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PREFACE

The better understanding of the changing problems facing the marine environment is a continuing goal of UNEP's ocean programme, as it provides the necessary scientific background for shaping UNEP's policy towards the protection of the oceans.

The main sources of factual information used in the assessment of the state of the marine environment are data published in open scientific literature, data available in various reports published as "grey literature" and data generated through numerous research and monitoring programmes sponsored by UNEP and other organizations.

Several procedures are used to evaluate critically the large amount of available data and to prepare consolidated site-specific or contaminant-specific reviews.

GESAMP, the IMO/FAO/Unesco/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on Scientific Aspects of Marine Pollution, is charged by its sponsoring bodies with the preparation of global reviews. Reviews dealing with several contaminants have been already published by GESAMP and others are being prepared for publication. The first global review on the state of the marine environment was also published by GESAMP in 1982, and the second global review was published in 1990[1/].

In parallel with the preparation of global assessments, the preparation of a series of regional assessments, following the general format of the second global review by GESAMP, was initiated by UNEP in 1986, with co-operation of the Food and Agriculture Organization of the United Nations (FAO) and the Intergovernmental Oceanographic Commission of Unesco (IOC). Fifteen task teams of scientists were set up, involving primarily experts from the relevant regions, to prepare the regional reports under the joint overall co-ordination of UNEP, FAO and IOC, and with the collaboration of a number of other organizations.

The present document is the product of the Task Team for Antarctica. The final text of the report was prepared by J.O. Strömberg as Rapporteur of the Task Team for Antarctica, with collaboration of L.G. Anderson, G. Björk, W.N. Bonner, A.C. Clark, A.L. Dick, W. Ernst, D.W.S. Limbert, D.A. Peel, J. Priddle, R.I.L. Smith and D.W.H. Walton whose contributions are gratefully acknowledged.

The report was edited and prepared for publication by Philip Tortell of Environmental Management Limited, New Zealand.

1/ Publications of GESAMP are available from the organizations sponsoring GESAMP.

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1. INTRODUCTION

Although the Antarctic Circumpolar Ocean has wide connections with the three major oceans, there is a marked physical delineation between them, with cold northward flowing Antarctic surface water that meets southward flowing warmer waters from lower latitudes at the so-called Antarctic Convergence. At deeper levels there are northward flowing, intermediate and deep water currents and a warm deep current going south between them.

This means a relatively marked isolation of the Antarctic Ocean at the surface and bottom levels, which is also marked by a strong endemic component in the marine biota (e.g. Laws, 1985). Another example of the isolation is that only two species of vascular plants have been able to establish themselves firmly on the Antarctic Peninsula, although the climatic conditions on land are contributing factors to this (Smith, 1984).

Thus the spreading of pollutants via surface water from lower latitudes to the Antarctic Ocean is limited by hydrographic factors.

The most obvious human influence on the Antarctic environment is through direct activities in the area itself, e.g. fishing, hunting, pollution and debris from research stations and ships. In contrast to the Arctic there is virtually no river runoff that could transport material into the surrounding ocean in the Antarctic. The only transport is by ice flow and the melting of glaciers and shelf ice. Sea ice, that covers extensive areas (4 to 20 x 10^6 km^2, Zwally et al, 1983) does not contribute to this transport.

The history of whale and seal hunting and the subsequent decline in stocks of these animals are well documented as is the recovery of some species, particularly the Antarctic fur seal, after hunting was banned (Laws, 1984; Brown & Lockyer, 1984). The decline in whales meant less predatory pressure on the main food source, the Antarctic krill (Euphausia superba), which allowed other species to expand and use this source, e.g. Crabeater seals and a number of penguins (Laws, 1984; Croxall, 1984; Everson, 1984).

Human activities have thus already had a major effect on the balance of the Antarctic marine ecosystem. The commercial exploitation of mineral resources might have a more profound impact on the ecosystem and lead to irreversible damage. The achievements within the Antarctic Treaty System and the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) are of great importance for the future of the Antarctic marine environment (e.g. Laws, 1985).

While local input of pollutants might be of limited importance and have only local effects, and while commercial exploitation of non-living resources might be postponed and hopefully will only be carried out in the future under effective international control, there is still the risk of damage to one or more links in the food chain, that could have major impact on the total ecosystem.

One way in which damage or at least major perturbations can be caused is through changes in the atmosphere. Studies of Antarctic ice cores have revealed an increased CO_2 level in the atmosphere over the last century from a level of about 260 parts per million by volume before major anthropogenic influences ("pre-industrial", before 1850) to the present 345 p.p.m.v. This change may not only be related to the burning of fossil fuels. One calculation indicates a "pre-industrial" level of 295 p.p.m.v. which could be the result of natural, but so far poorly understood, changes. The ice core analyses indicate that the CO_2 level was not stable during the centuries preceding 1850 (Raynaud & Barnola, 1985; Neftel et al, 1985). Evidence also seems to indicate that ice ages have an effect

on the atmospheric CO_2 level with a decrease during such periods (Schackleton et al, 1983). Thus the ocean plays an important role in the CO_2 flux (Golitsyn, 1985). It is generally accepted that an increase in CO_2 level in the atmosphere will create a green-house effect with increased melting of the polar ice-caps (Bolin, 1986). If this does occur, we can expect changes also in the Antarctic Ocean circulation and in its marine ecosystems.

Another effect of human activities is the reduction of the stratospheric ozone layer above the poles. Much effort is directed towards research in this field. Farman et al, (1985) have proposed that the Antarctic stratosphere is particularly sensitive to increase of inorganic chlorine, primarily by the effect of this increase on the NO_2/NO ratio, during the cold winter and early spring. In combination with the height distribution of UV irradiation peculiar to the polar stratosphere this would account for the observed losses in O_3.

An increase in the ozone hole above the Antarctic could adversely affect phytoplankton reproduction and growth if ocean areas are exposed to an elevation of UV radiation. Wood (1987) has shown that the UV component of solar radiation inhibits growth and causes ultrastructural damage in large algae, such as kelp. There are good reasons to believe that pelagic, unicellular algae that dominate the Antarctic marine flora e.g. 100 species of diatoms and 60 species of dinoflagellates (Heywood & Whitaker, 1984) would suffer in the same way in the upper 5 m of the water column.

A reduction in algal production that would result from increased UV radiation would most likely also reduce the algal production of dimethylsulphide. This is oxidized in the atmosphere to form a sulphate aerosol, which seems to be a major source of cloud condensation nuclei over the oceans (Charlson et al, 1987). If this occurs there might be a reduction in cloud formation and an enhanced radiation which would then further increase the effect. More research is needed to verify this feedback system.

2. GENERAL WATER CIRCULATION

The Antarctic Circumpolar Ocean can be defined as the water between the Subantarctic Convergence, situated between 45°S and 50°S and the Antarctic continent. The following discussion is based to a large extent on Deacon (1984).

The circulation in the Antarctic Circumpolar Ocean (Fig. 1) is dominated by the deep-reaching Antarctic Circumpolar Current. The transport in this current system which is driven by predominantly westerly winds is about 130 Sv. The velocities are usually between 1-2 knots. Close to the continent easterly winds often generate westward currents.

The meridional circulation pattern shows much smaller velocities but the mass transport may be comparable to that of the circumpolar current. At the surface it is a northward flow up to the Antarctic Convergence (at 50-60°S), where this cold, relatively low salinity water sinks below the warmer and more saline water north of the convergence. This northward flow is compensated by a warmer and slightly more saline southward flow at deeper levels. It enters the circumpolar ocean at 500-1000 metre depth and forms there a relatively warm layer with maximum temperature about 2oC. This southward transport has been estimated to be about 80 Sv. Around the Antarctic continent high salinity, low temperature bottom water is formed. This water originates at the shallow shelf areas or below the ice shelves. Most of the bottom water is believed to form in the Weddell Sea. This water then flows along the bottom into the surrounding oceans. A schematic picture of the meridional circulation is shown in Fig. 2.

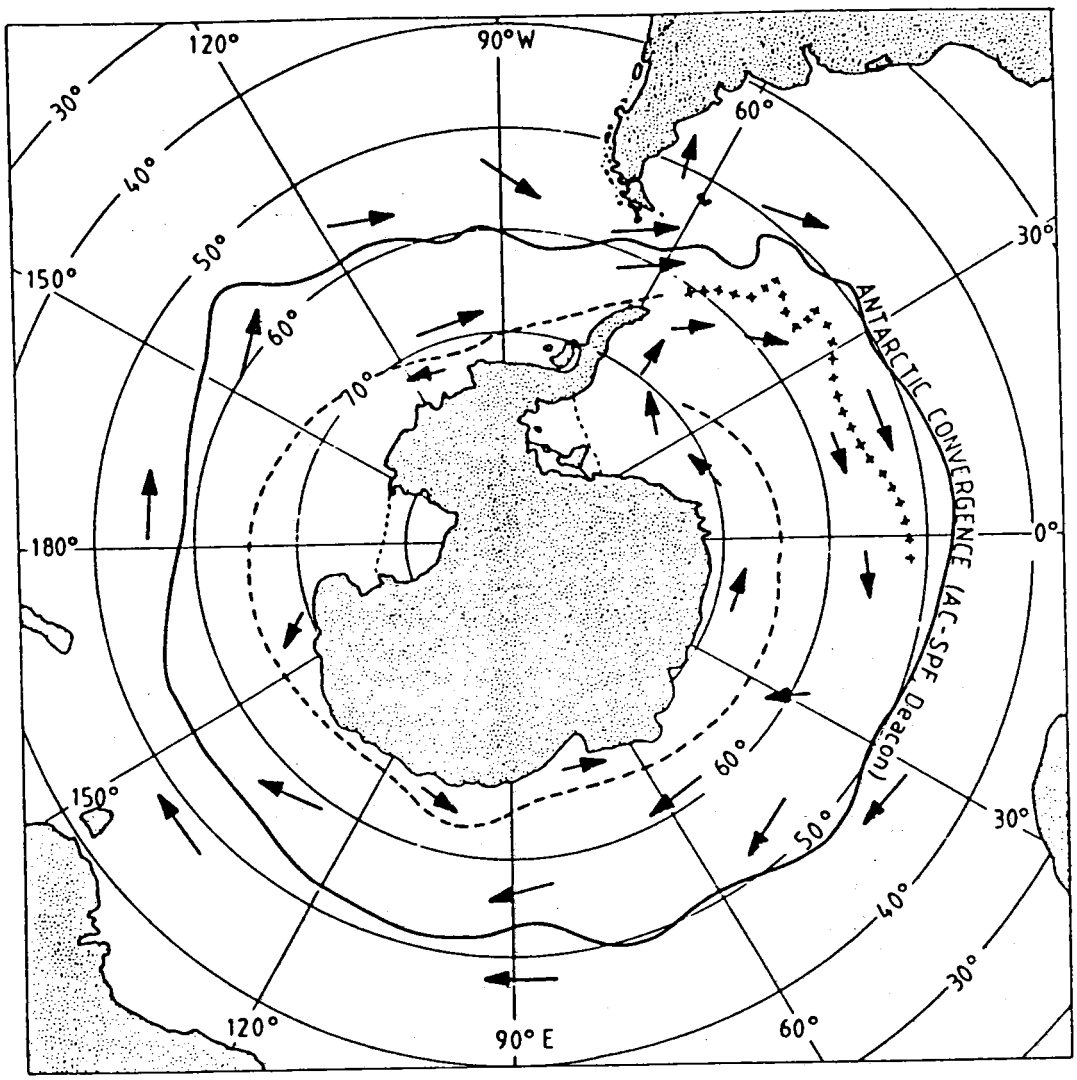

Fig. 1. The surface circulation in the Antarctic Circumpolar Ocean.

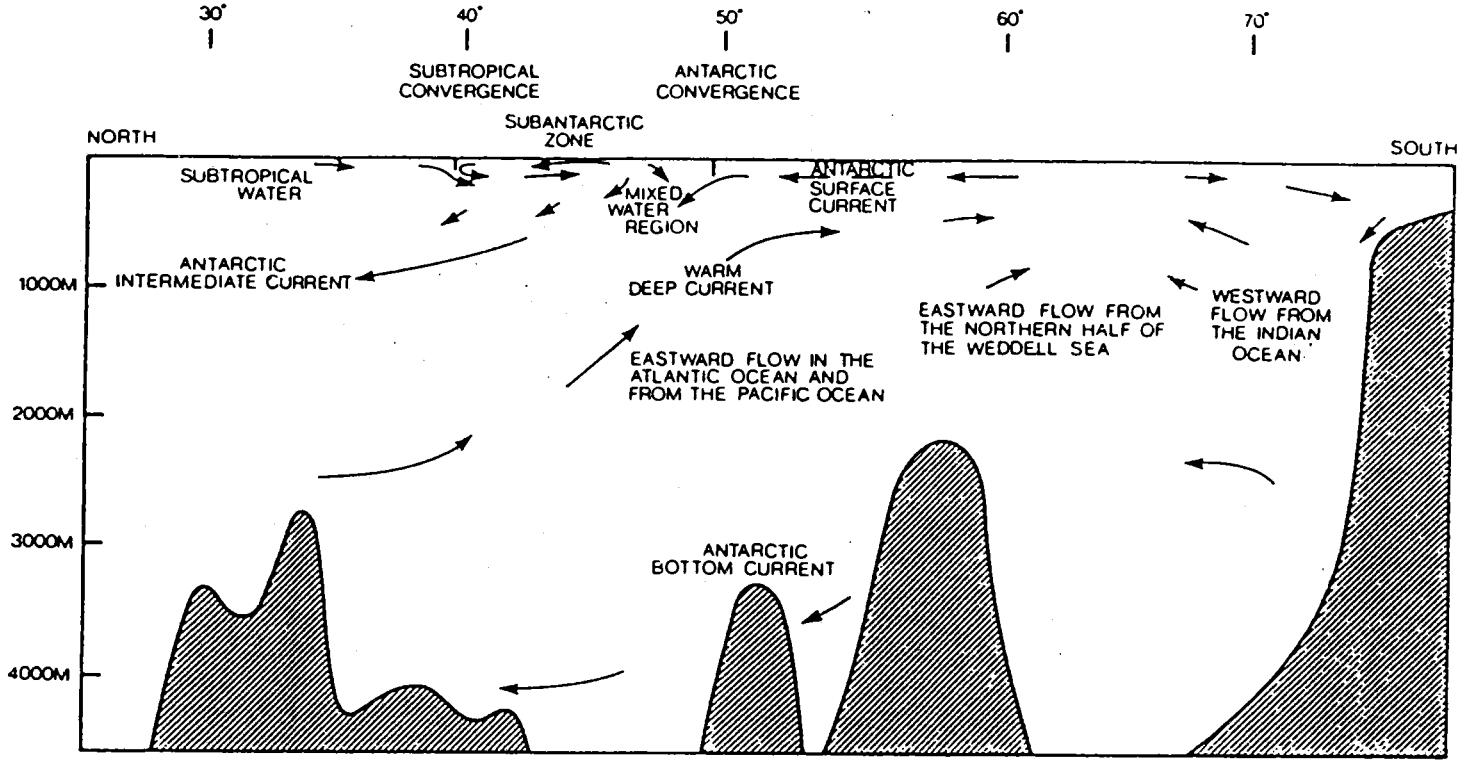

Fig. 2. The meridional circulation in the Antarctic Circumpolar Ocean in a section along 30°W (Deacon, 1984).

It is difficult to find any specific place where marine pollutants could be advected with water into this ocean. One suggested area is the Drake Passage region where eddy formation could help Southeast Pacific water into the Antarctic Circumpolar Current (e.g. Bryden, 1983; Nowlin & Klinck, 1986). The warm, deep current from lower latitudes reaching the surface at about 60°S could be another pathway.

3. HYDROCARBONS IN THE SOUTHERN OCEAN ECOSYSTEM

Monitoring of the Southern Ocean environment and organisms for hydrocarbons has been carried out over the past ten years. This has had two main objectives - the examination of Antarctic systems as possible pristine sites for the establishment of "global" background concentrations of pollutants, and the need to establish baselines for possible future pollution studies of the Southern Ocean.

3.1 Historical background

Studies of hydrocarbons and other contaminants in the Southern Ocean have progressed as methodology has developed. In most cases, detected levels have been low and this requires more refined methods in many cases (G.C. Cripps, pers. comm). Although there have been several sampling campaigns resulting in data on hydrocarbon concentrations and distribution, most have been directed primarily at activities other than pollution monitoring. This has resulted in patchy coverage in space and no useful time series data. In particular, a large proportion of early work was carried out at coastal localities, determined by convenience of access from research stations. It is dubious that these are representative of the majority of the Southern Ocean.

Whilst some compounds are identifiable as pollutants, most are of natural origin (Tables 1,2,3). It is often necessary to carry out extensive analyses of organisms to determine the "natural" biogenic contribution to the hydrocarbon pool.

Table 1. Concentrations of aliphatic hydrocarbons in Southern Ocean seawater, particulates and sediments

	Total n-alkanes	Pristane	Phytane	Reference
Seawater		($\mu g\ dm^{-3}$)		
Inshore	5.8	0.2	nd*	(1)
Effluent from McMurdo base	170	nd	nd	(2)
Particulates and sediments		($\mu g\ kg^{-1}$)		
S. Indian Ocean, particulates	30000-160000	1000-4400	0-580	(3)
King Edward Cove, S. Georgia, sediment	2600-17900	200-1600	100-1000	(1)

*nd = not determined

References: (1) Platt & Mackie (1980)
(2) Matsumoto et al, (1979)
(3) Matsueda & Handa (1986)

Table 2. Concentrations of aliphatic hydrocarbons (mostly of biogenic origin) in Antarctic and other zooplankton

	Total n-alkanes	Pristane	Phytane	Reference
		($\mu g\ kg^{-1}$ wet weight)		
Antarctic zooplankton				
Krill (*E. superba*)	500	1400	40	(1)
	500-1300	390	23	(2)
	110	630	1.5	(3)
	13325	6500	nd*	(4)
Euphausid (*Thysanoessa* sp.)	3134	626850	nd	(4)
Amphipod (*T. gaudichaudii*)	bdl**	46250	nd	(4)
Salp (*Salpa* sp.)	15187	2430	nd	(4)
Other zooplankton				
North Sea zooplankton	300-2630	133000	900	(5)
Brown shrimp (*Crangon* sp.)gut	100-4400	nd	nd	(5)
muscle	300- 800	nd	nd	(5)

* nd = not determined
**bdl = below detectable limits

References: (1) Platt & Mackie (1980)
(2) GC Cripps, unpublished data
(3) Clarke & Law (1981a)
(4) Reinhardt & van Vleet (1986) - converted from dry weight
(5) Whittle et al, (1977)

Table 3. Concentrations of aliphatic hydrocarbons (mostly of biogenic origin) in tissues of Antarctic and other fish

		Total n-alkanes	Pristane	Phytane	Reference
			($\mu g\ kg^{-1}$ wet weight)		
Antarctic fish					
Antarctic cod (*N. rossii*)	muscle	50	200	trace	(1)
	liver	1200	3400	bdl*	(1)
Icefish (*C. gunneri*)	muscle	100	20	20	(1)
	liver	2500	400	20	(1)
Myctophiid (*Electrona*)	muscle	2858	187615	60	(2)
	liver	2032	23843	11	(2)
Other fish					
Mackerel (North Sea)	muscle	600-1400	nd*	nd	(3)
	liver	1300-6300	nd	nd	(3)

*bdl = below detectable limits
**nd = not determined

References: (1) Platt & Mackie (1980)
(2) GC Cripps, unpublished data
(3) Whittle et al, (1977)

Ventajas (1985, 1986a,b) has analyzed water samples to assess the horizontal and vertical variation in concentrations of polycyclic aromatic hydrocarbons in the Drake Passage, Weddell and Bellingshausen Seas (Table 4). Her findings indicated that levels were sometimes higher than might be expected in open ocean water. Contamination of surface water could be associated with emission from the research vessel (Ventajas, 1985) but samples from deep water with elevated concentrations (the highest concentration being reported from 1000 m) could not be explained in this way. Whiticar et al, (1985) examined sediment cores from the Bransfield Strait for thermogenic hydrocarbons, possible indicators of seepage from submarine hydrocarbon reserves. Their results suggest that such a source was possible for hydrocarbons in deep water.

Table 4: Concentration of polycyclic aromatic hydrocarbons in seawater samples from the Southern Ocean (from Ventajas, 1985)

Site	Depth	Total polycyclic aromatic hydrocarbons ($\mu g\ dm^{-3}$)
Drake Passage	surface	0.1 - 0.3
Weddell Sea	surface	0.13 - 2.8
	200 m	1.3
	1000 m	0.9 - 3.46
near Belgrano II base	surface	0.6 - 2.7
	200 m	1.7 - 2.5
Bellingshausen Sea	surface	2.6 - 3.1
	200 m	0.6 - 2.0

There has been a paucity of work at more representative oceanic sites. Matsueda & Handa (1986) include a range of hydrocarbons (principally alkanes) in their analyses of the organic constituents of material from sediment traps in the Southern Ocean. Their results indicate that sinking particles contained hydrocarbons which were derived from phytoplankton. Sediments at the same site had a very different composition, possibly indicating transformation as the result of bacterial action.

Platt & Mackie (1979, 1980, 1981) studied hydrocarbons in benthic animals and sediment layers at King Edward Cove, South Georgia. This site had a history of pollution associated with shore-based whaling and these authors were able to identify the course of hydrocarbon pollution associated with this activity as shown by sediment core profiles of aromatic compounds (Platt & Mackie, 1979). They concluded that the hydrocarbon concentrations in benthos and contemporary sediment at the site indicated input of allochthonous compounds which was not local (Platt & Mackie, 1981), probably representing pyrolysis products derived from the burning of fossil fuels at lower latitudes. (Platt & Mackie assumed that no marine organism synthesizes polycyclic aromatic hydrocarbons). Clark & Law (1981a,b) examined the hydrocarbon content and composition of animals from South Georgia and from Signy Island (South Orkney Islands). They found that the samples from the more southerly Signy Island had consistently lower hydrocarbon content and used this fact to argue that the source of aromatic hydrocarbon contamination at South Georgia was local pollution rather than long-distance atmospheric transport (Table 5).

Table 5: Concentrations of aromatic hydrocarbons in Antarctic fish and echinoderms

Species:	**Antarctic cod** (*N. rossii*) (1)		**Starfish** *Odontaster* (2)		*Diplaster* (3)
Tissue:	**Muscle***	**Liver**	**Whole animal** (SG)+	(SI)+	**Whole animal** (SG)
Naphtalene	bdl**	0.01	330	2.3	0.002
Phenanthrene	0.5	0.1	430	2.0	0.003
Fluoranthene	0.2	0.08	nd***	nd	0.007
Pyrene	0.2	0.11	nd	nd	0.005
Benz(a)pyrene	0.04	0.03	nd	nd	0.001

*Concentrations in $\mu g\ kg^{-1}$ wet weight
**bdl = below detectable limits
***nd = not determined
+Localities for specimens - SG = South Georgia
SI = Signy Island, South Orkney Islands

References: (1) Platt & Mackie (1980)
(2) Clarke & Law (1981a)
(3) Platt & Mackie (1981)

Other analyses have been carried out for zooplankton and fish samples from the Ross Sea (Nachman, 1985) and for a variety of zooplankton from Croker Passage (near Anvers Island) (Reinhardt & van Vleet, 1986). These studies are important in that they identify the biogenic components of the hydrocarbon pool in the Southern Ocean ecosystem (Tables 2,3). Nachman (1985) suggests that the composition of n-alkanes indicates unusual biochemical pathways, although the unusual results highlighted by Nachman may arise from methodological errors.

3.2 Limitations of existing data

Methodologies are not consistent and this makes comparisons between different authors' data impossible in some cases. Many methods have been used at the lower limits of detection (G.C.Cripps, personal communication). Few authors provide any estimate of analytical precision, even for total hydrocarbon concentrations. Data may also be presented in a form which is difficult to interpret or compare with others.

There has been little systematic survey of the Southern Ocean environment and most of the samples described above are serendipitous, derived from other biological and oceanographic sampling. The bias towards coastal areas was also noted. No formal monitoring scheme has been proposed although the need for it is recognized if future exploitation of living and non-living resources is to be assessed (for example the CCAMLR and US-AMLR).

As with studies of hydrocarbons in other marine ecosystems, it is sometimes difficult to determine what is "natural" (i.e. biogenic or autochthonous) and what represents environmental contamination. Cripps (pers. comm, Table 6) has found that much of the aromatic hydrocarbon content of Southern Ocean surface water is associated with fine particulates indicative of a high content in phytoplankton. Hydrocarbons have low solubility in water and they are therefore preferentially adsorbed onto particulate matter such as phytoplankton. This accords with observations by Zsolnay (1977) for the euphotic zone near Nova Scotia, where there was a positive correlation between total hydrocarbons and particulate chlorophyll a concentrations.

Composition of the hydrocarbon content has been used to determine the source of these compounds. For instance, n-alkanes can be characterized by the proportion of odd- and even-carbon numbers, with a preponderance of odd-carbon compounds being associated with biogenic material. Cripps (pers. comm) shows that samples of Southern Ocean seawater from the Bransfield Strait region showed a predominance of odd-even ratio less than one whereas most animal samples examined had higher odd-even ratios. Nachman (1985) and Reinhardt & van Vleet (1986) indicate that even-carbon compounds predominated in their animal samples. However, Cripps comments that such a "rule is at best ambiguous".

3.3 Possible sources for hydrocarbons in the Southern Ocean

Biogenic input is likely to account for all but a very small fraction of the hydrocarbons present in the ocean and its biota. It is therefore difficult to estimate the small quantities of contaminants against this background. Allochthonous sources for these contaminants can be suggested, sometimes by analogy with other pollutants which act as tracers for transport mechanisms.

The local human activity in the Southern Ocean and on land may result in hydrocarbon contamination. This will be associated with permanent research stations and temporary camps, with the use of land vehicles and with shipping and aviation. Most shipping and aviation is associated with logistic and survey work within the Southern Ocean, although in some localities intense fishing activity will increase the density of ships. The disposal of waste and accidental contamination associated with Antarctic research activity is the subject of a working group of SCAR (draft report prepared). This has detailed the waste products produced by research activity and has suggested protocols for minimizing the impact of waste. However, accidental spillage of fuel or lubricants remains a risk. Croxall (1987) cites three documented incidents of oiling of seabirds - Jehl et al, (1979), Wilson (1979), Williams (1984). Croxall points out that penguins will be particularly vulnerable to such pollution, although cases vary in severity from the sighting of a few oiled birds (Wilson, 1979) to a small oil slick in sub-Antarctic Marion Island which killed hundreds of Southern Rockhopper Penguins (Williams, 1984). Ventajas (1985) points out that the presence of sea-ice may restrict the spread of light fuel or lubricants on the seawater surface, giving rise to local high concentrations e.g. around a ship which spends a long time surrounded by ice. Ogrodowczyk (1981) has carried out toxicological investigations of the effects of crude oil on Antarctic krill (Euphausia superba) and an Antarctic fish, the marbled rockcod (Notothenia rossii). Krill proved to be especially sensitive to oil pollution. There remains, however, the inescapable fact that shipping and other sources of liquid and particulate hydrocarbon contamination in the Southern Ocean are scarce and very widely scattered. Sampling of the sea-surface on transects between New Zealand and the Ross Sea failed to encounter tar balls (the typical traces of large oil slicks) in oceanic Antarctic waters (Gregory et al, 1984). Any local pollution may be dispersed rapidly under most conditions.

Table 6. Concentrations of aromatic hydrocarbons in Southern Ocean seawater, phytoplankton, zooplankton and nekton (from GC Cripps, pers. comm)

	Surface Seawater*			Phytoplankton	Zooplankton ($\mu g\ kg^{-1}$ wet weight)								Mid water fish			
	Mean value ($\mu g\ L^{-1}$)	Detection frequency	Detection limit ($\mu g L^{-1}$)	($\mu g\ kg^{-1}$ dry wt.)	Euphausia superba	Euphausia crystallorophias	Euphausia triacantha	Thysanoessa sp.	Salpa sp.	Notocrangon antarctica Exoskeleton	Muscle	Viscera	Electrona antarctica Gonad	Liver	Muscle	Gut
Napthalene	0	0	0.0006	-	-	-	-	-	0.02	4.72	0.04	-	tr.**	-	0.12	4.89
Phenanthrene	0.021	2	0.0168	427	-	-	1.12	2.11	0.51	1.28	2.95	-	tr.	3.47	0.28	10.90
Anthracene	0.063	11	0.0038	395	-	-	tr.	1.60	0.04	tr.	-	-	0.38	0.24	0.61	3.97
Fluoranthene	0.043	8	0.0011	220	3.57	0.89	0.28	0.48	0.03	0.70	0.61	0.31	2.34	1.85	0.61	2.98
Pyrene	0.016	15	0.0024	130	1.45	0.67	0.10	0.36	0.05	0.45	0.32	0.58	1.30	1.35	0.40	1.89
Benz(a)anthracene	0.043	5	0.0004	tr.	0.09	0.13	0.05	0.04	0.02	0.03	0.08	0.15	0.12	0.17	0.11	0.10
Chrysene	0.069	3	0.0010	tr.	0.22	0.34	0.10	0.05	tr.	0.19	0.19	0.57	0.81	0.65	0.17	0.31
Benz(e)pyrene	0	0	0.0010	0	-	0.21	1.42	0.40	0	-	0.29	-	tr.	tr.	tr.	-
Benz(b)fluoranthene	0.011	4	0.0003	33	0.20	0.21	0.18	tr.	0.04	0.10	0.10	0.19	0.88	0.41	0.16	0.07
Benz(k)fluoranthene	0.003	3	0.0001	10	0.11	0.02	0.15	0.08	0.01	0.03	0.03	0.07	0.25	0.11	0.06	0.12
Benz(a)pyrene	0.022	7	0.0001	7	0.22	0.09	0.21	0.08	tr.	0.03	0.03	0.03	0.11	0.10	0.29	0.12
Bibenzanthracene	0.081	1	0.0018	25	tr.	tr.	tr.	-	tr.	0.15	tr.	tr.	tr.	0.41	tr.	-
Benz(ghi)perylene	0.014	5	0.0012	32	tr.	tr.	0.54	0.31	tr.	0.15	0.33	0.40	tr.	0.62	0.38	tr.

* 50 samples, depth 10 m

** tr = trace

Atmospheric transport of pyrolysis products has been implicated in hydrocarbon contamination of inshore habitats in the Southern Ocean by Platt & Mackie (1981), although a contrary viewpoint has been presented (Clarke & Law, 1981b). Given present data, it is very difficult to assess the importance of long-distance atmospheric transport in the total hydrocarbon contamination of the Southern Ocean. Spatial variability in the seawater concentrations and hydrocarbon content of pelagic animals over mesoscale distances militates against the importance of such input. However, Dick & Peel (1985) and Dick (1987) suggest that aerosol transport is the dominant mechanism for input of metals such as Pb to Antarctic precipitation. This implies that atmospheric transport is a feasible route for hydrocarbon contaminants from lower latitudes but gives no indication of its importance. However, the levels involved would be expected to be undetectable against natural background and local contamination.

There is evidence to suggest that the western Weddell Sea and the Ross Sea are likely sites of submarine hydrocarbon reserves (see MacDonald et al, in press). Such areas may give rise to seepage of hydrocarbons into the overlying water, e.g. McIver (1975) and Whiticar et al, (1985). As yet there is no evidence that this contributes markedly to concentrations of hydrocarbons in the water, although the possibility is noted by Ventajas (1985). Such seepage would tend only to contaminate water close to the seabed, especially where sedimentary particles might scavenge these compounds and transport them to the sediment.

4. CHLORINATED HYDROCARBONS IN THE SOUTHERN OCEAN ECOSYSTEM

4.1 Introduction

Early reports on the occurrence of DDT compounds in Antarctic biota (Sladen et al, 1966; George & Frear, 1966) furnished proof that the world-wide dispersion of those pollutants can even reach ecosystems of these high latitudes. Since then continuing research in Antarctica has supplied data confirming these early findings, and also generated data on a number of compounds other than DDT. The use of improved analytical techniques such as high resolution gas chromatography and mass-spectrophotometry resulted not only in the confirmation and in the detection of "new" halogenated contaminants e.g. hexachlorocyclohexanes (HCH), PCBs, chlordane and toxaphen in biota but also made quantitative data more reliable.

In addition to those of biota, samples of snow, ice, and more recently water and air have been included for analysis. The available data base, however, still appears to be rather scarce for an assessment of routes for transport and distribution as well as for possible effects of organohalogen compounds on the Antarctic ecosystems.

4.2 Levels in air, water, ice and snow

An early report on the occurrence of DDT in Antarctic snow was given by Peterle (1969), who found 0.04×10^{-9} g/g of a composition of 29.2% o,p'-DDT and 70.8% p,p'-DDT in a melted snow sample. In the light of more recent measurements, however, this high concentration appears to be rather unlikely; also the DDT-composition was almost the same as in commercial mixtures. It is therefore highly probable that the components found resulted from contamination and were not constituents of the original snow sample. This indicates that the methods for collection, preservation and analysis of samples from pristine areas are extremely vulnerable to contamination during processing.

Research stations may also play a role in local pollution of snow, ice and water. Risebrough et al, (1976) analyzed DDT and PCB in Antarctic snow from Doumer Island (64°51.3'S; 63°35'W) and found elevated levels of 4 to 10 x 10^{-12} g/g PCB in snow, sampled at a distance of 0.5-1.5 km from Palmer Station (Anvers Island). They argued from these findings, that a portion of PCB measured in the snow samples of Doumer Island (0.5 to 4 x 10^{-12} g/g total DDT; 0.03 to 1.2 x 10^{-12} g/g PCB) may be derived from local input. Similar PCB concentrations in snow samples were found at Mizuko Station (70°42'S; 44°20'E) and near Syowa Station (69°00'S; 39°35'E) in 1981 but total DDT concentrations were considerably lower than in Doumer Island. Furthermore, HCH-compounds were detected in the range of ng/l (Table 7) (Tanabe et al, 1983a). Ice samples analyzed by those authors near Syowa Station exhibited concentrations similar to those in snow (Table 7).

Table 7. Concentrations of ΣDDT, ΣHCH and PCBs in Antarctic snow, ice and seawater (pg/l) (from Tanabe et al, 1983a)

Location	Sampling date	ΣDDT	ΣHCH	PCBs
Snow				
Mizuho station	May 1981[a)]	15	2300	160
	May 1981[b)]	9.0	1500	220
Tottuki point near Syowa station 68°55'S, 39°50'E	Nov 1981	17	2800	160
Ice				
near Syowa station	July-Sep 1981	11	2200	610
Seawater from under fast ice				
Tottuki point 68°55'S, 39°50'E	July 1981	1.3	570	54
Langhovde	Oct 1981	1.5	210	35
Kitano-ura Cove	Jan 1982	1.5	570	69
Seawater from outer margin of pack ice				
64°55'S, 124°40'E	Jan 1981	5.4	930	52
62°38'S, 157°38'E	Jan 1981	15	290	42
62°00'S, 160°06'E	Feb 1981	21	290	72

a) surface
b) deep, determined age: 1960

For the detection of chlorinated hydrocarbons in seawater (Tanabe et al, 1983a), 300-500 l samples were passed through Amberlite XAD-2 resin columns, which have high absorption efficiencies for HCH, DDT and PCBs.

As indicated in Table 7 concentrations of DDT in sea water from the outer margin of fast ice are higher than those found in samples from under fast ice. Although their concentrations are nearly at the same level in both samples, PCBs exhibit lower chlorine contents (38-39%) under fast ice than at its margin (46-47%). Furthermore the composition of PCB in the latter sample showed a higher proportion of higher chlorinated biphenyls (pg/l):

Location	2 Cl	3 Cl	4 Cl	5 CL	6 CL	Total
Under fast ice	26	21	4.8	1.8	<0.2	54
	16	13	4.2	1.3	<0.2	35
	25	33	9.6	1.4	<0.2	69
Outer margin of fast ice	11	17	12	8.2	3.7	52
	8	14	11	7.1	1.7	42
	18	26	15	11	2.3	72

An explanation for the observed distribution of PCB congeners may be that more highly chlorinated PCBs associate more readily with particulate matter, which is generated under fast ice by primary productivity. By sinking of these particles, the associated compounds are removed into deeper layers.

Atmospheric transport of PCBs, HCH and DDT was investigated by measuring latitudinal variations of these compounds between Mauritius (20°10'S, 57°30'E) and Antarctica (Syowa Station). Their aerial concentrations of between 200 and 300 pg/m^3 decline in Antarctica to below 100 pg/m^3 at Syowa Station. Seasonal variations of aerial concentrations of the compounds were analyzed in 1981/82: DDT-values were in the range of 10-50 pg/m^3; PCBs: 20 to 120 pg/m^3 (one exceptional value was about 170 pg/m^3); HCH: 30 to 130 pg/m^3 (Tanabe et al, 1982; 1983a). Values of DDT, HCH and PCBs in air samples from Antarctica and adjacent seas are shown in Table 8.

Table 8. Concentrations of ΣDDT, ΣHCH and PCBs in air samples (pg/m^3) (from Tanabe et al, 1983a)

Location	Sampling date	ΣDDT	ΣHCH	PCBs
off Sabrina coast 61-65°S, 121-125°E	Jan 1981	240	120	180
near Balleny Islands 60-67°S, 155-164°E	Jan 1981	190	170	64
off Syowa Station 68-69°S, 39°E	Feb 1982	20	49	81
near Amundsen Bay 66°S, 47-50°E	Feb 1982	22	44	96

4.3 Levels in biota

4.3.1 **Fish and zooplankton** (see also Table 9)

First reports on the occurrence of pesticides in Antarctic fish were given by George & Frear (1966). More detailed ones came from Tatton & Ruzicka (1967), who analyzed livers of yellowbellied rockcods (Notothenia neglecta). Besides DDT and DDE these authors detected α-, β- and γ-HCH, dieldrin and heptachlorepoxide at levels of 3 ppb.

Table 9. Chlorinated hydrocarbons in fish and zooplankton (Krill) (ng/g fresh weight, if not stated otherwise)

Location Date of sampling	Species	DDT	DDE	PCB	Reference
Signy Island	Notothenia neglecta Liver	7	7		(1)
South Georgia 55°S, 40°W	Dissostichus eleginoides	DDT 11.5[a)]		32[a)]	(2)
near Syowa Station 69°S, 39°35'E 1981 Jan-Dec	Pagothenia borchgrevinki Whole body	0.3-1.9 (0.8)		0.18-0.77 (0.31)	(3)
	Trematomus bernacchii Whole body	0.5-0.9 (0.7)		0.12-0.24 (0.17)	
	Trematomus hansoni Whole body	0.6-1.5 (1.0)		0.28-0.59 (0.48)	
	Trematomus newnesi Whole body	0.4-0.5 (0.5)		0.08-0.33 (0.21)	
Drake Passage 1976	Krill E. superba Adult	59.2	5.3		(4)
Bransfield Strait 1976	E. superba Adult	18.9	4.2		
South Georgia 1976	E. superba Juvenile	5	4		
South Sandwich 1976	E. superba Juvenile	1.7	2.3		
62°39'S, 60°27'W 1975	Krill Euphausia sp.	19[a)]	14[a)]	3[a)]	(5)

[a)] lipid basis; in brackets: mean values

References:
(1) Tatton & Ruzicka (1967)
(2) Ballschmiter & Zell (1980)
(3) Subramanian et al, (1983)
(4) Lukowski (1978)
(5) Risebrough et al, (1976)

A number of contaminants other than 4,4'-DDT, 4,4'-DDE and PCB could be identified in one specimen of a Patagonian toothfish (Dissostichus eleginoides) from South Georgia: (concentrations in ppb in extractable lipids) (Ballschmiter & Zell 1980): 2,4'-isomers of the DDT-Group (0.2-1), HCB (7.5) α-, β- and γ-HCH (0.1) and toxaphen (68).

Two pelagic fish, bald and dusty rockcods (Pagothenia borchgrevinki and Trematomus newnesi) and two benthic fish, striped and emerald rockcods, (Pagothenia hansoni and P. bernacchii) showed PCB-patterns different from those of sea water (Subramanian et al, 1983; Hidaka et al, 1984). The higher chlorinated PCB-compounds are preferentially accumulated; furthermore the amounts of higher chlorinated PCBs in fish increase with the size of animals. In small fish, lower chlorinated compounds dominate, obviously as a consequence of different uptake and clearance phenomena associated with the two PCB-groups. For PCB as well as for DDT an increase of their concentrations with body size was observed in the bald rockcod (P. borchgrevinki) indicating a significantly higher slope of the regression line for DDTs: y(DDT)=0.018x +0.31; y(PCB=0.011x +0.20; (y: ng/g wet weight; x: body weight in g).

Chlordane compounds, (cis-, trans-chlordane + cis-, trans nonachlor + oxychlordane) were also detected in the emerald rockcod (P. bernacchii) (0.34-0.56 ng/g wet weight) and krill (E. superba), (0.061 ng/g wet weight) (Kawano et al, 1986). Low levels of contamination in krill are also reported for DDT; 33 ng/g (Risebrough et al, 1976) and 4-65 ng/g (Lukowski, 1978).

4.3.2 **Seals**

Weddell seals (Leptonychotes weddelli) and crabeater seals (Lobodon carcinophagus) were used for the analysis of DDT-compounds, PCBs, HCH, dieldrin and chlordane compounds (Table 10). Concentrations of DDT compounds show little variation, at best a minor increase since 1964; slightly increased values can be observed in Ross seals (Ommatophoca rossi) where DDE-values were preferentially elevated. Dieldrin was found in these animals from undetectable levels (0.1 ppb wet weight) to 19 ppb in the blubber (McClurg, 1984). In Weddell seals up to 170 ng/g DDT were detected. A significant variation of PCB-concentrations, from 5 to 760 ng/g in the blubber of twenty seals had values of 148, 279 and 760 ppb, respectively (McClurg, 1984).

The main storage site for the lipophilic halogenated hydrocarbons in seals is the blubber. An animal of 383 kg body weight contained, in 115,7 kg of blubber, 19,700 µg DDT and 4370 µg PCB representing 98.3% and 97.5% resp. of the total body burden. Various muscle tissues and also samples from various organs, such as liver, kidney, heart, lungs, stomach and other, exhibited DDT and PCB concentrations below 4 and 1 ppb wet weight, respectively.

Differences exist in the patterns of distribution of PCB-congeners and also chlordane compounds in the sea water - krill - fish - Weddell seal chain. Concentrations of higher chlorinated biphenyls increase in the PCB compositions from sea water to Weddell seals; this is also true for trans-nonachlor (Hidaka et al, 1984). The observed distributions of the compounds at different trophic levels may be due to physico-chemical properties of the compounds but also to metabolic capabilities of the animals.

In comparison with DDT levels of mammals from lower latitudes and the northern regions e.g. Bering Sea (Tanabe et al, 1983b), concentrations in Weddell seals are one to two orders of magnitude lower; the differences in PCB levels are even more pronounced. In mammals at the other localities it is two to three orders of magnitude higher.

Table 10. Chlorinated hydrocarbons in seals (ng/g wet weight)

Location Date of sampling	Species	DDT	DDE	PCB	Chlordane	Reference
Ross Sea, McMurdo Sound 1967	Weddell seal, Leptonychotes weddelli Fat	37[a)]	20[a)]			(1)
Ross Island Cape Crozier	Crabeater seal Loboden cinophagus Liver Fat	4 15	7 17			(2)
Syowa station 69°S; 39°35'E 1981	Weddell seal L.weddelli Blubber	ΣDDT				(3,4,5)
	male	170; 150		37.8	62	
	female	94.9		26.5	36	
	Muscle	1.8		0.68		
	Whole body					
	female	29.4		8.4	11	
	male	52.3		11.7	19	
	Newborn (found dead)	3.6-24.2		0.64-5.4	0.8-2.3	
Queen Maud Land between 4°E&4°W	Ross seals Ommatophoca rossi Blubber	bdl*-52 (15)	bdl-95 (56)	5-760 (88)		(6)

[a)] lipid basis; in brackets: mean values
bdl* = below detectable levels (≤0.1 ng/g wet weight)

References:
(1) Brewerton (1969)
(2) Sladen et al, (1966)
(3) Hidaka et al, (1983)
(4) Kawano et al, (1984)
(5) Kawano et al, (1986)
(6) McClurg (1984)

4.3.3 **Birds**

Adelie penguins (Pygoscelis adeliae) have significantly lower concentrations (less than 0.4 µg/g DDT and 0.06 µg/g PCB in their fat) than birds of other parts of the world (cit. in Subramanian et al, 1986). Investigating the PCB and DDE burdens of Antarctic Adelie penguins in connection with their breeding ecology showed that starvation of these animals during breeding resulted in a significant increase of the compounds in the declining fat reserves of subcutaneous and abdominal fat (Subramanian et al, 1986). Up to more than 90% of the total body burden of PCB and DDE is stored in these fat reserves, which are the main energy storage sites. Muscle and liver contain minor amounts of DDE (1.4-9 ng/g wet weight) according to the degree of starvation, and less than 1 ng/g PCB. The transfer of PCB and DDE is transferred at a level of 4% of the mother burden, with no significant modification of the PCB comparison.

In Subantarctic penguins from the Falkland Islands a broader range of organochlorines was identified, such as HCB, 2,4'-DDT, toxaphen and Mirex. It should also be noted that a number of unknown compounds were present (Ballschmiter et al, 1981).

Blue-eyed shags (Phalacrocorax atriceps) which lived at Signy Islands contained HCH and DDTs in the same order of magnitude as penguins (Tatton & Ruzicka 1967).

Other birds that do not permanently spend their time in Antarctica are less representative as bioindicators for that area. The Brown skua (Catharacta maccormicki) although nesting in Antarctica, often appears in the tropics outside the breeding season. As predators and scavengers they often carry large burdens of pesticides (Table 11).

4.3.4 Plants

Mosses and lichens sampled 1984/1985 on the Antarctic Peninsula contain HCB, HCH, p,p'-DDE, p,p'-DDT and PCB in the order of ng/g d.w. (Bacci et al, 1986).

Species	PCB	HCB	α-HCH	γ-HCH	p,p'DDE	p,p'DDT
Lichens	<5-12	0.32-2.16	0.2 -0.8	0.5-1.03	0.1 -0.6	0.05-0.9
Mosses	<5-16	0.3 -0.8	0.23-1.15	0.4-1.70	0.17-0.53	0.25-0.55

Most samples showed PCB concentrations below or near the detection limit of 5 ng/g d.w. Trichlorobiphenyls constitute more than 60% and tetrachlorobiphenyls 25% of the total PCB. HCH levels were found to be one to two orders of magnitude lower than the levels in different plants in Europe, whereas HCB levels were similar to those reported for lichens and mosses in Sweden and Finland.

4.4 Conclusions and remarks

From analytical work of various authors it can be concluded that Antarctica is the least contaminated region in the world. Concentrations of pesticides and other chlorinated hydrocarbons are orders of magnitude lower than those in the Northern Hemisphere. Since no pesticides and technical chemicals are used in Antarctica, the question arises about the sources of the chlorinated hydrocarbons are. Various research stations are possibly responsible for very local contamination. The low, but measurable quantities of these compounds everywhere in Antarctica may more likely derive from aerial transport from northern latitudes, but ocean currents may also be transport media. Contaminated water may have access to Antarctica via warm deep currents passing upwards between the Antarctic intermediate and Antarctic bottom water. Another possibility is mixing at the Antarctic Convergence, although spreading across the Convergence seems less likely.

Regarding the low levels of contaminants in water and biota, it seems unlikely that these concentrations have adverse effects on the Antarctic ecosystem provided that the same ecotoxicological criteria can be applied as for ecosystems in lower latitudes. It is desirable for future work, especially for base line studies, to coordinate international work in order to establish a coherent strategy for measurements.

Table 11. Chlorinated hydrocarbons in birds (ng/g wet weight if not stated otherwise)

Location date of sampling	Species	DDT	DDE	DDD	PCB	Reference
Signy Island 1968/69	Giant petrel *Macronectus giganteus*					(1)
	Liver	bdl*	2-30	bdl	bdl	
	Emperor penguin *Aptenodytes forsteri*		<1	<1	<1	
Rumpa Island near Syowa station 69°00'S,39°35'E	Adelie penguin *Pygoscelis adeliae*					
	Subcutan. fat					
	male		347[a)]	52[a)]		(2)
	female		296[a)]	56[a)]		(2)
Atka Bay 1981	Adelie penguin *Pygoscelis adeliae*		361[a)]	346[a)]		(3)
Signy Island	Chinstrap penguin *Pygoscelis antarctica*					(4)
	Liver	1-10	1-18			
	Blubber	5-12	13-48			
	Abdominal fat	6-11	29-48			
	Eggs	8	21			
	Brown skua					
	Liver	230; 330	4000; 890			
	Fat	890; 2500	4800; 26000			
Cape Hallett 1966	Adelie penguin *Pygoscelis adeliae*					(5)
	Fat	5	51			
Ross Island 1967	Adelie penguin *Pygoscelis adeliae*					
	Fat	36	293			
Cape Crozier 1964	Adelie penguin *Pygoscelis adeliae*					(6)
	Parent, Liver	8	28			
	Pre-moult, Liver	1;13;10	15;10;14	-;2;-		
	Fat	5; 18	19; 63	-;-;6;		
	Post-moult, Liver	16	83	16		
	Fat	69	83	-		

a) lipid basis
bdl* = below detectable limits (≤0.1 ppb wet weight)

References: (1) Conroy & French (1974); (2) Subramanian et al, (1986)
(3) Schneider et al, (1985); (4) Tatton & Ruzicka (1967)
(5) Brewerton (1969); (6) Sladen et al, (1966)

5. HEAVY METALS

5.1 Levels in water

Information on heavy metals in the water of the Antarctic Circumpolar Ocean is extremely scarce. There are some data from the Weddell Sea but nothing from coastal waters. Only cadmium is mentioned, and the relatively high values were believed to be associated with the nutrient-rich upwelling water in the Weddell Sea (17-54 ng/g l^{-1}) (Mart et al, 1982).

On the other hand Orren & Monteiro (1985) found cadmium levels of 65-165 ng kg^{-1} in surface waters south of South Africa at latitudes between 47°S and 68°S. There was no latitudinal gradient. Levels also varied with depth within the same range without a consistent pattern.

In the same area copper levels varied with station and depth between 43 and 263 ng kg^{-1} and zinc between 351 and 1549 ng kg^{-1}. Cu levels are clearly influenced by oxidative regeneration, scavenging, and by rate of primary production. The first processes are also active in the case of Zn. By oxidative regeneration Zn becomes dissolved and can be scavenged by primarily silicate-based particulates sinking through the water column.

A number of other factors influence metal fluxes, but the data base is still too poor for any conclusive remarks. Surface values are, however, higher in the Antarctic Ocean than in the gyres of the central Atlantic and Pacific Oceans. Again this is attributed to upwelling. High values in impact areas are to be expected.

Earlier investigations on particulate heavy metals are summarized in Harris & Fabris (1979). They found that concentrations of particulate metals during the early summer in the Indian sector of the Antarctic Ocean averaged for Cd 3.5 ng l^{-1}, Cu 100 ng l^{-1}, Pb 35 ng l^{-1}, and Zn 230 ng l^{-1}. A summary of levels found in various oceans is given in Table 12.

5.2 Levels in biota

Seals have been investigated for a number of heavy metals. Yamamoto et al, (1987) studied the Weddell seal (Leptonychotes weddellii) from around the Syowa Station. McClurg (1984) sampled Ross seals (Ommatophoca rossi) from Queen Maud Land and Steinhagen-Schneider (1986) investigated Weddell and crabeater seals (Lobodon carcinophagus) from the Weddell Sea. Schneider et al, (1985) studied the same species of seals from Atka and Gould Bays, in relation to Cd and Cu levels.

The data are still too few to allow definite conclusions. Relatively high values of Cu and Cd in all the Antarctic seals, compared to seals from other areas, indicate that mammals poorly reflect the differences in environmental concentrations of these metals (Fig. 3).

The same seems to be the case for birds (Steinhagen-Schneider 1986; Schneider et al, 1985) (Table 13).

Moreover, the variability of the data indicates analytical problems.

Table 12. Reported values for particulate Cd, Cu, Pb and Zn from various parts of the world oceans in ng l^{-1}. (From Harris & Fabris 1979)

Reference	Area	Cd		Cu		Pb		Zn	
		Range	Mean	Range	Mean	Range	Mean	Range	Mean
Spencer & Sachs, 1970	Gulf of Maine			51- 253	138			71-490	235
Slowey & Hood, 1971	Gulf of Mexico								
coastal				260-1300	710			380-1800	1100
open Gulf				110- 930	390			<100-2200	400
Belyaev & Gordeev,1972	Pacific Ocean	1-16	8			0.030-2500	620		
Spencer et al, 1972	Black Sea							31-2320	380
Seki et al, 1973	Norway fjord			<100-2040	640	<100-58000	13900	520-5230	1930
Lisitzin & Gordeev,1974	Pacific Ocean			< 10-2700	200			<10-3500	630
Price & Seki, 1975	Norway fjord								
unwashed						100-2000	670	<100-4400	540
washed						<100- 600	210	<100-2400	310
Wallace & Duce, 1975	Narragansett Bay	2-24	11	250- 630	410	240- 670	430	80-2930	1710
Eaton, 1976	North Atlantic	<0.1-1.8	0.24						
Krishnaswami & Sarin, 1976	Atlantic Ocean			1.4-38.3	9.1				
Duinker & Noltin, 1976,1977	North Sea			100-3000				200-13000	
Schaule, 1977	Barbara Basin				0.6-1.5	1.2			
Wallace et al, 1977	North Atlantic	0.008-6.0	1.05	1.9- 8.9	4.0	0.84-22	5.0	1.6-75	18.1
Weigel, 1977	Baltic Sea								
Surface waters		* - 28	6	* - 200	70	* - 490	130	40-6050	990
Deep waters		* - 32	7	* - 410	90	* - 620	150	80-3260	800
Buat-Menard & Chesslet, 1979	North Atlantic								
Surface waters				1.0-6.6	3.6	2.6-6.1	4.5	5.1-26	16
Deep waters**					30		8.6		15
Harris & Fabris, 1979	Antarctic	0.2-11.5	3.5	20-260	100	16-76	35	30-1700	230

* not detected
** Geometric mean

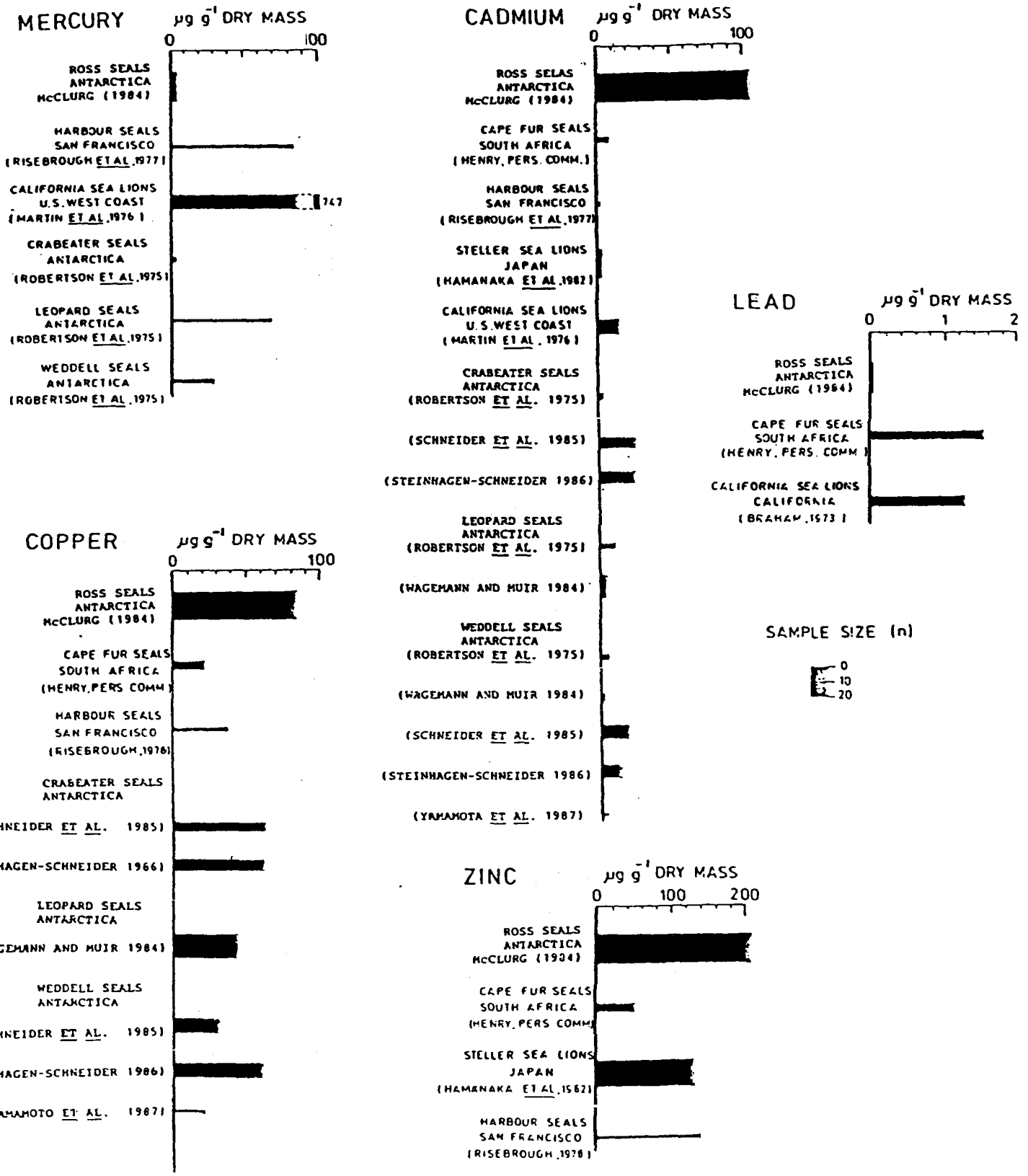

Fig. 3. A comparison of some trace metal concentrations in seal livers. (µg g^{-1} dry weight, bar width: sample size) (Partly from McClurg 1984)

Table 13. Copper and cadmium concentrations in marine birds from Antarctica. (Concentrations in μg g^{-1} dry weight; arithmetic means ± standard deviation or * range; in brackets - number of samples analysed; nd - not determined)

	Species and station	Muscle	Liver	Kidney	Reference
Cu	Emperor penguin				
	Gould Bay	3.70±1.44 (7)	30.7±14.5 (9)	21.2±11.1 (8)	1/
	Atka Bay	3.70±0.93 (3)	61.8±36.5 (3)	24.8± 4.0 (3)	1/
	Atka Bay	5.5 ±2.0 (4)	23.4± 4.0 (4)	19.1± 3.0 (4)	2/
	Adelie penguin				
	Atka Bay	7.23±1.01 (8)	22.9± 6.9 (9)	15.9± 3.4 (9)	1/
		8.2 ±2.4 (5)	19.9±5.8 (5)	17.8± 4.1 (5)	2/
	McCormick's skua				
	Gould Bay	20.3 ±1.20 (3)	15.4± 1.3 (3)	28.0± 8.8 (3)	1/
	Atka Bay	13.8 ±0.95 (3)	20.9± 5.1 (3)	25.4± 5.7 (3)	1/
		12.3 ±3.8 (10)	28.3± 5.6(10)	31.1± 5.1(10)	2/
	Wilson's petrel				
	Hallett Station	46.8±17.2	18.7±2.3	nd	3/
	Palmer Station	41.3±10.0	17.4±1.8	nd	3/
	Snow petrel				
	Hallett Station	40.9± 7.1	18.1±2.1		3/
Cd	Emperor penguin				
	Gould Bay	0.28±0.37 (5)	5.7± 7.7 (8)	23.8±39.3 (8)	1/
	Atka Bay	1.67±1.03 (2)	48.3±21.0 (3)	382±199 (3)	1/
		0.35±0.09 (4)	27.7±15.6 (4)	270±127 (4)	2/
	Adelie penguin				
	Atka Bay	0.30±0.14 (8)	15.2± 7.0 (9)	175±88.1 (9)	1/
		0.32±0.02 (5)	7.5± 2.4 (5)	264±217 (5)	2/
	Weddell Sea	0.45±0.07	19.8± 0.7	173±12.3	4/
	McCormick's skua				
	Gould Bay	0.32±0.10 (3)	26.2± 2.3 (3)	179±74.1 (3)	1/
	Atka Bay	0.16±0.04 (3)	17.3± 5.7 (3)	132± 8.4 (3)	1/
		0.44±0.22(10)	27.0±16.8(10)	142±43.4(10)	2/
	Wilson's petrel				
	Hallett Station	3.67±2.14	20.3±5.8	nd	3/
	Palmer Station	3.25±0.97	20.7±4.9	nd	3/
	Snow petrel				
	Hallett Station	5.57±1.88	27.7±12.2	nd	3/
	Ashy petrel				
	California	8.00±4.52	53.2±20.5	nd	3/
	Great skua				
	Shetland Islands	nd	1-31 *	13-336 *	5/

(References as quoted by Steinhagen-Schneider (1986))

References:
1/ Schneider et al, 1985
2/ Steinhagen-Schneider (1986)
3/ Anderlini et al, (1972)
4/ Schneppenheim (1981)
5/ Furness & Hutton (1979)

6. RADIONUCLEIDES

Tritium and other radionucleid fallout from bomb tests are not dealt with here. Reference is made to Jouzel et al, (1979) and Taylor (1987).

In a recent paper Cherry et al, (1987) reported on the first substantial measurements on polonium -210 and lead -210 in Antarctic marine biota and sea water (Tables 14-16).

The data base is small, particularly on levels in sea water, but some results are worth noting. Observations were made in the SIBEX I area (62°-65°S, 52°-64°E).

Concentrations of polonium -210 in mesozooplankton and phytoplankton are comparable with those found in such organisms from other areas, e.g. Caribbean, North Sea, Mediterranean and East Pacific Ocean.

Higher than normal values of polonium -210 in euphausiids were found in Euphasia superba from the SIBEX area. Although more research is needed, a tentative explanation is the change from an almost entirely phytoplanktonic diet in summer to a more varied diet in winter.

Data from sea water show unusually high polonium -210/lead -210 activity ratios, i.e. > 1 in six out of eight water samples (2.0-6.8). There is still no valid explanation for this.

7. ANTHROPOGENIC DEBRIS IN THE SOUTHERN OCEAN ECOSYSTEM

Anthropogenic debris, especially non-degradable material, is associated with research stations, field camps and logistic support ships, vehicles and aircraft. In some localities, additional marine input is derived from the activities of fishing fleets. Historically, shore-based and pelagic whaling and sealing has left refuse on the coast and in the sea.

Waste and waste-disposal is being examined by a SCAR working group, whose draft report is being prepared at the same time as writing this document. Several of the chapters in Parker (1972) also deal with this problem.

Although the volume of garbage discharged into the Southern Ocean is probably small, there is no measurement at present. It is certainly very noticeable where it does occur. Gregory et al, (1984) collected plastics and other litter from the surface waters between New Zealand and Ross Sea. As with seabird species in other parts of the world, the ingestion of plastic pellets and other floating fragments presents a hazard to Southern Ocean surface feeders such as petrels (Bourne & Imber, 1982) and albatrosses (Prince, 1980). Waste around research bases affects the Southern Ocean food web through vertebrate scavengers such as skuas (Stonehouse, 1965; Johnston, 1971). Other floating debris may present special hazards to particular members of the biota. For instance, Bonner & McCann (1982) document the occurrence of neck collars of floating line or plastic box-banding which affect Southern Fur Seals at South Georgia (albeit a very small proportion of a rapidly expanding population). With the increase in fishing effort in the Southern Ocean, it seems likely that the incidence of such debris in parts of the Southern Ocean may increase with particular impact on shore-breeding seabirds and seals on islands in the centre of fishing areas (such as South Georgia, Iles Kerguelen).

Table 14. Euphausiids, ^{210}Po and ^{210}Pb concentrations in sundry euphausiid samples

Sample	Collection date	Dr.wt per individual (g)	^{210}Po (pCi g^{-1}dr.wt)	^{210}Pb (pCi g^{-1}dr.wt)
Meganyctiphanes norvegica	26 Apr 1985	0.056	0.95±0.03	0.09±0.01
	26 Apr 1985	0.015	1.57±0.11	0.23±0.05
Euphausia superba	13 Apr 1983	0.103	0.86±0.08	0.07±0.01
	15 Sep 1983	0.090	1.11±0.13	0.14±0.01
Euphausia spp.	10 May 1981	0.023	3.0 ±0.4	nd
Thysanopoda sp.	15 May 1981	0.405	0.99±0.09	nd
	15 May 1981	0.160	0.26±0.13	nd
Thysanopoda cornuta	6 Jan 1983	0.961	0.32±0.04	0.08±0.01
	6 Jan 1983	1.315	0.61±0.05	nd
Nematoscelis sp.	12 May 1981	0.024	1.8 ±0.2	nd
	15 May 1981	0.0076	5.3 ±1.0	nd
Unidentified sp.	15 May 1981	0.0229	2.5 ±0.7	nd
	12 May 1981	0.0097	4.1 ±0.4	nd
Mixed euphausiids	10 May 1981	0.0093	1.3 ±0.3	nd

Table 15. Summary of ^{210}Po and ^{210}Pb data from SIBEX I cruise. n: no. of samples. Although ranges of ^{210}Po concentrations in meso-zooplankton and phytoplankton overlap, note that the concentrations in these two sets of samples represent populations which are statistically significantly different (Mann-Whitney U-test. $P<0.01$)

	^{210}Po (pCi g^{-1}dr.wt)			^{210}Pb (pCi g^{-1} dr.wt.)		
	n	Range	Median	n	Range	Median
Euphausia superba						
whole krill	17	1.0-5.3	3.6	17	0.03-1.94	0.07
hepatopancreas	10	12.6-118	54	2	0.8-2.8	1.8
stomach and contents	8	5.4-114	23	4	1.4-17	10.5
Mesozooplankton	8	4.7-18.1	12.9	8	<0.08-<0.88	<0.22
Phytoplankton	17	2.6-12.2	4.9	16	0.06-6.5	0.81
Sea water pCi 100 kg^{-1}	6	2.8-8.9	5.7	6	1.3-4.5	2.0

Table 16. Summary of previously published data for ^{210}Po and ^{210}Pb in the euphausiids Meganyctiphanes norvegica and Euphausia pacifica, mesozooplankton, phytoplankton and sea water from specified latitudes. n: no. of samples

	^{210}Po (pCi g^{-1}dr.wt)			^{210}Pb (pCi g^{-1}dr.wt)			Source
	n	Range	Median	n	Range	Median	
M. norvegica							
whole	17	0.08-1.5	0.58	5	0.02-0.15	0.06	(1);(2);
hepatopancreas	6	3.7-25	22.8	2	0.13-0.68	0.41	(3);(4);
stomach contents	4	19.2-21.1	20.3	0	-	-	(5)
empty stomach	3	3.2-4.7	3.2	0	-	-	
faeces	4	16.7-27.9	21.4	4	6.3-14.0	10.8	
E. pacifica							
whole	8	0.90-5.4	1.36	6	0.09-0.41	0.16	(1);(6); (7);(8)
Mesozooplankton	57	3.2-53	11.7	52	0.06-3.5	0.64	(9);(10); (4)
Phytoplankton	9	1.2-6.4	3.2	9	0.44-2.4	0.74	(11);(12); (13);(14); (15);(16)
Sea water >55°S	7	2.1-3.2	2.8	36	2.8-6.3	3.9	(12);(13); and twelve other references
5-55°N	44	1.8-6.8	4.0	66	2.6-12.1	6.6	

(See Cherry et al (1987) for references)

References:

(1) Holtzmann (1969)
(2) Heyraud et al, (1976)
(3) Beasley et al, (1978)
(4) Heyraud & Cherry (1979)
(5) Heyraud (1982)
(6) Beasley et al, (1973)
(7) Folsom & Beasley (1973)
(8) Hoffman et al, (1974)
(9) Shannon et al, (1970)
(10) Karkar et al (1976)
(11) Spencer et al, (1980)
(12) Bennett & Carpenter (1979)
(13) Tsunogai & Nozaki (1971)
(14) Nozaki et al, (1976)
(15) Somayajulu & Craig (1976)
(16) Chung & Applequist (1980)
(17) Chung & Craig (1983)
(18) Chung (1981)
(19) Bacon (1977)

8. ATMOSPHERIC TRANSPORT OF POLLUTANTS TO THE SOUTHERN OCEAN

Long-distance transport in the atmosphere provides a mechanism for the dispersal of contaminants such as gases, aerosols or larger particles (in decreasing order of residence time). So far there has been no work to measure directly the flux of pollutants from the atmosphere to the Southern Ocean, although fluxes of some normal gaseous constituents (e.g. CO_2) have been measured. There is, however, considerable interest in snow and ice cores as means of estimating trends in concentration and distribution of several chemicals, including pollutants. Such studies provide a useful source of data on atmospheric transport to the Antarctic where it is possible to assign a source for the material analysed. A summary is provided by Alderton & Coleman (1985).

There are four major sources for aerosol material - the oceans, crustal rocks, anthropogenic emissions and extraterrestrial sources. Except for some exotic elements, the sources are in decreasing order of importance. Equatorial atmospheric circulation forms an effective barrier for constituents with relatively short residence time in the atmosphere (i.e. particles rather than gases). Thus the two hemispheres are effectively isolated from each other with respect to aerosol transport and the Antarctic is unlikely to receive contamination from the majority of anthropogenic sources which lie in the industrialised Northern Hemisphere (Alderton & Coleman 1985).

Dick (1987) has carried out investigations of trace element concentrations in both low-latitude aerosol and in snow at southerly latitudes of the Antarctic Peninsula. He found very low airborne levels of heavy metals. He suggests that approximately 90% of aerosol Pb in Antarctica is anthropogenic in origin, with a similar proportion for Zn. Of the Pb, some was likely to be of local origin but most was derived from lower latitudes in the Southern Hemisphere.

Data on PCB concentrations in Antarctic snow also suggest derivation from lower latitudes (e.g. Risebrough et al, 1976; Tanabe et al, 1986). These compounds are important tracers in that they have no known natural source. However, caution needs to be exercised in the interpretation of some studies and stricter controls are required before unambiguous assessment of airborne transport can be made (Peel, 1983; Alderton & Coleman, 1985).

9. POTENTIAL EXPLOITATION OF NON-LIVING MARINE RESOURCES

The possibility of exploitation of non-living resources in the Southern Ocean presents potential problems of pollution. This arises both from exploratory activities such as seismic survey and the extraction itself.

9.1 Potential hydrocarbon resources

So far, no exploratory drilling has been carried out with the direct purpose of detecting submarine hydrocarbon reserves (oil or gas), although legs of the Deep-Sea Drilling Project have been carried out in Southern Ocean waters and this and other coring activity has suggested the presence of hydrocarbons in sediment (McIver, 1975; Whiticar et al, 1985). Seismographic profiling and theoretical models of hydrocarbon formation and accumulation have been used to suggest that the likely sites are in the Ross Sea Basin and in the Larsen Basin (western Weddell Sea) (Davey, 1985; MacDonald et al, in press).

The potential hazards of offshore oil or gas extraction resemble those encountered in the Arctic, although aspects of the Southern Ocean present more extreme conditions. Very large tabular icebergs have been indicated as being a major hazard. The continental shelf around the Antarctic continent is unusually deep (shelf-slope-break at approximately 500 m) and this also poses extreme technical problems. In contrast to the Arctic, there is no land route for oil transport to lower latitude sites. Possible hazards of petroleum exploitation in the Southern Ocean are summarized by Zumberg (1979) and Behrendt (1983).

9.2 Other mineral resources

The extraction of submarine mineral deposits is not covered by appraisals of potential mineral resources in the Antarctic (e.g. Behrendt 1983; De Wit 1985) or their environmental impact (SCAR-EAMREA 1977; Zumberge 1979), apart from a passing reference to manganese nodules in the latter papers. The possibility of environmental impact of terrestrial exploitation is also explored by SCAR-EAMREA (1977) and Zumberge (1979), who note not only the potential local impact of tailings, heavy metals etc., but also point out that some possible sites for such exploitation are adjacent to the Weddell Sea where much of the world's deep water is formed. However, dilution would be expected to render any concentrations of toxic compounds negligible (Zumberge, 1979).

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