have been spilled out to the ground adjacent to the buildings. Sheppard *et al.* (in review) have traced the flow of this to near the shore and it is presumed to flow into the sea. The characteristic metal in this flow is silver.

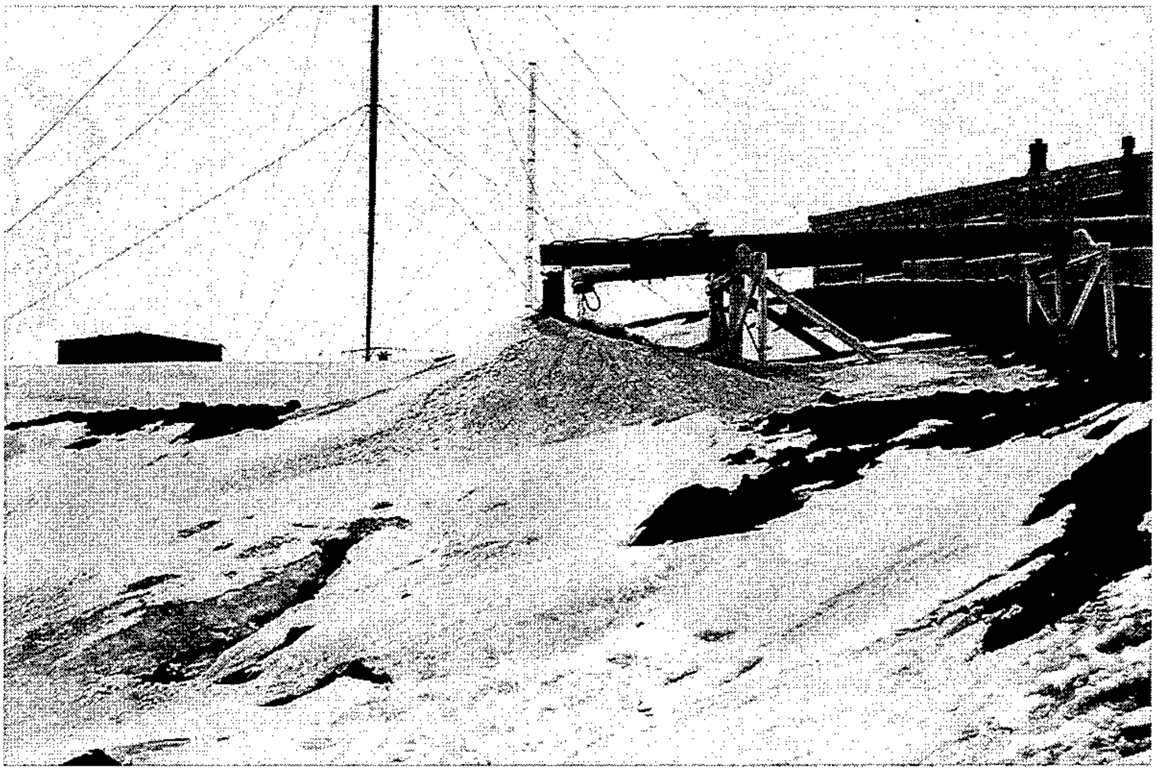

Figure 4: The domestic sewage and wastewater effluent outfall, Scott Base

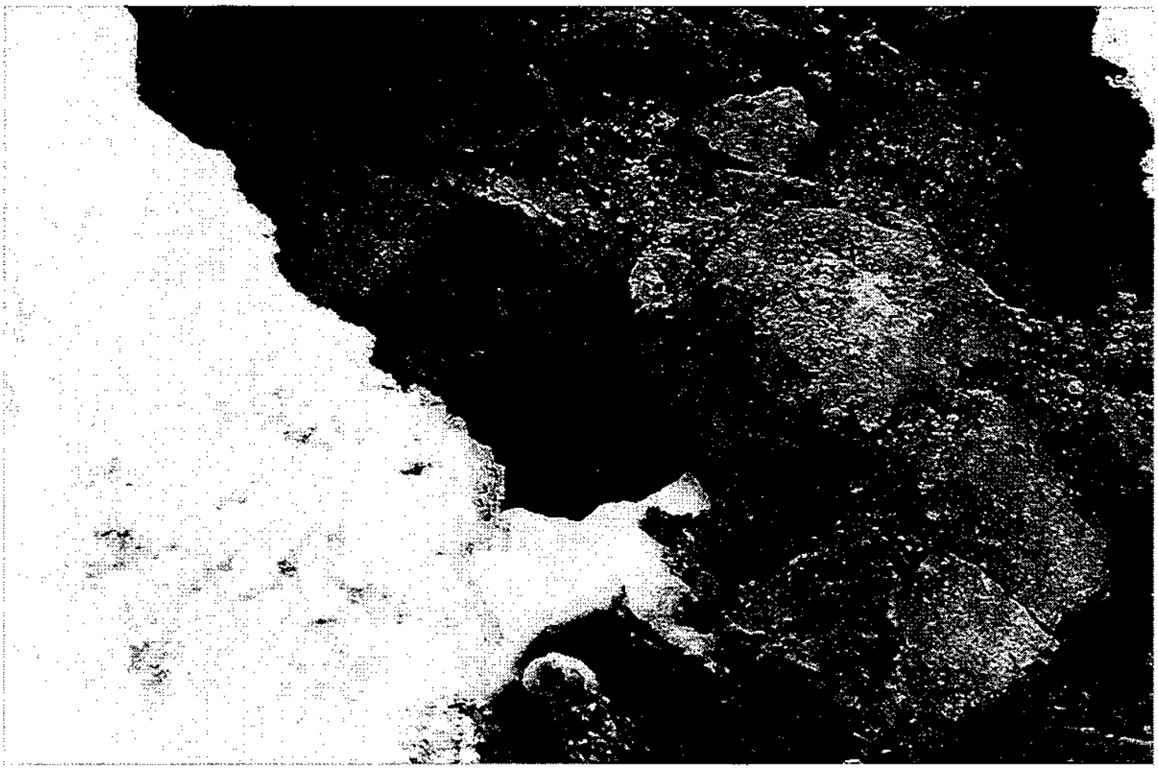

Figure 5: Sewage stream below Scott Base outfall flows down slope toward the sea. Accumulation of sewage occurs on the ground in the region of the outfall and sewage stream

Figure 6: Sewage and wastewater effluent point of entry into the sea. Note the foam from detergents in the lower left corner and the food scraps on the rocks in the centre of the photograph.

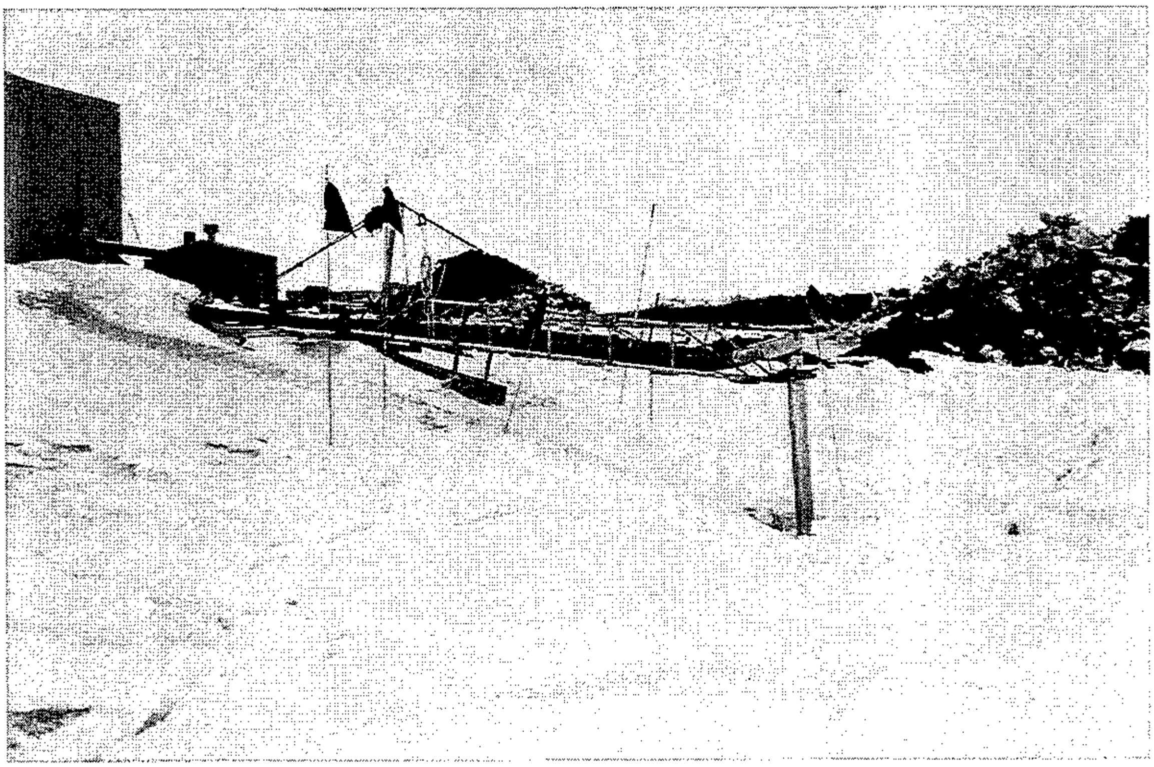

Figure 7: The reverse osmosis intake and brine return, Scott Base

Month	Lowest vol. of water used per day	Maximum vol. water used per day	Average used per day	Total water used during month	Water used per person
October	3,601	10,459	7,078	219,415	181
November	4,297	11,179	7,411	222,718	144
December (till 18 Dec)	4,036	10,585	8,002	144,035	164

Table 3: Volume of water used at Scott Base in October-December 1994 (in litres).

Figure 8: Wet laboratory outfall with the wet laboratory in the background, Scott Base

PREVIOUS STUDIES

No detailed studies have been conducted on the effects of sewage and wastewater discharges from Scott Base on the marine environment offshore from Pram Point.

In 1991, a quantitative SCUBA diver survey of the Pram Point reef slope was carried out in by Dr Chris Battershill of the National Institute of Water and Atmospheric Research (NIWA). The primary objectives of Battershill's project were to compare the marine communities with previously surveyed reef flat communities at Cape Armitage, to examine the relationships between the benthos and reef-associated fish populations, to design an environmental monitoring programme, and to assess the effects of wastewater discharge from Scott Base on adjacent benthic communities. Battershill (1992) found no evidence for any detrimental effect from sediment runoff or discharges from Scott Base on the marine community.

Sheppard *et al.* (in review) analysed the heavy metal content of meltwaters from the Ross Dependency of Antarctica. Eleven samples were collected from the Scott Base-McMurdo Station area. Sampling sites included ponds at Discovery Hut, streams to the south of Observation Hill, road drains on the McMurdo Station-Scott Base road, and melt-ponds in the Scott Base area. They found elevated concentrations of silver, mercury, lead, copper, cadmium, chromium, nickel and zinc in the Scott Base area, when compared to other areas sampled in the study. Furthermore, levels of trace metals in some Antarctic meltwaters are higher than in pristine waters in temperate climates such as New Zealand. Sheppard *et al.* (in review) inferred that the source of the trace metals is in particulate matter derived from materials introduced as a result of human activities.

In 1988, the Division of Polar Programs of the National Science Foundation (NSF) began a three-tiered programme of clean-up and abatement, rigorous recycling, and a scientific programme aimed at documenting the type, extent and biological impact of marine pollution in the region of McMurdo Station (Lenihan, 1992). This programme examined the concentrations of chemical contaminants, changes in community patterns, and the toxicity of sediments to invertebrate species and infaunal communities. Lenihan (1992) concluded that the primary contaminants in the region of McMurdo Station are petroleum hydrocarbons in the sediments and that the highest concentrations occurred in Winter Quarters Bay. Lenihan (1992) also stated that the total hydrocarbon levels were comparable to the levels recorded in the most polluted harbours in temperate latitudes.

Lenihan *et al.* (1990) studied the contamination and general changes in benthic communities around McMurdo Station. They found that benthic sediments and animals were highly modified by human activity. SCUBA diver surveys found anthropogenic debris, mainly in Winter Quarters Bay, the site of an old refuse tip. Analyses of marine sediment showed high levels of trace metals and hydrocarbons. Other workers (Lenihan *et al.*, 1990; Risebrough *et al.*, 1990; Kennicutt *et al.*, 1994; 1995; Liu *et al.* 1994) have found high levels of PCBs in both sediment and marine organisms in the region of McMurdo Station.

Previous studies of the benthic environment in front of McMurdo Station show that the area contains high levels of contaminants sourced from anthropogenic activities. High levels of contaminants have entered the food chain, with the highest concentrations of toxins confined to Winter Quarters Bay sediments. Contaminant concentrations beyond the bay decrease to near pristine conditions over a distance of a few hundred metres.

METHODS

Seven water samples (six of seawater, one of wastewater effluent) and 14 grab samples were collected. Sampling sites were chosen to provide an even distribution about the sewage discharge point but this distribution was limited by accessibility. Sampling localities are shown in Figure 2. At each site a one metre diameter hole was drilled in sea-ice using a hydraulic bucket auger and then a Shipek grab was used to collect the top 4 cm of the sea floor sediment. The majority of samples collected are of sponge spicule mat with abundant calcareous tests from dead organism and trapped fine particulates of indeterminate origin. The Shipek sample was then divided into 3 sub-samples for foraminifera studies, trace metal analysis, and archive.

Fifteen trace metal elements were analysed in outfall discharge, sea water and sediment using an induced coupled plasma-mass spectrometer (ICP-MS). Analytical methods are described in the Appendix.

RESULTS

Trace Metals

Wastewater and Seawater

Due to the cost and difficulty of analysing trace elements in a saltwater matrix, only two water samples have been analysed. Sample SV is of effluent and wastewater from the outfall, while sample 12SW is an effluent and seawater mix collected from Site 12 (Figure 6). At this site, minimal mixing of seawater and effluent had occurred because slumping of sea-ice had isolated the sewage entry point from the sea.

Results of ICP-MS analysis are presented in Table 4. Data represent the total recoverable (USEPA, 1979) fraction of metals in samples following microwave digestion with redistilled nitric acid.

The data presented for sample SV represents only the trace metal concentration in the effluent being discharged at the time of sample collection. A more representative measure of the trace metal composition of Scott Base sewage and wastewater would be obtained by collecting samples over an extended period of time. Sample SV shows elevated levels of copper, lead and zinc.

Mixed seawater and sewage wastewater effluent at Site 12SW contains high levels of copper, nickel, lead and zinc. Table 4 also contains the ANZECC (1992) trace metal level guidelines for the protection of aquatic ecosystems. The levels of copper, lead, nickel (only 12SW) and zinc in SV and 12SW exceed those recommended in the ANZECC guideline. The trace metal composition of Scott Base discharges (12SW) exceeds that of McMurdo Station for chromium, copper, nickel and zinc.

Sediment

Sediment samples were digested using cold redistilled nitric acid and analysed on an ICP-MS (Appendix). Trace metal concentrations of marine sediments off Pram Point are reported in Table 5 and in Figures 9a to 9m. Contouring for the figures was achieved using a statistical computer program, Systat™. Elemental concentration of marine sediments off McMurdo Station (McM) and at Winter Quarters Bay (WQB) (Kennicutt, pers. comm., 1995), as well as in front of the sewage outlet of McMurdo Station (SEW) (Lenihan *et al.*, 1990) are also included in the table for comparison. The TEL (threshold effect level) represents the level below which adverse effects are expected to rarely

Site	Ag	Al	As	Ba	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Ti	Zn
							Trace metals							
12SW	1.0	3290.0	7.4	18.5	1.0	1.9	25.7	1378.6	2766.7	60.9	19.5	23.9	737.8	3692.9
SV	0.6	1234.7	2.4	3.4	0.4	0.7	4.3	324.0	659.9	11.3	10.5	7.6	344.1	93.6
ANZECC	1.0	n.a.	50.0	n.a.	2.0	n.a.	50.0	5.0	n.a.	n.a.	15.0	5.0	n.a.	50.0
McMurdo	16.9	n.a.	11.0	n.a.	<7.1	n.a.	<12.9	834.0	n.a.	n.a.	15.9	53.7	n.a.	738.0
Det. lim.	0.04	2.78	0.02	n.a.	0.02	0.01	0.11	0.1	4.39	0.06	0.08	0.07	n.a.	n.a.

Table 4: Total recoverable trace metal concentrations (ppb) in wastewater effluent (SV) and mixed effluent-seawater 12SW. The table also includes; ANZECC guidelines from the Australian Water Quality Guidelines for Fresh and Marine Waters (1992); McMurdo wastewater concentrations (Crockett, 1994); and ICP-MS detection limits (Det. lim.) (ppb).

Site	Ag	Al ppm	As	Cd	Co	Cr	Cu	Fe ppm	Mn ppm	Ni	Pb	Ti ppm	Zn
						Trace metals (in ppb unless otherwise noted)							
1	45	12380	420	321	10490	2839	11480	9458	200	28650	11860	213	24000
2	37	19170	986	25	2807	1381	7154	3865	85	6698	30280	224	14380
3	223	16840	870	65	4173	2609	9230	4820	103	10600	9990	197	17720
4	28	6367	1275	436	2447	2082	10520	2395	138	12000	3020	121	26980
5	11	9880	610	493	4050	1714	10610	2530	101	9114	2200	111	31080
6	112	13910	1321	368	4941	3198	11230	5982	181	16650	2786	519	28640
7	48	4534	1021	290	1781	2287	9502	1943	101	10460	1715	206	20370
8	12	5821	1348	546	2260	1886	13360	1998	173	12730	2185	111	24940
9	15	6630	1330	830	2328	1796	10960	2112	158	12060	3168	112	27950
10	32	14970	833	89	4419	1501	5520	4637	106	11240	3416	226	15250
11	21	8042	1131	291	2818	1848	11320	2783	147	11330	1597	199	20770
12	199	10540	1276	986	3672	14240	2754000	5508	92	13420	91200	420	462200
12(p)	96	4484	1535	1482	2461	8744	2106000	3278	62	21060	35520	142	407000
12(s)	148	17200	732	712	5921	6021	1028000	7957	149	23170	31540	854	174600
13	74	11560	984	3578	3660	2167	9183	3948	110	11160	2349	447	25490
13(f)	25	18670	1515	2485	6027	5393	24700	7039	190	19420	4632	602	55530
14	175	4413	1879	762	1497	2199	8927	1910	117	11380	2693	192	27660
WQB	530	78700	6290	890	n.a.	196000	76600	72100	1320	71100	55700	n.a.	166000
McM	840	79000	7090	960	n.a.	193000	76800	77000	1390	77000	37700	n.a.	149000
SEW	600	n.a.	n.a.	3000	n.a.	n.a.	40000	n.a.	n.a.	70000	62000	n.a.	63000
TEL	730	n.a.	7240	676	n.a.	52300	18700	n.a.	n.a.	15900	30200	n.a.	124000
PEL	1770	n.a.	41600	4210	n.a.	160000	108000	n.a.	n.a.	42800	112000	n.a.	271000

Table 5: Trace metal concentration in sediment off Pram Point (sites 1 to 14), McMurdo Station, TEL and PEL. WQB and McM are trace metal data after Kennicutt (pers. comm., 1995) and SEW are trace metal data after Lenihan *et al.* (1990). TEL (threshold effect level) and PEL (probable effect level) are after Smith *et al.* (in review). Sample names represent the site number. Three analyses are listed for Site 12. 12(p) is of fibrous organic material thought to be toilet paper, 12(s) is of other material excluding the paper and 12 represents the whole sample before the (p) &(s) fractions were separated. Sample 13(f) represents the trace metal concentration in fine grained suspended material collected by centrifugation, while sample 13 represents the whole sample.

occur and is generally recommended as an interim Canadian sediment quality guideline (Smith *et al.*, in review). The PEL (probable effect level) on the other hand defines the concentration above which adverse effects are predicted to occur frequently and concentrations which fall in the range between the TEL and the PEL are occasionally expected to be associated with adverse biological effects (Smith *et al.*, in review).

Elements analysed for in Scott Base sediment samples can be grouped as 1) exceed PEL, 2) exceed TEL but below PEL, 3) below TEL and 4) those elements not used in the TEL/PEL classification.

Exceed PEL

Copper concentrations (Figure 9a) are extremely high close to the sewage entry point, being 200 orders of magnitude higher than in the remaining sites. The concentration of copper is over 0.27% at site 12 and exceeds the PEL (108000 ppb) by more than 25 times the value. Sediment from Winter Quarters Bay and the McMurdo Station outfall contain an average of 76000 ppb of copper (Kennicutt, pers. comm., 1995). Lenihan *et al.* (1990) measured 40000 ppb copper in front of the sewage outfall of McMurdo Station. The highest Zn levels (Figure 9b), which are recorded at site 12 (462200 ppb), exceed the PEL of 271000 ppb. Elevated levels also occur at site 5 (131080 ppb), over the TEL (124000 ppb), while concentrations are considerably lower at the other sites. Sediments from Winter Quarters Bay and off McMurdo Station contain up to 166000 ppb Zn (Kennicutt, pers. comm., 1995).

Exceed TEL but below PEL

The highest concentrations of lead (Figure 9c), which are found at site 12 (91200 ppb) exceed the TEL (30200 ppb) and are close to the PEL (112000 ppb). Pb levels decrease with increasing distance from the source point (sewer outfall), with levels exceeding the TEL at site 2 (30280 ppb). Sediments from Winter Quarters Bay contain an average of 55700 ppb Pb, while they average 37700 ppb at the McMurdo Station outfall (Kennicutt, pers. comm., 1995). Lenihan *et al.* (1990) measured 62000 ppb Pb in front of the sewage outfall of McMurdo Station. The concentration of cadmium in sediment shows a complex pattern (Figure 9d). The highest level of 3578 ppb is recorded at site 13, while the next highest concentration is found at site 12 (986 ppb). Cd concentrations at sites 9, 12, 13 and 14 exceed the TEL of 676 ppb. Levels of up to 960 ppb were recorded in front of McMurdo Station (Kennicutt, pers. comm., 1995), and concentrations of up to 3000 ppb were measured in front of the sewage outfall of McMurdo Station (Lenihan *et al.*, 1990). The highest Ni levels are recorded at site 1 (28650 ppb) (Figure 9e), and this exceeds the TEL of 15900 ppb.). Ni concentrations in sediment in front of McMurdo reach 77000 ppb (Lenihan *et al.*, 1990; Kennicutt, pers. comm., 1995).

Below TEL

Highest silver concentrations (Figure 9f) occur at sites 3 and 12 (223 ppb and 199 ppb, respectively). Levels generally decrease with increasing distance from the shoreline, except for site 14, which displays an anomalous high concentration (175 ppb). Ag concentrations are lower than those measured off McMurdo Station. Arsenic concentrations (Figure 9g) range from 420 ppb (site 1) to 1879 ppb (site 14 - a distant site). There appears to be no distinct pattern in relation with sewer or lab outfall. Substantially higher levels of ~7000 ppb arsenic have been measured in sediment in front of McMurdo Station. The highest concentrations of chromium (Figure 9h) occur at the point sewage and wastewater enters into the sea at site 12 (14240 ppb). Levels decrease with increasing distance from the source point. Elevated concentrations were recorded in front of McMurdo station (Kennicutt, pers. comm., 1995).

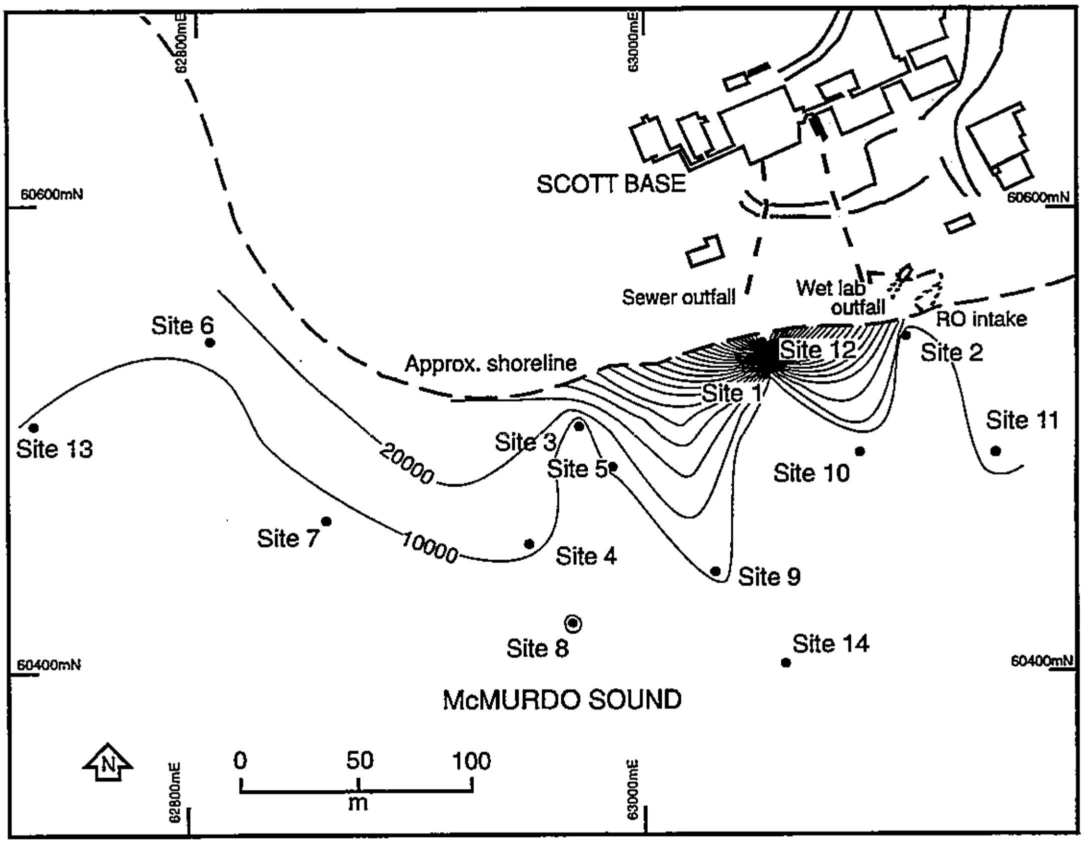

Figure 9a: Copper distribution in sediment off Pram Point (concentrations in ppb)

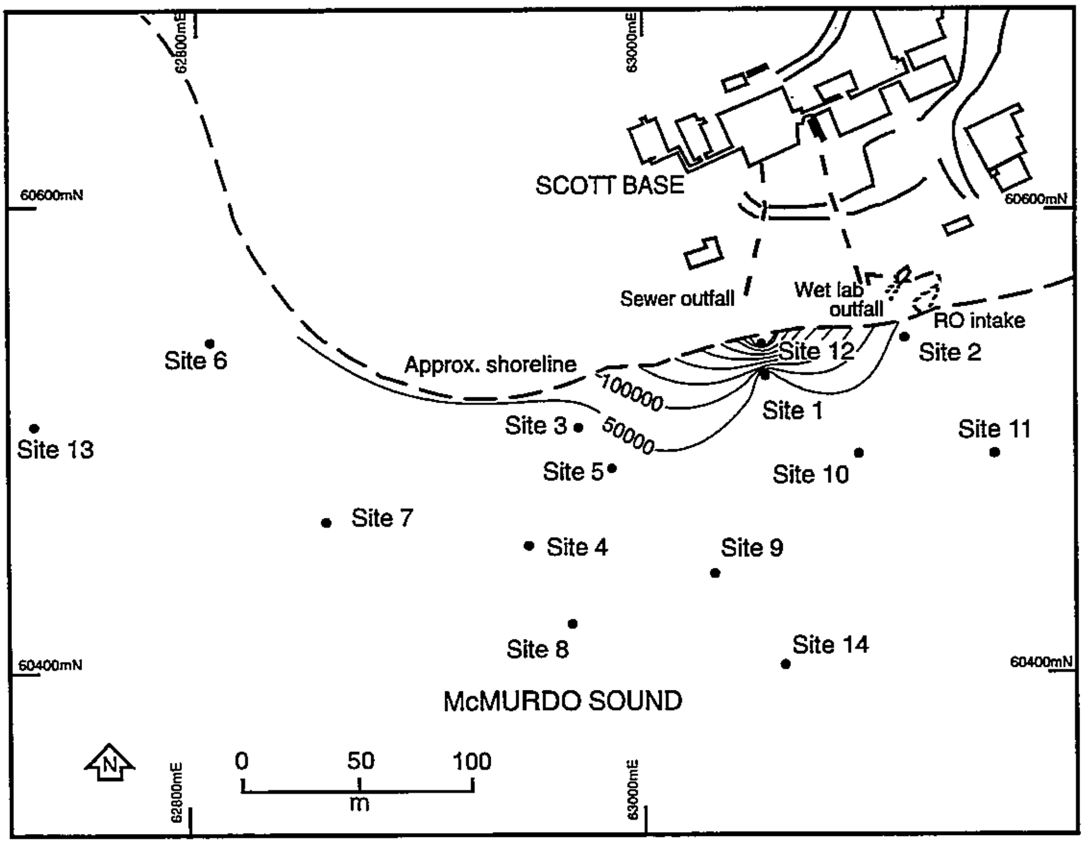

Figure 9b: Zinc distribution in sediment off Pram Point (concentrations in ppb)

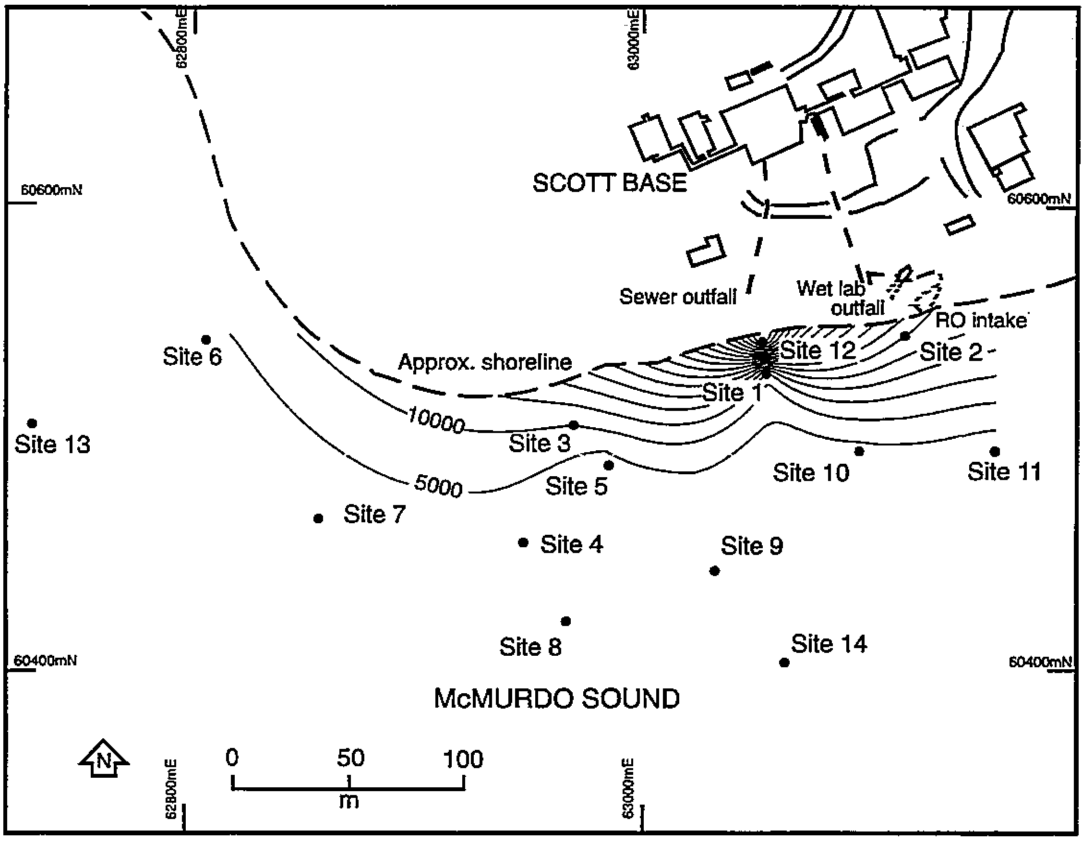

Figure 9c: Lead distribution in sediment off Pram Point (concentrations in ppb)

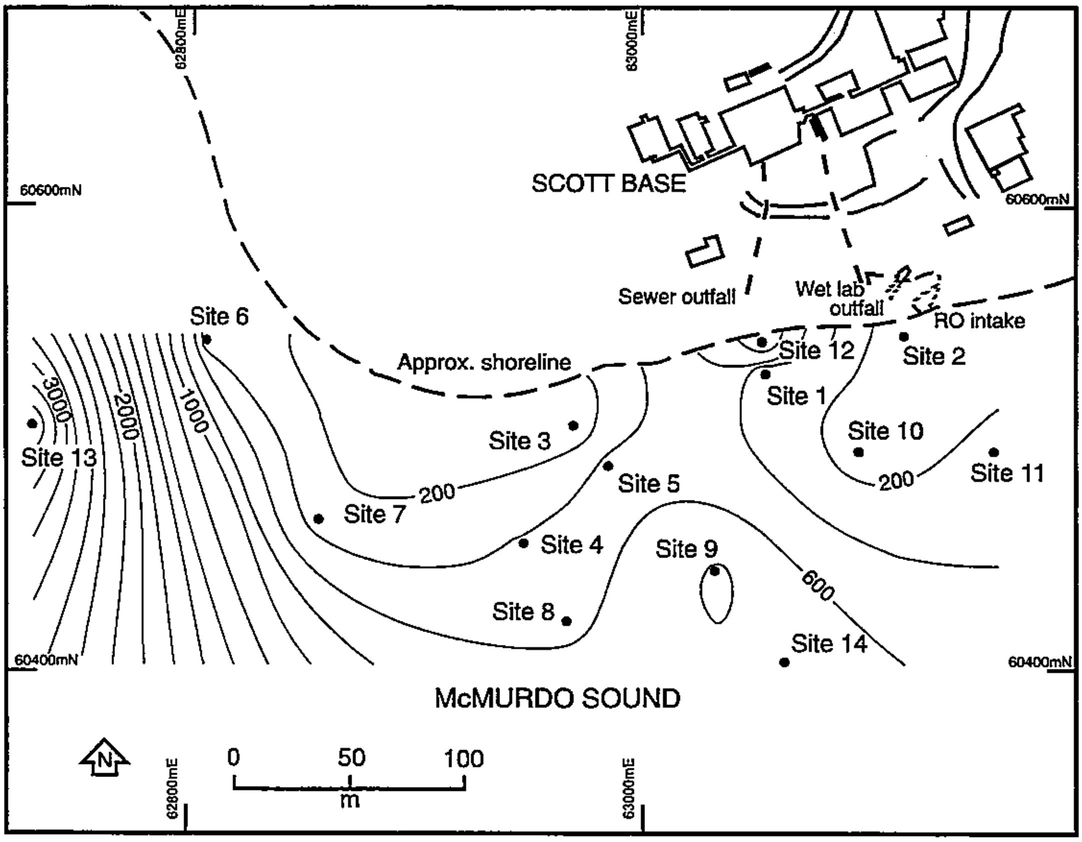

Figure 9d: Cadmium distribution in sediment off Pram Point (concentrations in ppb)

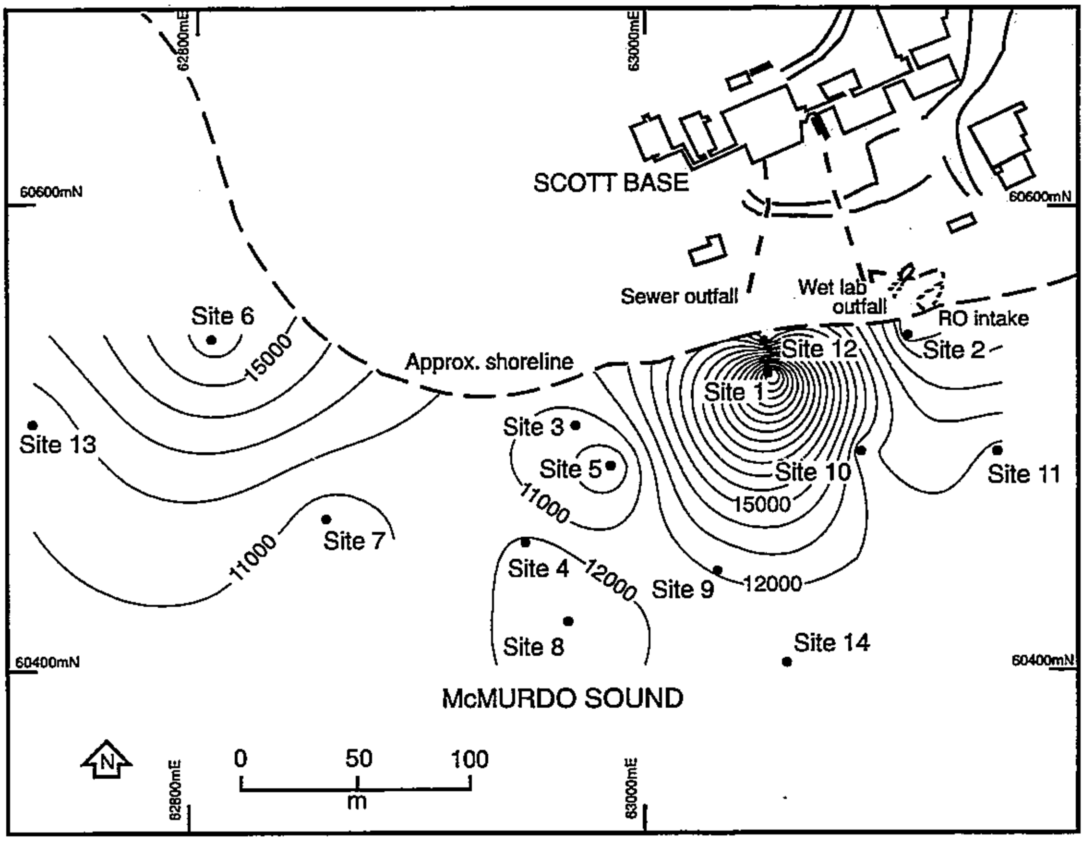

Figure 9e: Nickel distribution in sediment off Pram Point (concentrations in ppb)

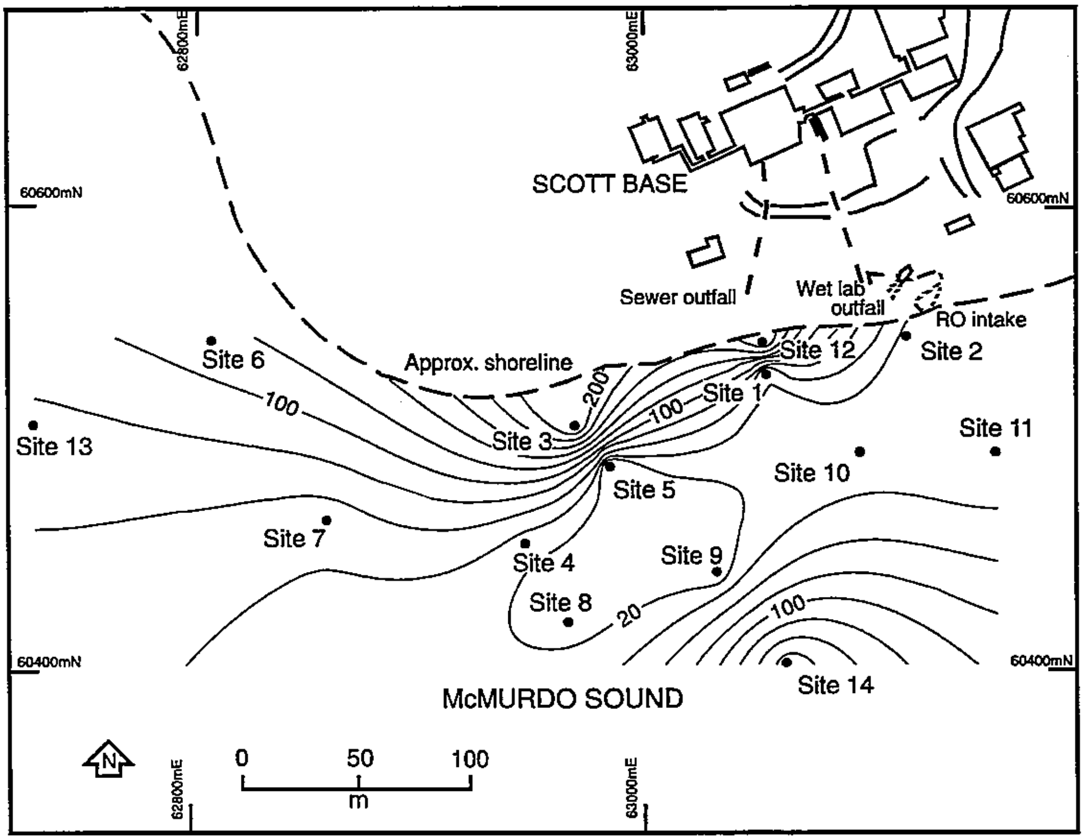

Figure 9f: Silver distribution in sediment off Pram Point (concentrations in ppb)

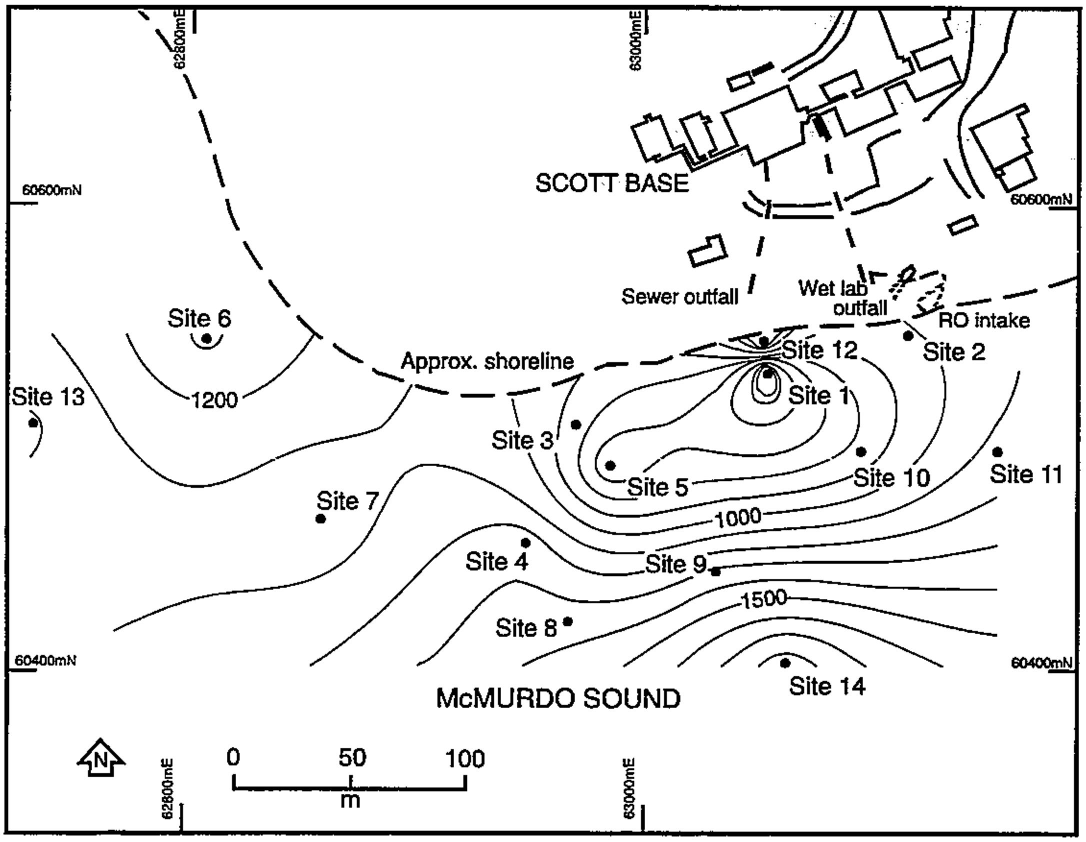

Figure 9g: Arsenic distribution in sediment off Pram Point (concentrations in ppb)

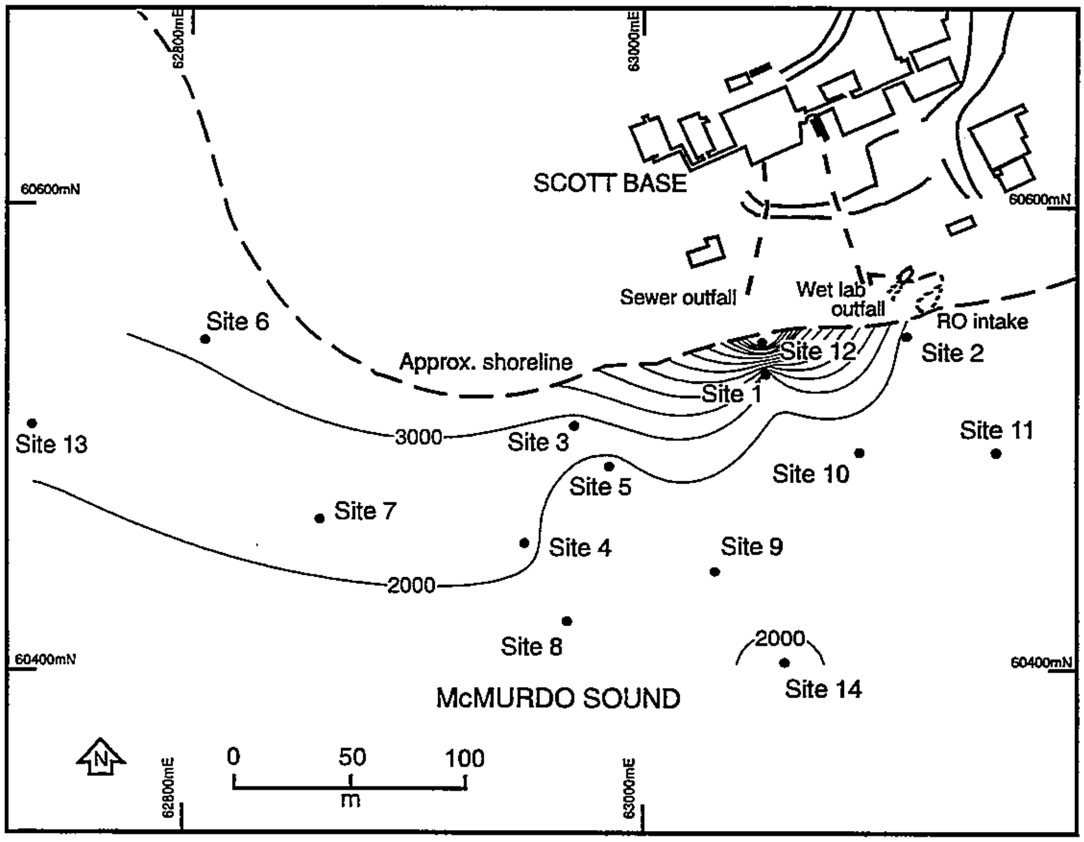

Figure 9h: Chromium distribution in sediment off Pram Point (concentrations in ppb)

Elements not included in the TEL/PEL classification

The following elements have not been included in the PEL/TEL classification scheme of Smith *et al.* (in review); Al, Co, Fe, Mn, Ti. Aluminium concentrations (Figure 9i) range from 4500 ppm (site 7) to 19700 ppm (site 2), and show a general decrease with increasing distance from the coastline. The highest concentration of cobalt (Figure 9j) is found at site 1 (10490 ppb). The next highest level is recorded in the fine fraction of the sediment at site 13. Iron concentrations in Pram Point sediment (Figure 9k) range from 1910 ppm (site 14) to 9458 ppm (site 1) while at Winter Quarters Bay and McMurdo Station, Fe levels reach 76800 ppm (7.6%). The highest Mn concentration is recorded at site 1 (200 ppm) (Figure 9l). There appears to be no distinct pattern of Mn distribution in relation with the sewage outfall. Sediments in front of McMurdo Station reach levels of 1390 ppm Mn. Titanium is not normally used as an environmental indicator but it has been noted that this element is highly concentrated in sediment close to the sewage and wastewater entry point (Figure 9m). Titanium is a major component of volcanic rocks and is also used in special "corrosion resistant" metals and is a very common component of paints. Elevated titanium concentrations occur at sites 6, 12 and 13 (519 ppm, 420 ppm and 447 ppm, respectively).

Foraminifera

From sediment of 14 sampling sites at Pram Point, over 5000 benthic foraminifera of 28 different species were identified. A foraminiferal faunal list and population count are detailed in Table 6. Sample populations ranged between 0 and 545 specimens. Except for sites 2 and 12, sample sizes are above 250. At site 2, only one foraminifer was found in 34 g of sediment and no specimens were found at site 12 although the sample collected from this site contained large concentrations of ostracoda. At the remaining sites a common association of the five following species was observed: *Ehrenbergina glabra, Cribrostomoides jeffreysii, Trifarina earlandi, Cassidulinoides porrectus and Rosalina globularis.* This association of five species forms between 79 - 92% of the total specimens.

The foraminifera assemblages at sites 4 to 11, 13 and 14 were relatively similar and were dominated by *E. glabra.* This species formed between 34 and 74% of the total population. The next most abundant form at these sites was *C. jeffreysii.* At Sites 1 and 3 the percentage of E. glabra was lower; 11 and 14%, respectively and the assemblages were dominated by *C. porrectus, T. earlandi, C. jeffreysii* and *R. globularis* (Table 6).

Statistical Analysis

Cluster analysis and principal component analysis (PCA) are forms of multivariate analyses that have been applied to Pram Point foraminifera data. Cluster analysis classifies (or identifies) discrete groups within a data set, and principal component analysis is an ecological ordination method, which is the ordering or arranging of samples or variables in an ecological space in relation to environmental gradients (Shi, 1993).

The raw data in Table 6 was edited by the removal of outliers, which may be the result of sampling failures or which may represent forms of very low diversity. This allowed the data to be effectively manipulated by multivariate methods and the computer programs used (Shi, 1993). Specifically, the Pram Point data was modified by the removal of site 2 because it contained only one foraminifer, and of site 12 because it contained no foraminifera, as well as the removal of species with only one representative. Data was then transformed to remove the effects of the different total population counts by converting each species count to the relative abundance (percentage) of the species at that site.

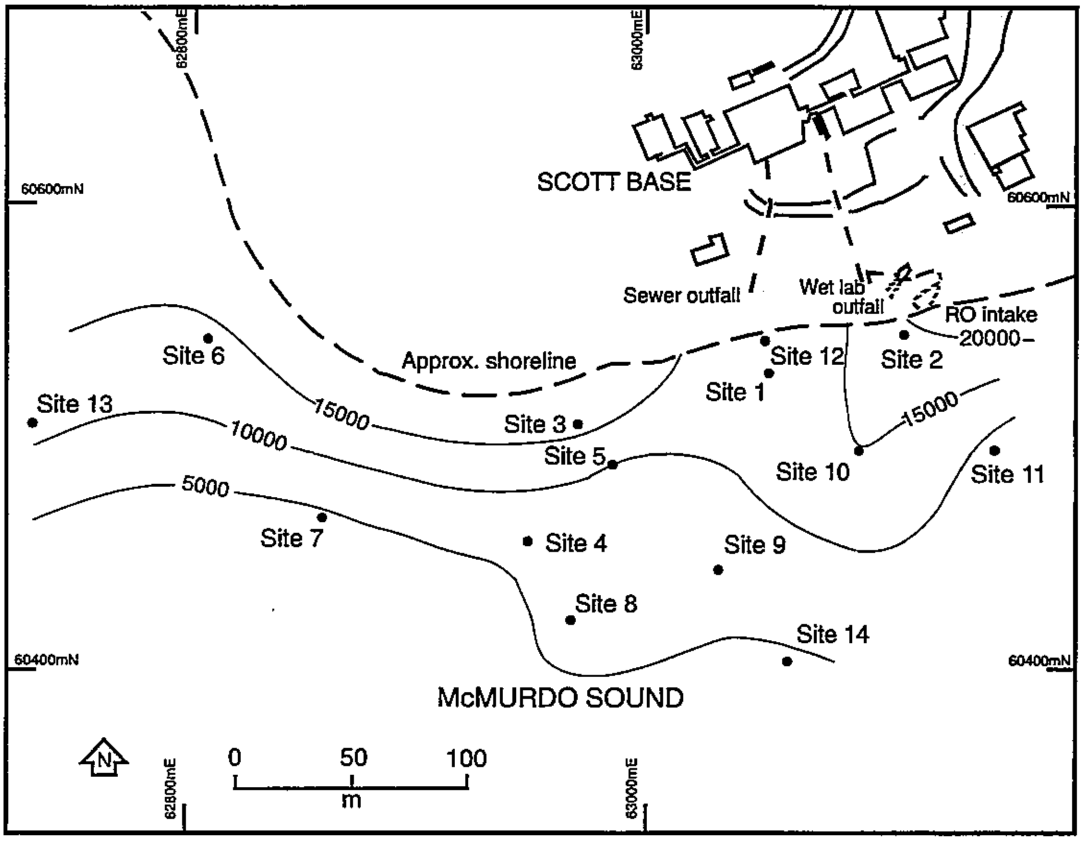

Figure 9i: Aluminium distribution in sediment off Pram Point (concentrations in ppm)

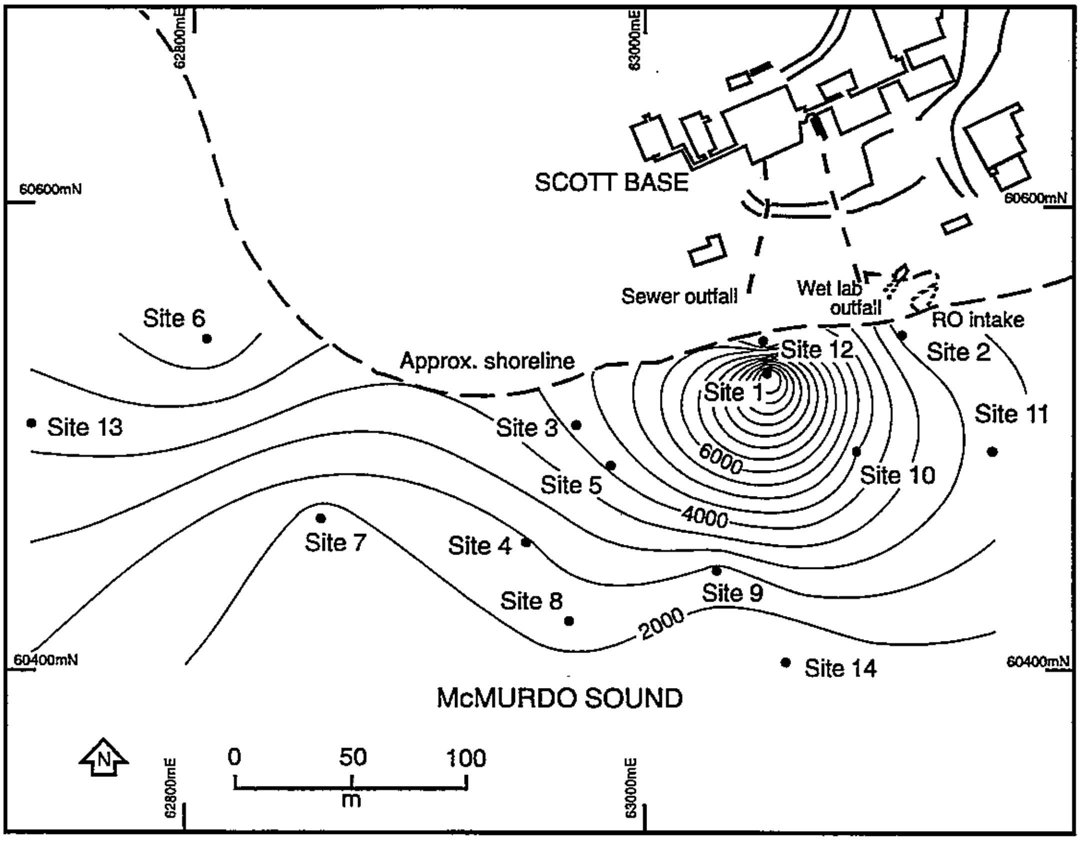

Figure 9j: Cobalt distribution in sediment off Pram Point (concentrations in ppb)

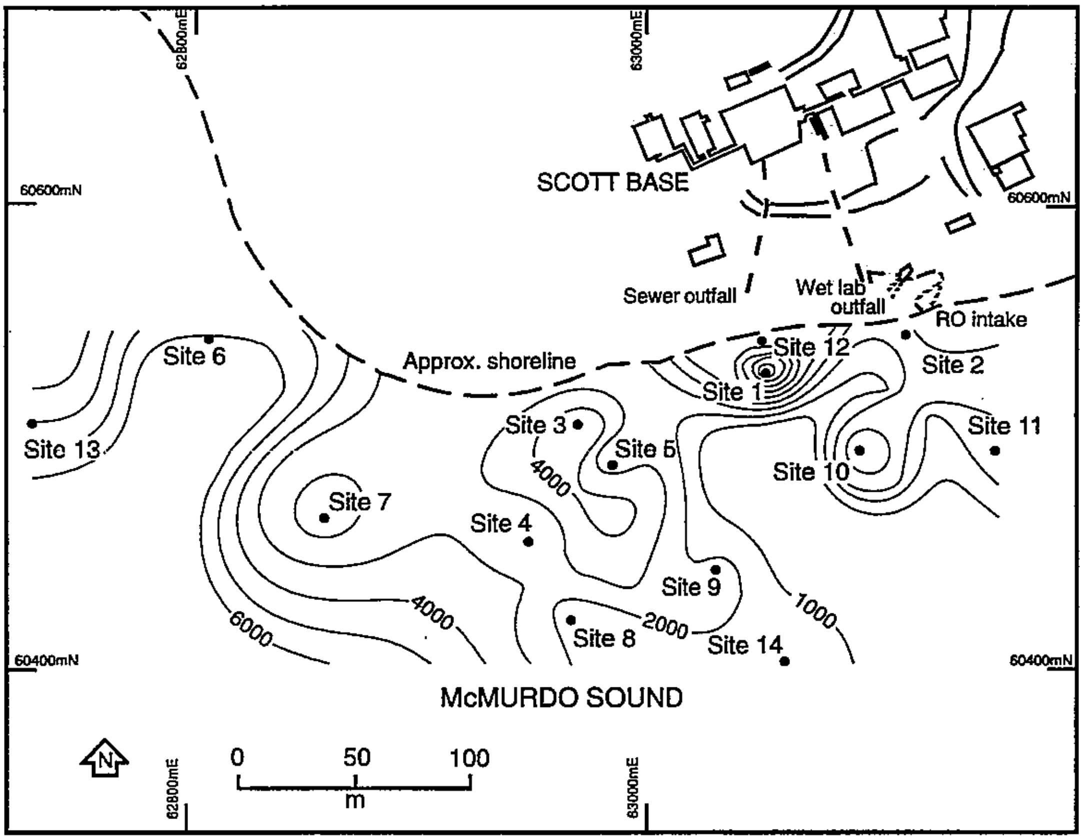

Figure 9k: Iron distribution in sediment off Pram Point (concentrations in ppm)

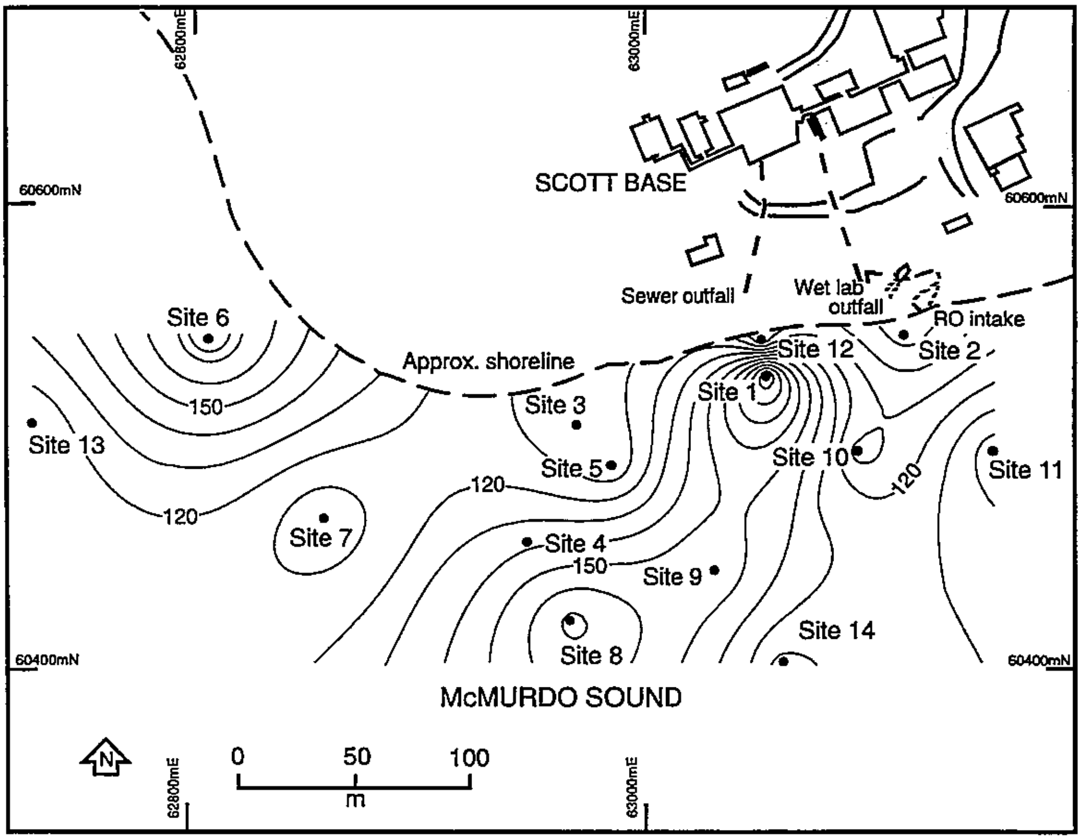

Figure 9l: Manganese distribution in sediment off Pram Point (concentrations in ppm)

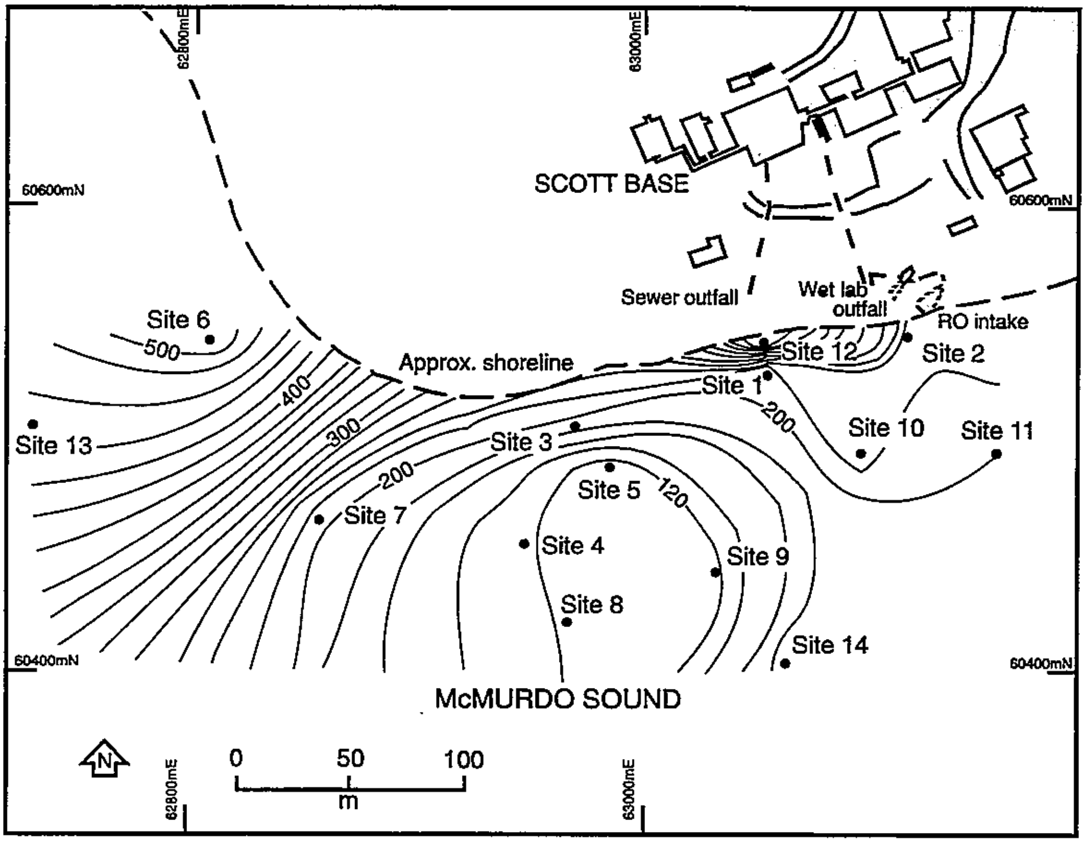

Figure 9m: Titanium distribution in sediment off Pram Point (concentrations in ppm)

Site Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Total counted	283	1	251	402	269	385	545	481	512	471	531	0	397	403
Species														
Ehrenbergina glabra	31		34	298	162	272	405	340	327	213	271		135	254
Cribrostomoides jeffreysii	81		27	36	35	31	42	49	46	21	40		27	27
Trifarina earlandi	28		66	13	23	20	19	11	33	73	15		92	24
Cassidulinoides porrectus	91		49		1	7	10	5	12	87	48		56	33
Rosalina globularis	18		49	18	22	22	31	29	42	16	83		11	26
Cibicides lobatulus	2		5		7	3	8	9	3	22	7		22	7
Globocassidulina crassa	17		1	7	6	8	3	6	12	6	4		9	1
Pullenia subcarinata		1	1	3	3	5	1	7	6	22	5		23	7
Patellina corugata	1		10	17	1	10	2	4	5		4			2
Portatrochammina antarctica	4			1	5			2	8	1	33		4	7
Astrononion antarcticum	4		1	1	1	2	4	9	3	4	8		6	6
Cyclogyra involvens			1	3		2	9		1		7		3	1
Pseudobulimina chapmani			2		1	1	4	3	2	2	4		1	3
Planispirinoides bucculentus	1		3		1	1	2		2	1			3	1
Nonionella iridea	5			1	1									
Spirillina radiosa				1				2	4		1			
Fissurina marginata			2				1	1						1
Fissurina subformosa						1			2				3	
Fissurina semimarginata								1						
Fissurina tingellifera								1						
Fissurina mennellae									1					
Cruciloculina triangularis				1				1	2					1
Polymorphina sp.							2		1		1			
Oolina striatoppunctata				1			1	1		2				
Oolina melo														2
Pyrgo elongata				1			1						1	
Glandulina antarctica													1	
Sigmoilina umbonata										1				

Table 6: Foraminiferal faunal list and population counts from sediment samples, Pram Point

Cluster analysis using the single linkage method was conducted on transformed percentage total foraminifera assemblages at each site using a statistical program, Systat™. Cluster analysis results are shown graphically in a two-dimensional dendrogram (Figure 10). The distances reported at the top of Figure 10 represent the Euclidean distance, which is a measure of similarity between sites. Cluster analysis identifies four main groupings of sites: sites 1 and 3, sites 13, 10 and 11, sites 5, 9 and 14 and a final grouping of sites 7, 8, 6 and 4 (Figure 10). Although not included in the cluster analysis and therefore unable to be compared directly, sites 12 and 2 form a distinct "fifth" group because of their lack of, or absence of foraminifera in the samples. The assemblages of sites 1 and 3 have a high degree of similarity but vary greatly from the second cluster of sites. The second cluster (sites 13, 10 and 11) is also noticeably different from the other clusters. There are only minor differences in Euclidean distance between the third group (sites 8, 7, 6 and 4) and the fourth group (sites 5, 9 and 14). This indicates that the assemblage composition of the last two vary by only a minor amount.

A problem identified with cluster analysis is that a dendrogram is a two-dimensional plot and therefore it does not show the relationships of clusters to underlying environmental gradients nor the graduations between clusters (Warshauer and Smosna, 1981). These problems are overcome using principal component analysis (PCA) (Shi, 1993). PCA is an indirect ordination method that reduces large data sets to a more manageable size. The method involves finding linear combinations of variables so that the first component loading has the maximum variance. Subsequent component loading scores are also linear combinations of the maximum possible variance and are uncorrelated to the first loading. The sum of the variances of the original variables is the same as the sum of the new variables (principal component loadings) (Srivastava and Khatri, 1982).

Table 7 lists the component loadings of a PCA ordination of Pram Point foraminifera data. Again sites 2 and 12 were excluded from the analysis for the reasons outlined above. The percentage of total variance explained by the three component loadings are 82.080%, 13.047% and 2.892%, respectively. The majority of the variance is explained by component loadings 1 and 2.

Sites		**Component Loadings**	
	1	**2**	**3**
Site 1	0.404	-0.801	0.439
Site 3	0.526	-0.771	-0.292
Site 4	0.973	0.214	0.046
Site 5	0.985	0.111	0.021
Site 6	0.982	0.181	0.021
Site 7	0.979	0.199	0.033
Site 8	0.977	0.199	0.062
Site 9	0.988	0.145	0.016
Site 10	0.958	-0.168	-0.084
Site 11	0.971	0.041	0.045
Site 13	0.889	-0.314	-0.227
Site 14	0.993	0.102	0.019

Table 7: Principal component loadings for transformed foraminifera population data from Pram Point

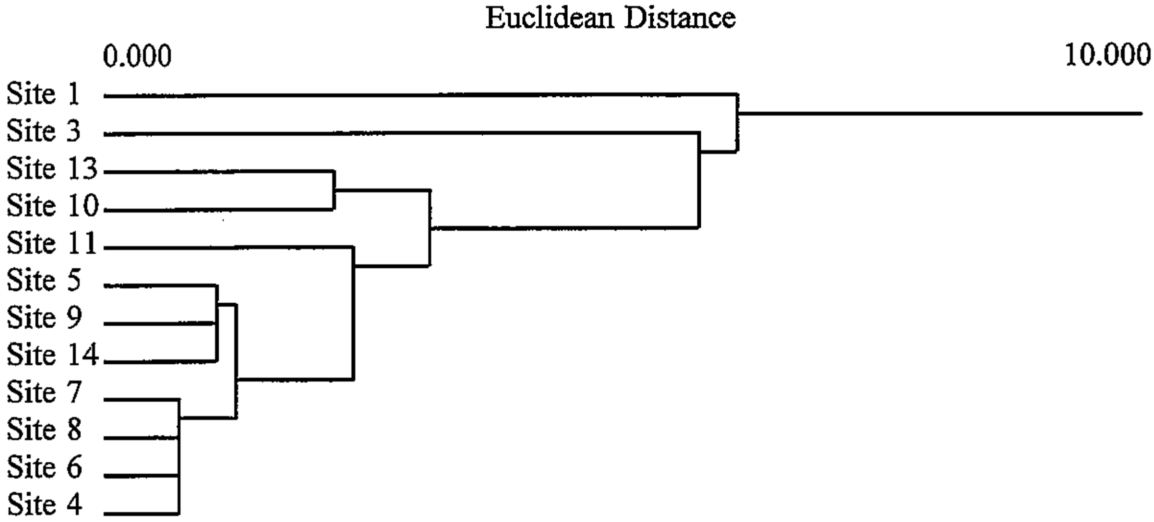

Figure 10: Dendrogram of Pram Point foraminifera data calculated using the single linkage method.

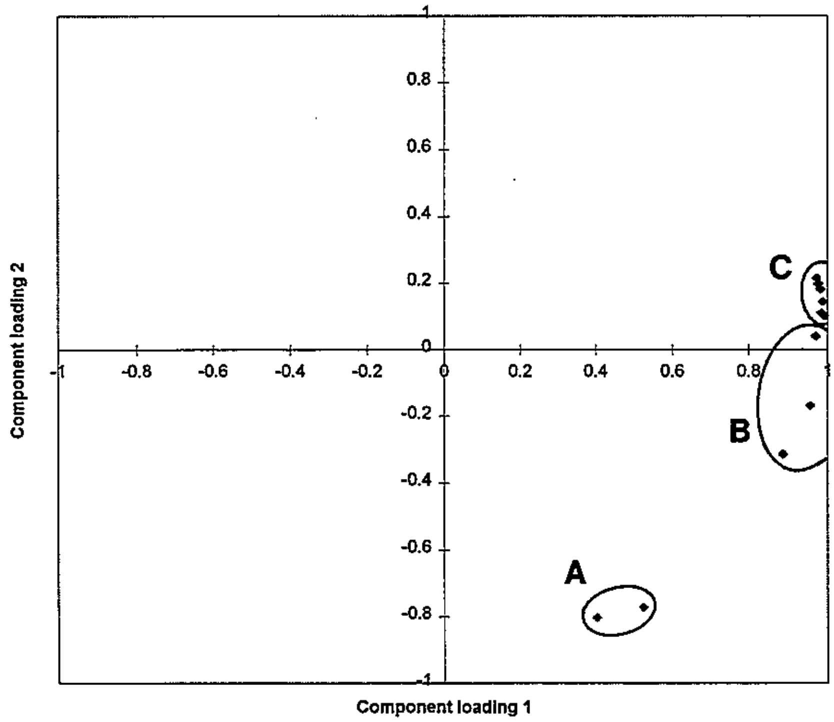

Figure 11: Component loading 1 against component loading 2. This figure shows the sampling sites grouped into three areas. These groups are; A. sites 1 and 3, B. sites 13, 10 and 11, and C. the remaining sites.

The component loading scores for sites 1 and 3 are significantly different from the majority of other sites (sites 4-9, 11 and 14) and this larger group shows only minor variation of about 0.98. With a CL1 score of 0.889, site 13 also varies from the majority of sites. The trend observed in CL1 is repeated in the scores for component loading 2 (CL2). However there is an increase in the variance of loadings for sites 10, 11 and 13. The pattern shown in component loading 2 is repeated in component loading 3. A plot of component loading 1 against component loading 2 shows that the sampling sites can be grouped in three areas (Figure 11).

DISCUSSION

Sediment contamination off Pram Point appears to be restricted to the area closest to the sewage outfall (site 12) for copper, zinc, lead and chromium. Levels of Cu, Pb and Zn at this site largely exceed the TELs (Smith *et al.*, in review). Cu concentrations in particular are at least one order of magnitude higher than the PELs, while Zn levels are almost twice the PELs. High levels of Cu, Zn and Pb in the sediments near the sewage outfall outlet are directly related to sewage effluent discharge, as shown by similarly high concentrations in the water sample taken from the sewage effluent (12SW). These trace metals are most likely to result from plumbing at Scott Base. The present configuration of the outfall does not allow for rapid dispersal of sewage and wastewater effluent. The point where sewage enters the sea is only one metre deep and in December 1994 it became isolated because of slumping of sea-ice. Current measurements at selected sites show that current velocities are low (Table 2). Both low current velocities and shallow sewage entry point probably contribute to accumulation of high trace metal levels in sediment at closest proximity to the sewage outlet (at site 12).

Other trace metals display a complex distribution pattern in the sediments of Pram Point. Although Cd levels are high at site 12, they are three times higher at site 13, suggesting possible resuspension and redeposition. Ag, As and Ni distribution also suggests mobilisation and redeposition. Similarly, Cd and Ni concentrations were higher at the reference sites (non impacted sites) than at the sites near the outfall outlet of McMurdo station (Lenihan *et al.*, 1990).

Fe, Al and Ti are common components of basaltic rocks, which constitute the geology of Hut Peninsula and their distribution in sediments off Pram Point does not suggest any direct relation to anthropogenic activity.

Normalisation to Fe or Fe has been used in previous studies (e.g. Rule, 1986; Din, 1992) to compensate for mineralogical and grainsize variability in the chemical composition of sediments. However, in the present study, no relationship was found between trace metals and Al or Fe. Similarly, no correlation was found between trace metal concentration and percentage silt and clay fraction in a previous study of sediments off McMurdo Station (Lenihan *et al.*, 1990). Elemental distribution in sediments off Pram Point cannot be solely explained in terms of grainsize variability. Elevated levels near the sewage outlet clearly indicate anthropogenic input, while localised high concentrations may suggest transport and redeposition. Previous studies of sediments off McMurdo Station (Lenihan *et al.*, 1990; Kennicutt *et al.*, 1995) also show that contamination of sediments as a result of human occupation is generally limited to the close proximity to human source.

At site 12 high metal levels occur concurrently with the absence of foraminifera. The elevated concentrations of Cu, Zn and Pb are likely to have a toxic influence on the benthic fauna (Smith *et al.*, in review). The decrease in the trace metal concentrations below the TELs with increasing distance from the sewage effluent outlet coincides with a marked increase in foraminifera population (from 0 to 251 specimens and greater). This is further evidence for the effect of contaminants in sediments on the benthic fauna.

The near absence (only one specimen) of foraminifera at site 2, which is located in front of the reverse osmosis intake, appears to be caused by a change of temperature and/or salinity rather than high levels of contaminants. As shown in Table 5 and Figures 9a to 9m, trace metal concentrations at site 2 do not exceed the background levels, except for Pb. Lead levels at this site are equal to the TELs. Previous studies (e.g. Thorp and Gibbons, 1978) show that water temperature has a substantial effect on the functioning of aquatic ecosystems and the physiology of biota. ANZECC (1992) provides a guideline of a 2°C change from the natural ambient temperature before effects are recorded. While seawater maintains a temperature of -1.9°C in Antarctic, the brine from the RO plant is returned at the intake site at 12-14°C. The change of temperature appears to have a negative effect on the foraminifera population. This is supported by video observations, which show that the area is barren except for mobile infauna.

The distribution and abundance of foraminifera is affected by abiotic factors such as temperature, salinity, dissolved oxygen availability, pH, etc. and by biotic factors such as food, competition, predation (Murray, 1991). Changes in environmental conditions or ecological disturbances are rapidly reflected in foraminifera assemblages (eg Siegle, 1968; Bates and Spencer, 1979; Schafer *et al.*, 1991; Alve, 1991; Corliss and van Weering, 1993). Figures 12a-c show contoured plots of component loadings from Table 7 superimposed on a Scott Base sampling site map. Figure 12a maps component loading 1 and shows low component loadings scores at sites close to the sewer outfall (sites 1 and 3) and a steep gradient in the loading scores to the more distant sites. In figure 12b, which illustrates component loading 2, there is a trend of low negative factors at sites 1 and 3 and an increase in loading values at sites more distant to the outfall region. The exception is site 13 that has consistently shown a component loading signature similar to sites close to the outfall.

The sites highlighted as significantly different in the statistical analyses are 1, 3 and followed to a lesser extent 13, 10 and 11. The underlying cause for these statistical differences appears to be the reduction in the abundance of *E. glabra* and an increase in the percentage of the other dominant species. This is particularly noticeable in the differences in distribution of *E.glabra* and *C. porrectus.* At sites of low *E. glabra* there is a corresponding increase in the number of *C. porrectus*. This trend is repeated in the other dominant species but the variations are less.

A variable that shows a large change in the Pram Point study area is water depth. If water depth were the variable that was causing the changes in foraminifera distribution then a correlation between water depth and component loadings would be observed. Figure 13 shows the component loadings graphed against water depth at each sampling localities. Multiple regression lines of best fit and R^2 for component loadings versus water depth show that the correlation between these variables is very poor. R^2 of 0.25, 0.22 and 0.03 for component loadings 1, 2 and 3 respectively suggest that water depth is not the environmental variable that is controlling the distribution of foraminifera at Pram Point.

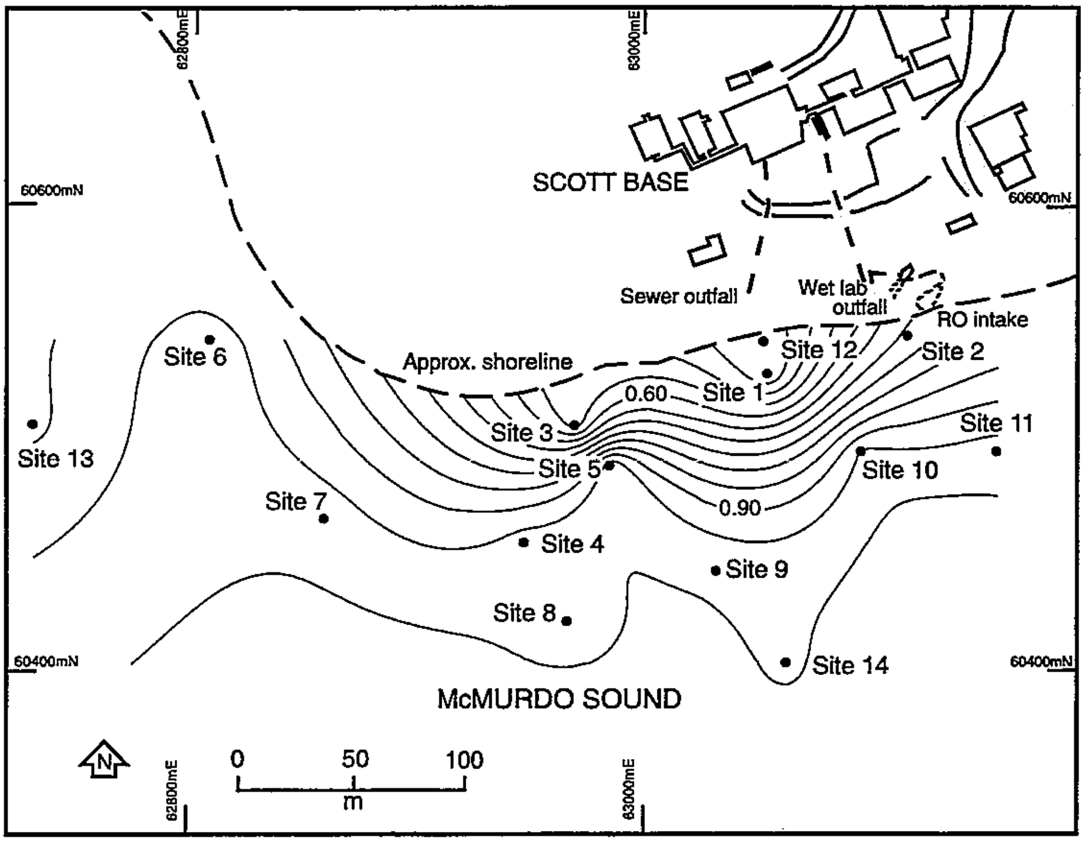

Figure 12a: Contour plot of component loading 1

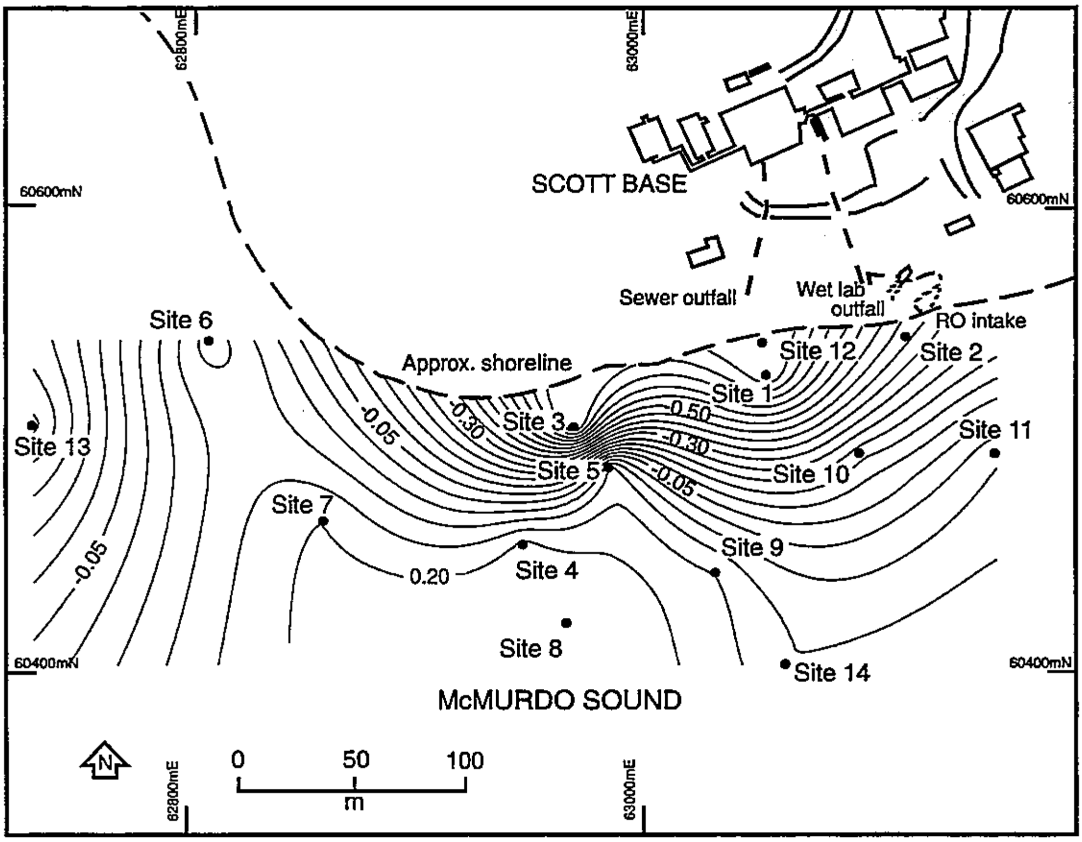

Figure 12b: Contour plot of component loading 2

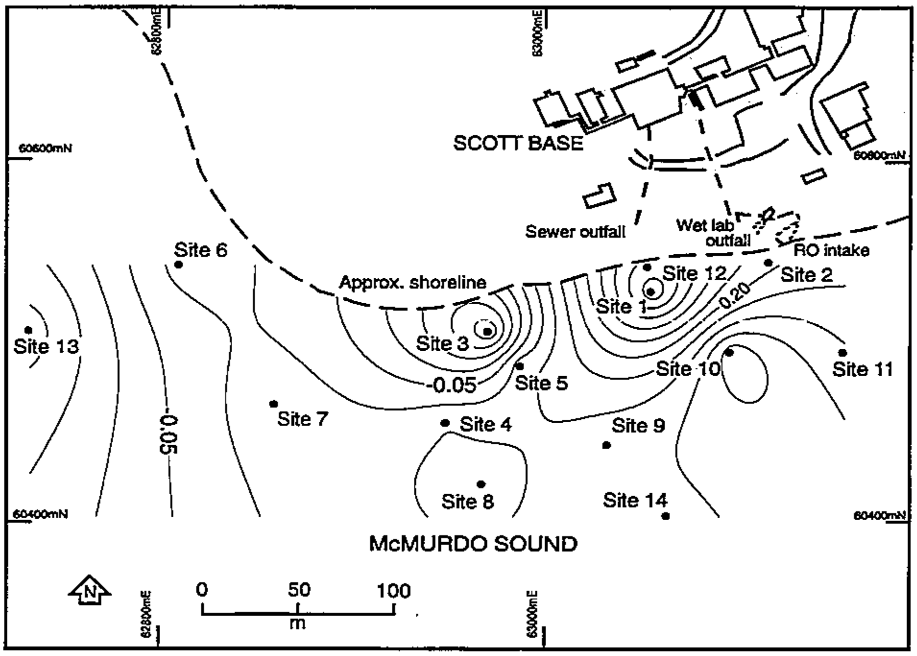

Figure 12c: Contour plot of component loading 3

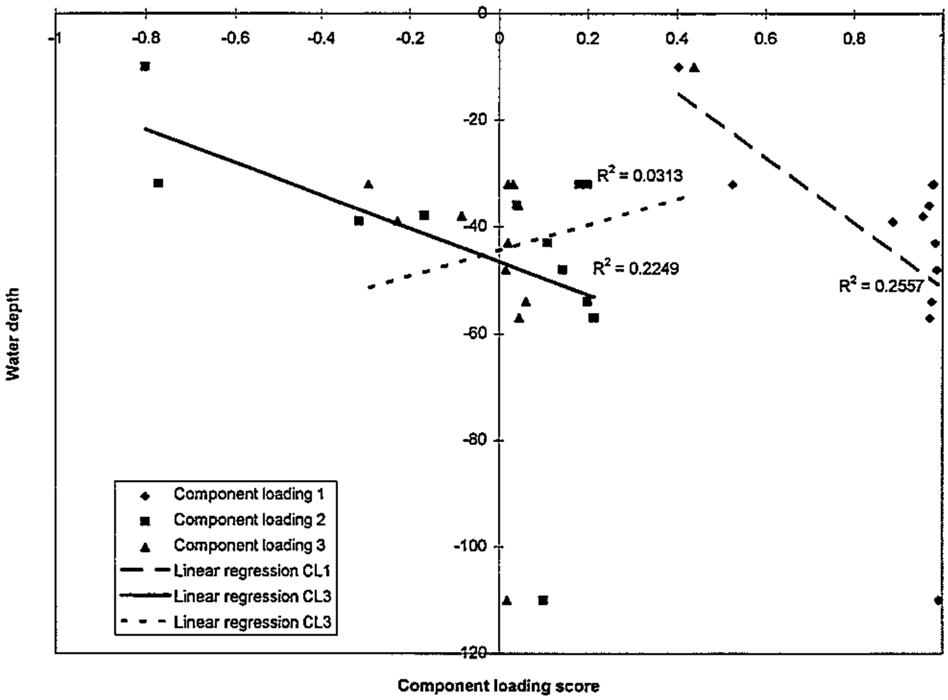

Figure 13: Component loadings versus water depth

CONCLUSION

This study shows that elevated levels of contaminants, particularly copper, lead and zinc, in sediments situated near the sewage outfall of Scott Base are directly related to sewage and wastewater discharge from the base. Sediment contamination is restricted to the area closest to the sewage outfall, while trace metal concentration in the sediments off Pram Point is generally low. High levels of contaminants in the sewage wastewater effluent and in sediments near the discharge point have a toxic effect on the marine benthic fauna, as shown by the absence of foraminifera in this area and the changes in foraminifera assemblages between the sites close to the outfall and the more distant sites. Temperature and salinity changes related to the discharge of water and brine from the reverse osmosis plant also appear to have negative effects on the benthic fauna at immediate proximity to the reverse osmosis intake point. This reconnaissance study suggests that discharge of sewage effluent has a toxic effect on the benthic microfauna. Further study is required to assess the extent of contamination off Pram Point and its effect on micro- and macrofauna. Hydrocarbons, pesticides and PCBs levels should also be determined in sediment, water (sewage, wastewater and seawater) and marine organisms.

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APPENDIX

METHODS

Foraminifera

Foraminifera samples were stained with heated saturated Sudan black B (after Walker *et al.*, 1974) so that live and dead foraminifera could be distinguished, as Sudan black stains the lipids that are contained in the protoplasm of living foraminifera. On collection sediment was soaked with a 4% solution of formalin for a minimum of 30 minutes to preserve foraminifera protoplasm. Formalin was decanted off and heated saturated Sudan Black (Walker *et al.*, 1974) was added to the sediment. Sediment and stain were then heated to 40°C for 30 minutes. Excess stain was decanted off and samples were washed with ethanol. Samples were oven dried at 60-70°C.

Dried samples were weighed and then split using a sample splitter. Small pebbles were removed and all weights recorded. Initially one split was dry sieved with all fractions being retained. The 250-60 μm fraction was placed in a container for later counting, and the <60 μm fraction was checked for juvenile forms. Foraminifera were identified using a grided tray and populations were counted. A selection of all species in a sample were mounted on a grided slide so that the identifications could be checked. Unidentified species were collected and mounted on slides for later counting. Live foraminifera were identified by black stain in the outer chambers and species were identified, counted and recorded.

Trace Metals in Wastewater and Seawater

Waste water samples, 12SW and SV, were collected directly from the sewage and effluent flow by submerging polyethylene bottles into the water. Seawater samples were collected using an all plastic water sampler designed by Dr D. Sheppard of the Institute of Geological and Nuclear Sciences Ltd.

The special seawater samplers were manufactured from acid washable polyethylene and other plastics to remove potential sources of contamination that occur in present water collection systems. The removal of potential contaminants allows the concentration of trace elements in seawater to be measured at ultra trace levels (ppt). Water samplers and weights were acid washed in a Class 100 metal free lab prior to packing and freighting to Antarctica. Samplers were assembled on plastic sheeting on clean snow immediately prior to use.

Polyethylene bottles and caps used for the storage of samples were acid washed and rinsed according to a seven stage schedule (USEPA, 1986; Fellows, 1994). The final three stages were conducted in a Class 100 metal free laboratory.

Collection of seawater was conducted using two people wearing full nylon over-suits and polythene gloves as per the method described in Fellows (1994). Field blanks were used during Scott Base sampling. All seawater and wastewater samples were preserved with 5 ml of redistilled nitric acid and frozen immediately. Samples remained frozen until processed in a Class 100 metal free laboratory at ESR Ltd.

Approximately 1 ml of wastewater was microwave digested with 1 ml of nitric acid and 28 ml of metal free deionised water. Trace metal concentrations were measured on digested waters using an ICP-MS at ESR Ltd., Wellington.

Trace Metals in Sediment

Samples were collected using a Shipek grab. Samples intended for trace metal analysis were stored in acid cleaned containers (USEPA, 1986; Fellows, 1994). After collection samples were kept at temperatures below zero until they were placed in the Scott Base freezer. The freezer maintained an average temperature of -18°C. Samples were kept frozen until pre-treatment for analysis. Analyses for trace metal concentrations were conducted using an induced coupled plasma mass spectrometer (ICP-MS) at the Environmental Chemistry Section of ESR Ltd.

Samples were washed three times using deionised water to remove seawater, as the matrix of seawater interferes with the analysis of many metals. Seawater and deionised water were decanted off most samples except for samples 12 and 13 where large quantities of fine mud required centrifuging to retain the suspended mud fraction. This fine fraction, as well as bulk sediment, was analysed. Sediment was then dried at 60°C.

Approximately 1 gram of dried sediment was digested using a cold nitric acid method (USEPA, 1986). The 'total recoverable' fraction of metals was determined, which corresponds to the metal concentration extracted from the sediment with a solution that does not completely dissolve the sediment (Horowitz, 1985). Quality assurance was carried out using blank at all stages of processing, duplicate samples, spikes, standards and reference materials.