Interim oceanographic description of the North-East Atlantic site for the disposal of low-level radioactive waste

Edited by
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NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

January 1983

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NEA now groups all the European Member countries of OECD and Australia, Canada, Japan, and the United States. The Commission of the European Communities takes part in the work of the Agency.

The primary objectives of NEA are to promote co-operation between its Member governments on the safety and regulatory aspects of nuclear development, and on assessing the future role of nuclear energy as a contributor to economic progress.

This is achieved by:

— *encouraging harmonisation of governments' regulatory policies and practices in the nuclear field, with particular reference to the safety of nuclear installations, protection of man against ionising radiation and preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;*
— *keeping under review the technical and economic characteristics of nuclear power growth and of the nuclear fuel cycle, and assessing demand and supply for the different phases of the nuclear fuel cycle and the potential future contribution of nuclear power to overall energy demand;*
— *developing exchanges of scientific and technical information on nuclear energy, particularly through participation in common services;*
— *setting up international research and development programmes and undertakings jointly organised and operated by OECD countries.*

In these and related tasks, NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has concluded a Co-operation Agreement, as well as with other international organisations in the nuclear field.

Publié en français sous le titre :

ÉTAT DES CONNAISSANCES OCÉANOGRAPHIQUES RELATIVES
AU SITE D'IMMERSION DES DÉCHETS RADIOACTIFS DE FAIBLE ACTIVITÉ
DANS L'ATLANTIQUE NORD-EST

FOREWORD

Under the terms of the Decision of the OECD Council establishing a Multilateral Consultation and Surveillance Mechanism for Sea Dumping of Radioactive Waste, NEA is requested to assess, in consultation with the OECD Environment Committee, the suitability of dumping sites proposed by the national authorities of Participating Countries and to keep under review those previously considered suitable.

Since 1974 radioactive waste sea dumping operations undertaken by Participating Countries have been carried out in a single site located in the North-East Atlantic region. To fulfil the objectives of the Council Decision, an international group of oceanographic and radiation protection experts was convened by NEA in November 1979 to undertake a review of the continued suitability of the dumping site, taking into account the relevant provisions of the London Dumping Convention and the IAEA Definition and Recommendations for the purpose of the Convention. The results of the review are contained in the report *Review of the Continued Suitability of the Dumping Site for Radioactive Waste in the North-East Atlantic* disseminated by NEA in 1980. The Steering Committee for Nuclear Energy confirmed in April 1980 that, on the basis of the review, the existing site was suitable for continued dumping of radioactive waste for the next five years, under the conditions specified by the Group of Experts in their conclusions and recommendations.

At the same time, the Steering Committee for Nuclear Energy agreed on the need for developing a co-ordinated site-specific scientific programme to increase current knowledge of the processes controlling the transfer of radionuclides in the marine environment, so that future assessments can be based on more accurate and comprehensive scientific data. A programme-plan was adopted and implemented in 1981 with the participation of thirteen Member countries and the Monaco International Laboratory for Marine Radioactivity of the International Atomic Energy Agency (IAEA).

A comprehensive description of the work undertaken was published by NEA in 1981 under the title *Research and Environmental Surveillance Programme related to Sea Disposal of Radioactive Waste*. The present document, edited by Dr. P.A. Gurbutt and Dr. R.R. Dickson from the MAFF Fisheries Laboratory at Lowestoft, United Kingdom,

provides a first report on scientific information relevant to the description of the NEA North-East Atlantic dumpsite using all available observations.

This document and additional reports which will be issued when subsequent data become available will be used for the review of the continued suitability of the dumping site for radioactive waste, which NEA will be requested to prepare before 1985 under the provisions of the Multilateral Consultation and Surveillance Mechanism.

CONTENTS

Chapter	Subject	Author
1	Introduction	P. A. Gurbutt
2	History of dumping and description of waste	N. T. Mitchell
3	The local bathymetry	R. R. Dickson
4	Sediment distribution and sedimentary processes at the dumpsite	R. B. Kidd
5	Currents (a) The flow field	R. R. Dickson and W. J. Gould
	(b) The 'Topographic Study'	R. R. Dickson
6	Tide gauge results	J. M. Vassie
7	Historical hydrochemistry in and around the site	J. A. Durance
8	Recent near-bottom hydrochemistry	R. R. Dickson and A. R. Folkard
9	Seawater radionuclide analyses	J. W. Dutton
10	Radioactivity in surface layers of box-cored sediments	W. Feldt, G. Kanisch and R. Lauer
11	Adsorption and geochemical partitioning of long-lived radionuclides on dumpsite sediments	S. R. Aston
12	Biological studies	R. J. Pentreath
13	Fallout concentrations in sediments and some biota from regions of the north-east Atlantic	V. E. Noshkin
14	Isopycnal topography	P. A. Gurbutt
15	Stratification and windstress	J. Wooltorton

Chapter 1

INTRODUCTION

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During the last few decades, there has been increasing activity in medical and industrial use of radionuclides and use of nuclear power for generating electricity. The associated problem for dealing with radioactive wastes in an appropriate fashion was appreciated at an early stage. For low-level radioactive waste, one of the options is controlled dumping in the deep sea. In the fifties and sixties, this was practised without international control. Since 1967, these dumping operations have normally taken place under the auspices of the NEA. To further the objectives of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (The London Dumping Convention - LDC), the OECD Council established a Multilateral Consultation and Surveillance Mechanism for Sea Dumping of Radioactive Wastes (OECD, 1977). While the creation of this Mechanism provides for international consultation and scrutiny to confirm that actions under the LDC and the IAEA Definition and Recommendations (IAEA, 1978) for the purposes of the convention are fulfilled, responsibility for the control of dumping operations remains with the national authorities.

Within the terms of the Mechanism, NEA is requested to assess the suitability of dumping sites proposed by Participating countries and to keep under review those previously thought suitable for dumping of radioactive waste. In 1980, a review of the continued suitability of the North-east Atlantic dumpsite was published by NEA (NEA, 1980) and contained a description of the site based on data acquired up until then. However, since the time of compilation of the report there have been a number of oceanographic cruises to the site and data gathered earlier have been analysed.

The aim of this volume is to provide a further interim description of the North-east Atlantic dumpsite itself using all available and relevant observations, partly to identify remaining gaps in our knowledge of conditions at the site and partly to relate these conditions to the physical environment of the North-east Atlantic Ocean as a whole. It should prove useful to the task groups associated with the

NEA Executive Group on Coordinated Research and Environmental Surveillance (NEA, 1981) in providing a collected scientific description of the site and also to those compiling the next review of continued suitability of the dumpsite.

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Chapter 2

HISTORY OF DUMPING AND DESCRIPTION OF WASTE

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The source term

Disposal of solid or solidified radioactive waste in packaged form has been an established practice over the past 30 years and the North-east Atlantic has been the recipient of such wastes from a number of countries over this period. In a majority of operations, sites well beyond the continental shelf have been used, that is, in very deep water. The sites used, the years in which dumping occurred and the quantities known to have been dumped are set out below. Table 2.1 shows detailed yearly data, the summary total quantities being displayed in Table 2.2. These records cover UK dumping since the first operation in 1949 and all those which have been organised either jointly within ENEA/NEA 1967, 1969 and 1971-76 or under NEA surveillance 1977-81. The entries of dumps which were subject to ENEA/NEA control or surveillance therefore include wastes from western European countries other than the UK. With the exception of dumping in 1960 and 1962 which included some waste from Belgium dumped on behalf of that country by the UK, the entries for other years refer only to UK wastes.

The overall composition of these wastes is shown, latterly within the headings as required to demonstrate conformity to LDC requirements of the IAEA Definition of High Level Waste Unsuitable for Dumping at Sea. In consequence separate data for tritium distinct from other β and β/γ activity is recorded only since 1975. It should be noted that this had been a component nuclide of the wastes prior to this date and accounted for most of the activity in the 1968 and 1974 dumps. Radium-226 is only a very small component of waste, it is not therefore shown separately but included in the estimate of total alpha. It is to be noted that due to the nature of the operations involved in the waste management processes, steps are taken to ensure that the estimates of quantities of activity present are never underestimated. Where there is doubt as to the exact quantities involved, due to it not being possible to sample representatively or perform *in situ* measurement, upper

values are recorded and the data below are therefore overestimates of the amounts actually dumped.

The nature of the waste materials dumped is varied and complex as is the radionuclide composition. Wastes come from a number of sources both within the nuclear industry - fuel element manufacture and reprocessing, nuclear power plant operation, nuclear research and development centres - and without. Sources outside the nuclear industry include hospitals, universities and other research/teaching centres, industrial users and centres where isotopes are made. The radionuclides present thus cover a wide spectrum and include a number of both fission and activation products as well as the major transuranium radionuclides. Some naturally-occurring radionuclides are present, over and above the concentrations typical of materials at large but quantities are generally low and they make up but a small proportion of the total activity. In particular there is now little radium in the wastes. Though at one time radium-226 was an important component, there has been little in wastes in recent years making up only an estimated 1 percent of the alpha activity over the period 1975-81.

Table 2.1 Quantities of radioactive waste dumped at sea 1949-81

	Dumping site				Quantities dumped										
	Latitude N		Longitude W		By the UK				By other countries (d)				By all countries		
	°	'	°	'	Weight gross Te	Activity α Ci	Activity β & γ Ci	Tritium (a) Ci	Weight gross Te	Activity α Ci	Activity β & γ Ci	Tritium (a) Ci	Weight gross Te	Activity α Ci	Activity β & γ Ci	Tritium (a) Ci
1949	48	30	13	00	9		1			NIL				AS UK	
50	49	50	02	18	350	2	20			"				"	
51	49	50	02	18	319	1	18			"				"	
51	55	20	11	20	33	1	5			"				"	
52	49	50	02	18	534	2	29			"				"	
53	55	08	12	10	57	2	2			"				"	
53	49	50	02	18	758	10	39			"				"	
54	49	50	02	18	1145	23	55			"				"	
55	49	50	02	18	1164	35	44			"				"	
55	32	37	14	05	1453	12	33			"				"	
56	49	50	02	18	1038	44	33			"				"	
57	49	50	02	18	1537	109	161			"				"	
57	32	42	19	30	4404	955	808			"				"	
58	32	42	19	30	2694	695	1085			"				"	
58	49	50	02	18	1011	58	57			"				"	
59	49	50	02	18	1198	4	74			"				"	
60(b)	49	50	02	18	2551	74	218			"				"	
61	49	50	02	18	1967	20	308			"				"	
61	32	38	20	05	4360	563	1630			"				"	
62	46	27	06	10	253	17	163			"				"	
62(c)	49	50	02	18	1444	5	76			"				"	

Table 2.1 (continued)

	Dumping site				Quantities dumped										
	Latitude N		Longitude W		By the UK				By other countries (d)				By all countries		
	°	'	°	'	Weight gross Te	Activity α Ci	Activity β & γ Ci	Tritium (a) Ci	Weight gross Te	Activity α Ci	Activity β & γ Ci	Tritium (a) Ci	Weight gross Te	Activity α Ci	Activity β & γ Ci	Tritium (a) Ci
63	49	50	02	18	1543	3	44			NIL				AS UK		
63	45	27	06	16	5809	368	7071			"				"		
64	45	27	06	36	4392	444	15090			"				"		
65	48	15	13	15	1759	114	13754			"				"		
66	48	15	13	15	1044	78	2742			"				"		
67	42	50	14	30	722	91	1682		10178	159	5918		10900	250	7600	
68	48	20	13	16	3164	731	74837		NIL				AS UK			
69	49	05	17	05	1878	390	17590		7302	110	4410		9180	500	22000	
70	48	19	13	15	1674	233	20224		NIL				AS UK			
71	46	15	17	25	1434	323	8615		2536	307	2585		3970	630	11200	
72	46	15	17	25	1885	674	19049		2245	6	2551		4130	680	21600	
73	46	15	17	25	1453	739	11641		2897	1	1019		4350	740	12660	
74	46	15	17	25	1256	399	94126		1009	17	6230		2265	416	100356	
75	46	15	17	25	1350	704	52481	25840	3110	76	8019	4160	4460	780	60500	30000
76	46	15	17	25	2269	789	49777	18730	4501	91	3723	2270	6770	880	53500	21000
77	46	00	16	45	2140	930	74830	31328	3465	28	1621	558	5605	958	76451	31886
78	46	00	16	45	2080	814	69307	32700	5966	287	10321	3913	8046	1101	78629	35614
79	46	00	16	45	2014	1381	81080	40991	3402	33	2286	1449	5416	1414	83366	42440
80	46	00	16	45	2693	1791	106079	40169	5698	61	59818	57966	8391	1852	165897	98135
81	46	00	16	45	2517	2032	104709	38243	6918	85	48858	36129	9435	2117	153567	74372

Notes:

(a) Specific data available for tritium only since 1975; prior to that year tritium was included in β and γ. For consistency with earlier years tritium is also included in β and γ for 1975-81 in the above Table.

(b) Includes 289 Te from Belgian sources.

(c) Includes 438 Te from Belgian sources.

(d) Estimates for 'other countries' in 1967, 1969 and 1971-81 were deduced by subtracting the UK contribution (exact figures) from the NEA totals (rounded values).

Table 2.2 Summary of known waste dumpings in the NE Atlantic 1949-1981

	UK[a]	Other countries	Total
Gross weight (Te)	71355	59227	130582
Alpha activity (Ci)	15588	1261	16849
Beta + gamma activity (Ci)	828588	157359	985947
Tritium[b] (Ci)	227002	106445	333447

(a) Including 727 Te Belgian waste
(b) Specific to 1975-79; tritium included in beta + gamma category prior to this date

Chapter 3

THE LOCAL BATHYMETRY

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Figure 3.1 illustrates the best-available chart of local bathymetry, with the present dumpsite (rectangle) and the pre-existing dumpsite (inner circle) superimposed. The depth contours around the periphery of the site are at 200 m intervals, interpolated from Chart C6568 (in fathoms) by the NERC Experimental Cartography Unit (1975) from a compilation by Laughton, Roberts and Graves, IOS Wormley. The inner area of the site has been corrected using PDR data collected during RV CIROLANA Cruises 10/76 and 6/79; where this improved coverage is available depth contours are plotted at 100 m intervals.

The dumpsite is located in the foothills of the Mid-Atlantic Ridge, close to its junction with the Porcupine Abyssal Plain. The principal features are the flat-floored valley trending NNE-SSW across the western part of the present site, with maximum depths slightly in excess of 4750 m and with valley walls rising to summits of 3600-3800 m to east and west. The remaining (eastern) part of the present site is occupied by irregular and often abrupt topography with hills reaching to $\sim$ 3750 m and basins to $>$ 4700 m. In this area topographic slopes of 1:2.4 were found between the hilly region centred on 46°N, 16°33'W and the basin immediately to its west. This region of abrupt topography is described in greater detail in Chapter 5b.

It is self-evident that an accurate knowledge of the topography of the site is a baseline requirement; it determines the direction and very possibly the strength of near-bottom water movements, the thickness of the sediment layer and even the depth distribution of the dumped waste. As such our present knowledge is imperfect, being based on relatively few PDR transects.

Action

Accurate charting of the site and its immediate surroundings within 20 miles (37 km) of the present site using the SEABEAM system currently installed on RV JEAN CHARCOT or ships of opportunity. The SEABEAM, while being more costly would also allow sub-bottom profiling to be done.

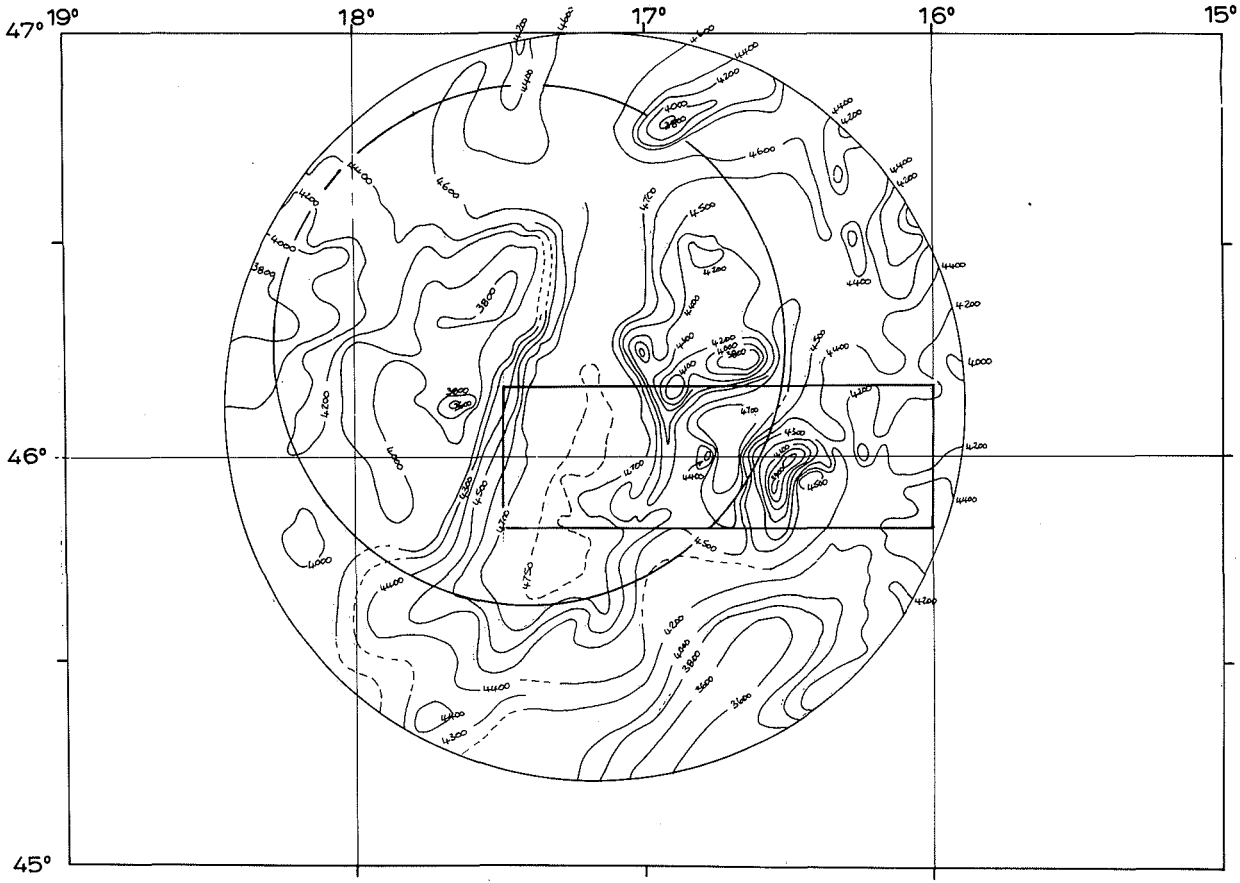

Figure 3.1 Local bathymetry of the NEA dumpsite; the rectangle indicates the area of the current NEA dumpsite and the inner circle shows the region of the previous dumpsite. Depths are given in metres.

Chapter 4

SEDIMENT DISTRIBUTION AND SEDIMENTARY PROCESSES AT THE DUMPSITE

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Introduction

This chapter summarises the available published data on the sedimentary environment at the Nuclear Energy Agency dumpsite for low-level radioactive waste, which is centred on 46°N, 17°W in the north-east Atlantic at between 3600 and 4750 metres water depth. No sampling has been specifically undertaken to characterise the sediment types at the site. Investigations of box-core samples have been carried out to determine increases in the amounts of radioactivity present in the sediments since dumping began in 1971 but core descriptions of these samples are not available (see Feldt et al., Chapter 10 this report). A review of the available data on sediment distributions in the area is presented here as well as some comments on how the facies relate to the distribution of sediment as a whole in the north-east Atlantic. The review relies upon isolated piston core samples only two of which are actually in the area, and on four seismic reflection (air gun) profiles that cross the area. (The cores are all from the Lamont Doherty Geological Observatory core collection and are described in core descriptions supplied by LDGO or from published papers.)

Information on sediment distribution and processes derived from techniques such as high-resolution (3.5 kHz) seismic profiling, bottom photography and long-range sidescan sonar are, at present, completely lacking in this area. Nevertheless, it is possible to predict the type of sediment likely to be present from a consideration of the general oceanographic setting of the site and then to compare the predicted facies with the available sample descriptions and air-gun profiling in and around the area. This approach should allow one to assess general sedimentary conditions at the site since the late Pleistocene and to recommend what further studies might be useful to determine sedimentary processes there.

General sedimentary setting

The physical location of the NEA Atlantic site allows inferences to be made about its sedimentary environment. The site is about halfway between the Mid-Atlantic Ridge and the west European continental margin. More precisely, it is located in the easternmost part of the ridge-flank province where this province begins to merge with the Porcupine Abyssal Plain (Dickson, Chapter 3 this report). The oceanic igneous basement in this area has been continuously draped with pelagic sediment throughout its spreading history and this has produced a rough terrain of sediment-covered abyssal hills and ridges still largely reflecting the Mid-Atlantic Ridge trend (Laughton et al., 1975). Gravity-controlled bottom transport of sediment probably has ponded material between the hills. Sediment sources could either be local (slumping from the slopes of the hills, i.e. pelagic turbidites) or distant incursions of distal turbidites from the Porcupine abyssal plain. The pelagic-draped sediment on the hills could be volumetrically the most prevalent sediment type in the area. This prevalence is reflected in most published maps of generalised sediment distributions of the North Atlantic (Rawson and Ryan, 1978; Lizitzin, 1972; Barron and Whitman, 1981) that show the area as one of pelagic carbonated ooze and marl. Figure 4.1 shows the portion of the Rawson and Ryan map where the disposal site is located and its position is in the ridge-flank pelagic marl province close to the terrigenous clays ponded in the Porcupine Abyssal Plain.

Regional sedimentary components and processes

The area is dominated by a marl facies rather than a pure carbonate ooze facies. Calcium carbonate values in surface sediment from this general region are 50-75% (Biscaye et al., 1976). These medium-range values suggest either that the site is within the lysocline or it experiences some non-carbonate dilution. The calcite compensation depth in this part of the North Atlantic lies at ≃ 5000 metres water depth (Biscaye et al., 1976). Some carbonate dissolution in surface sediment may indeed be occurring but the area's proximity to distal abyssal plains, and beyond these to land areas, suggests that dilution of carbonate by terrigenous material may be more important.

Biogenic siliceous material in the form of diatoms and radiolaria and to a lesser extent silicoflagellates probably represent only a very minor component of the sediment. The terrigenous component that makes up most of what is not biogenic carbonate, that is 25% and upwards, is probably primarily clay-size material that has been transported in the water column from initial river and wind input. Part of this terrigenous input could be true clay mineral material, part however, could be in the form of quartz. Sediments deposited during Holocene time, that is the last 11 000 years, over this region of the Atlantic contain around 5-10% quartz (Kolla et al., 1979). The percentage increases to around 15% in the deposits of the last glacial period. The terrigenous quartz input is reinforced by ice-rafted transport and deposition from icebergs. The region lies close to the locus of maximum ice-rafted sand deposition during the last glacial period (Ruddiman, 1977). Ice-rafted input can be terrigenous material of all types and sizes that

when deposited can be found both at sediment/water interface and within the sediment column. Much of this material is found as erratics in the coarse sand to pebble-size range; generally no more than 2 cm diameter (Kidd and Huggett, 1981). The area is sufficiently remote from volcanic centres so that a significant volcanogenic sediment component is unlikely. Coarse tephra horizons are also unlikely, at least in the upper few metres. Authigenic mineral components are probably rare. These components attain importance only in areas of major volcanogenic or hydrothermal input, or those below the local CCD.

Sediment cores from ridge-flank areas in the North Atlantic invariably display alternations of carbonate ooze and marl in phase with the glacial/ interglacial intervals of the Late Quaternary (Ruddiman and McIntyre, 1976). Coccoliths and foraminifers were deposited two to three times more rapidly during interglacial than in glacial periods (Ruddiman and McIntyre, 1976) whereas ice-rafted terrigenous material was preferentially input into North Atlantic sediments during glaciations (Ruddiman, 1977).

When local redistribution of sediment occurs in pelagic areas the fine coccolith component of the carbonate sediments is most easily transported. Cores taken on local highs in the bathymetry commonly contain horizons of foraminifer-rich lag deposits. The fine material, principally coccoliths and diatoms, have been 'winnowed' away by localised currents. Local slumping generated by instability on slopes most often produces pelagic turbidite beds - a graded carbonate deposit with foraminiferal sand at its base.

Bottom currents locally increase their velocity around upstanding topography. Erosional features are frequently developed around the bases of slopes in areas of major bottom water circulation (Davies and Laughton, 1972). These 'moats' are not expected in the site area because of the absence of major bottom water mass circulation in this region.

Relevant airgun profiles and piston cores

Figure 4.2 is a generalised bathymetric map of the region in and around the 'old' (circular outline) and 'new' (rectangular outline) NEA dumpsites. The contours are extrapolations of those mapped by Laughton et al. (1975) in fathoms. Dickson's updated detailed map (this report, Figure 3.1), which has closer control, should be referred to in order to obtain the details of the slopes around the central depression. The depression connects northward with the Porcupine Abyssal Plain and locally reaches below 4700 m water depth. The tracks of all the available air gun seismic profiles that cross the areas, as well as the locations of piston cores known to have been taken either within or close to the dumpsite areas, are shown on Figure 4.2.

Figures 4.3 to 4.6 illustrate the seismic profiles run through the area and each profile has the location marked of piston cores. Only two of the cores are actually from the dumpsite area. The other core locations are shown to relate sediment types to the topography on the profiles so that the initial two cores can be placed in a regional

perspective. A full list of cores described from this region is given in Table 4.1.

The DISCOVERY cruise 93 profile (Figure 4.3) shows the characteristically hummocky 400-800 m relief of ridge-flank topography interrupted by the low north-south trough of the dumpsite below 4700 m. The sediment, presumably a pelagic carbonate drape, is about 350 m thick above a regional reflector. The uppermost sediments are acoustically more finely layered in the low area but clearly are not as flatly ponded as in lows farther west. This may reflect more local redeposition of pelagic turbidites and less influence of terrigenous material transported across the Porcupine Abyssal plain. No cores were taken on this line although Vema 27-123 lies close to it (Figure 4.2). This core shows an alternation of foraminiferal marl and ooze that reflects the draped pelagic sediments on the eastern flank of the central trough. Scarps in the topography of the sediment-draped areas probably reflect basement faults; however, it is never clear in such areas whether more recent movements on the faults have assisted in maintaining their outline (Searle, 1977). There is no evidence of large-scale erosional features such as moats, however, in at least two of the low areas immediately to the east of the dumpsite, the sedimentary infill has a sediment drift-like appearance that suggests possible preferential deposition of sediment by currents against upstanding topography e.g. 0400Z on Figure 4.3 (Hollister et al., 1978).

The intersecting profile Vema 2305 (Figure 4.4) has a greater vertical exaggeration. This profile also shows a draped pelagic upper sediment sequence with a thickness (to the topmost strong reflector) of around 350 m. Unfortunately, no data were recorded over the low area of the new dumpsite, but there appears to be some evidence of sediment drifting immediately east and south of the site (1430Z on Figure 4.4). The 10.75 m-long core, Vema 23-84 taken on this profile at 4513 m came from the slopes of the trough area. The sediment has alternations of foraminiferal marl and ooze typical of Late Pleistocene pelagic carbonate sequences. The sand fractions contain a fairly high percentage of terrigenous material, but this is probably from ice-rafting rather than from redeposition by turbidity currents. No graded (turbidite) units were described. Stratigraphic studies on this core (Ruddiman and McIntyre, 1976) yield accumulation rates of about 2 cm/1000 years and the core's record extends well beyond 127 000 years BP.

The other seismic profile through the area that passes over a core site is Vema 2706 (Figure 4.5). This profile runs from the ponded turbidites of the Porcupine Abyssal plain in the north, along the eastern flank of the dumpsite's central trough. The record is not particularly clear but sediment thicknesses measure around 370 m to the regional reflector. Again, no evidence of erosional features is found on this profile. A 9.52 m-long piston core (Vema 27-123) taken at 4539 m has an alternation of foraminiferal marl and ooze similar to the facies of core V23-84. Terrigenous sand is described at various levels; much of the sand is basic volcanic rock fragments, quartz and volcanic glass. Some pebbles occur that suggest this and is mostly of glacial origin. No turbidite units or distinct sand layers were described. There is no evidence in the core descriptions of erosion in the form of scour marks or winnowed layers.

One other seismic profile Vema 2805 (Figure 4.6) traverses the edge of the dumpsite area (Figure 4.2). The hummocky ridge-flank topography is again draped by an uppermost pelagic (carbonate) sequence around 370 m thick. No ponding is observed at the dumpsite area, a reflection of the lack of any abyssal plain connection. The nearest core to the profile is Vema 28-86, outside the area. It shows the typical late Pleistocene marl/ooze cycles. In contrast, other cores taken on this profile to the northwest in the ponded (turbidite) sequences of the abyssal plain contain terrigenous silt, clay and sand units.

Summary

The core data available in the form of preliminary core log descriptions is inadequate because no interpretations of processes were made by the observers. Also, the coring in and around the NEA dumpsite is clearly biased towards the draped pelagic carbonate sequences of the hill areas. No long cores are, at present, available from the central trough area of the dumpsite. There is little evidence in the preliminary descriptions of cores outside the trough of erosion, slumping or other redeposition of sediment nor have any major hiatuses been detected in the cores with a known stratigraphy. Where available this has a rather good resolution around 10 000 to 20 000 years (Ruddiman and McIntyre, 1976). The sections reflect overall sedimentation rates of around 2 cm/10^3 years, which is typical of North Atlantic pelagic areas. Consequently, any erosion or redeposition of sediment at these locations must be assumed on the basis of the available core logs and the isolated cores with known stratigraphies, to be minor; at least, not in the form of submarine slides or slumps.

The sedimentary record in the trough area of the dumpsite is likely to be more erratic than that from the hill areas with pulses of rapid deposition. It is impossible from the available data to assess whether locally-derived turbidity currents or distal turbidity current incursions from the north are likely to be erosive or whether slumps or slides have occurred.

There is no evidence on the available air-gun profiles across the area of any large-scale erosion but there is some indication of sediment drifting in places to the east. It must be said, however, that a much clearer picture of Quaternary sedimentary processes would emerge from high-resolution (3.5 kHz) echo character mapping (Damuth, 1980) than from the air-gun profiling so far carried out across the area.

The sediments recovered and the available air-gun profiling can be interpreted to show conditions that do not contradict the inferred conditions derived from the initial consideration of the general sedimentary setting of the dumpsite.

Action

The major gaps in our geological knowledge of this area are a lack of core information for the sedimentary history of the trough area and no long-range sidescan sonar or high-resolution seismic coverage of the site. Combination of the latter techniques would allow a detailed interpretation of sediment distribution processes (Kidd, 1982). In addition, the available bathymetry upon which interpretation of sedimentary processes will rely is based upon individual echo-sounder tracks made over a period of years and using varying navigational accuracy. A dedicated SEABEAM bathymetric survey would enhance all levels of study of the area. These information gaps should certainly be filled before more detailed sedimentary studies could be recommended.

Acknowledgements

Dr James Gardner and Dr. Roger Searle are thanked for their review and their useful comments on this contribution.

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Table 4.1

Core No.	Lat. (°N)	Long. (°W)	Depth (m)	Length (m)
V23 - 84[1]	46°00'	16°55'	4513	10.75
V27 - 123[1]	46 29	16 55	4539	9.52
V27 - 124	44 22	16 27	4197	6.13
V27 - 127	44 37	14 58	5095	6.80
V27 - 136	43 58	15 49	5475	≈11.13
V28 - 83	47 28	19 59	4559	9.09
V28 - 84	46 55	19 27	4206	10.08
V28 - 85	44 55	17 02	3828	3.72
V28 - 86	45 55	19 15	4515	8.23
V28 - 87[1]	45 49	20 18	4616	10.38
RE5 - 36[1]	46 55	18 35	4500	≈ 6.7
MB/M2[2]	46 09	19 04	4375	2.25
D7298[3]	43 58	16 48	3642	3.0
RC9 - 212[4]	44 12	14 54	5083	≈ 9.25
RC9 - 215[4]	44 16	15 46	5336	12.00
RC9 - 216[4]	44 21	15 25	5503	16.30
RC9 - 217[4]	44 31	15 28	5266	

1. Reference: Ruddiman and McIntyre, 1976.
2. Reference: Buchan et al., 1971.
3. Reference: RRS Discovery Cruise 33, NIO Cruise Report.
4. Reference: Addy and Kagami, 1979.

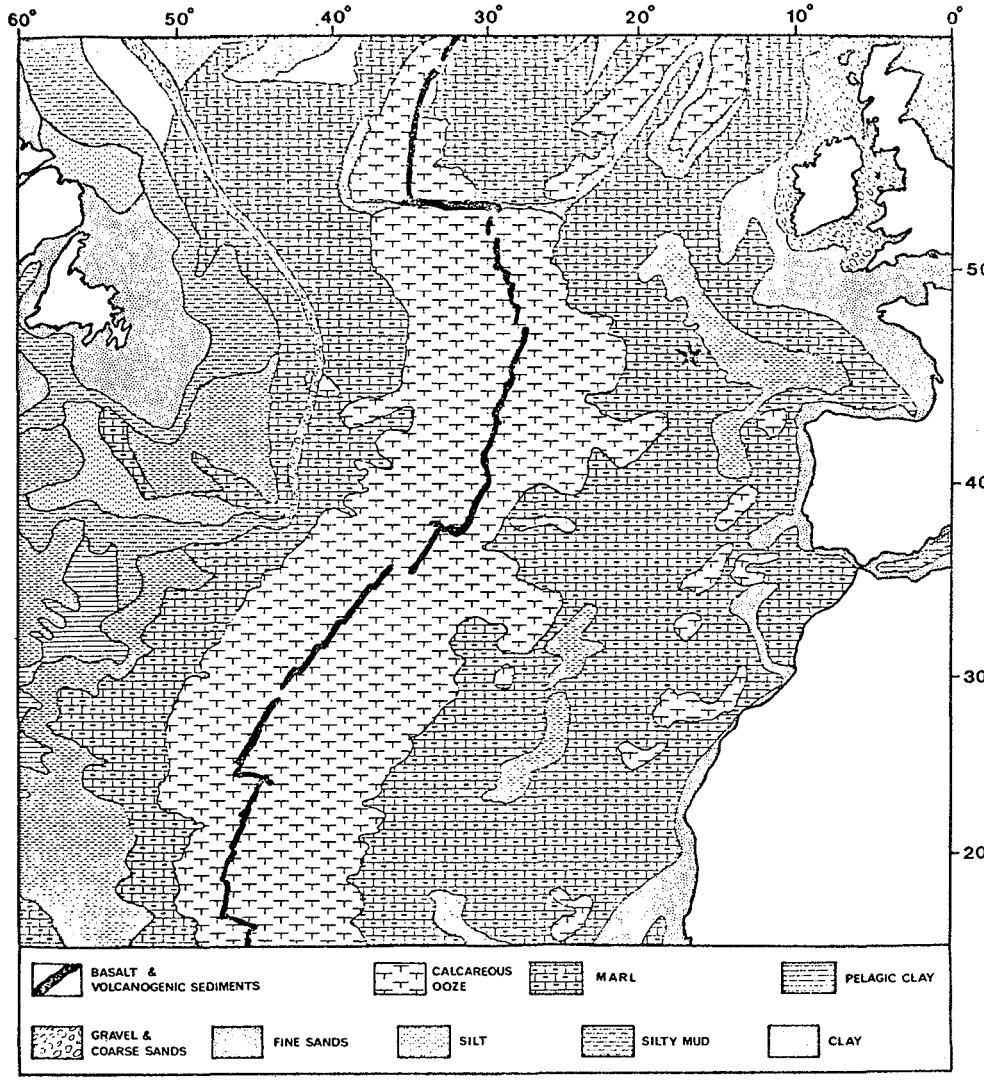

Figure 4.1 Generalised ocean floor sediment distributions in the North Atlantic modified from Rawson and Ryan, 1978. The star symbol locates the NEA low level R.W. dumpsite.

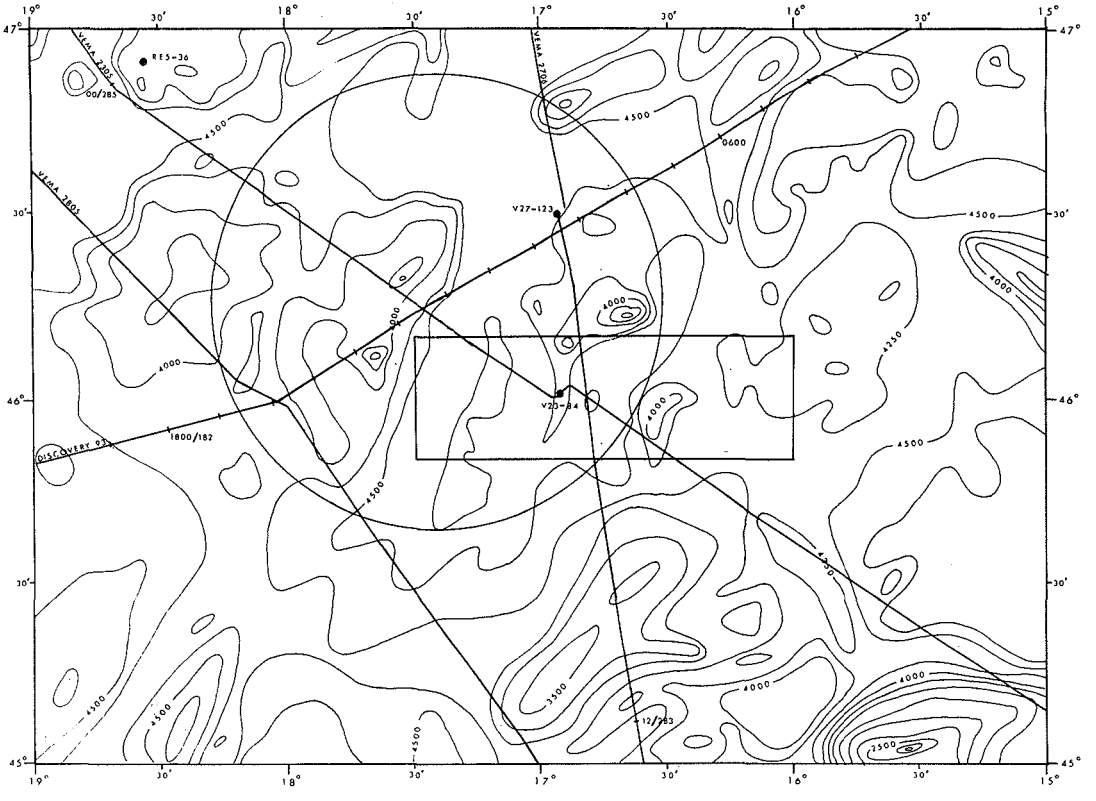

Figure 4.2 Bathymetry of the region around the NEA dumpsite (after Laughton et al., 1975) with locations of seismic profiles through the area and relevant piston cores referred to in the text. Contours are in metres below sea level. Seismic profiles are shown with notation as to ship and cruise number along with day numbers and times. Sediment core locations are shown as black dots with core numbers.

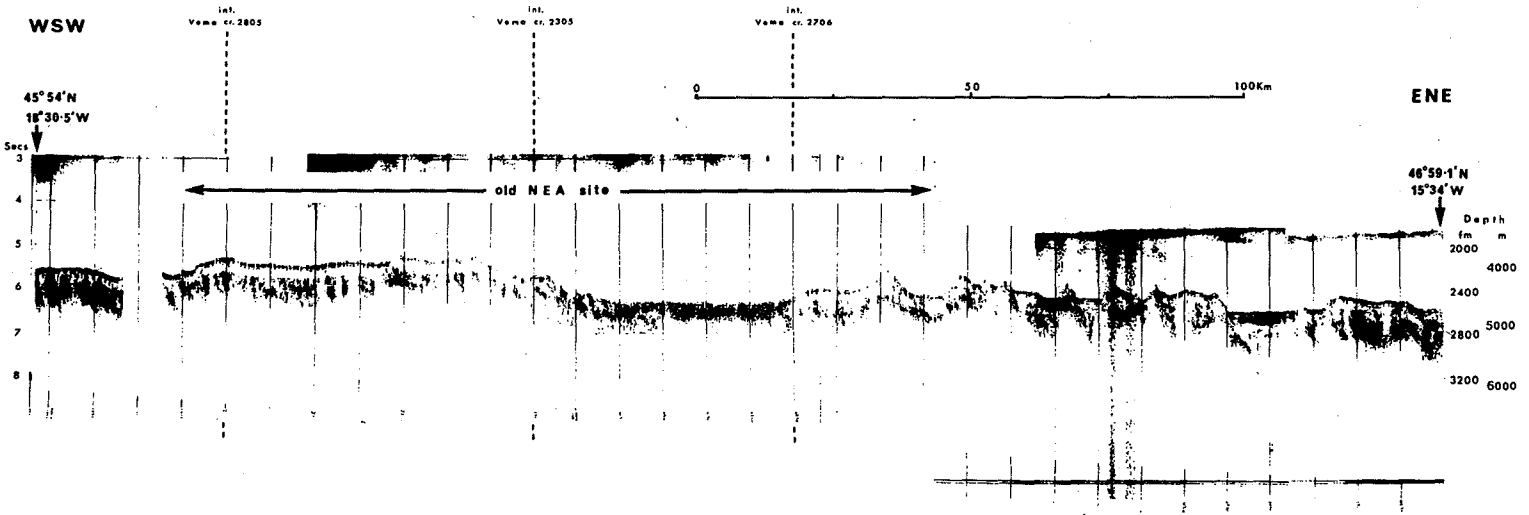

Figure 4.3 DISCOVERY Cruise 93 air-gun seismic profile showing the portion which traverses the circular outline of the 'Old NEA' site and positions that this profile crosses others in the area.

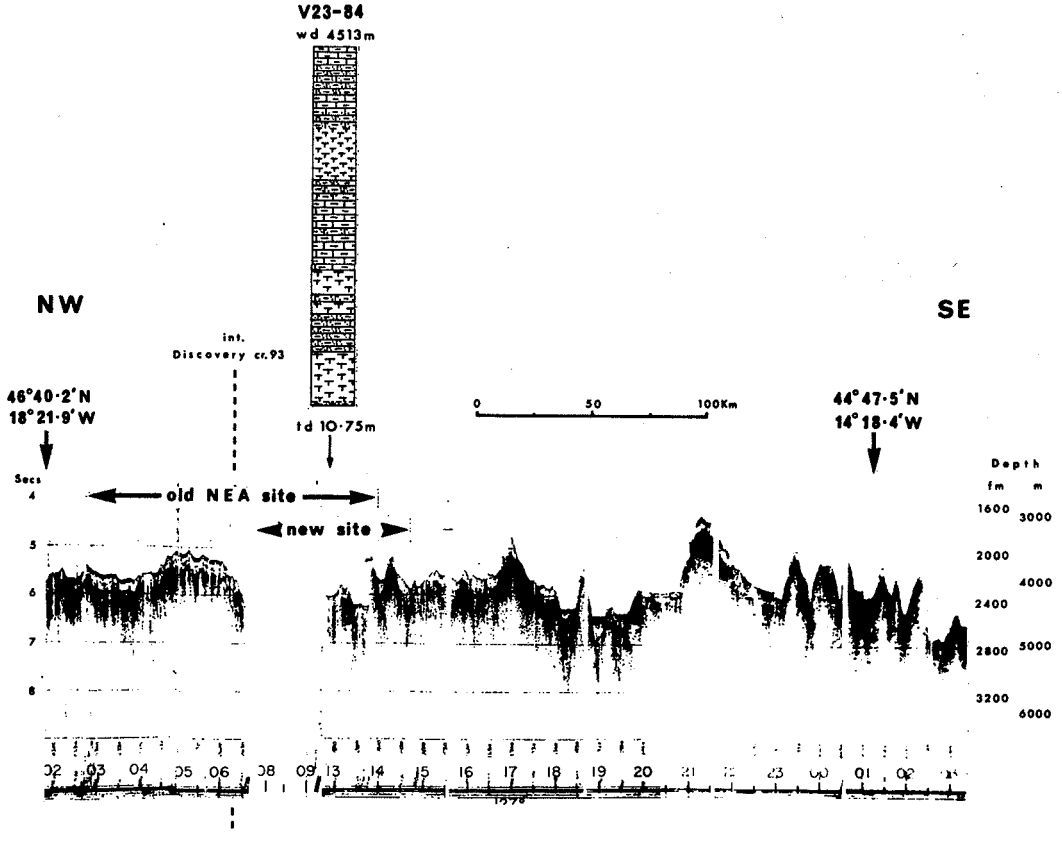

Figure 4.4 Vema Cruise 2305 air-gun seismic profile with the areas of the 'old' and 'new' NEA sites outlined and the intersection of the DISCOVERY 93 profile. Above is a graphic log of the Vema 23 core 84 taken on the profile. Lithologic symbols used are as for Figure 4.2 and water depth (W.D.) and terminal depth below the seafloor of the core are noted.

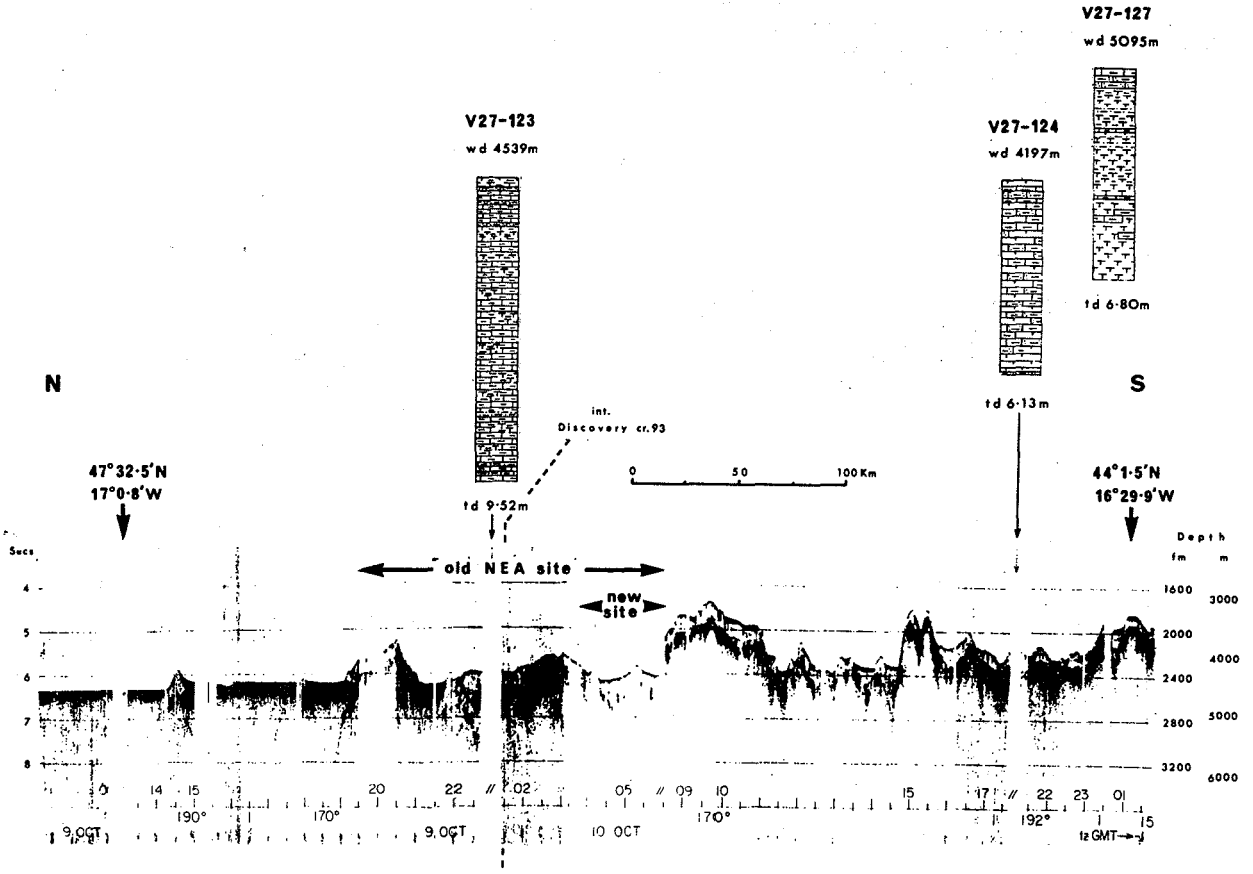

Figure 4.5 Vema Cruise 2706 air-gun seismic profile with above graphic logs of core Vema 27-123 taken on the area of Vema 27-124 and 127 recovered further south on this profile. Symbols and notation as for Figure 4.4.

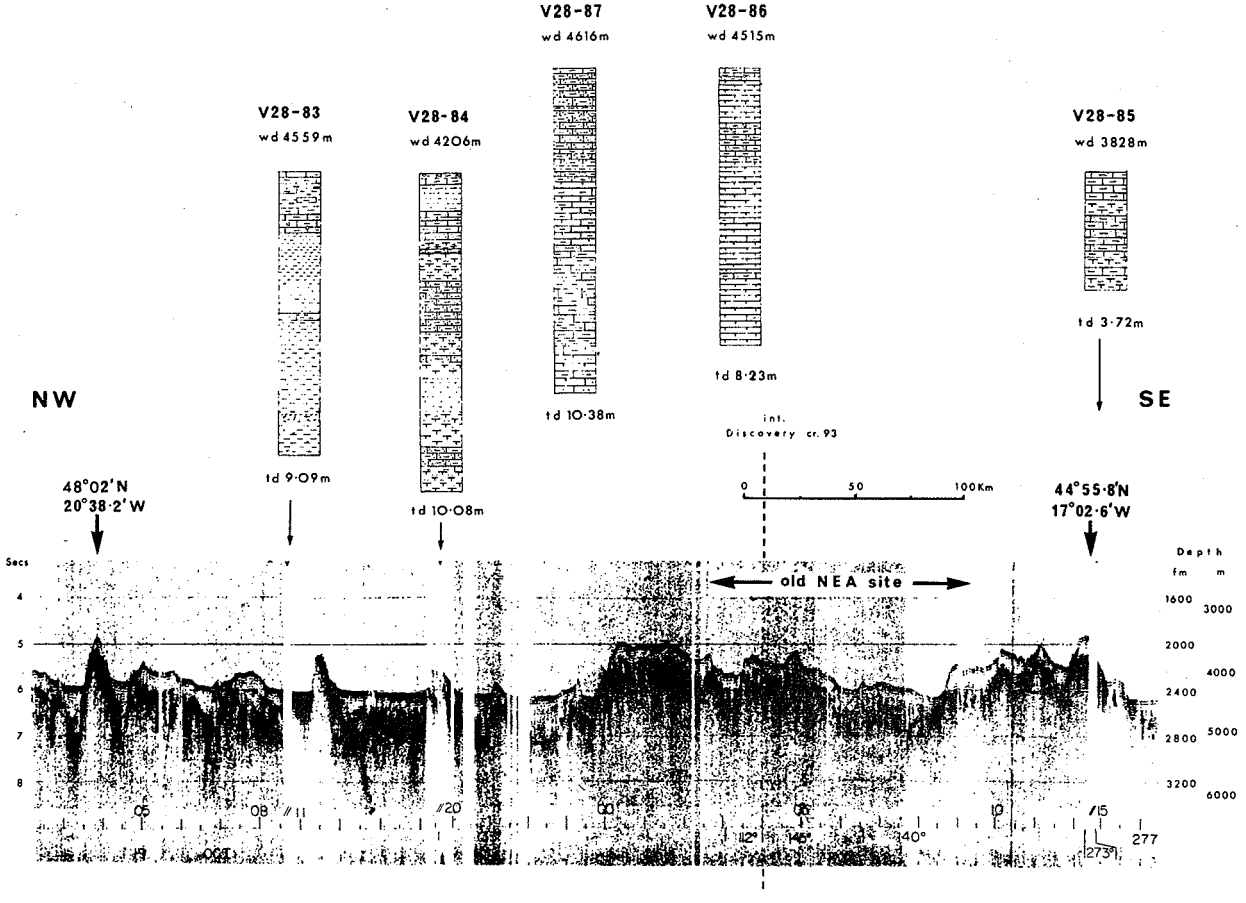

Figure 4.6 Vema Cruise 2805 air-gun seismic profile with graphic logs of cores taken in the region but away from the dumpsite area. Symbols and notation as for Figure 4.4.

Chapter 5

CURRENTS

The first part of this chapter aims to describe the flow field at the site itself (from current meter and float deployments) and to set these local observations into the larger-scale context of the North Atlantic circulation and its variability. The second part will describe an experiment to determine the influence on the deep flow of large scale topographic features at the dumpsite.

5A THE FLOW FIELD

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5.1 Short-term In November-December 1976 a short-term array of three current meter moorings (76-01 to 76-03, two current meters per mooring, 10 min sampling interval) was deployed around the margins of the main valley which occupies the 'old' dumpsite area (inner circle Figure 3.1). These were maintained for 22-25 d and were supplemented with nine neutrally-buoyant float deployments at depths between 1000 and 4675 m. The floats were tracked by RV CIROLANA for up to 17 d. The location of current meter moorings, progressive vector diagrams from the current meter records and the tracks of the seven successful floats are shown together in Figure 5.1 (Hill and Dickson, 1977).

The flow in the near-bottom layer was found to be cyclonic around and above the main valley, with an apparently strong morphological control. The current meter records, summarised in Table 5.1, were dominated by motions close to the local inertial period of 16.5 h, and speeds did not exceed 14 cm s^{-1}. Average speeds of 1.8-2.6 cm s^{-1} were observed at 50 m above the bottom and 1.0-4.7 cm s^{-1} at 1000 m above the bed. The overall mean speeds of 5 floats at depths > 3000 m ranged from 2.2-3.4 cm s^{-1}. The two floats set in the Mediterranean water at depths of 1000 and 1172 m were apparently unaffected by the underlying topography, drifting steadily to the west or north-west at mean speeds of 7.7-8.8 cm s^{-1} (Table 5.2).

Table 5.1 Summary of current-meter data, NEA Dumpsite 17 November-13 December 1976

Mooring	Position	Water depth (m)	Sampling depth (m)	Duration (d)	Max speed cm s^{-1}	Mean residual speed cm s^{-1}
76-01	46°34.8'N	4705	3700	24	12	2.2
	17°07.2'W		4655	24	13	1.9
76-02	45°38.8'N	4520	3700	23	8	1.0
	17°45.8'W		4470	6	9	1.8
76-03	45°47.3'N	4567	3697	21	12	4.7
	16°44.1'W		4517	21	13	2.6

5.2 Long term The NEADS-5 mooring, at 46°00'N, 17°00'W within the NEA dumpsite, is one of an incoherent array of long-term current-meter moorings maintained by the NEADS Subgroup of SCOR WG 34. The basic aim is the provision of time-series which are of adequate duration for the study of dynamics and circulation-variability within the eastern basin. The location of the NEADS-5 mooring is shown in Figure 5.2.

Initially, from December 1976 to December 1978, the mooring was maintained by IOS Wormley, recovering records of varying continuity from 600, 1500, 3000 and 4000 m depth. Later, between June 1979 and June 1980 the Fisheries Laboratory, Lowestoft reoccupied the site specifically to provide an adequate record at the ~ 4000 m level where the good-data return had been poorest during the earlier deployment. Instruments were set at 4050, 4200, and 4710 m depths with a good-data return of 95%.

Basic flow statistics from these NEADS-5 records are listed in Table 5.3.

Table 5.3 Flow statistics from the NEADS-5 mooring

Originator	Water depth (m)	Position N	Position W	Sampling depth (m)	Duration (d)	K_E cm^2 s^{-2}	K_M cm^2 s^{-2}	K_E/K_M
IOS	4756	46°00'	17°00'	600	450	61.5	3.08	20.0
				1500	600	10.0	1.05	9.5
				3000	485	2.5	0.25	10.0
MAFF	4760	46°06'	17°09'	4050	362	1.0	0.50	2.0
				4200	362	0.6	0.33	1.9
				4710	307	1.2	0.55	2.2

When compared with other long-term records from the North Atlantic these observations show the following characteristics.

(a) Eddy kinetic energies are (as normal) greater than those of the mean flow and are less energetic than at equivalent latitudes and depths of the western basin. Charts of K_E for the North Atlantic as a whole show that this result is typical for the eastern basin, both in the upper ocean (Figure 5.3) and at depth (Figure 5.4) (from Dickson, in press).

(b) The dominant eddy time-scales are complex. To the south of the site records tend to be dominated by eddy motions with periods $\geq$ 100 d at all depths (e.g. Gould, in press; Dickson, in press). To the north, records tend to be dominated by a seasonal (winter/spring) input of eddy energy at short or intermediate time-scales, during the period when windstress is maximal and the seasonal thermocline is absent (Dickson et al., 1982). Both of these characteristics are identifiable in the NEADS-5 records. Figure 5.5 for example by Gould confirms that the longest periods dominate in summer at 600 m depth but with shorter periods dominating the winter spectrum. Figure 5.6, from Dickson et al. (1982), describes the seasonal modulation of eddy energy in the period bands 3-27 d and 3-80 d for five of the long-term records at NEADS-5 (panels a-e) which represent a range of depths between 600 and 4710 m.

(c) Mean flow The length of record (T) required to compute reliable estimates of mean flow and variances depends upon the dominant frequency of the fluctuations. However it is also true that we can estimate the variances much more reliably than the means with present-day lengths of record (1-1.5 y); the error in estimating the latter decays like $1/T$ and has the same periodicity (τ) as the original signal whereas the error in estimating the former decays at least partly as $1/T^2$ with periodicity $\tau/2$.

This effect, coupled with the facts that the mean is often small compared with the fluctuating component, that the record lengths are only a small multiple of the dominant frequency in the record, and that the current meter network remains sparse, means that we cannot place any great reliance on the amplitude or even the sign of individual estimates of zonal or meridional mean flow components.

Despite these uncertainties in the reliability of any given mean we may derive some confidence from the fact that in the region surrounding the dumpsite (Figure 5.7) the combined records from all deployments are to some extent mutually-supportive, providing evidence of a slow but apparently systematic northward drift of 1-2 cm s^{-1} in the deepest layers (within $\sim$ 1000 m of the bottom). A general deep northward flow in the eastern basin is anticipated from the models of Veronis (1978) and Stommel (1958) and recent large-scale investigations of radiochemical tracer distributions also provide evidence that the deep eastern basin appears to be ventilated from the south. Nevertheless, no firm conclusion can be drawn from Figure 5.7 until the coverage and duration of Eulerian (or Lagrangian) measurements of the flow field is improved.

At shallower depths in the water column, the coverage is at present too sparse to form even a tentative picture of the mean circulation.

Action Nil

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Table 5.2 Float release and recovery positions, CIROLANA cruise 10/76 (from Hill and Dickson, 1977)

Channel	Planned depth (m)	Actual depth (m)	Release time	Position	Recovery time	Position	Duration of tracking	Mean speed (cm s^{-1})*
7	3350	3356	0207/19 Nov	46°06'N 17°12'W	1210/ 5 Dec	45°52'N 17°21'W	16d 10h	3.3
8	4700	on bottom	1619/20 Nov	46 02 17 14	1230/22 Nov	46 02 17 14	-	-
9	3700	3576	1813/20 Nov	46 14 17 11	0928/ 8 Dec	45 58 17 33	17d 15h	2.8
11	3700	3648	2006/20 Nov	46 20 17 10	1304/27 Nov	46 29 17 21	6d 17h	3.4
14	3700	4234	1239/22 Nov	46 02 17 14	1316/ 5 Dec	45 56 17 22	13d 1h	2.2
8	1000	1172	1616/22 Nov	46 10 17 13	1050/26 Nov	46 10 17 36	3d 18h	8.8
4			0324/24 Nov	46 08 17 11		L O S T		
15	4700	4675	0200/25 Nov	46 08 17 11	1022/ 8 Dec	45 58 17 27	13d 8h	2.7
8	1000	c.1000	2243/26 Nov	46 10 17 03	1332/ 4 Dec	46 30 17 36	7d 15h	7.7

*The mean residual current speeds indicated by the floats varied in magnitude by up to 50% during the tracking period.

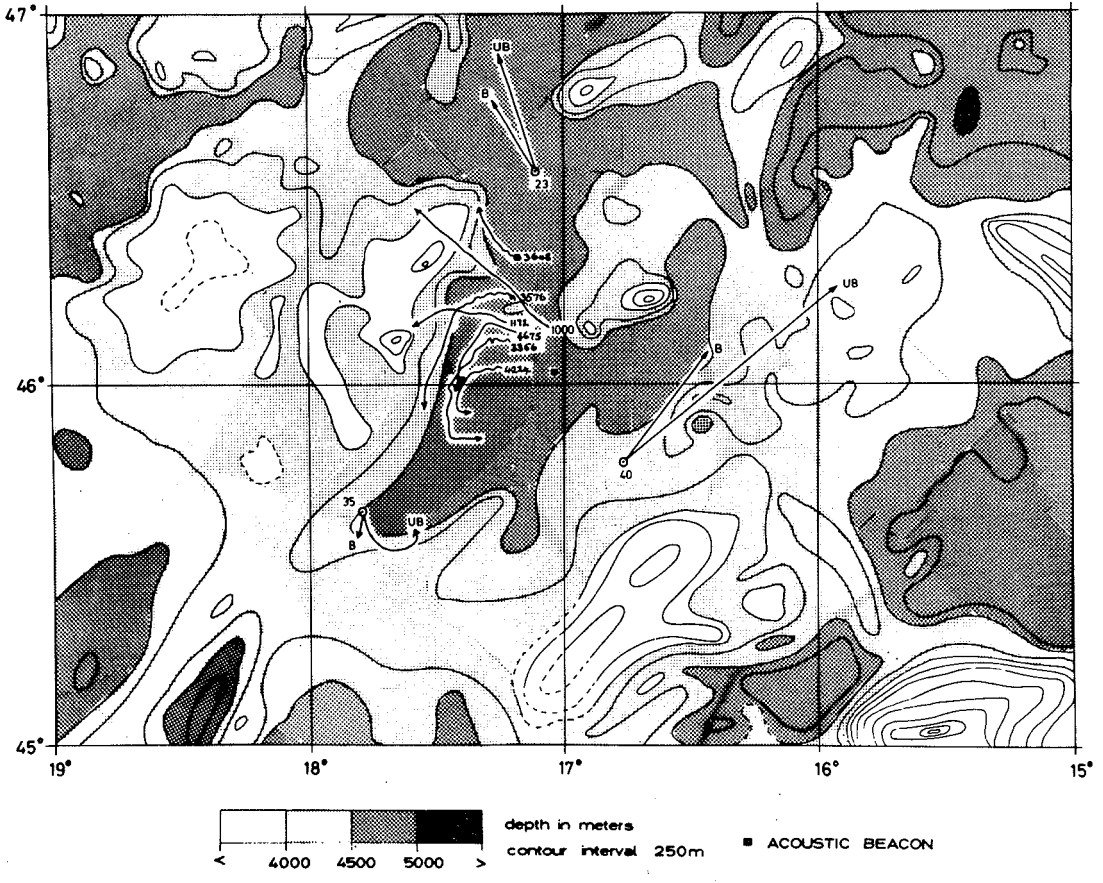

Figure 5.1 Bathymetry of study area together with the paths of neutrally buoyant floats at the listed depths and residual flow vectors for the bottom (B) and upper bottom (UB) current meters at stations 23, 25 and 40. All depths are in metres.

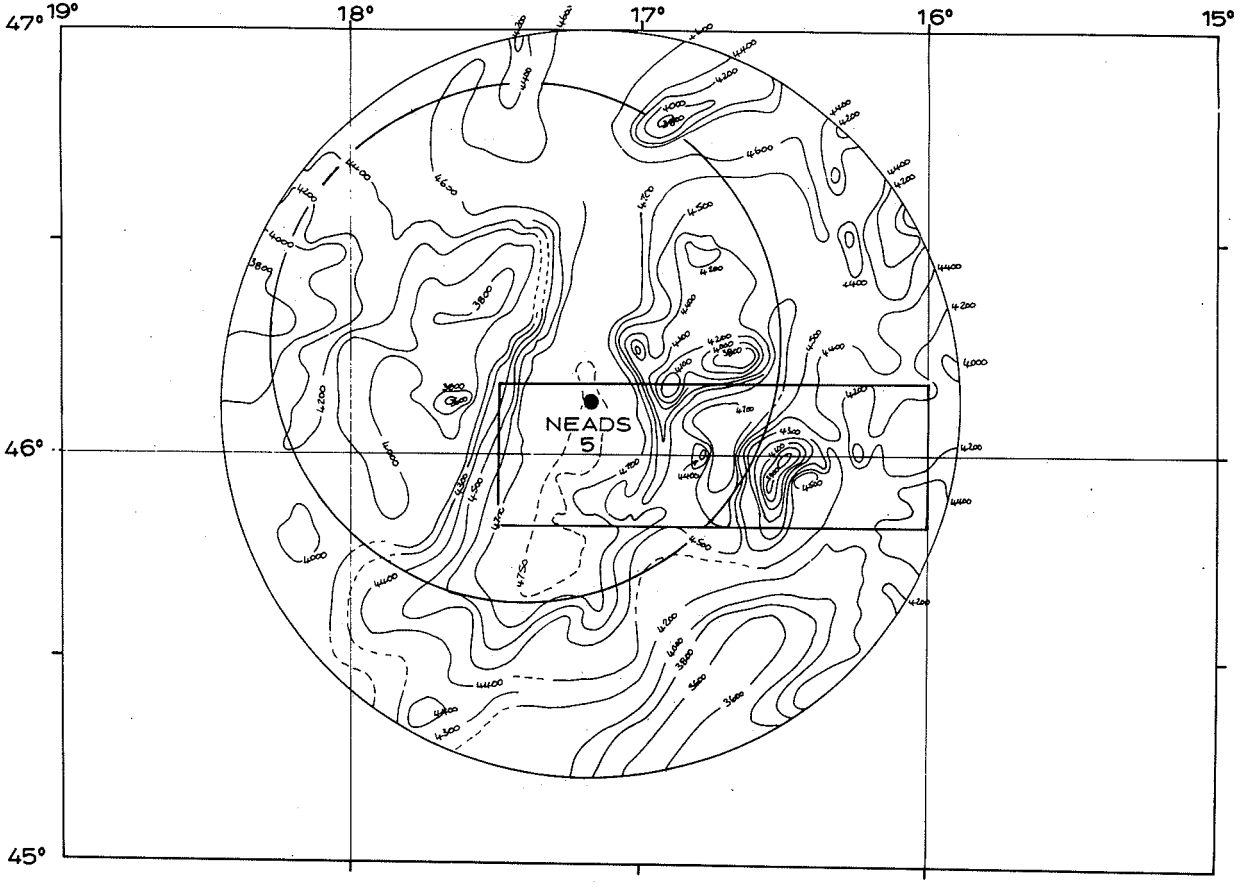

Figure 5.2 The location of current meter mooring NEADS 5. The depths are in metres.

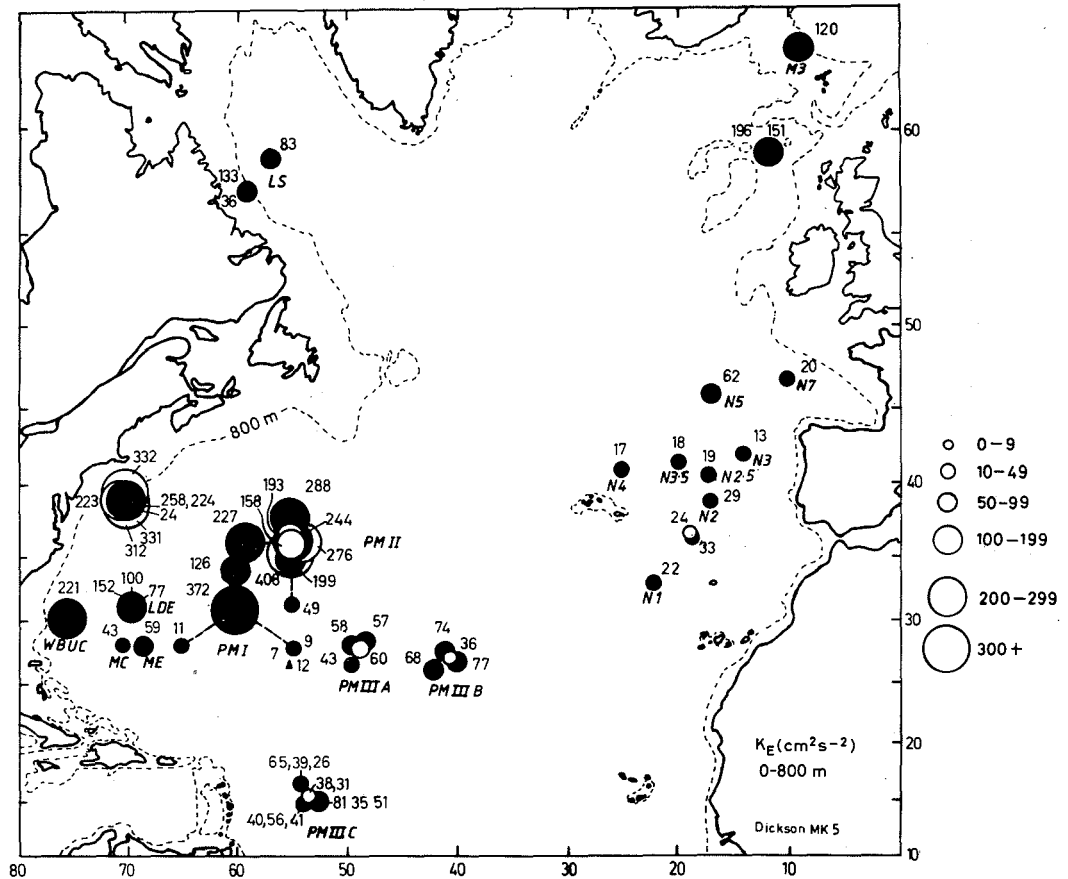

Figure 5.3 The eddy kinetic energy, K_E, from all current meter records of 9-months duration, or longer, at depths between the surface and 800 m.

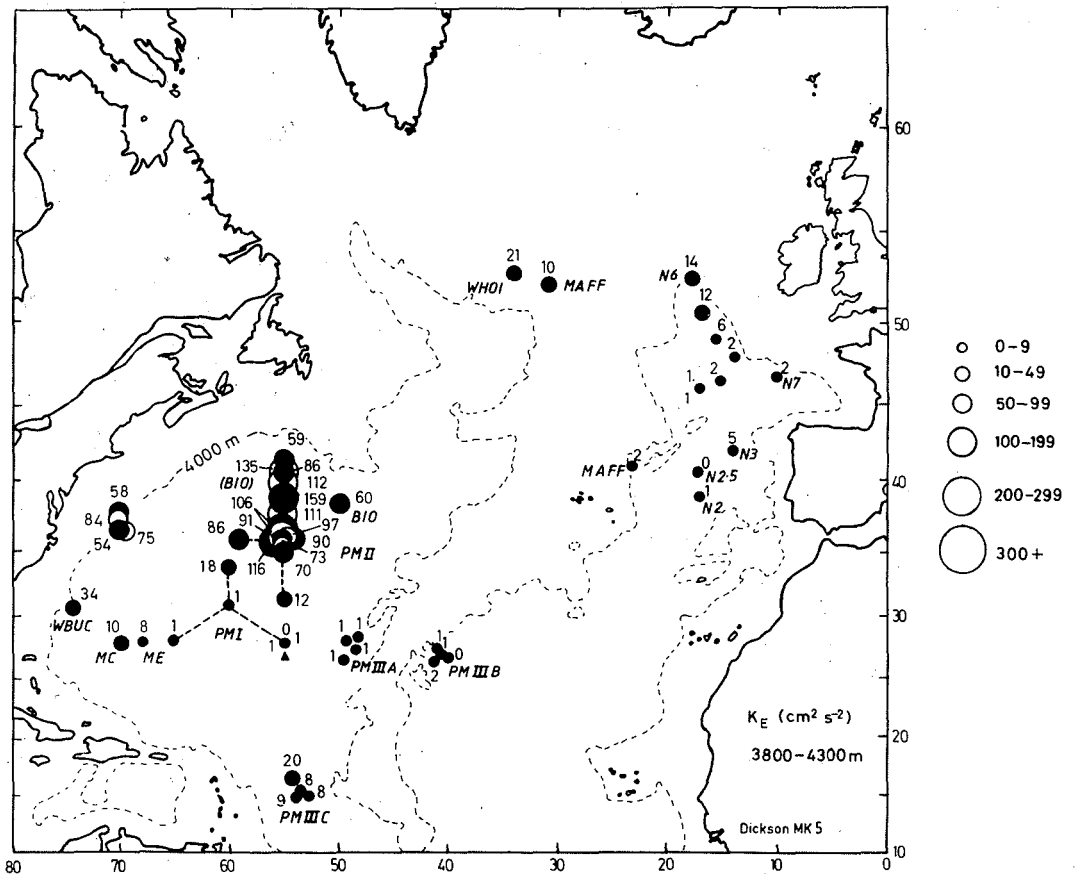

Figure 5.4 The eddy kinetic energy, K_E, from all the current meter records of 9-months duration, or longer, at depths between 3800 and 4300 m.

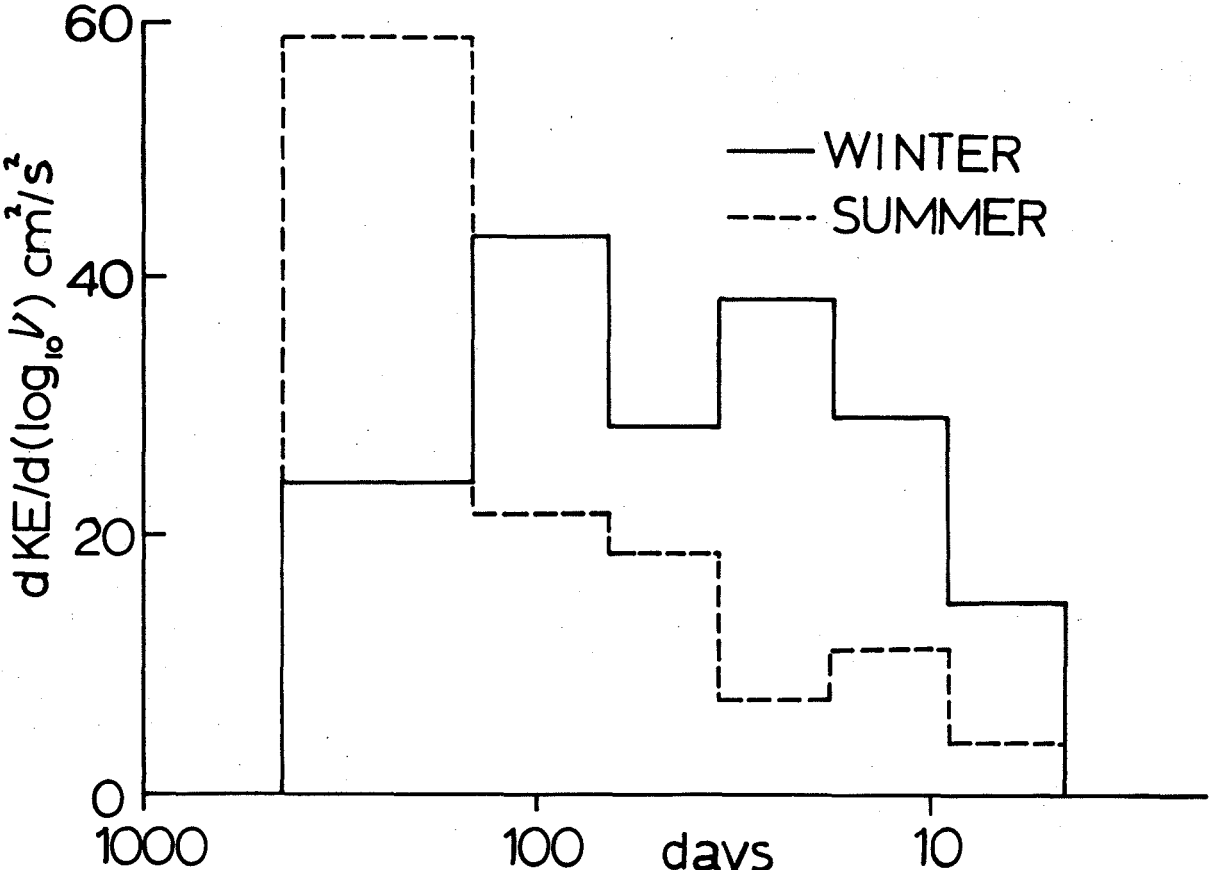

Figure 5.5 Block spectra from 600 m records at NEADS 5 (46°N 17°W) showing the differences between summer and winter.

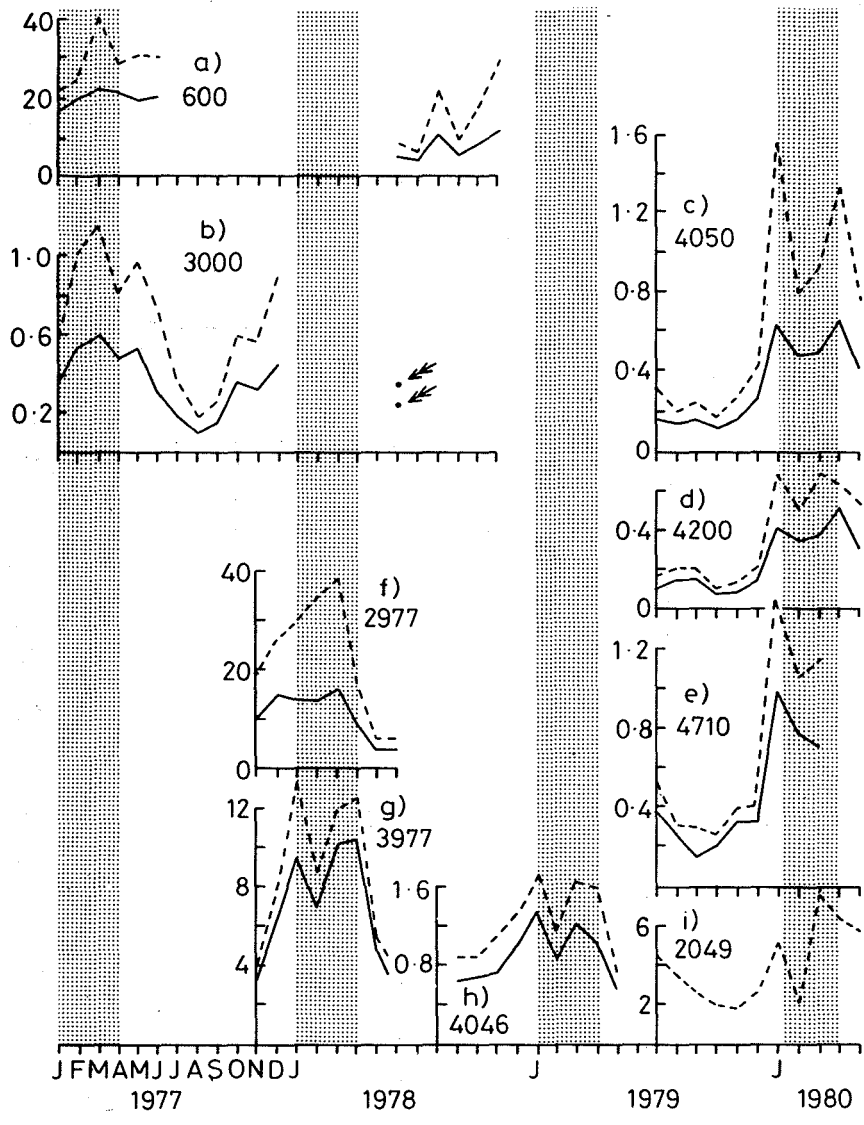

Figure 5.6 Time series of eddy kinetic energy estimates in the period bands 3-27 days (——) and 3-80 days (---) at
(a) 600 m depth, NEADS-5 (46°N 17°W)
(b) 3000 m depth, NEADS-5 "
(c) 4050 m depth, NEADS-5 "
(d) 4200 m depth, NEADS-5 "
(e) 4710 m depth, NEADS-5 "
(f) 2977 m depth, mooring 'B', Charlie-Gibbs Fracture Zone, Southern trench (52°09'N 31°00'W)
(g) 3977 m depth, mooring 'B', Charlie-Gibbs Fracture Zone, Southern trench (52°09'N 31°00'W)
(h) 4046 m depth, mooring 'L', Azores Array (41°00'N 23°18'W)
(i) 2049 m depth, mooring 'R', European Continental Slope (48°59'N 12°53'W)

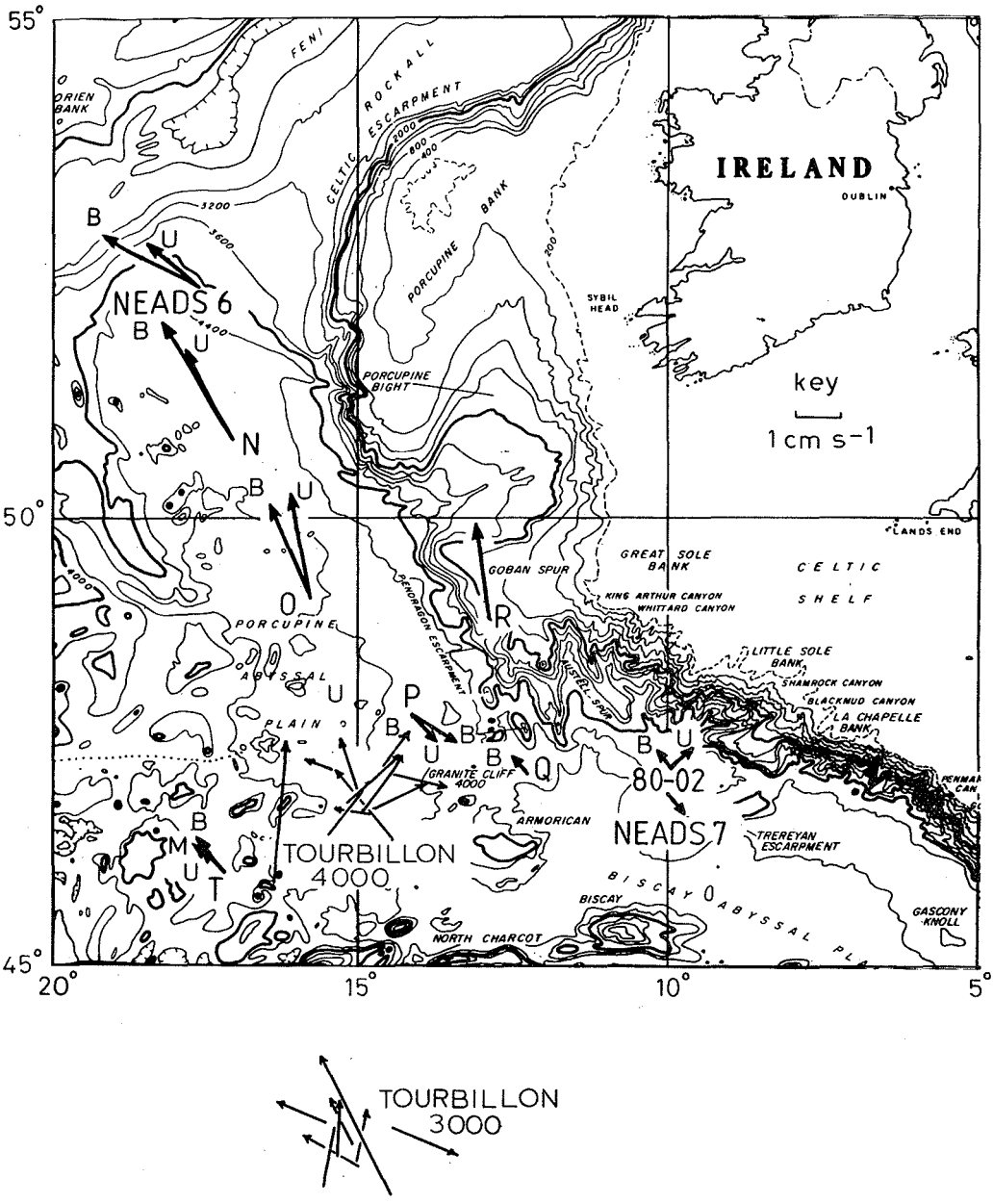

Figure 5.7 The bathymetry of the Porcupine Abyssal Plain with residual deep flow vectors from the bottom (B) and upper bottom (U) long-term current meter moorings. Stations NEADS 6, N, O, P, Q, R, T, (NEA dumpsite) and 80-82 were MAFF deployments. The results from NEADS 7 are by kind permission of COB, Brest, France as are most (7 of 9) of the results of the Tourbillon experiment, a joint exercise between COB and MAFF. For clarity the results of the Tourbillon exercise at 3000 m are shown separately from those at 4000 m.

5B THE 'TOPOGRAPHIC STUDY'

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During the first ad hoc working group meeting on coordination of research related to the control of deep sea disposal of low level radioactive waste (MAFF, 1980) the Physical Oceanography Task Group recommended the collection of long-term current meter records in the vicinity of an isolated seamount in the east-central part of the dump-site area. The rationale was that abrupt topographic features can, in theory, lead to an intensification of currents and hence to enhanced mixing (both horizontal and vertical) in the vicinity of the seamount. Three exploratory long-term moorings were therefore set close to this peak in October 1980 during CIROLANA 9/80 after the bathymetry of the seamount had been surveyed in detail (CIROLANA 6/80 and 9/80). Mooring positions in relation to this feature are shown in Figure 5.8. Moorings 80-10 and 80-11 carried instruments set at heights of 50 m and 1050 m from the bottom, and were recovered after about a 6-month deployment in April 1981 (CIROLANA 4/81). Mooring 80-12 carried three instruments at heights of 50, 800 and 1550 m from the bed and was recovered after 8.7 months in June 1981 (CIROLANA 6/81). The measurements were at 1-hour intervals using Aanderaa RCM-4 instruments adapted for deep-water use. The 7 instruments yielded an overall good-data return of 88%.

The relevant statistics from these moorings are listed in Table 5.4 below and histograms of current speed and direction are shown in Figures 5.9-5.11.

Table 5.4 Statistics of current speed from the 6 records of the 'topographic study'

Mooring	Position	Water depth (m)	Sampling depth (m)	Duration (d)	Maximum hourly speed (cm s^{-1})	Mean hourly scalar speed (cm s^{-1})
80-10	45°54.8'N	4025	2975	0	-	-
	16°31.4'W		3975	185	18.03	7.03
80-11	45°50.1'N	4349	3299	185	13.08	4.53
	16°35.8'W		4299	185	15.32	4.38
80-12	45°54.4'N	4280	2730	257	17.75	4.72
	16°37.2'W		3480	257	19.71	4.55
			4230	257	14.20	4.76

As shown, maximum hourly speeds were in the range 13.0-19.7 cm s^{-1} and gave no indication of topographically-induced violent 'events' in the near-bottom flow.

Action

Since these data are of adequate duration and quality and since they were located in reasonably close proximity to the most abrupt topography known within the dumpsite area, they appear to be adequate to answer the question posed by the POTG. No further investigation of this type is thought necessary.

Reference

MAFF, 1980: Report of Ad Hoc Working Group Meeting on Co-ordination of Research Related to the Control of Deep Sea Disposal of Low-Level Radioactive Waste. Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Internal Report No.7, 24 pp.

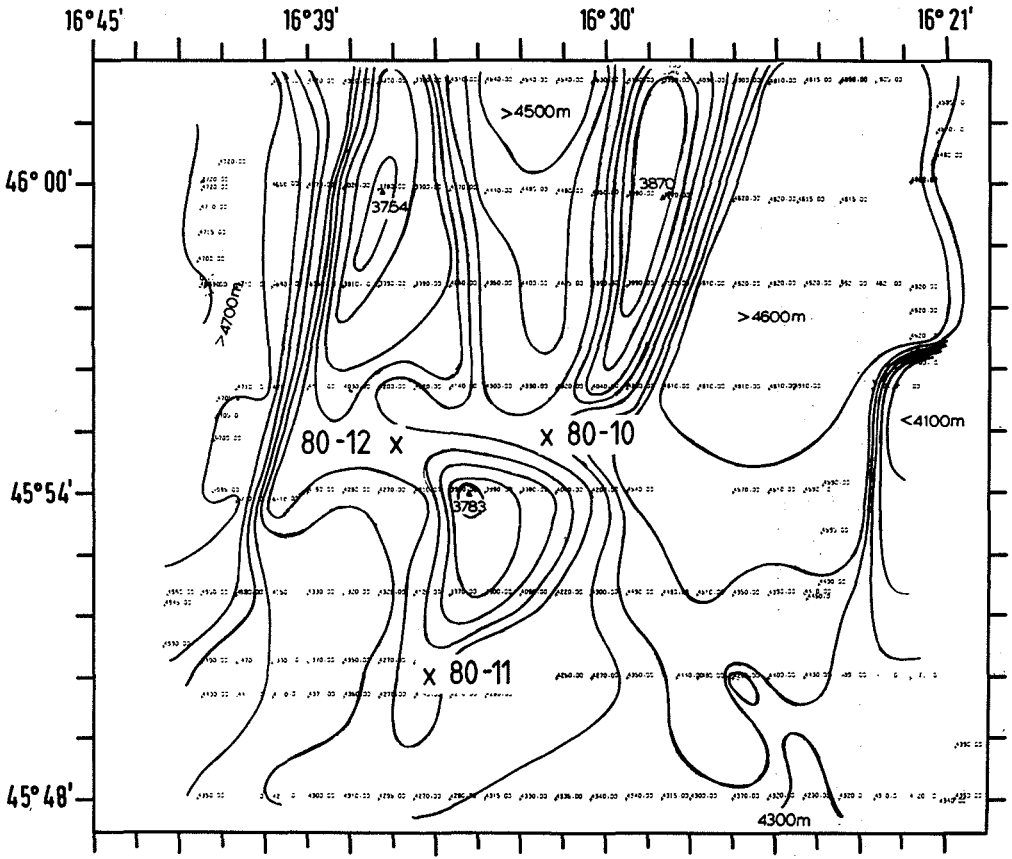

Figure 5.8 The mooring positions (80-10, 80-11 and 80-12) for the topographic experiment around the 'Finn' seamount on the NEA low-level dumpsite. The depth contours are based on precision depth recorder (PDR) survey carried out on CIROLANA 6/79 in June 1979.

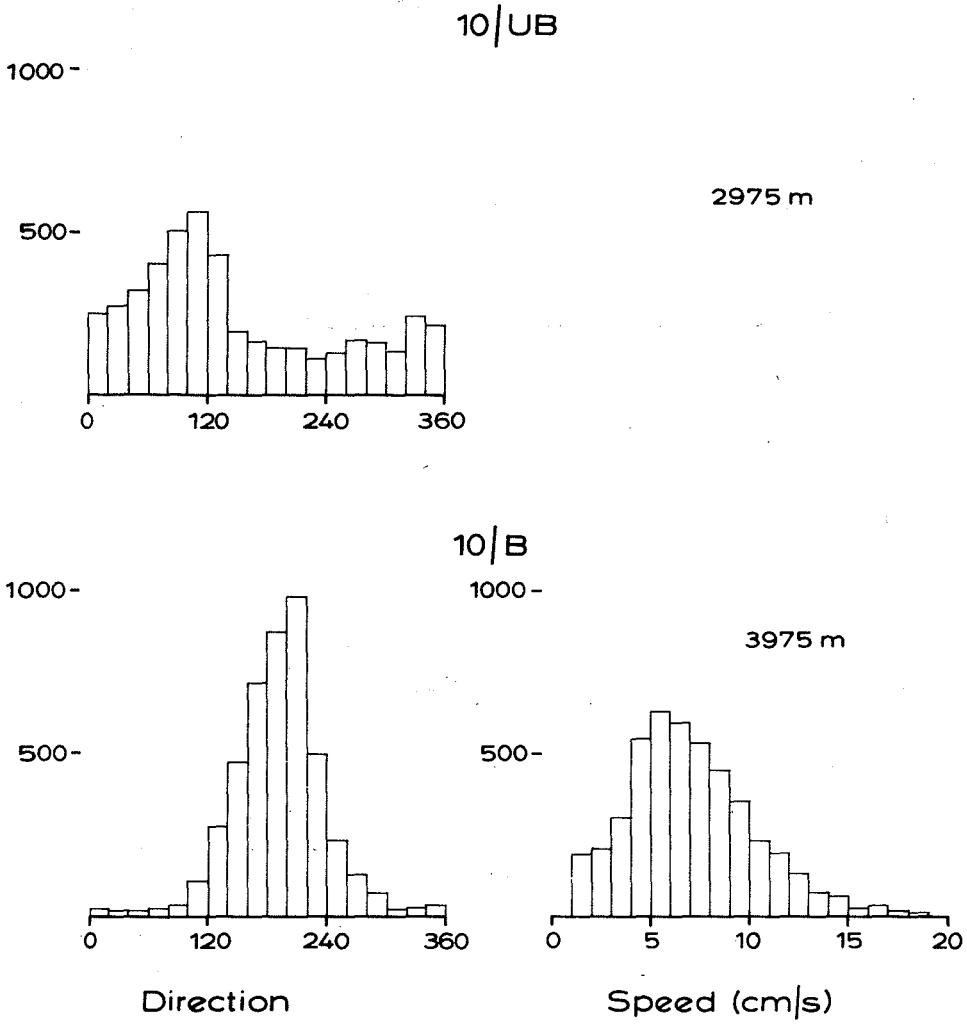

Figure 5.9 Histograms of speed and direction for mooring 80-10 at 45°54.8'N 16°31.4'W.

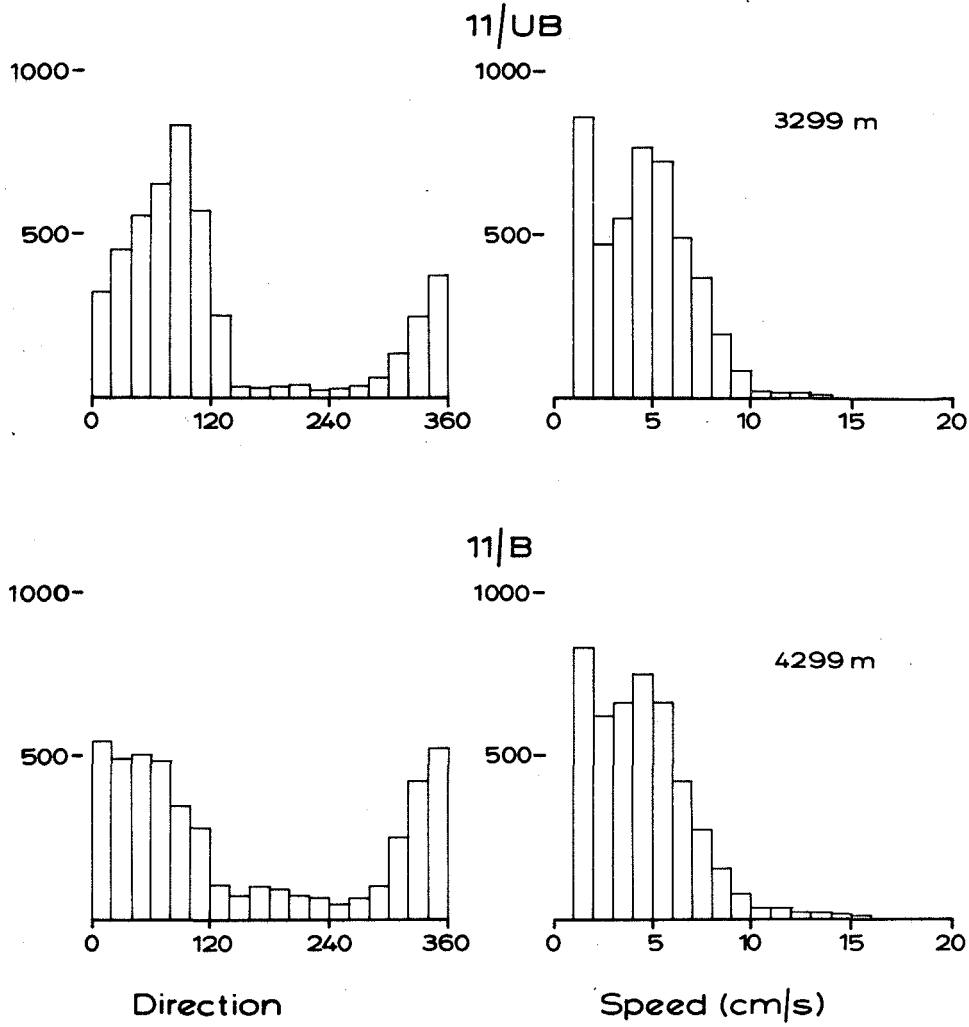

Figure 5.10 Histograms of speed and direction for mooring 80-11 at 45°50.1'N 16°35.8'W.

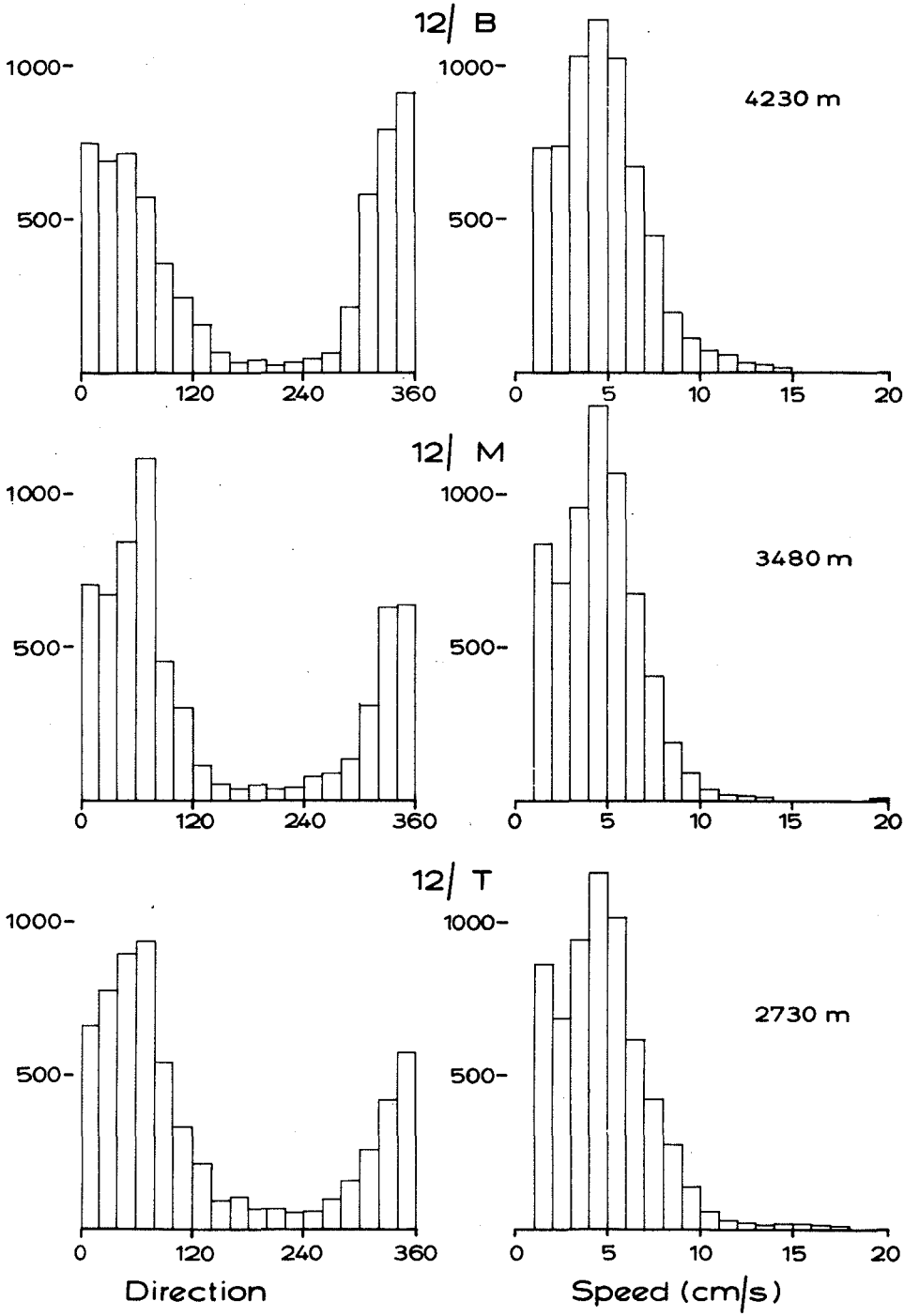

Figure 5.11 Histograms of speed and direction for mooring 80-12 at 45°54.4'N 16°37.2'W.

Chapter 6

TIDE GAUGE RESULTS

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One year of tidal measurements was made some 90 n miles south-east of the proposed low level dumping site in the north-east Atlantic using an IOS Mark IV tidal pressure recorder. The instrument was placed on a sea mount which rose 1500 m above the surrounding topography in a depth of approximately 3000 m of water. Suitable sites are rare in this area due to the enormous depths which exceed the limits of most pressure sensors. Strain gauge sensors are available which can operate to 5000 m but the zero stability of these devices is inferior to the quartz crystal type of transducer which, at present, is limited to depths less than 3800 m.

The Mark IV recorder measures bottom pressure which, apart from the hydrostatic pressure, includes changes due to variations in surface elevation and to atmospheric variations. The objectives were to study the tides and large scale low frequency waves in this area, therefore the instrument at site Y1 was only one of a series deployed around the Azores and extending as far as the Labrador shelf. The bulk of the measurements were made from August to December 1980. This series of measurements is in fact a continuation of a study of tides in the whole North Atlantic (Cartwright *et al.*, 1981).

The instrument at site Y1 was in position for 4 months when it was recovered, was redeployed, and was allowed to record for a further 7 months. The record from Y1 has therefore two distinct parts which are not strictly from the same geographical location, but are within 11 miles of each other (Figure 6.1).

Table 6.1 Details of tide gauge stations

Mooring	Position	Depth	Duration
Y1 Part A	45°01'N 15°25'W	2830 m	Day 227/1980 - Day 349/1980
Y1 Part B	44 57 N 15 35 W	3164 m	Day 350/1980 - Day 202/1981

The recorder contained two pressure sensors and one temperature sensor. Comparison of the pressure signals yields a measure of the accuracy of the measurements whereas the sea-bed temperature is necessary for a second order correction to the pressure signals.

A sample of the time series measured during the deployment is shown in Figure 6.2. At the top of the diagram the measured data is dominated by the tidal signal, and below is shown the extent of the instrumental drift and the amplitude of the low frequency variations. The temperature at the sea bed has excursions of 0.1°C which is typical of these depths and indicates a fair degree of water movement. The changes in temperature are rapid in relation to the sampling interval which is 3.75 min and the measured values may be reduced in amplitude by the averaging effect of the instrument.

The major harmonic constants, which were extracted from the tidal signal at Y1, are presented in Table 6.2. The units of amplitude are mbars which are almost directly equivalent to centimetres of surface elevation. No attempt has been made to introduce sea water density into the calculations to convert the pressure signal into a surface elevation as density profiles were not made at the site.

Table 6.2 Harmonic constants

Constituent	Quartz crystal		Strain gauge	
	H(‡)	G(*)	H(‡)	G(*)
O1	5.5	334	5.3	335
K1	7.6	88	7.1	90
M2	87.2	93	87.3	93
S2	29.5	121	29.3	121

(‡) Amplitudes H are in mbars
(*) Phases G are in degrees relative to Greenwich epoch

These results are only provisional as work on the analysis of the data is still proceeding.

An impression of the accuracy of the measurements can be obtained from a comparison of the constants from the two sensors. The largest harmonic constant, namely M2, agrees within one-tenth of a millibar (1 mm) and the smaller constituents are within a few tenths of a mbar. This is a relative accuracy applicable to the tidal and perhaps the low frequency signals. The ability of the instrument to measure mean sea level and very low frequency signals is limited by instrumental drift which is caused by creep in the sensor diaphragm due to the large hydrostatic pressure. In general the drift is monotonic being rapid during the first few days and settling to a more gradual change thereafter. At Y1 the instrumental drift was of the order of 50 mbars which is as low as can be achieved at the present time.

The low frequency component of the signal can be extracted by removing the drift using an analytic function and filtering the remaining series with a low pass filter whose cut-off frequency is near

the lower limit of the diurnal band (0.65 cycles per day). The very long periods present in the low frequency signal are contaminated by the drift component but waves with periods between 30 hours and 5 days are easily detectable.

The amplitudes are relatively small, being of the order of 10 mbar, and are a response to surface waves and to variations in the internal structure of the water column. It is not possible to distinguish between the two without additional information but elsewhere (Vassie, 1982) large-scale features have been observed between recorders separated by several hundred kilometres. Oscillations of 3-5 day period have been observed in current meter records during the GATE experiments in the equatorial Atlantic (Weisberg, 1979).

There is strong evidence of a seasonal cycle in the low frequencies despite the effect of sensor drift. However the analysis of data from Y1 is not complete as it has yet to be compared with data from other locations and with coastal sites.

References

Cartwright, D. E., Edden, A. C., Spencer, R. and Vassie, J. M., 1981. Tides of the NE Atlantic. Phil. Trans. R. Soc., Lond., A 298, 87-139.

Vassie, J. M., 1982. Tides and low frequency variations in the equatorial Atlantic. Oceanol. Acta. 5. (1), 3-6.

Weisberg, R. H., 1979. Equatorial waves during GATE and their relation to the mean zonal circulation. Deep Sea Res., 26, A Suppl. 11, 179-198.

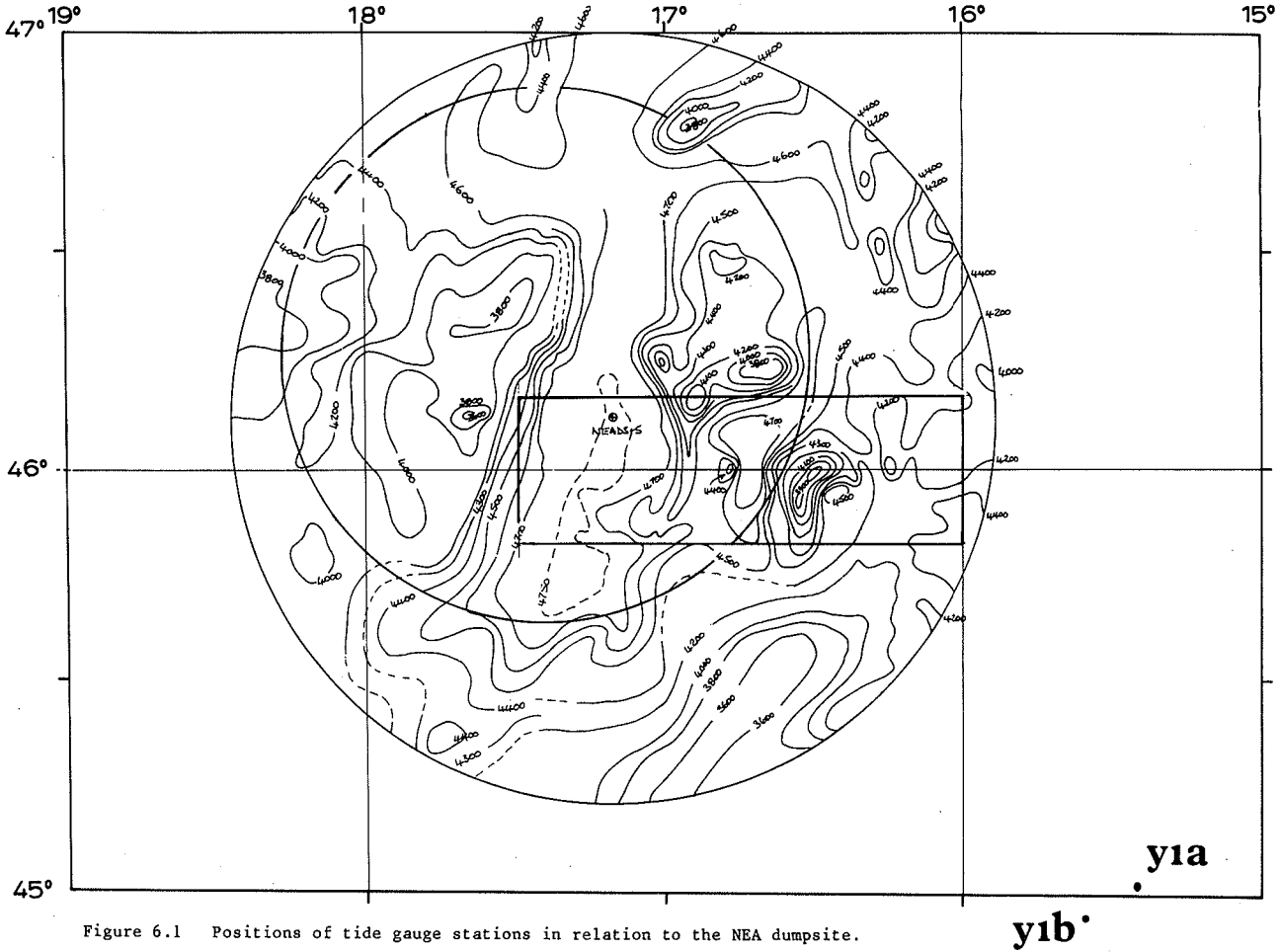

Figure 6.1 Positions of tide gauge stations in relation to the NEA dumpsite.

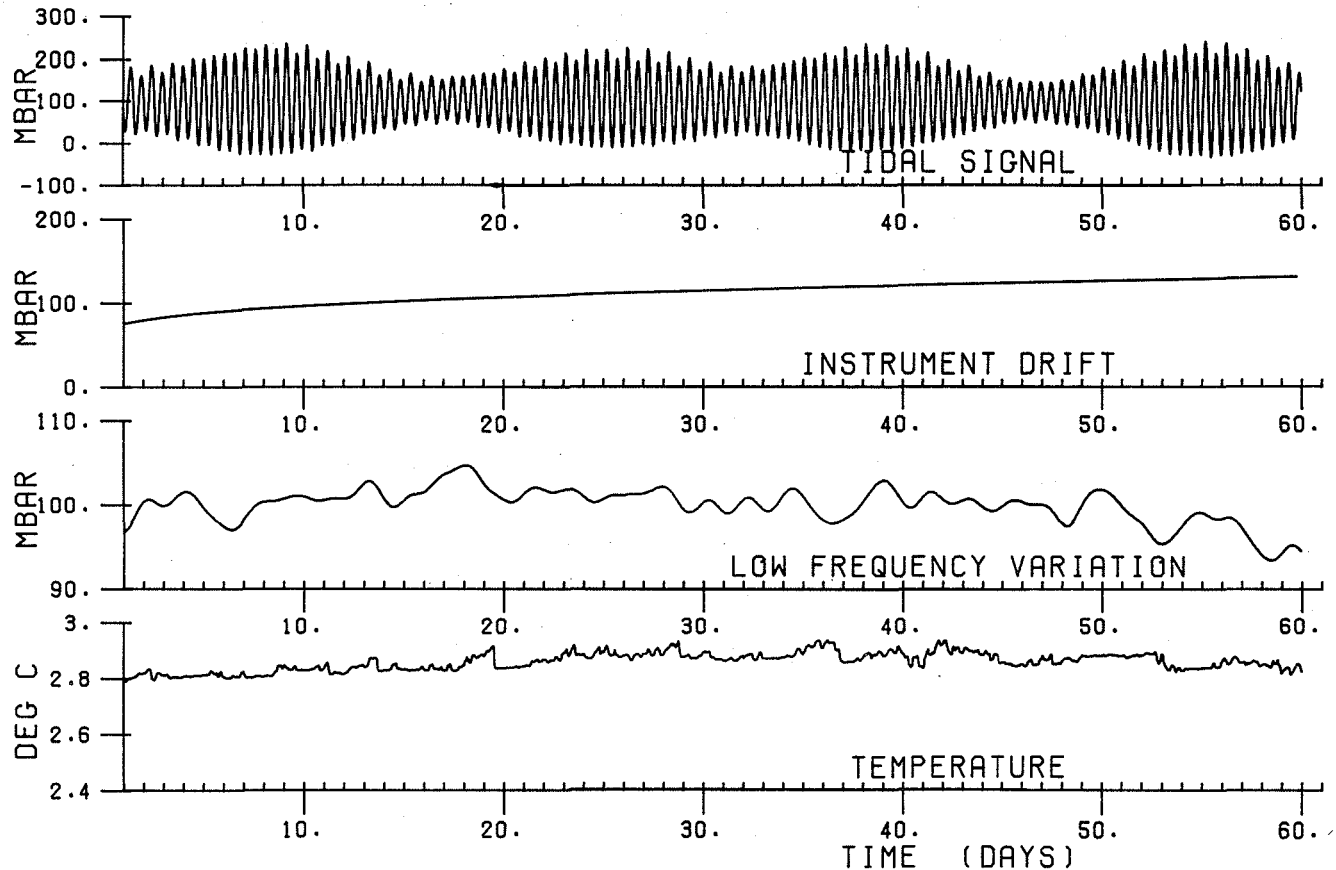

Figure 6.2 Pressure and temperature records from site Y1. Pressure units are mbar (equivalent to cm of sea water). Starting date = 15 December 1980.

Chapter 7

HISTORICAL HYDROCHEMISTRY IN AND AROUND THE SITE

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Introduction

This review summarises the state of knowledge prior to 1977 of the hydrographic and chemical conditions to be found in the vicinity of the NEA dump site at 46°N 17°W. Apart from the fisheries statistics which refer to a much larger area than the dump site no biological data have been found. The bulk of the hydrographic and chemical data have been provided by the United States National Oceanographic Data Centre via the file copy held by the Marine Information and Advisory Service, Institute of Oceanographic Sciences, Wormley. These data, which were all collected prior to 31 December 1971, were augmented by trace metal data collected by the MAFF research vessel CIROLANA in July 1975 and hydrographic data collected by the same vessel in November 1976.

The data available

The data inventory is summarised in Figures 7.1 and 7.2 and Table 7.1. Figure 7.1 shows the positions of all stations within 40 nautical miles of the dump site. In the dumping area there are three hydrographic stations with maximum observation depths in excess of 4000 m. The only chemical data within the area are from two stations at which dissolved oxygen was measured and neither of these extends below 2500 m depth. The stations where chemical measuremesnts were made are shown in Figure 7.2. This figure covers a larger area than Figure 7.1 and includes all data within 70 nautical miles of the dumping area. Stations at which only temperature and salinity data are available have been omitted from this figure. The only deep stations within 10 miles of the dumping area are station 290 at which dissolved oxygen, phosphate and silicate data are available to within 20 m of the sea bed, and station C58 at which trace metal data are available to 3795 m. The nearest nitrite and pH measurements are at station 284, and the nearest nitrate measurements are at station 308. Further details of the stations shown on Figures 7.1 and 7.2 are given in

Table 7.1. The stations are grouped in bands of 10 nautical miles distance from the boundary of the dumping area. At distances exceeding 30 nautical miles from the area only stations at which chemical measurements were made are listed, and at distances greater than 40 nautical miles only those stations with chemical data other than dissolved oxygen are listed.

Temperature and salinity

Temperature and salinity profiles from stations 274, 286, C86 and C100 are shown in Figures 7.3 and 7.4. The data from stations C86 and C100 are typical of those stations within the dumping area whereas stations 274 and 286 show the extent of the observed variations. The pronounced salinity maximum at about 900 m shown at the latter station indicates the presence of Mediterranean water in the area. It is possible that the weaker maximum shown at station C86 is the result of inadequate resolution of the feature, but the salinity profile at station 274 clearly shows a maximum which is reduced in magnitude and at a greater depth, presumably caused by vertical mixing between 500-1200 m depth. The close proximity of stations 274 and 286 suggests that the observed variations are temporal rather than spatial.

Station 286 which was sampled in August 1970 shows a thermally stratified surface layer in the top 50 m of the water column. Stations 274 and C86 sampled in December 1970 and November 1976 respectively show the formation of a fixed layer which varies in thickness from 50 to 100 m.

Observations from Ocean Weather Station KILO (45°N 16°W) for the years 1963-66 presented by Dixey and Kelf (1973) confirm the general pattern. Although the depth intervals between samples (200 m) are too great to resolve the Mediterranean water salinity maximum satisfactorily it is clear that this feature varies in both magnitude and depth but no systematic seasonal variation is apparent from these data. The near surface observations confirm the build-up of a stratified layer in the summer with surface temperatures in excess of 18°C decreasing to between 12°C and 13°C at 100 m. In winter a mixed layer forms at the surface and gradually deepens to a depth of about 100 m, although there is some evidence to suggest that mixing may extend to 200 m in some winters.

Phosphate, silicate and dissolved oxygen

There are no phosphate or silicate data available from within the dumping area, nor any oxygen data below 1500 m. However, all three parameters are available to within 20 m of the bottom at station 290, which is within 20 miles of the centre of the site, and the profiles are shown in Figures 7.5, 7.6 and 7.7. Comparison of the oxygen measurements with those from stations 288 and 291 shows very little variation; with the exception of the surface value the observations from stations 288 and 291 are within 0.5 ml l^{-1} of those from station 290.

The phosphate and silicate data from stations 284, 285 and 293 are also shown in Figures 7.5 and 7.6. With the exception of the phosphate at station 284 all the values are in close agreement suggesting that spatial variations are not significant within 30 miles of the dumping area. These three stations were all sampled in September 1958 whereas station 284 was sampled in March of the same year, and may indicate a seasonal depletion of phosphate between 250 m and 750 m in the early spring. The depletion of silicate shown in Figure 7.6 may not be significant since the reduction is not markedly greater than the spatial variation between stations 285, 290 and 293.

Nitrite and pH

There are no measurements of these parameters within 30 miles of the dumping area. Nitrite data to 3749 m from station 284 shows a steady decrease in nitrite from 0.14 μg at l^{-1} at the surface to 0.00 at about 900 m. Measurements of pH from the same station show a maximum value of 8.18 in the top 700 m and a minimum value of 8.08 at about 900 m. Data from stations 144 and 308 are broadly similar, the values at the latter being approximately 0.1 lower than at station 284.

Nitrate

The only nitrate data available are from station 308 almost 70 miles from the dumping area. These show an increase from a surface value of 8 μg at l^{-1} at 300 m and then a more gradual increase to a maximum value of 19 μg at l^{-1} at 2000 m, the maximum depth of observation.

Trace metals and caesium

Station C58 provides the trace metal data nearest to the dumping area. Cadmium, copper, nickel and zinc were sampled at the surface and at depths of 20 m, 1995 m and 3795 m. With the exception of zinc, which shows a maximum concentration of 0.82 μg l^{-1} at 20 m and 0.52–0.63 μg l^{-1} elsewhere, all the metals have maximum values in the deeper layers. Cadmium and nickel reach values of 0.042 μg l^{-1} and 0.05 μg l^{-1} respectively at both 1995 and 3795 m, but the maximum concentration of copper of 0.29 μg l^{-1} is confined to the deepest sample.

Caesium samples were taken at station C58 but have not yet been analysed and therefore no data are available.

Cores

Two cores have been taken within the dumping area, one of which is within 10 miles of the centre of the area and is 10.75 m in length (Kidd, Chapter 4 this volume). This core was taken by Lamont Doherty Geological Observatory in October 1966; the general description is a series of foraminiferal marls and sandy marls alternating with

foraminiferal oozes. The second core is much shorter and was taken by the Institute of Oceanographic Sciences for MAFF. Only a preliminary examination of this core has been made. Further cores taken by Lamont are indicated on Figure 7.2 together with their lengths.

Fishing Activity

There are no catch data relating specifically to the area around the dump site, but annual catch statistics are available for the ICES FISHING AREAS in Bulletin Statistique des Pêches Maritimes. The area which includes the dumping ground (Area VII) extends from 43°N to 48°N and from the Bay of Biscay to 18°W. The average annual catch from this area from 1973-77 was 250 000 tonnes, but the bulk of this is caught on the continental shelf and consists of species which do not spend any part of their lives in the deep ocean.

The only species which could conceivably be caught commercially in the dumping area are the tuna-like fishes. If it is assumed that the catch density in the dumping area is no greater than the average for area VIII, a not unreasonable assumption since no major fisheries are known to exist in the area, then the average annual catch density of tuna over the years 1973-77 was 10 tonnes per 100 square nautical miles. Using a similar argument for the adjacent area X, which extends from 36°N to 48°N and from 18°W to 42°W, an average annual catch density of only 0.5 tonnes per 100 square nautical miles is obtained. Using these figures an upper bound for the annual catch from within 100 nautical miles of the centre of the dumping area is 2500 tonnes. Perhaps a more realistic estimate is obtained by using the catch density from area X only, since this is an open ocean area more similar in character to the dumping area than area VIII. Using this figure the estimated annual catch reduces to 160 tonnes.

Conclusions

Sufficient hydrographic data exist from within the dumping area to provide an estimate of the average conditions. Although few oxygen data and no phosphate or silicate data are available within the area, measurements from nearby stations are sufficient to determine average conditions over the dump site. Neither the hydrogaphic nor the chemical data are sufficient to provide an accurate description of possible seasonal variations in the top 1000 m. Nitrite and pH data are barely adequate to give an accurate estimate of values on the dump site, but suggest that nitrite is not detectable below 1000 m and that pH is fairly uniform throughout the water column.

Trace metal data from near the dumping area indicate that the values are low and one deep core in the area shows there to be at least 10 m of sediment on the site.

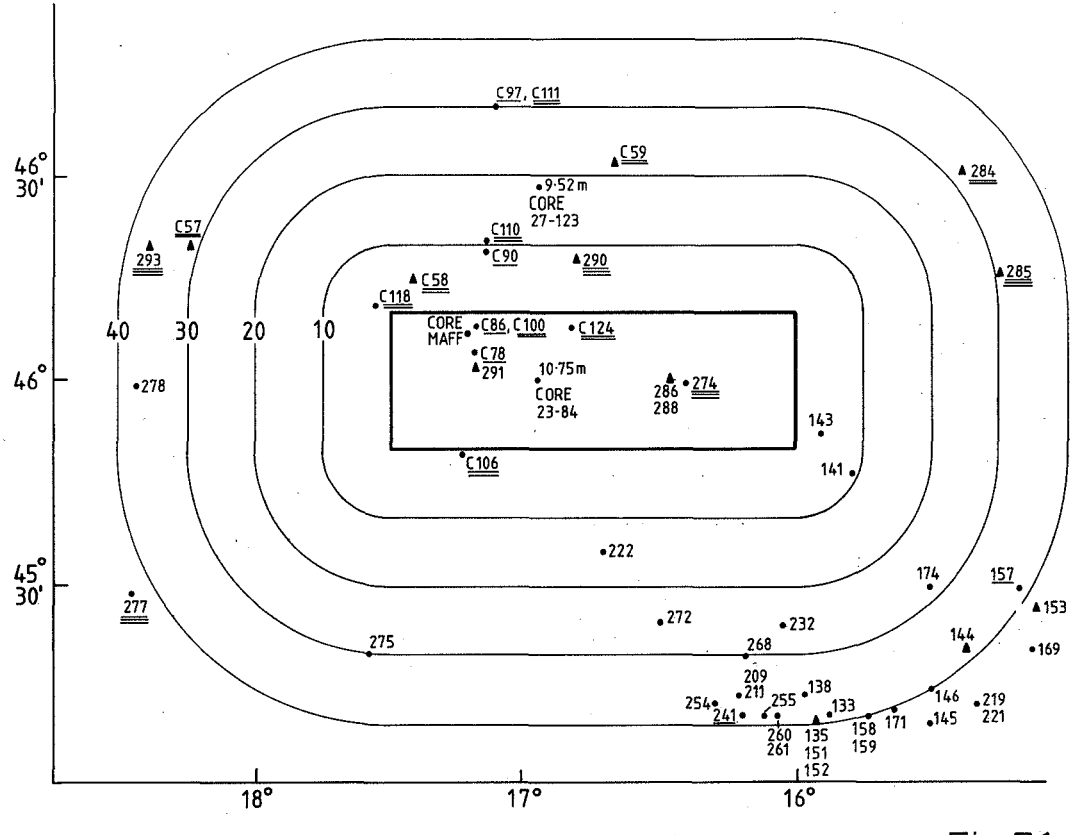
No reliable estimate of fish catch in the area can be made although it is unlikely that the annual catch from within 100 nautical miles of the site can exceed 160 tonnes.

Reference

Dixey, D. J. and Kelf, D. L., 1973. A progress report on the presentation of oceanographic data from O.W.S. KILO for the years 1963-1966. ICES CM 1973/C:9, 8 pp., 12 tables + 24 figures.

Table 7.1 MEASUREMENTS WITHIN 70 NAUTICAL MILES OF THE DUMPING AREAS

LOCATION	STATION NUMBER	DATE Dy Mh Yr	WATER DEPTH	MAXIMUM OBSERVATION DEPTH								
				TEMPERATURE & SALINITY	OXYGEN	PHOSPHATE	SILICATE	NITRITE	NITRATE	pH	TRACE METALS	CAESIUM
In Area	274	10 /12 /70	4501	4637								
	286	22 / 8 /70	4246	1500								
	288	22 / 8 /70	4246	1474	1474							
	291	18 / 5 /11	4791	1000	1000							
	C78	21 /11 /76	4756	3160								
	C86	22 /11 /76	4764	3186								
	C100	24 /11 /76	4762	4666								
	C124	26 /11 /76	4713	4651								
0-10 miles	141	22 / 5 /52		0200								
	143	22 / 5 /63		2283								
	290	8 / 9 /58	4296	4277	4277	4277	4277					
	C58	26 / 7 /75		3815							3795	3795
	C90	23 /11 /76	4703	3195								
	C106	24 /11 /76	4728	4585								
	C110	24 /11 /76	4706	4660								
	C118	26 /11 /76	4202	4124								
10-20 miles	222	22 / 5 /52		1000								
20-30 miles	174	22 /12 /63		2303								
	232	9 / 6 /65	3440	0493								
	268	26 /11 /57		2010								
	272	4 /12 /57		0955								
	275	22 / 5 /52		0300								
	C59	27 / 7 /75										3
	C97	23 /11 /76	4690	3130								
	C111	25 /11 /76	4696	4620								
30-40 miles	144	8 / 6 /14		2000	1600					2000		
	284	6 / 3 /58	4220	3868	3749	3749	3749	3749		3749		
	285	7 / 9 /58	4590	4554	4554	4554	4554					
	293	8 / 9 /58	3738	3727	3727	3727	3727					
	C57	26 / 7 /75										3
40-50 miles	126	23 / 6 /61	4880	1582	1582	1582				1582		
	282	15 /10 /58	4440	3950	3950	3950	3950	3950		3950		
50-60 miles	83	8 / 6 /14		2000	2000					2000		
60-70 miles	122	6 / 3 /58	4960	4406	4406	4406	4406	4406		4406		
	298	7 / 3/ 58	5080		5080	5080	5080	5080		5080		
	300	15 /10 /58	4811	2500	2500	2500	2500	2500		2500		
	308	31 / 5 /31	4050	2000					2000	2000		



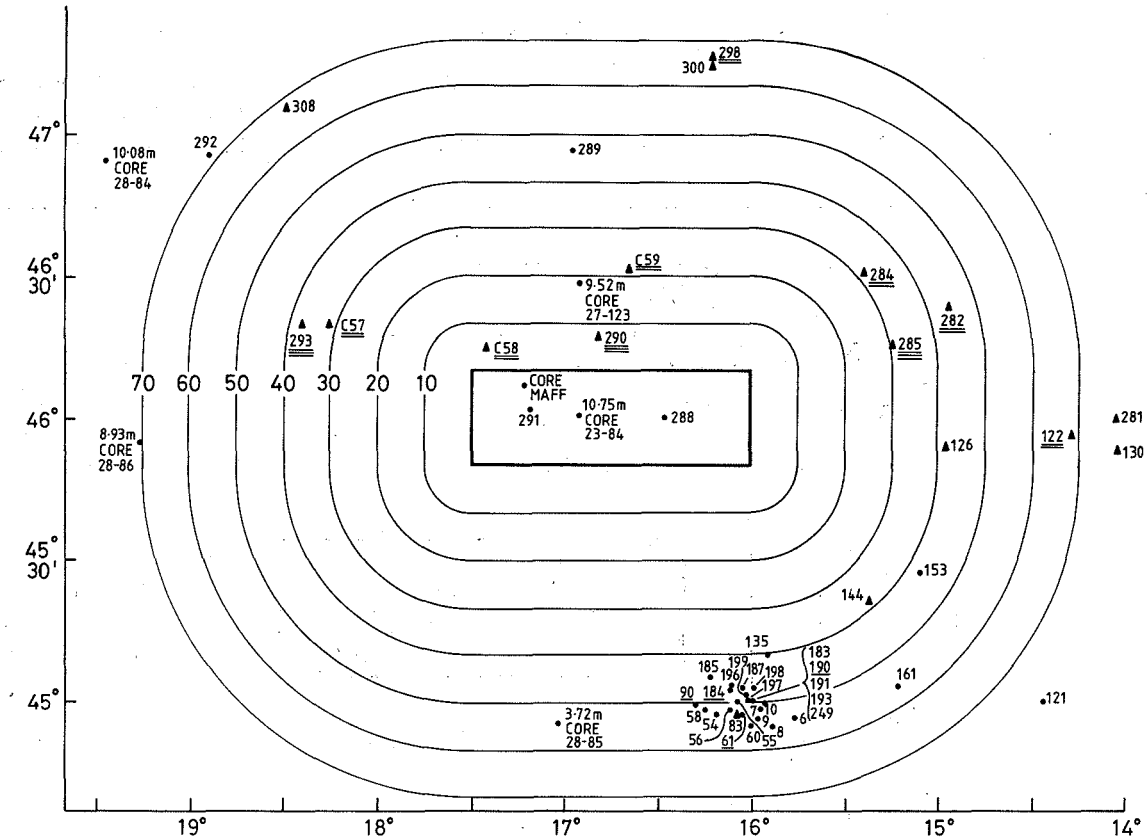
Measurements within 40 nautical miles of the dumping area

- • Temperature & salinity
- ▲ Other parameters

Measurements at depths

- — ⩾3000m
- ═ ⩾4000m or within 500m of bottom
- ≡ Within 50m of bottom

Fig. 7.1



Chemical measurements within 70 nautical miles of the dumping area

- Dissolved oxygen
- Other parameters

Measurements at depths

- ⩾ 3000 m
- ⩾ 4000 m or within 500 m of bottom
- Within 50 m of bottom

Fig. 7.2

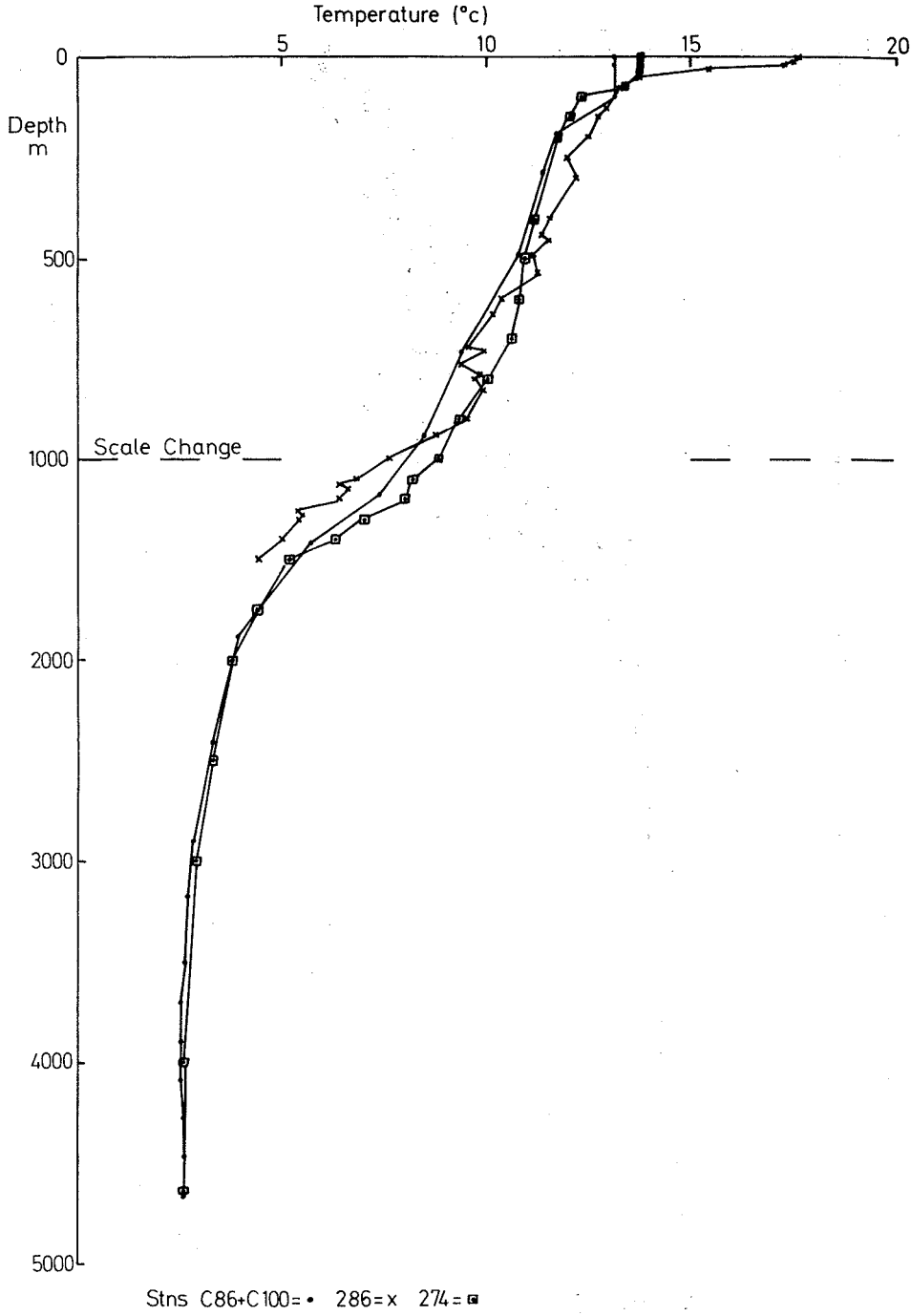

Temperature (°c)
0
5
10
15
20
Depth
m
500
Scale Change
1000
2000
3000
4000
5000
Stns C86+C100=• 286=x 274=◘

Figure 7.3

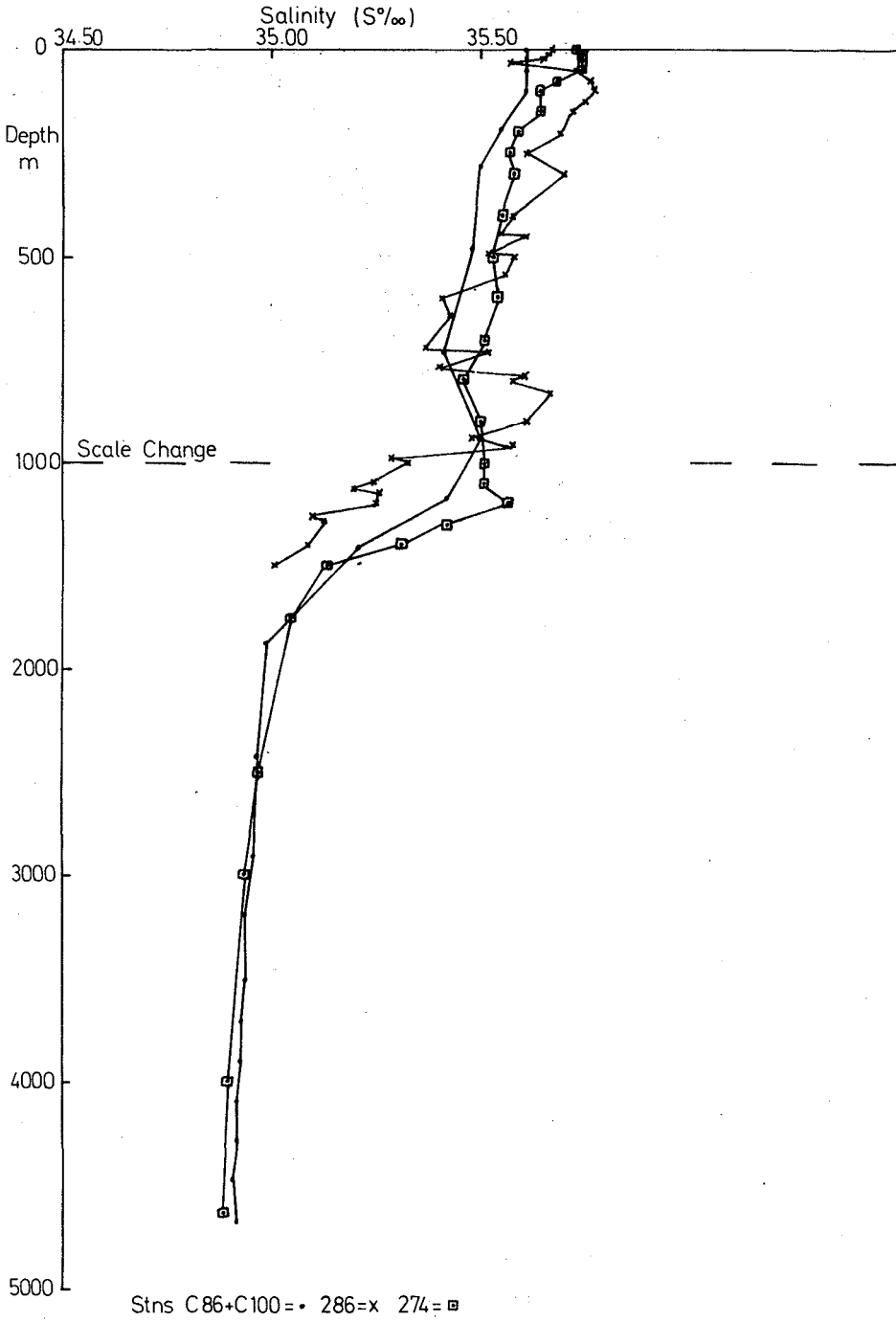
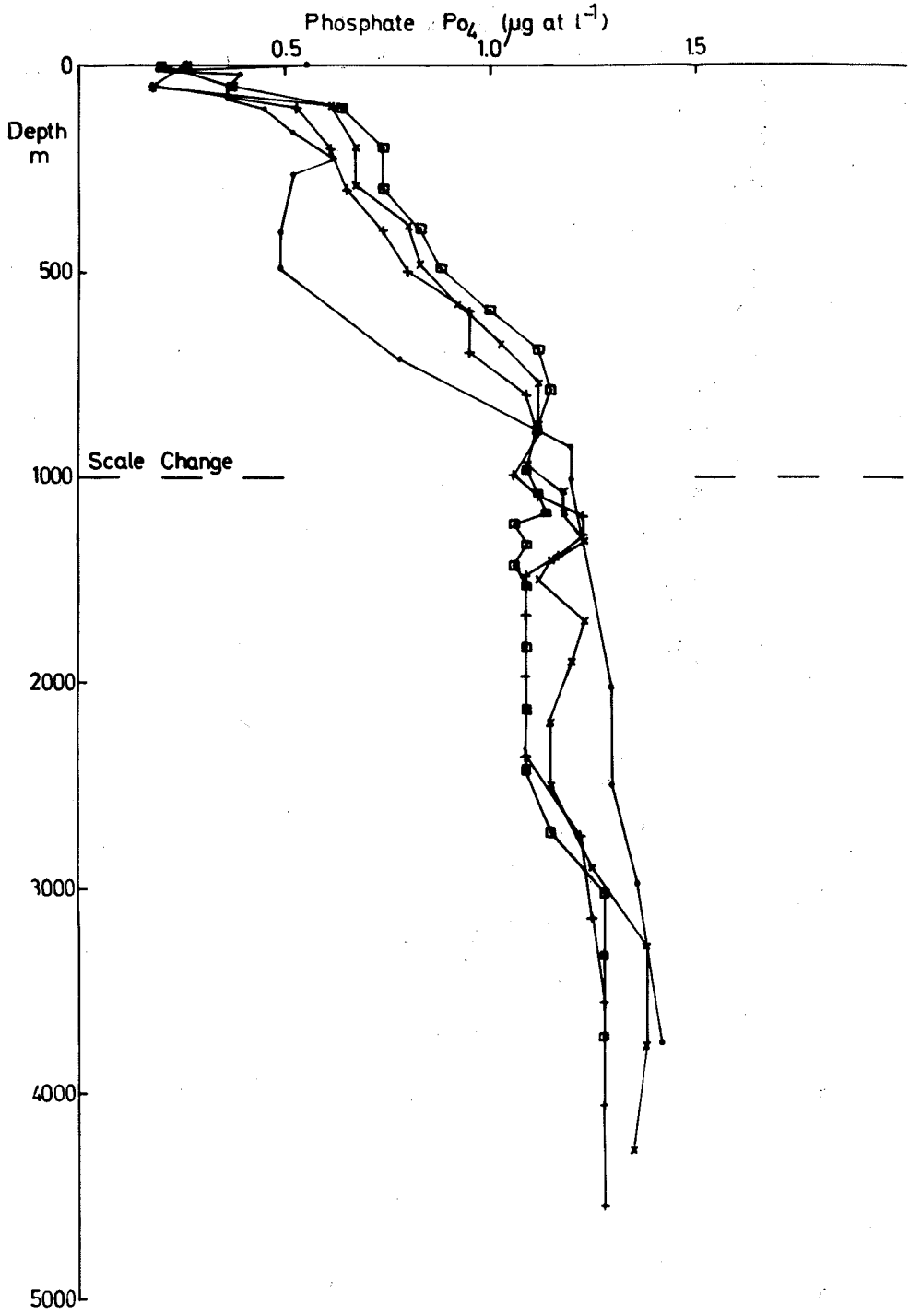
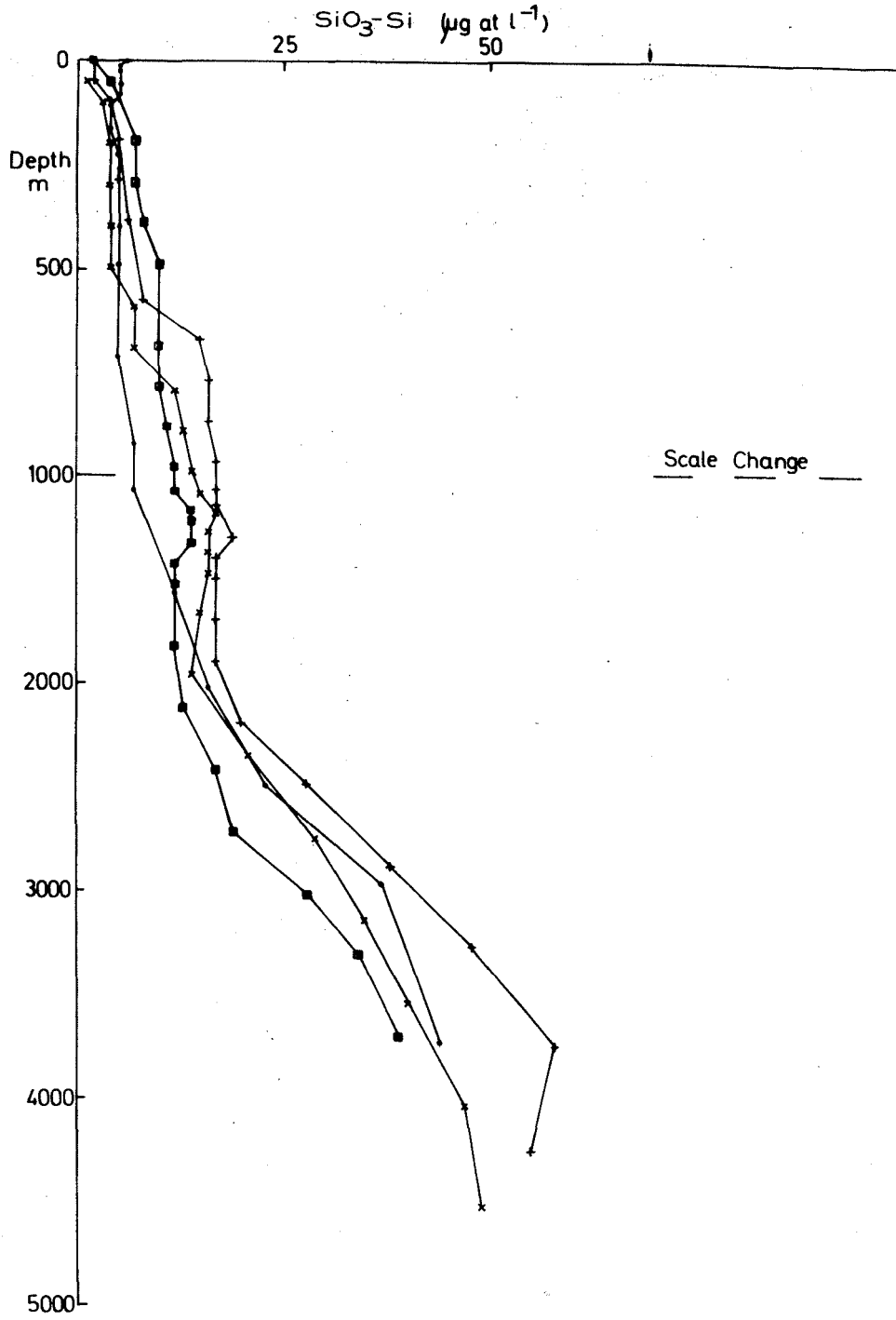

Salinity (S‰)
34.50
35.00
35.50
0
Depth
m
500
1000
Scale Change
2000
3000
4000
5000
Stns C86+C100 = • 286 = x 274 = ⊡

Figure 7.4



Stns 284 = • 285 = + 290 = × 293 = ■

Figure 7·5



Stns 284 = • 285 = ✱ 290 = + 293 = ⧈

Figure 7·6

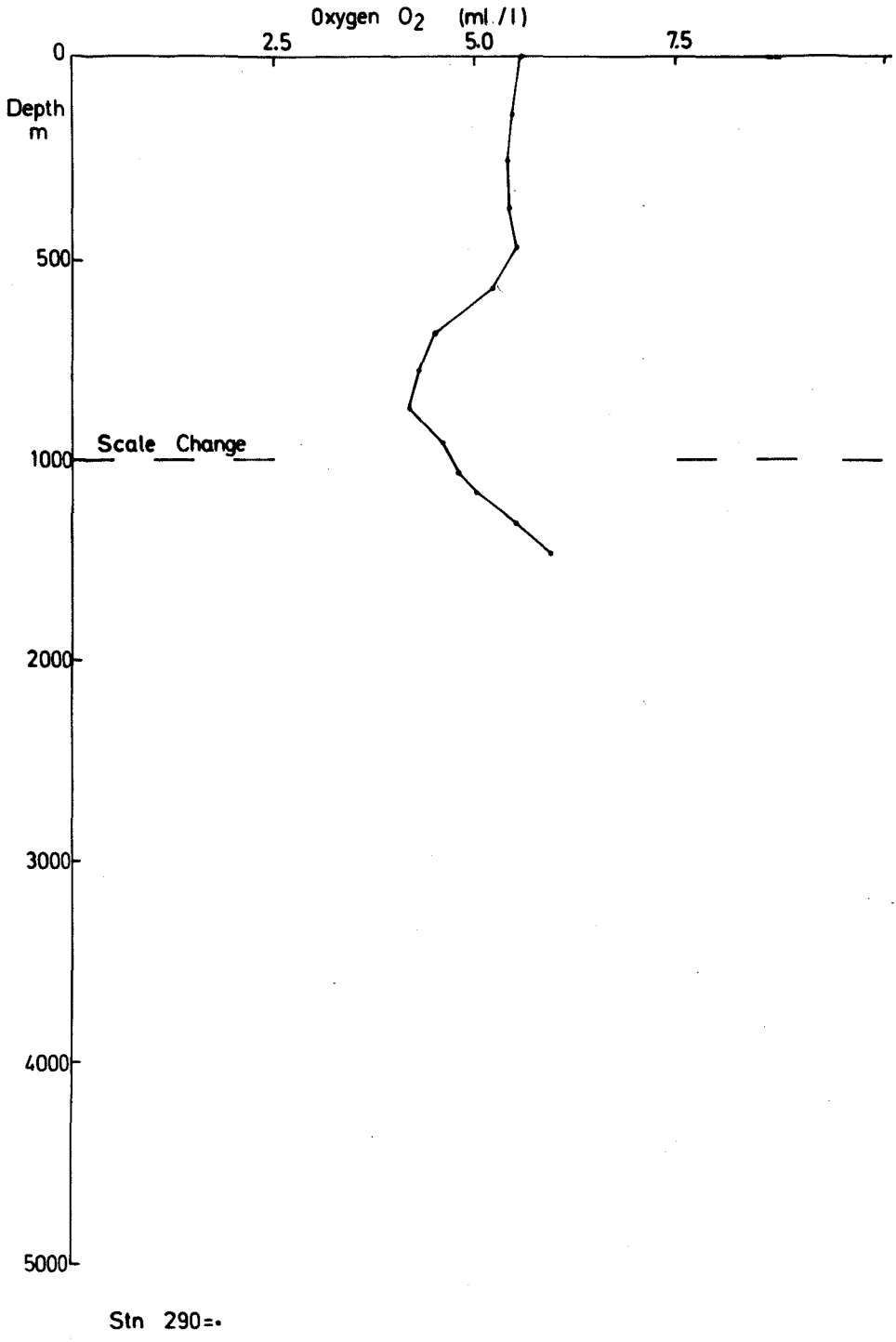

Oxygen O_2 (ml/l)
2.5
5.0
7.5
0
Depth
m
500
Scale Change
1000
2000
3000
4000
5000
Stn 290

Figure 7.7

Chapter 8

RECENT HYDROCHEMISTRY

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Annex III of the London Dumping Convention (Great Britain - Parliament, 1972) sets out the 'provisions to be considered in establishing criteria governing the issue of permits for the dumping of matter at sea'. Section B.6 of that Annex lists examples of the seawater chemical parameters to be measured as part of these provisions.

Though the previous Chapter has indicated that a general knowledge of many of these parameters already existed from the historical database, full implementation of the London Convention requirement implied the collection of observations on the full list of parameters, preferably with greater emphasis on the near-bottom layer where the historical archive was poorest.

These requirements were met during CIROLANA Cruise 6/79 (9-21 June 1979) during which a total of 13 stations were worked across the old and new dumpsite areas (Figure 8.1; stations H1 and H3-14). The emphasis was on sampling within the bottom 1000 m of the water column with exponentially closer sample-spacing towards the sea bed, but at one site (H3) sampling was conducted at a total of 50 levels from near-bottom to near-surface. The deepest sampling at the 13 sites ranged from 5 to 17 m from the sea bed.

The primary and derived parameters at each station are listed in Tables 8.1-8.13.

Methods

Water for analysis was collected with TPN - Hydrobios reversing water bottles. Duplicate samples for salinity determination were taken from each depth and analysed using an Autolab model 610 Inductive Salinometer. The cell of the salinometer was rinsed out with sample before each analysis and the instrument was standardised daily.

Oxygen content was determined by the Winkler method as modified by Carritt and Carpenter (1966). Samples for the determination of nutrient parameters were analysed with the minimum of delay. Phosphate concentrations were determined manually using the single mixed reagent technique as described by Strickland and Parsons (1968); nitrate, nitrite, ammonia and silicate samples were analysed by automatic techniques as described by Folkard (1978).

Estimates for precision for the above parameters at the levels of concentration found are given below:

Salinity $^0/oo$	$\pm$ 0.006$^0/oo$
Oxygen ml l^{-1}	$\pm$ 0.04 ml l^{-1}
Phosphate µg at PO_4-P l^{-1}	$\pm$ 0.02 µg at PO_4-P l^{-1}
Nitrate µg at NO_3-N l^{-1}	$\pm$ 0.3 µg at NO_3-N l^{-1}
Nitrite µg at NO_2-N l^{-1}	$\pm$ 0.01 µg at NO_2-N l^{-1}
Ammonia µg at NH_4-N l^{-1}	$\pm$ 0.04 µg at NH_4-N l^{-1}
Silicate µg at SiO_3-Si l^{-1}	$\pm$ 0.16 µg at SiO_3-Si l^{-1}

Action

Annex III (B.6) of the London Dumping Convention requires that a knowledge of the water characteristics at the dumping site should be considered when establishing criteria governing the issue of permits for dumping of matter at sea. The new data set, coupled with the historical archive, provides this information, and no further hydrochemistry for this purpose is thought to be necessary.

References

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Great Britain - Parliament, 1972. Final Act of the Inter-Governmental Conference on the Convention on the Dumping of Wastes at Sea. HMSO, London, Cmnd (5169), 18 pp.

Strickland, J. D. H. and Parsons, T. R., 1968. A practical handbook of seawater analysis. Bull. Fish. Res. Bd Can., (167), 311 pp.

CIROLANA 6/79 Station: 189 Position: 45°50.6'N
Date: 9 June 1979 17°12.5'W
Depth: 4704 m Wire angle: 0°

H_1

Station	Depth	Height	S_1	S_2	S_1-S_2	Tw	θ	σ_t	σ_θ	PO_4-P		Si_3O_3-Si		NO_3-N		O_2			Eh	pH
	(m)	(m)	(‰)	(‰)	(‰)	(°C)	(°C)			µg at/l	µM/kg	µg at/l	µM/kg	µg at/l	µM/kg	µM/kg	ml/l_{20}	% sat.		in situ
189	3736	968	34.917	34.918	0.001	2.59	2.26	27.877	27.905	1.43	1.39	42.3	41.2	20.6	20.0	250	5.75	76.4	301	8.14
	4214	490	34.910	34.910	0.000	2.60	2.21	27.871	27.904	1.44	1.40	46.3	45.0	20.8	20.2	244	5.61	74.5	301	8.14
	4452	252	34.908	34.907	0.001	2.58	2.16	27.870	27.905	1.49	1.45	47.1	45.8	21.0	20.4	243	5.59	74.2	302	8.14
	4596	108	34.905	34.906	0.001	2.61	2.17	27.866	27.903	1.46	1.42	47.8	46.5	20.9	20.3	241	5.54	73.6	304	8.14
	4619	85	34.906	34.906	0.000	2.60	2.16	27.868	27.905	1.48	1.44	47.7	46.4	21.0	20.4	243	5.58	74.1	305	8.14
	4643	61	34.906	34.905	0.001	2.61	2.17	27.866	27.903	1.51	1.47	48.0	46.7	21.2	20.6	241	5.54	73.6	306	8.14
	4662	42	34.903	34.904	0.001	2.62	2.18	27.864	27.902	1.51	1.47	48.1	46.8	21.2	20.6	243	5.58	74.1	307	8.14
	4672	32	34.902	34.902	0.000	2.60	2.15	27.864	27.902	1.50	1.46	48.0	46.7	21.4	20.8	243	5.58	74.1	308	8.14
	4681	23	34.902	34.902	0.000	2.60	2.15	27.864	27.902	1.52	1.48	48.0	46.7	21.0	20.4	241	5.54	73.6	309	8.14
	4690	14	34.898	34.900	0.002	2.61	2.16	27.861	27.899	1.52	1.48	48.0	46.7	21.0	20.4	243	5.60	74.4	309	8.15
	(4704 m bottom)																			

Table 8.1

CIROLANA 6/79 Station: (a) 169, 18 June 1979 (b) 190, 22 June 1979 Positions: 169/1: 46°00'4'N 17°10.5'W
190/4: 45°58.6'N 17°12.2'W
190/2: 45°59.1'N 17°12.0'W
190/3: 45°58.4'N 17°12.1'W
190/1: 45°59.5'N 17°11.3'W
Depth: 4754 m
Wire angle: 0-5°

H3

Station/ Cast	Depth	S_1	S_2	S_1-S_2	Tw	ϑ	σ_t	σ_ϑ	PO_4-P		SiO_3-Si		NO_3-N		O_2			Eh	pH
	(m)	(‰)	(‰)	ppm	(°C)	(°C)			µg at/l	µM/kg	µg at/l	µM/kg	µg at/l	µM/kg	µM/kg	ml/l_{20}	% sat.		in situ
190/4	0	35.619	35.625	6	16.41	16.41	26.148	26.149	0.08	0.08	0.8	0.8	0.0	0.0	268	6.16	111.8		
	96	35.669	35.669	0	-	(12.49)	27.029	27.032	0.51	0.50	3.6	3.5	8.9	8.7	247	5.68	-		
	193	35.614	35.617	3	-	(12.17)	27.047	27.052	0.56	0.54	4.0	3.9	9.9	9.6	252	5.81	-		
	289	35.567	35.567	0	11.61	11.57	27.122	27.129	0.66	0.64	4.5	4.4	10.5	10.2	246	5.67	93.3		
	385	35.524	35.524	0	11.28	11.23	27.150	27.160	0.69	0.67	4.9	4.8	11.3	11.0	243	5.60	91.4		
	482	35.430	35.430	0	10.72	10.66	27.180	27.191	0.85	0.83	5.8	5.6	13.5	13.1	229	5.26	84.7		
	578	35.425	35.427	2	10.45	10.39	27.223	27.236	0.89	0.87	6.0	5.8	14.6	14.2	217	4.99	80.0		
	675	35.402	35.402	0	10.04	9.96	27.278	27.292	0.98	0.95	7.6	7.4	15.9	15.5	209	4.82	76.5		
	771	35.288	35.289	1	8.86	8.76	27.387	27.401	1.16	1.13	10.4	10.1	18.6	18.1	197	4.53	70.0		
	819	35.307	35.307	0	8.60	8.45	27.451	27.466	1.20	1.17	10.9	10.6	18.9	18.4	196	4.50	69.1		
190/2	859	35.304	35.304	0	8.28	8.18	27.490	27.504	1.18	1.15	11.5	11.2	18.2	17.7	196	4.51	69.8		
	956	35.309	35.312	3	7.53	7.41	27.610	27.625	1.17	1.14	12.0	11.7	18.4	17.9	209	4.80	72.0		
	1049	35.249	35.250	1	6.78	6.67	27.666	27.680	1.17	1.14	12.1	11.8	18.5	18.0	217	4.99	73.6		
	1144	35.219	35.227	8	6.30	6.19	27.710	27.725	1.16	1.13	11.9	11.6	18.3	17.8	214	4.93	71.9		
	1239	35.128	35.133	5	5.52	5.41	27.737	27.751	1.17	1.14	11.9	11.6	18.2	17.7	241	5.54	79.3		
	1334	35.056	35.056	0	5.00	4.88	27.740	27.754	1.16	1.13	11.6	11.3	17.9	17.4	250	5.75	81.1		
	1381	35.032	35.032	0	4.82	4.70	27.743	27.757	1.17	1.14	11.6	11.3	17.9	17.4	255	5.87	82.4		
	1429	35.020	35.020	0	4.66	4.54	27.751	27.765	1.17	1.14	11.6	11.3	17.7	17.2	259	5.95	83.2		
	1476	34.999	34.999	0	4.50	4.36	27.754	27.768	1.14	1.11	11.6	11.3	18.0	17.5	243	-	-		
	1524	34.990	34.991	1	4.40	4.27	27.757	27.771	1.14	1.11	11.6	11.3	17.8	17.3	265	6.10	84.8		
190/3	1616	34.961	34.967	6	4.16	4.02	27.762	27.777	1.08	1.05	11.5	11.2	17.0	16.5	271	6.24	86.4		
	1713	34.959	34.960	1	3.93	3.87	27.774	27.789	1.15	1.12	11.7	11.4	17.1	16.6	269	6.20	85.4		
	1809	34.961	34.961	0	3.99	3.84	27.778	27.794	1.15	1.12	12.2	11.9	17.5	17.0	276	6.35	87.5		
	1906	34.958	34.958	0	3.90	3.74	27.785	27.801	1.13	1.10	13.1	12.7	17.4	16.9	269	6.20	85.2		
	2004	34.961	34.963	2	3.80	3.63	27.798	27.815	1.13	1.10	13.5	13.1	17.9	17.4	268	6.17	84.5		
	2100	34.961	34.962	1	3.74	3.56	27.804	27.821	1.13	1.10	14.2	13.8	17.5	17.0	267	6.14	84.0		
	2197	34.962	34.958	4	3.65	3.46	27.812	27.830	1.13	1.10	15.1	14.7	17.7	17.2	269	6.19	84.5		
	2294	34.961	34.961	0	3.52	3.34	27.825	27.844	1.15	1.12	16.2	15.8	17.8	17.3	267	6.14	83.5		
	2391	34.955	34.956	1	3.43	3.22	27.831	27.850	1.13	1.10	16.4	16.0	17.7	17.2	269	6.19	84.0		
	2488	34.958	34.957	1	3.35	3.14	27.840	27.860	1.14	1.11	17.8	17.3	17.7	17.2	268	6.16	83.5		
190/1	2561	34.957	34.957	0	3.26	3.03	27.849	27.869	1.14	1.11	19.5	19.0	17.4	16.9	265	6.10	82.4		8.15
	2657	34.956	34.954	2	3.18	2.96	27.854	27.875	1.17	1.14	21.7	21.1	17.3	16.8	264	6.08	82.0		8.16
	2752	34.956	34.957	1	3.10	2.87	27.862	27.884	1.22	1.19	23.8	23.2	18.1	17.6	262	6.04	81.3		8.15
	2847	34.954	34.955	1	3.04	2.80	27.866	27.888	1.26	1.23	25.9	25.2	18.1	17.6	259	5.97	80.1		8.15
	2942	34.952	34.949	3	2.97	2.72	27.870	27.892	1.33	1.29	27.8	27.0	18.5	18.0	258	5.93	79.6		8.15
	3037	34.948	34.949	1	2.92	2.66	27.873	27.896	1.34	1.30	30.4	29.6	19.0	18.5	255	5.87	78.7		8.14
	3132	34.941	34.943	2	2.85	2.59	27.873	27.897	1.35	1.31	32.4	31.5	19.0	18.5	252	5.80	77.6		8.14
	3226	34.937	34.935	2	2.80	2.52	27.874	27.898	1.36	1.32	34.5	33.6	19.2	18.7	251	5.77	77.1		8.13
	3321	34.929	34.933	4	2.74	2.45	27.875	27.900	1.42	1.38	36.7	35.7	20.0	19.5	249	5.72	76.4		8.13
	3416	34.928	34.925	3	2.70	2.39	27.876	27.901	1.38	1.34	38.4	37.4	20.0	19.5	248	5.71	76.1		8.14
169/1	3810	34.913	34.910	3	2.60	2.26	27.872	27.901	1.52	1.48	45.4	44.2	19.9	19.4		5.42	72.0		8.14
	4274	34.906	34.912	6	2.60	2.21	27.870	27.904	1.57	1.53	48.0	46.7	20.2	19.7	244	5.61	74.5		8.16
	4508	34.902	34.902	0	2.62	2.20	27.863	27.899	1.52	1.48	48.6	47.3	21.7	21.1	246	5.66	75.2		8.16
	4649	34.900	34.900	0	2.62	2.18	27.861	27.899	1.50	1.46	49.1	47.8	20.8	20.2	241	5.55	73.7		8.16
	4672	34.903	34.902	1	2.62	2.16	27.864	27.901	1.50	1.46	47.8	46.5	20.5	19.9		5.33	70.8		8.18
	4695	34.902	34.901	1	2.61	2.16	27.863	27.901	1.48	1.44	49.4	48.1	20.5	19.9	246	5.65	75.0		8.18
	4714	34.898	34.899	1	2.60	2.15	27.862	27.900	1.54	1.50	49.4	48.1	20.5	19.9		-	-		8.17
	4723	34.898	34.902	4	2.61	2.16	27.862	27.900	1.58	1.54	49.3	48.0	20.5	19.9	248	5.70	75.7		8.17
	4732	-	-	0	2.58	2.14	-	-	1.54	1.50	48.3	47.0	20.2	19.7	246	5.67	75.3		8.17
	4741	34.909	34.909	0	2.62	2.16	27.869	27.908	1.56	1.52	47.7	46.4	20.5	19.9	245	5.64	74.9		8.18

Table 8.2

CIROLANA 6/79 Station: 175 Position: 45°59.7'N
Date: 9 June 1979 16°55.6'W
Depth: 4498 m Wire angle: 5°

H_4

Station	Depth	Height	S_1	S_2	S_1-S_2	Tw	ϑ	σ_t	σ_ϑ	PO_4-P		SiO_3-Si		NO_3-N		O_2			Eh	pH
	(m)	(m)	(‰)	(‰)	(‰)	(°C)	(°C)			µg at/l	µM/kg	µg at/l	µM/kg	µg at/l	µM/kg	µM/kg	ml/l_{20}	% sat.		in situ
175	3545	953	34.920	34.922	0.002	2.61	2.32	27.877	27.904	1.40	1.36	43.5	42.3	20.6	20.0	246	5.67	75.3	251	8.17
	4018	480	34.910	34.910	0.000	2.59	2.23	27.872	27.903	1.48	1.44	47.5	46.2	21.4	20.8	242	5.57	74.0	260	8.16
	4254	244	34.907	34.907	0.000	2.59	2.20	27.869	27.903	1.45	1.41	48.7	47.4	21.7	21.1	241	5.54	73.6	258	8.16
	4396	102	34.908	34.908	0.000	2.62	2.21	27.868	27.902	1.46	1.42	48.7	47.4	22.1	21.5	242	5.56	73.8	257	8.16
	4420	78	34.905	34.905	0.000	2.60	2.19	27.867	27.902	1.54	1.50	48.5	47.2	22.0	21.4	242	5.56	73.8	258	8.16
	4444	54	34.905	34.907	0.002	2.61	2.19	27.867	27.902	1.46	1.42	50.2	48.8	23.1	22.5	242	5.57	74.0	260	8.17
	4463	35	34.903	34.904	0.001	2.63	2.21	27.863	27.899	1.52	1.48	49.5	48.2	22.3	21.7	240	5.53	73.4	260	8.17
	4472	26	34.905	34.903	0.002	2.61	2.19	27.865	27.901	1.54	1.50	49.5	48.2	-	-	242	5.56	73.8	262	8.17
	4482	16	34.906	34.902	0.004	2.60	2.18	27.866	27.902	1.53	1.49	49.5	48.2	21.4	20.8	242	5.57	74.0	262	8.18
	4491	7	34.905	34.905	0.000	2.60	2.18	27.867	27.903	1.52	1.48	48.5	47.2	21.7	21.1	242	5.58	74.1	261	8.19
	(4498 m bottom)																			

Table 8.3

CIROLANA 6/79 Station: 174 Position: 46°00.0'N
Date: 19 June 1979 16°43.0'W
Depth: 4729 m Wire angle: 0°

H_5

Station	Depth	Height	S_1	S_2	S_1-S_2	Tw	θ	σ_t	σ_θ	PO_4-P		SiO_3-Si		NO_3-N		O_2			Eh	pH
	(m)	(m)	(‰)	(‰)	(‰)	(°C)	(°C)			µg at/l	µM/kg	µg at/l	µM/kg	µg at/l	µM/kg	µM/kg	ml/l_{20}	% sat.		in situ
174	3768	961	34.914	34.915	0.001	2.58	2.26	27.875	27.903	1.51	1.47	45.6	44.4	21.3	20.7	244	5.61	74.5	253	8.15
	4243	486	34.909	34.909	0.000	2.58	2.19	27.872	27.905	1.47	1.43	48.3	47.0	21.6	21.0	242	5.58	74.1	258	8.15
	4480	249	34.904	34.904	0.000	2.60	2.18	27.866	27.902	1.45	1.41	48.7	47.4	21.8	21.2	241	5.54	73.6	255	8.15
	4623	106	34.904	34.905	0.001	2.62	2.18	27.864	27.902	1.60	1.56	49.0	47.7	22.0	21.4	248	5.58	74.1	258	8.15
	4647	82	34.905	34.905	0.000	2.63	2.19	27.864	27.902	1.54	1.50	48.0	46.7	21.8	21.2	242	5.56	73.8	255	8.16
	4671	58	34.906	34.904	0.002	2.62	2.17	27.865	27.903	1.47	1.43	49.6	48.3	21.9	21.3	241	5.54	73.6	251	8.16
	4690	39	34.904	34.905	0.001	2.64	2.19	27.863	27.901	1.47	1.43	50.4	49.0	22.1	21.5	241	5.55	73.7	252	8.16
	4699	30	34.908	34.902	0.006	2.63	2.18	27.864	27.902	1.48	1.44	49.5	48.2	21.8	21.2	241	5.55	73.7	255	8.16
	4708	21	-	34.905	0.008	2.62	2.17	27.865	27.903	1.45	1.41	50.0	48.6	22.1	21.5	241	5.55	73.7	255	8.16
	4718	11	34.901	34.902	0.001	2.62	2.17	27.862	27.900	1.49	1.45	49.1	47.8	22.1	21.5	240	5.52	73.3	257	8.16
	(4729 m bottom)																			

Table 8.4

CIROLANA 6/79 Station: 173 Position: 46°00.3'N
Date: 19 June 1979 16°29.8'W
Depth: 3912 m Wire angle: 0°

H_6

Station	Depth	Height	S_1	S_2	S_1-S_2	Tw	θ	σ_t	σ_θ	PO_4-P		SiO_3-Si		NO_3-N		O_2			Eh	pH
	(m)	(m)	(‰)	(‰)	(‰)	(°C)	(°C)			µg at/l	µM/kg	µg at/l	µM/kg	µg at/l	µM/kg	µM/kg	ml/l_{20}	% sat.		in situ
173	2949	963	34.937	34.943	0.006	2.84	2.59	27.878	27.896	1.22	1.19	34.4	33.5	18.6	18.1	253	5.83	77.9	218	8.16
	3423	489	34.920	34.921	0.001	2.61	2.32	27.879	27.904	1.39	1.35	45.0	43.8	20.8	20.2	233	5.37	71.3	224	8.15
	3660	252	34.917	34.915	0.002	2.58	2.26	27.877	27.905	1.49	1.45	47.0	45.7	20.8	20.2	245	5.63	74.8	225	8.16
	3802	110	34.913	-	0.008	2.60	2.26	27.873	27.903	1.54	1.50	47.5	46.2	21.3	20.7	242	5.57	74.0	228	8.15
	3826	86	34.910	-	0.011	2.60	2.26	27.872	27.900	1.45	1.41	46.4	45.1	21.3	20.7	242	5.58	74.1	227	8.16
	3850	62	34.908	34.914	0.006	2.61	2.27	27.871	27.900	1.47	1.43	47.7	46.4	21.0	20.4	241	5.55	73.7	228	8.16
	3869	43	34.911	34.913	0.002	2.63	2.28	27.870	27.900	1.49	1.45	47.8	46.5	21.1	20.5	240	5.53	73.4	231	8.15
	3879	33	34.908	-	0.017	2.60	2.25	27.869	27.899	1.54	1.50	47.8	46.5	21.0	20.4	241	5.54	73.6	232	8.16
	3888	24	34.909	34.909	0.000	2.60	2.25	27.870	27.900	1.44	1.40	47.4	46.1	21.5	20.9	241	5.55	73.7	236	8.16
	3898	14	34.913	34.909	0.004	2.60	2.25	27.872	27.901	1.47	1.43	46.5	45.2	21.4	20.8	239	5.51	73.2	235	8.17
	(3912 m bottom)																			

Table 8.5

CIROLANA 6/79 Station: 187 Position: 45°59.4'N
Date: 21 June 1979 16°17.9'W
Depth: 4398 m Wire angle: 0°

Station	Depth	Height	S_1	S_2	S_1-S_2	Tw	9	σ_t	σ_θ	PO_4-P		SiO_3-Si		NO_3-N		O_2			Eh	pH
	(m)	(m)	(‰)	(‰)	(‰)	(°C)	(°C)			µg at/l	µM/kg	µg at/l	µM/kg	µg at/l	µM/Kg	µM/kg	ml/l_{20}	% sat.		in situ
187	3444	954	34.919	34.923	0.004	2.63	2.33	27.877	27.903	1.42	1.38	41.1	40.0	19.6	19.1	246	5.67	75.3	282	8.15
	3916	482	34.915	34.915	0.000	2.61	2.26	27.874	27.904	1.51	1.47	45.2	44.0	20.4	19.8	242	5.57	74.0	284	8.14
	4153	245	34.910	34.912	0.002	2.58	2.20	27.873	27.906	1.48	1.44	46.3	45.0	20.4	19.8	241	5.54	73.6	287	8.14
	4294	104	34.910	34.910	0.000	2.61	2.21	27.870	27.904	1.49	1.45	46.3	45.0	20.4	19.8	242	5.58	74.1	290	8.14
	4318	80	34.912	34.911	0.001	2.61	2.21	27.871	27.905	1.51	1.47	46.3	45.0	20.4	19.8	242	5.58	74.1	292	8.15
	4342	56	34.914	34.910	0.004	2.62	2.22	27.871	27.905	1.52	1.48	46.3	45.0	20.6	20.0	241	5.54	73.6	291	8.14
	4361	37	34.912	34.908	0.004	2.63	2.22	27.868	27.903	1.52	1.48	46.4	45.1	20.4	19.8	239	5.51	73.2	290	8.14
	4370	28	34.910	34.909	0.001	2.62	2.21	27.869	27.904	1.48	1.44	46.4	45.1	20.5	19.9	242	5.57	74.0	290	8.16
	4379	19	34.907	34.908	0.001	2.61	2.20	27.868	27.902	1.50	1.46	46.4	45.1	20.2	19.7	242	5.56	73.8	294	8.14
	4388	10	34.910	34.911	0.001	2.63	2.22	27.868	27.903	1.54	1.50	46.4	45.1	20.6	20.0	242	5.57	74.0	290	8.14
	(4398 m bottom)																			

Table 8.6

CIROLANA 6/79 Station: 186 Position: 46°00.3'N
Date: 21 June 1979 16°03.7'W
Depth: 4123 m Wire angle: 0°

H8

Station	Depth	Height	S_1	S_2	S_1-S_2	Tw	θ	σ_t	σ_θ	PO_4-P		SiO_3-Si		NO_3-N		O_2			Eh	pH
	(m)	(m)	(‰)	(‰)	(‰)	(°C)	(°C)			µg at/l	µM/kg	µg at/l	µM/kg	µg at/l	µM/kg	µM/kg	ml/l_{20}	% sat.		in situ
186	3156	967	34.932	34.933	0.001	2.71	2.44	27.880	27.903	1.44	1.40	36.6	35.6	19.6	19.1	249	5.72	76.2	256	8.16
	3631	492	34.912	34.914	0.002	2.61	2.29	27.872	27.900	1.50	1.46	43.6	42.4	20.0	19.5	242	5.58	74.1	262	8.14
	3878	245	34.909	34.906	0.003	2.57	2.22	27.871	27.900	1.52	1.48	45.2	44.0	20.0	19.5	244	5.61	74.5	266	8.15
	4011	112	34.908	34.909	0.001	2.60	2.24	27.869	27.900	1.51	1.47	46.3	45.0	20.6	20.0	242	5.57	74.0	267	8.14
	4035	88	34.908	34.904	0.004	2.59	2.22	27.869	27.900	1.49	1.45	45.7	44.5	20.2	19.7	245	5.63	74.8	270	8.14
	4059	64	34.906	34.909	0.003	2.59	2.22	27.869	27.901	1.50	1.46	46.3	45.0	20.2	19.7	242	5.57	74.0	272	8.14
	4078	45	34.907	34.902	0.005	2.61	2.24	27.865	27.897	1.49	1.45	46.4	45.1	20.8	20.2	241	5.55	73.7	275	8.14
	4087	36	34.907	34.907	0.000	2.59	2.22	27.869	27.901	1.56	1.52	46.4	45.1	20.6	20.0	241	5.55	73.7	275	8.15
	4097	26	34.907	-	0.009	2.58	2.21	27.870	27.902	1.49	1.45	46.7	45.4	20.2	19.7	242	5.58	74.1	278	8.15
	4106	17	34.912	34.912	0.000	2.58	2.21	27.874	27.906	1.51	1.47	46.3	45.0	20.2	19.7	242	5.56	73.8	279	8.15
	(4123 m bottom)																			

Table 8.7

CIROLANA 6/79 Station: 194 Position: 46°05.7'N
Date: 22 June 1979 16°43.0'W
Depth: 4738 m Wire angle: 10°

H_9

Station	Depth	Height	S_1	S_2	S_1-S_2	Tw	θ	σ_t	σ_θ	PO_4-P		SiO_3-Si		NO_3-N		O_2			Eh	pH
	(m)	(m)	(‰)	(‰)	(‰)	(°C)	(°C)			µg at/l	µM/kg	µg at/l	µM/kg	µg at/l	µM/kg	µM/kg	ml/l_{20}	% sat.		in situ
194	3769	969	34.916	34.914	0.002	2.60	2.27	27.875	27.903	1.44	1.40	46.6	45.3	20.9	20.3	246	5.66	75.2	286	8.12
	4250	488	34.907	34.909	0.002	2.58	2.19	27.871	27.904	1.46	1.42	45.8	44.6	21.4	20.8	241	5.55	73.7	291	8.12
	4490	248	34.902	34.905	0.003	2.60	2.18	27.865	27.901	1.48	1.44	46.5	45.2	21.6	21.0	241	5.54	73.6	294	8.12
	4634	104	34.902	34.902	0.000	2.63	1.19	27.862	27.899	-	-	46.7	45.4	-	-	241	5.54	73.6	295	8.13
	4658	80	34.906	34.902	0.004	2.63	2.19	27.863	27.901	1.47	1.43	46.7	45.4	21.3	20.7	240	5.53	73.4	296	8.13
	4682	56	34.901	34.902	0.001	2.64	2.19	27.860	27.898	-	-	46.7	45.4	-	-	239	5.51	73.2	298	8.13
	4701	37	34.902	34.898	0.004	2.64	2.19	27.859	27.898	1.49	1.45	46.9	45.6	22.2	21.6	242	5.58	74.1	300	8.14
	4711	27	34.902	34.902	0.000	2.63	2.18	27.862	27.900	1.52	1.48	46.7	45.4	21.8	21.2	240	5.52	73.3	301	8.14
	4720	18	34.903	34.901	0.002	2.63	2.18	27.862	27.900	1.51	1.47	46.7	45.4	22.0	21.4	244	5.61	74.5	302	8.13
	4730	8	34.901	34.899	0.002	2.63	2.18	27.860	27.899	1.50	1.46	47.9	46.6	22.0	21.4	244	5.61	74.5	302	8.14
	(4738 m bottom)																			

Table 8.8

CIROLANA 6/79 Station: 178 Position: 46°07.2'N
Date: 19 June 1979 17°10.5'W
Depth: 4758 m Wire angle: 0°

H_{10}

Station	Depth	Weight	S_1	S_2	S_1-S_2	Tw	9	σ_t	σ_θ	PO_4-P		SiO_3-Si		NO_3-N		O_2			Eh	pH
	(m)	(m)	(‰)	(‰)	(‰)	(°C)	(°C)			µg at/l	µM/kg	µg at/l	µM/kg	µg at/l	µM/kg	µM/kg	ml/l$_{20}$	% sat.		in situ
178	3797	961	34.912	34.913	0.001	2.59	2.26	27.873	27.902	1.52	1.48	43.7	42.5	21.5	20.9	243	5.60	74.4	250	8.16
	4272	486	34.907	34.910	0.003	2.60	2.21	27.869	27.903	1.47	1.43	45.6	44.4	21.7	21.1		5.32	70.6	244	8.15
	4510	248	34.905	34.905	0.000	2.60	2.18	27.867	27.903	1.48	1.44	47.0	45.7	22.1	21.5	245	5.64	74.9	244	8.14
	4652	106	34.902	34.903	0.001	2.61	2.17	27.864	27.901	1.48	1.44	47.0	45.7	22.0	21.4	240	5.53	73.4	242	8.14
	4676	82	34.911	34.911	0.000	2.62	2.17	27.870	27.908	1.56	1.52	47.1	45.8	21.9	21.3	240	5.53	73.4	240	8.14
	4700	58	34.908	34.901	0.007	2.62	2.17	27.864	27.902	1.49	1.45	47.2	45.9	21.9	21.3	241	5.55	73.7	239	8.15
	4719	39	34.907	34.907	0.000	2.64	2.19	27.865	27.903	1.54	1.50	47.2	45.9	22.3	21.7	242	5.58	74.1	241	8.15
	4728	30	34.908	34.905	0.003	2.61	2.16	27.867	27.905	1.54	1.50	47.2	45.9	22.1	21.5	242	5.56	73.8	240	8.15
	4737	21	34.905	34.906	0.001	2.61	2.16	27.866	27.904	1.54	1.50	47.2	45.9	22.0	21.4	241	5.55	73.7	240	8.16
	4747	11	34.906	34.906	0.000	2.61	2.15	27.867	27.905	1.61	1.57	47.3	46.0	22.6	22.0	239	5.51	73.2	240	8.16
	(4758 m bottom)																			

Table 8.9

CIROLANA 6/79 Station: 179 Position: 46°16.0'N
Date: 20 June 1979 17°25.1'W
Depth: 4398 m Wire angle: 5°

H_{11}

Station	Depth	Height	S_1	S_2	S_1-S_2	Tw	ϑ	σ_t	σ_ϑ	PO_4-P		SiO_3-Si		NO_3-N		O_2			Eh	pH
	(m)	(m)	(‰)	(‰)	(‰)	(°C)	(°C)			µg at/l	µM/kg	µg at/l	µM/kg	µg at/l	µM/kg	µM/kg	ml/l_{20}	% sat.		in situ
179	3436	962	-	-	-	-	-	-	-	1.57	1.53	40.3	39.2	20.8	20.2	246	-	-	-	-
	3911	487	34.913	34.914	0.001	2.58	2.23	27.875	27.905	1.53	1.49	44.8	43.6	22.1	21.5	242	5.58	74.1	212	8.15
	4061	337	34.909	34.908	0.001	2.57	2.20	27.872	27.903	1.52	1.48	46.3	45.0	22.0	21.4	240	5.52	73.3	212	8.15
	4291	107	34.901	34.905	0.004	2.59	2.19	27.866	27.900	1.51	1.47	47.0	45.7	22.2	21.6	244	5.62	74.6	210	8.15
	4315	83	34.905	34.905	0.000	2.60	2.20	27.867	27.901	1.53	1.49	47.2	45.9	22.2	21.6	242	5.56	73.8	210	8.15
	4339	59	34.905	34.904	0.001	2.60	2.20	27.866	27.900	1.58	1.54	47.2	45.9	22.3	21.7	243	5.59	74.2	213	8.15
	4359	40	34.905	34.905	0.000	2.60	2.19	27.867	27.901	1.51	1.47	47.2	45.9	22.2	21.6	240	5.53	73.4	218	8.15
	4367	31	34.905	34.905	0.000	2.60	2.19	27.867	27.901	1.52	1.48	47.2	45.9	22.1	21.5	242	5.58	74.1	217	8.15
	4377	21	34.905	34.905	0.000	2.58	2.17	27.869	27.903	1.54	1.50	47.2	45.9	22.3	21.7	242	5.56	73.8	220	8.17
	4386	12	34.910	34.912	0.002	2.58	2.17	27.873	27.908	1.57	1.53	47.2	45.9	22.0	21.4	241	5.55	73.7	220	8.17
	(4398 m bottom)																			

Table 8.10

CIROLANA 6/79 Station: 180 Position: 46°15.6'N
Date: 20 June 1979 17°10.5'W
Depth: 4730 m Wire angle: 0°

H_{12}

Station	Depth	Height	S_1	S_2	S_1-S_2	Tw	θ	σ_t	σ_θ	PO_4-P		SiO_3-Si		NO_3-N		O_2			Eh	pH
	(m)	(m)	(‰)	(‰)	(‰)	(°C)	(°C)			µg at/l	µM/kg	µg at/l	µM/kg	µg at/l	µM/kg	µM/kg	ml/l_{20}	% sat.		in situ
180	3773	954	(34.921)*	(34.921)*	0.000	2.57	2.25	(27.881)*	(27.910)*	1.49	1.45	43.3	42.1	21.3	20.7	242	5.58	74.1	230	8.14
	4246	484	34.913	34.913	0.000	2.57	2.21	27.873	27.907	1.52	1.48	46.1	44.9	22.0	21.4	241	5.54	73.6	226	8.14
	4483	247	34.909	34.909	0.000	2.58	2.16	27.872	27.907	1.42	1.38	46.7	45.4	21.9	21.3	239	5.50	73.0	224	8.14
	4624	106	34.909	34.909	0.000	2.61	2.17	27.869	27.906	1.53	1.49	47.3	46.0	21.9	21.3	241	5.54	73.6	226	8.14
	4648	82	34.909	34.908	0.001	2.61	2.17	27.868	27.906	1.51	1.47	47.7	46.4	22.0	21.4	248	5.71	75.8	227	8.15
	4672	58	34.913	34.908	0.005	2.61	2.16	27.870	27.908	1.50	1.46	47.7	46.4	21.8	21.2	240	5.53	73.4	231	8.16
	4691	39	34.911	34.909	0.002	2.62	2.17	27.869	27.907	1.54	1.50	47.3	46.0	22.0	21.4	241	5.55	73.7	233	8.16
	4700	30	34.909	34.906	0.003	2.61	2.16	27.868	27.906	1.48	1.44	47.2	45.9	22.0	21.4	242	5.57	74.0	232	8.16
	4709	21	34.905	34.907	0.002	2.60	2.15	27.868	27.906	1.52	1.48	47.2	45.9	22.1	21.5	239	5.51	73.2	231	8.16
	4719	11	34.908	34.908	0.000	2.61	2.16	27.868	27.907	1.48	1.44	47.2	45.9	22.0	21.4	-			235	8.17
	(4730 m bottom)																			

* Possible leakage

Table 8.11

CIROLANA 6/79 Station: 181 Position: 46°14.7'N
Date: 20 June 1979 16°56.8'W
Depth: 4427 m Wire angle: 5°

H_{13}

Station	Depth	Height	S_1	S_2	S_1-S_2	Tw	θ	σ_t	σ_θ	PO_4-P		SiO_3-Si		NO_3-N		O_2			Eh	pH
	(m)	(m)	(‰)	(‰)	(‰)	(°C)	(°C)			µg at/l	µM/kg	µg at/l	µM/kg	µg at/l	µM/kg	µM/kg	ml/l_{20}	% sat.		in situ
181	3459	968	34.930	34.930	0.000	2.67	2.37	27.881	27.907	1.41	1.37	38.1	37.1	21.4	20.8	249	5.74	76.2	202	8.15
	3938	489	34.916	34.917	0.001	2.62	2.27	27.874	27.904	1.49	1.45	43.7	42.5	21.9	21.3	244	5.61	74.5	198	8.14
	4177	250	34.911	34.912	0.001	2.59	2.21	27.873	27.905	1.55	1.51	45.5	44.3	22.2	21.6	241	5.55	73.7	197	8.15
	4320	107	34.912	34.910	0.002	2.60	2.20	27.872	27.906	1.47	1.43	46.3	45.0	22.2	21.6	242	5.56	73.8	200	8.15
	4343	84	34.902	34.904	0.002	2.61	2.21	27.864	27.899	1.47	1.43	46.2	45.0	22.3	21.7	242	5.56	73.8	200	8.15
	4368	59	34.904	34.906	0.002	2.62	2.21	27.865	27.900	1.52	1.48	46.3	45.0	22.0	21.4	242	5.58	74.1	205	8.16
	4387	40	34.902	34.905	0.003	2.63	2.22	27.863	27.898	1.51	1.47	46.3	45.0	22.0	21.4	241	5.54	73.6	207	8.15
	4397	30	34.909	34.906	0.003	2.61	2.20	27.868	27.902	1.51	1.47	46.4	45.1	22.3	21.7	234	5.38	71.4	217	8.15
	4406	21	34.908	34.906	0.002	2.61	2.20	27.868	27.903	1.52	1.48	46.4	45.1	22.2	21.6	242	5.56	7.38	211	8.15
	4416	11	34.908	34.906	0.002	2.60	2.19	27.868	27.903	1.49	1.45	46.4	45.1	22.3	21.7	243	5.60	74.4	211	8.16
	(4427 m bottom)																			

Table 8.12

CIROLANA 6/79 Station: 188 Position: 45°51.6'N
Date: 21 June 1979 16°44.8'W
Depth: 4652 m Wire angle: 5-10°

H_{14}

Station	Depth	Height	S_1	S_2	S_1-S_2	Tw	ϑ	σ_t	σ_ϑ	PO_4-P		SiO_3-Si		NO_3-N		O_2			Eh	pH
	(m)	(m)	(‰)	(‰)	(‰)	(°C)	(°C)			µg at/l	µM/kg	µg at/l	µM/kg	µg at/l	µM/kg	µM/kg	ml/l_{20}	% sat.		in situ
188	3696	956	34.920	34.919	0.001	2.62	2.29	27.876	27.904	1.43	1.39	42.7	41.5	20.6	20.0	246	5.67	75.3	282	8.15
	4172	480	34.910	34.912	0.002	2.63	2.25	27.869	27.902	1.51	1.47	45.7	44.5	20.4	19.8	244	5.62	74.6	288	8.13
	4490	243	34.908	34.903	0.005	2.61	2.20	27.866	27.901	1.53	1.49	46.4	45.1	20.7	20.1	241	5.54	73.6	290	8.12
	4552	100	34.912	34.903	0.009	2.62	2.19	27.867	27.903	1.58	1.54	47.0	45.7	20.7	20.1	240	5.53	73.4	292	8.14
	4576	76	34.912	34.909	0.003	2.63	2.20	27.868	27.905	1.57	1.53	47.0	45.7	21.0	20.4	243	5.59	74.2	293	8.13
	4600	52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	4619	33	34.909	34.903	0.006	2.64	2.20	27.864	27.902	1.60	1.56	47.1	45.8	20.8	20.2	240	5.53	73.4	295	8.13
	4628	24	34.908	34.910	0.002	2.63	2.19	27.867	27.905	1.53	1.49	47.2	45.9	21.0	20.4	242	5.57	74.0	296	8.14
	4638	14	34.909	34.907	0.002	2.62	2.18	27.868	27.905	1.61	1.57	47.0	45.7	21.0	20.4	244	5.61	74.5	296	8.14
	4647	5	34.907	34.909	0.002	2.61	2.17	27.868	27.906	1.56	1.52	46.6	45.3	21.0	20.4	243	5.60	74.4	296	8.15
	(4652 m bottom)																			

Table 8.13

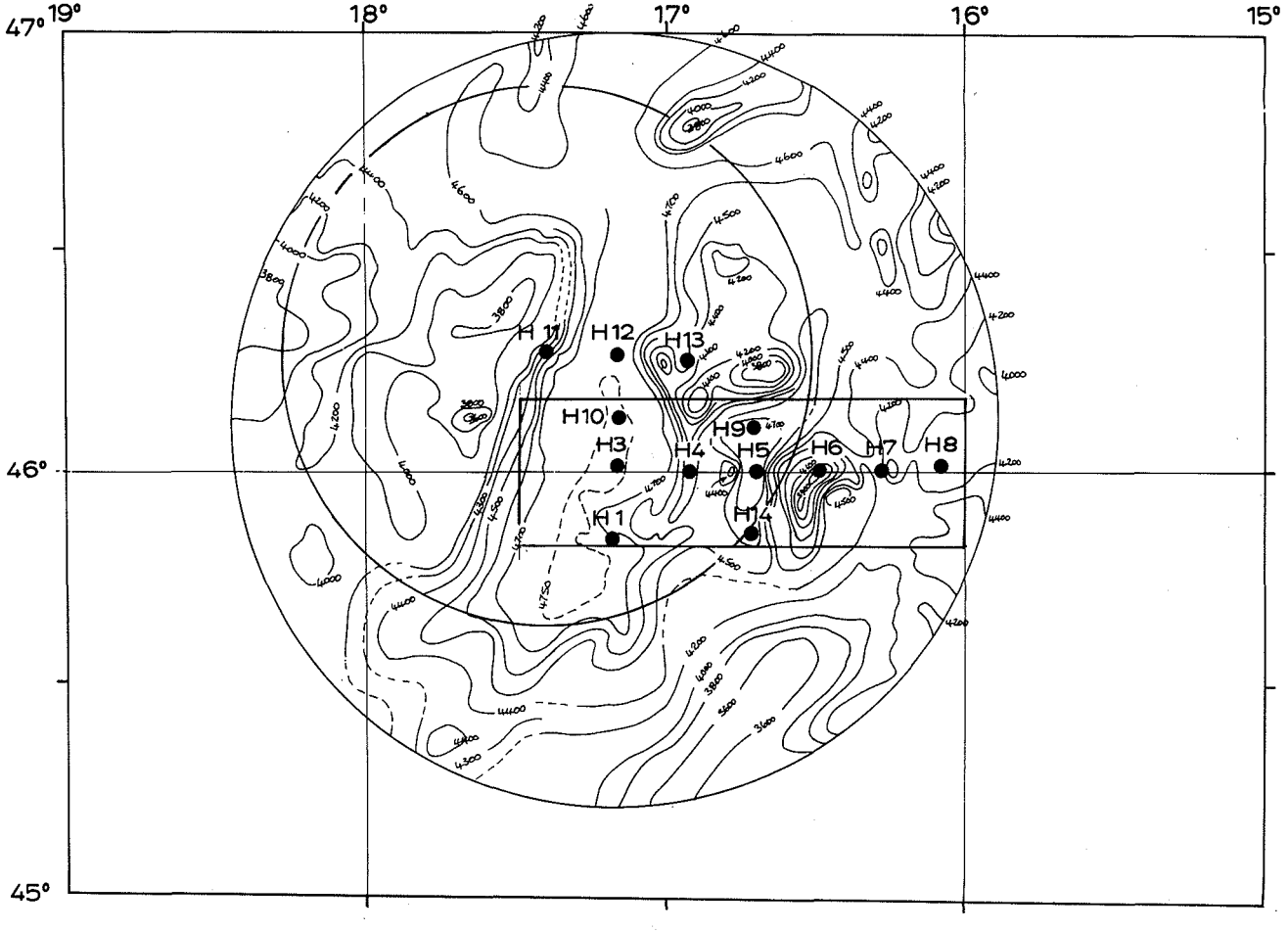

Figure 8.1 Location of hydrostations H1 and H3-14 at the current and previous NEA dumpsites.

Chapter 9

SEAWATER RADIONUCLIDE ANALYSES

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Only a limited series of radionuclide measurements in sea water appear to have been made in the region of 46°N 17°W.

In 1979, during the cruise CIROLANA 6/79, three samples were taken. On 18 June, at 46°00.35'N 17°10.45'W (Station 169.3) a 500 l surface sample was taken for caesium-137 measurement: a value of 0.10 pCi l^{-1} was obtained (Pentreath, unpublished). On 20 June, at 46°07.74'N 17°11.19'W (Station 183.3) a 50 l surface sample was also taken for caesium-137 measurement: the value of 0.10 pCi l^{-1} was confirmed. On 22 June, at 45°58.5'N 17°12.5'W (Stations 191 and 193) a bulk sample of 6 x 30 l was obtained at depths between 10 and 25 m from the bottom in 4760 m water depth: this sample is being processed for transuranic elements and caesium-137, but the data are not yet available.

In 1980, depth profiles for caesium-137 and strontium-90 were obtained at 45°59'N 16°46'W by Isotopenlaboratorium der Bundesforschungsanstalt für Fischerei, Hamburg (Feldt, Kanisch and Lauer, 1981). Their caesium values were reported as 0.10 pCi l^{-1} at the surface, falling to less than 0.01 pCi l^{-1} at 4000 m; the strontium-90 profile was similar viz. a surface level of 0.08 pCi l^{-1}, falling to 0.01 pCi l^{-1} at 4000 m. A graph of the profiles is shown in Figure 9.1 and the sampling positions are shown on the map (Figure 9.2) by their respective dates.

The data are not inconsistent with fallout levels.

References

Feldt, W., Kanisch, G. and Lauer, R., 1981. Radioactive contamination of the NEA Dumping Sites. In: Impacts of Radionuclide Releases into the Marine Environment, IAEA-SM-248/111. Vienna, 465-480.

Pentreath, R. J. Unpublished work at the Fisheries Radiobiological Laboratory, MAFF, Lowestoft.

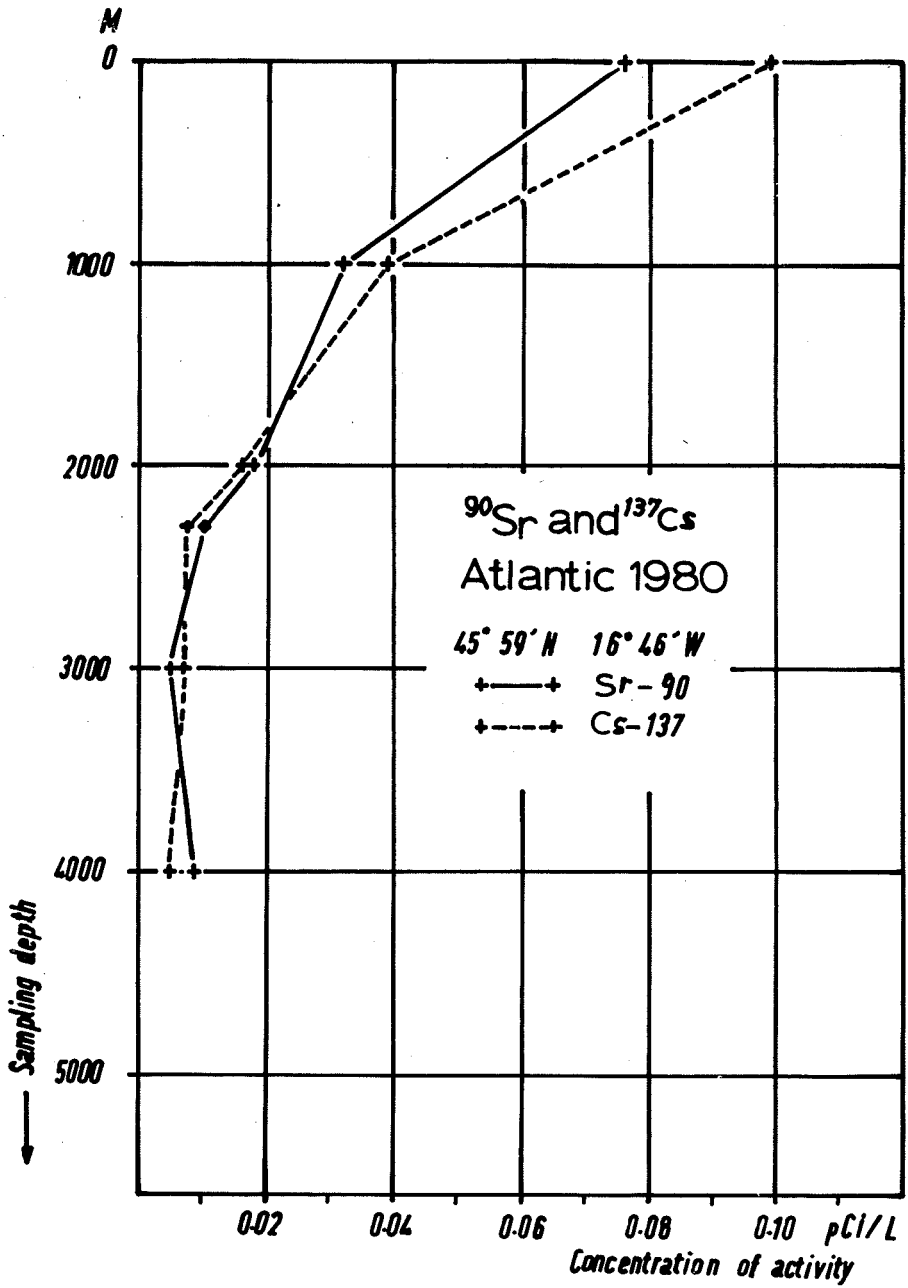

Figure 9.1 The concentration of Sr-90 and Cs-137 in the water column above the NEA dumpsite in the North-East Atlantic (from Feldt, Kanisch and Lauer, 1981).

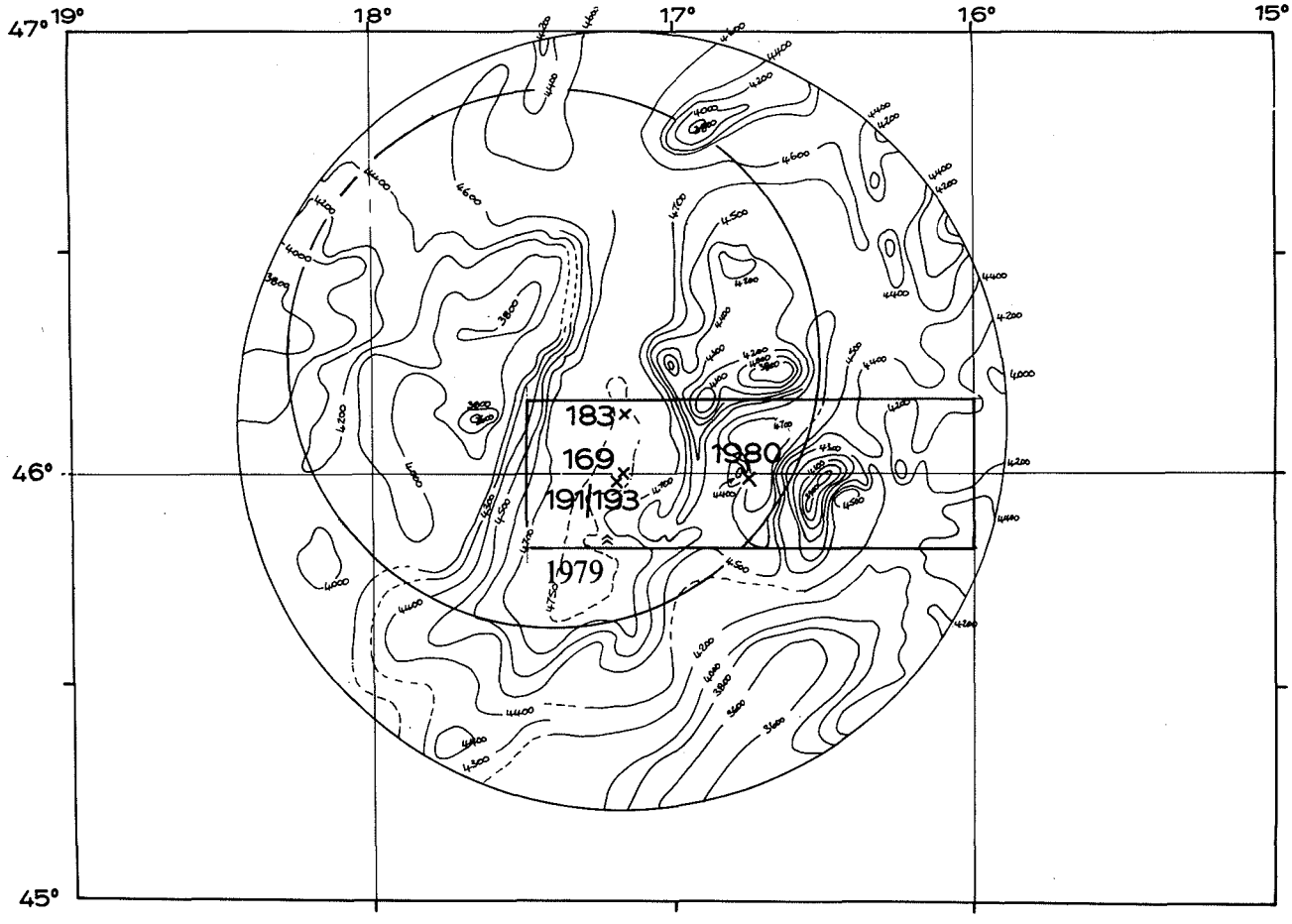

Figure 9.2 Sampling positions for Cs-137 and Sr-90 analysis with year of collection indicated.

Chapter 10

RADIOACTIVITY IN SURFACE LAYERS OF BOX-CORED SEDIMENTS

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10.1 Introduction

Three cruises were undertaken in 1979 (FFS ANTON DOHRN) and 1980, 1981 (FFS WALTER HERWIG) to monitor the NEA dumping sites. Samples of water, sediment and organisms from plankton, nekton and benthos were analysed and the results from 1979 and 1980 have been published (Feldt et al., 1981). Here, the results of the investigations on deep-sea sediment will be discussed.

The mean depths of the Atlantic study sites (A, B, C and II, see Figure 10.1) are 5200, 4300, 5000 and 5600 m, respectively. Study area A was the initial dumping site (about 9300 km^2), which had been used since 1967. Study area B is the present dumping site (about 6200 km^2), the study areas C and II are the sites chosen for comparison purposes. In 1979 nine samples were taken from each of the areas A and B, and two from area II. In 1980 three samples were obtained from area B and one from area C. Sub-cores, each 17 cm long, were taken from these four samples and sliced into layers for analysis.

In 1981 seven samples were obtained from area A, nine from area B, and four from area C.

The samples were first analysed by gamma-ray spectrometry. Thereafter a part of the sediments were radiochemically analysed for Sr-90 and Cs-137.

10.2 Methods

10.2.1 Sampling

The geographical positions, together with sampling dates of all samples, can be taken from Tables 10.1-10.3.

The sampling occurred in an average depth of 5000 m. The rectangular cross-section area of the bottom grab (Reineck box-core) was 20 x 30 cm.

In 1979 and 1981 the uppermost 3 cm layer of the sediment was used for radioactivity analysis. In 1980 four sub-cores were taken from the bottom grab samples, each having a total depth of 17 cm. The uppermost 5 cm were divided into five layers of 1 cm each. The lower 12 cm layer was divided into four layers of 3 cm each. In order to have enough material for measurement from each of the four bottom grab samples three different cores were taken, and sliced as described above; then three corresponding layers were combined into one sample for measurement. The diameter of each layer was 10 cm. The four different cores were labelled core 1 to core 4.

The preparations described above were performed on board ship. Each sample was then preserved in a plastic bag.

10.2.2 Sample preparation for the measurement

The samples were dried at a temperature of 130°C for a period of 24-30 hours. From each sample 180-250 g dry sediment was used for gamma-ray analysis. Radiochemical analysis of Sr-90 and Cs-137 was performed with 100 g dry sediment. The ratio of wet weight to dry weight gives values between 1.7 and 2.4.

10.2.3 Low-level gamma-ray analysis

Three Ge(Li)-gamma-ray spectrometers were used to determine gamma-ray emitting nuclides in the sediment samples. Each detector was shielded by 5 cm of lead to reduce the background. The counting time was 4000 min for each measurement.

Two Ge(Li)'s have relative efficiencies of 24% (Co-60)and the third has a relative efficiency of 13% (Co-60), but with lower background. The energy resolution is better than or equal to 2.3 keV (Co-60).

The calculations of the full energy peak intensity were carried out with the aid of an automatic peak search program using formulae for net peak areas similar to those given by Rogers (1970).

For the samples of 1979 and 1980 activities were derived from single peaks or as a weighted mean, if more than one line per nuclide was detected. The activities of the 1981 samples were calculated from the list of the net peak rates by solving a linear equation system using matrix methods. This method allows for automatic correction of interfering lines from different nuclides, even in the case where interference cannot be corrected by a peak fitting method.

The absolute full energy peak efficiencies were derived from a series of calibration measurements, which related the efficiency to the density of the dry sediment in the cylindrical measuring container

(6.7 cm diameter x 8 cm high) over an energy region of 100-1900 keV. Intercalibrations verified their standard deviation to be better than 5% (1 Sigma).

In some cases the fission and activation products Co-60, Cs-137 and Sb-125 were found. The natural radionuclides K-40 and nuclides of the decay chains of U-238 and Th-232 have been detected. The analysis of the 1979 samples gave a hint that the decay chain of U-235 could be present. Although the most intense lines of the U-235 chain interfere with lines of the chains of U-238 and Th-232, application of the above-mentioned matrix method confirmed this supposition.

10.2.4 Radiochemical analysis of Sr-90 and Cs-137

The determination of the Sr-90 content was performed by the conventional method, using fuming nitric acid for the separation of strontium from calcium and the separation and precipitation of yttrium as yttrium oxalate. The samples were counted with a low level beta counter having a background of 0.3 cpm. From each sample a decay curve of Y-90 was taken. Checking the expected decay it was confirmed that the count rates were due to Y-90.

Caesium was enriched after dissolution of the sediment samples in hydrochloric acid. The procedure starts with a purification of the solution by carrying out a sodium carbonate precipitation. The next step is the separation of caesium with sodium hexanitrocobaltate (III). Finally, the caesium will be beta-counted as a hexachloroplatinic (IV)-complex fixed on ring and disc with the low level beta counter described above.

10.2.5 Statistical treatment

In Tables 10.1-10.3 the results of the activity measurements are presented together with the associated relative standard deviations derived from counting statistics (68% confidence level). Detection limits are not stated generally. But if the relative standard deviation is greater than 20%, one calculates detection limits (according to Currie, 1968) to a satisfactory approximation in the following manner:

$$\text{detection limit} = (k\alpha + k\beta) * \text{SIGMA}$$

where SIGMA is the standard deviation of the activity, which can be read directly from the tables of results. $k\alpha$ and $k\beta$ are related to the probabilities α and β (Type I and Type II error) through the following table:

α,β	$k\alpha$, $k\beta$
0.010	2.326
0.050	1.645
0.100	1.282

Activity results of the gamma ray measurements of the samples from 1979 and 1980 are only presented if the characteristic lines of the radionuclides could be detected by the peak search.

For the 1981 samples the activities were calculated by the matrix method. To extract the standard deviations of these activities by propagation of error, it was necessary to include an overall standard deviation of the efficiency of 7% for each gamma line including also uncertainties due to coincidence summing losses. Therefore the activity standard deviations of the 1981 samples (presented in Table 10.3) may have larger values than those of 1979 and 1980. Detection limits have been given for Cs-137 if the gamma line was not detected by the peak search.

10.3 Composition of sediments

Study area A sediments can be described as hemipelagic marly containing calcite (42% CaCO), quartz, kaolinite, chlorite, illite, and talc. Study area B sediments are calcareous ooze (pelagic) containing calcite (80% $CaCO_3$), feldspar, illite and quartz. In some samples also aragonite and kaolinite were found.

10.4 Results

The results of the radioactivity determination in the surface layer (3 cm thick) of box cored sediments taken in 1979 and 1981 are shown in Tables 10.1 and 10.3, respectively. The results of determination of the vertical radioactivity profiles of the four 1980 sediment cores are presented in Table 10.2.

It can be seen that the fission and activation products Co-60 and Sb-125 were only detected in a few cases in the sediments of 1979, with a relatively large error. Their activities do not show a significant difference between study areas A and B.

The fission products Sr-90 and Cs-137 were detected more frequently in sediments of all three years (the determination of Sr-90 in the cores of 1980 are not yet finished and will be published later). Also in all samples the naturally-occurring nuclide K-40 and members of the decay chains of U-238 and Th-232 have been detected with associated errors smaller than those of the fission products. Gamma lines belonging to the chain of U-235 also have been detected in a part of sediments. Use of the above-mentioned matrix method made it possible to calculate average activities, but their errors still appear to be too large. So they were not presented in the tables. An approximate value for average activities is 100 pCi g^{-1} dry.

Analysing the state of equilibrium of the U-238 and U-235 series it was found that the activities of the parents U-238 and U-235 must be apparently smaller than those of the daughters Ra-226 and Th-227, respectively. This can be understood from the fact that the U-isotopes are much more soluble in the ocean water than the daughter-Th-isotopes leading to raised unsupported concentrations of the Th-isotopes in the sediments.

The amounts of K-40 and Ac-228 are obviously different between the study areas B, C and the area A, respectively. Study area A shows the higher amounts. The Ra-226 activities can be said to be roughly the same in the different study areas.

The specific activities of the fission products Sr-90 and Cs-137 which are interesting in the context of dumping sites do not show significant differences between the different study areas or the different years (except for one higher Sr-90 value in area B (1979), the presently used dumping site).

The analysis of the four cores (given in Table 10.2) results in vertical profiles of Cs-137 activity, which are presented in Figures 10.2 and 10.3. The shapes of the profiles (three from study area B, the presently used dumping site, and one from the control site C) correspond within their statistical fluctuations. The Cs-137 activity seems to fall off within the uppermost 10 to 15 cm.

10.5 References

Currie, L. A., 1968. Limits of qualitative detection and quantitative determination. Anal. Chem., 40, 586-593.

Feldt, W., Kanisch, G. and Lauer, R., 1981. The radioactive contamination of the NEA Dumping Sites. IAEA-SM-248/111. Vienna.

Rogers, V. C., 1970. Detection limits for gamma-ray spectral analysis. Anal. Chem., 42, 807-808.

Table 10.1: Specific activities (pCi/g dry) of radionuclides in Sediment; cruise 1979

Area of sampling	Sample number	Geographic position	Sampling date	K - 40	Co - 60	Sr - 90	Sb - 125	Cs - 137 **)	Ra - 226	Ac - 228
B	4504	46°02'N; 16°55'W	15.06.79	3.41±0.17 *)		0.009±0.002		0.010±0.004	1.54±0.19	0.19±0.03
	4505	46°05'N; 16°44'W	16.06.79	3.28±0.19		0.007±0.001		0.021±0.004	1.53±0.20	0.19±0.04
	4506	46°05'N; 17°14.8'W	17.06.79	3.88±0.18		0.006±0.003		0.031±0.004	1.70±0.17	0.18±0.04
	4507	46°01'N; 15°15'W	17.06.79	3.68±0.21	0.013±0.005	0.127±0.004		0.028±0.004	1.78±0.25	0.25±0.05
	4508	45°54'N; 17°14'W	17.06.79	3.58±0.18		0.027±0.002		0.023±0.004	1.54±0.19	0.23±0.03
	4509	45°54.5'N; 16°45.7W	17.06.79	2.70±0.15	0.012±0.006	0.023±0.002	0.025±0.013	0.026±0.004	1.22±0.15	0.16±0.03
	4510	45°54'N; 16°16'W	18.06.79	2.97±0.16		0.020±0.006		0.013±0.004	1.49±0.16	0.15±0.03
	4511	46°0'N; 16°15'W	18.06.79	2.65±0.18		0.016±0.003		0.022±0.004	1.31±0.21	0.19±0.04
	4512	46°05'N; 16°15'W	19.06.79	2.65±0.19		0.015±0.004		0.015±0.004	1.22±0.19	0.17±0.04
II	4513	44°30'N; 15°25.5'W	20.06.79	5.86±0.19		0.015±0.001	0.032±0.015	0.010±0.004	2.62±0.24	0.39±0.04
	4514	44°20'N; 15°32.4'W	20.06.79	6.93±0.19		0.013±0.001		0.010±0.004	2.84±0.17	0.41±0.04
A	4515	42°50'N; 14°50'W	21.06.79	11.0 ±0.19	0.014±0.006	0.025±0.001		0.016±0.004	1.96±0.18	0.67±0.03
	4516	42°50'N; 14°30'W	21.06.79	13.3 ±0.20		0.006±0.001		0.020±0.004	1.88±0.17	0.68±0.03
	4517	42°49'N; 14°10'W	22.06.79	14.6 ±0.19		0.003±0.001		0.006±0.004	1.80±0.16	0.79±0.04
	4518	42°30'N; 14°10'W	23.06.79	3.09±0.14		0.033±0.001		0.014±0.004	0.48±0.13	0.32±0.03
	4519	42°30.5'N; 14°29'W	23.06.79	12.5 ±0.19		0.001±0.001		0.009±0.004	1.91±0.15	0.65±0.03
	4520	42°30'N; 14°52'W	23.06.79	11.9 ±0.19		0.008±0.001		0.014±0.004	1.82±0.20	0.70±0.04
	4521	42°9.5'N; 14°9.2'W	25.06.79	15.2 ±0.21		0.024±0.001		0.006±0.004	2.56±0.18	0.89±0.04
	4522	42°10'N; 14°30'W	25.06.79	15.0 ±0.24	0.015±0.008	0.019±0.001		0.011±0.004	2.30±0.23	0.81±0.04
	4523	42°9'N; 14°50'W	25.06.79	10.4 ±0.18		0.006±0.001			2.16±0.17	0.62±0.03

*) Errors quoted are those due to counting statistics (1σ)

**) Cs-137 determined by radiochemical method

Table 10.2: Specific activities (pCi/g dry) of radionuclides in Sediment cores cruise 1980

Area of sampling	Sample number	Geographic position	Sampling date	Layer	K - 40	Cs - 137**)	Ra - 226	Ac - 228
B	5011	46°00'N; 17°18.2'W	01.05.80	0 - 1 cm, Core 1	3.66±0.20*)	0.031±0.007	1.32±0.20	0.13±0.04
	5012			1 - 2	3.72±0.19	0.026±0.005	1.53±0.20	0.15±0.04
	5013			2 - 3	3.50±0.09	0.031±0.006	1.60±0.22	0.15±0.02
	5014			3 - 4	3.26±0.19	0.029±0.004	1.39±0.18	0.16±0.04
	5015			4 - 5	3.34±0.19	0.023±0.004	1.76±0.21	0.22±0.04
	5016			5 - 8	3.50±0.19	0.018±0.006	1.56±0.20	0.19±0.04
	5017			8 - 11	3.57±0.19		1.95±0.21	0.24±0.05
	5018			11 - 14	4.42±0.19		2.29±0.19	0.20±0.04
	5019			14 - 17	4.64±0.19		2.39±0.19	0.27±0.05
B	5020	46°00'N; 16°45'W	01.05.80	0 - 1 cm, Core 2	3.26±0.19	0.052±0.007	1.32±0.20	0.13±0.04
	5021			1 - 2	3.01±0.19	0.031±0.006	1.32±0.18	0.14±0.04
	5022			2 - 3	2.81±0.19	0.029±0.004	1.39±0.21	0.15±0.05
	5023			3 - 4	3.03±0.18	0.043±0.005	1.26±0.18	0.17±0.04
	5024			4 - 5	2.97±0.18	0.025±0.005	1.51±0.18	0.14±0.04
	5025			5 - 8	3.15±0.19	0.022±0.005	1.49±0.18	0.18±0.04
	5026			8 - 11	3.38±0.18	0.015±0.004	1.79±0.18	0.11±0.04
	5027			11 - 14	3.96±0.18		1.95±0.18	0.22±0.04
	5028			14 - 17	4.29±0.17		2.30±0.17	0.18±0.04

*) 1σ error due to counting statistics
**) by gamma ray spectrometry

Table 10.2 (continued)

Area of sampling	Sample number	Geographic position	Sampling date	Layer	K - 40	Cs - 137	Ra - 226	Ac - 228
B	5029	46°01.8'N; 16°17'W	01.05.80	0 - 1 cm, Core 3	2.77±0.19	0.061±0.007	1.21±0.19	0.12±0.04
	5030			1 - 2	2.95±0.17	0.045±0.007	1.37±0.19	0.16±0.04
	5031			2 - 3	2.75±0.14	0.022±0.004	1.71±0.22	0.13±0.03
	5032			3 - 4	2.67±0.18	0.032±0.005	1.56±0.19	0.09±0.04
	5033			4 - 5	2.91±0.18		1.46±0.19	0.15±0.04
	5034			5 - 8	2.86±0.18		1.73±0.19	0.16±0.04
	5035			8 - 11	3.37±0.18	0.010±0.004	1.85±0.18	0.22±0.04
	5036			11 - 14	4.17±0.18	0.004±0.003	1.91±0.16	0.23±0.05
	5037			14 - 17	5.08±0.20		1.83±0.20	0.27±0.04
C	5038	43°30'N; 19°14'W	04.05.80	0 - 1 cm, Core 4	3.24±0.19	0.044±0.007	1.56±0.23	0.15±0.05
	5039			1 - 2	1.73±0.12	0.016±0.003	1.12±0.13	0.08±0.03
	5040			2 - 3	2.71±0.19	0.021±0.006	1.37±0.18	0.14±0.04
	5041			3 - 4	2.68	0.016±0.004	1.58±0.15	0.14±0.03
	5042			4 - 5	2.65±0.17	0.012±0.003	1.70±0.19	0.16±0.04
	5043			5 - 8	2.70±0.16	0.006±0.003	1.68±0.17	0.17±0.04
	5044			8 - 11	3.15±0.18		2.04±0.18	0.16±0.04

Table 10.3: Specific activities (pCi/g dry) of radionuclides in Sediment cruise 1981

Area of sampling	Sample number	Geographic position	Sampling date	Layer*)	K - 40	Sr - 90	Cs - 137****)	Ra - 226	Ac - 228
A	5772 a	43°30'N; 15°13'W	02.06.81	depth of 30 cm	16.4 ±1.2**)	a. u. ***)	< 0.013	3.5 ±0.3	0.82 ±0.22
	5772 b	43°30'N; 15°13'W	02.06.81		3.52±0.31	a. u.	0.025±0.006	1.5 ±0.2	0.21 ±0.08
	5773	43°00'N; 14°59'W	03.06.81	undef. depth	7.95±0.59	0.0028±0.0008	< 0.013	2.7 ±0.2	0.43 ±0.12
	5774	42°30'N; 14°29'W	04.06.81	undef. depth	12.3 ±0.90	0.0035±0.0011	0.032±0.011	1.6 ±0.2	0.75 ±0.21
	5775	42°00'N; 14°00'W	05.06.81		11.3 ±0.82	a. u.	< 0.023	1.6 ±0.2	0.75 ±0.18
	5776	41°29.5'N; 13°44'W	06.06.81		12.9 ±0.92	a. u.	0.016±0.005	1.9 ±0.2	0.70 ±0.04
	5777	42°59.2'N; 14°01'W	08.06.81		13.9 ±0.99	a. u.	0.030±0.007	1.7 ±0.2	0.70 ±0.06
B	5778	45°59.8'N; 17°30.4'W	11.06.81		3.28±0.29	a. u.	0.026±0.007	1.2 ±0.2	0.19 ±0.06
	5779	46°15'N, 17°29.2'W	11.06.81		4.02±0.32	a. u.	0.024±0.006	1.0 ±0.1	0.18 ±0.03
	5780	45°59.2'N; 16°59.4'W	12.06.81	undef. depth	2.84±0.28	a. u.	< 0.027	1.6 ±0.3	0.17 ±0.06
	5781	46°16.5'N; 16°26'W	12.06.81		2.65±0.29	0.011 ±0.0012	0.031±0.007	1.4 ±0.2	0.17 ±0.03
	5782	46°14.9'N; 17°08.8'W	12.06.81		2.36±0.25	a. u.	0.040±0.012	1.5 ±0.2	0.22 ±0.09
	5783	45°46.3'N; 16°58'W	13.06.81		2.88±0.25	0.0046±0.0011	0.028±0.006	1.3 ±0.1	0.20 ±0.06
	5784	45°45'N; 17°28'W	13.06.81		3.37±0.30	0.0045±0.0010	0.020±0.007	1.7 ±0.2	0.21 ±0.07
	5785	45°48'N; 16°39.4'W	14.06.81		3.09±0.30	0.0035±0.0009	< 0.030	1.7 ±0.2	0.20 ±0.11
	5786	45°59'N; 17°13.5'W	15.06.81		2.38±0.25	0.0042±0.0008	0.030±0.006	1.2 ±0.2	0.14 ±0.04
C	5787	43°20.3'N; 19°21'W	17.06.81		2.14±0.23	0.0040±0.0010	0.018±0.005	1.5 ±0.2	0.18 ±0.03
	5788	43°15'N; 19°20.2'W	17.06.81		1.51±0.23	a. u.	< 0.029	1.6 ±0.2	0.29 ±0.06
	5789	43°08.8'N; 19°25.4'W	17.06.81		1.62±0.18	0.0067±0.0009	0.020±0.007	0.85±0.09	0.095±0.032
	5790	43°15'N; 19°28.5'W	18.06.81		1.22±0.23	0.0042±0.0009	< 0.030	1.6 ±0.2	0.068±0.029

*) surface layer of 3 cm unless stated otherwise;

**) 1σ error

***) analysis unfinished at present;

****) by gamma ray spectrometry

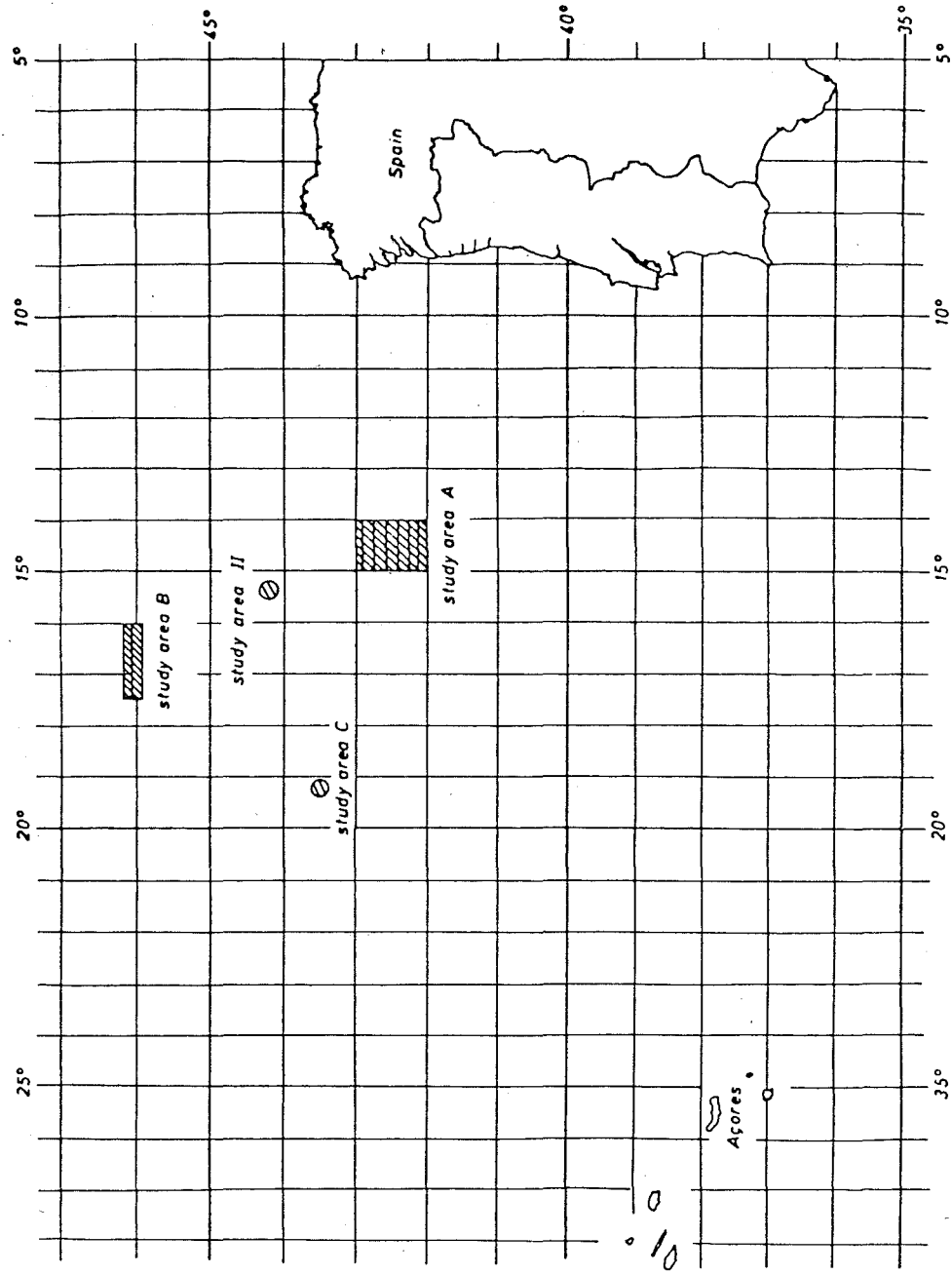
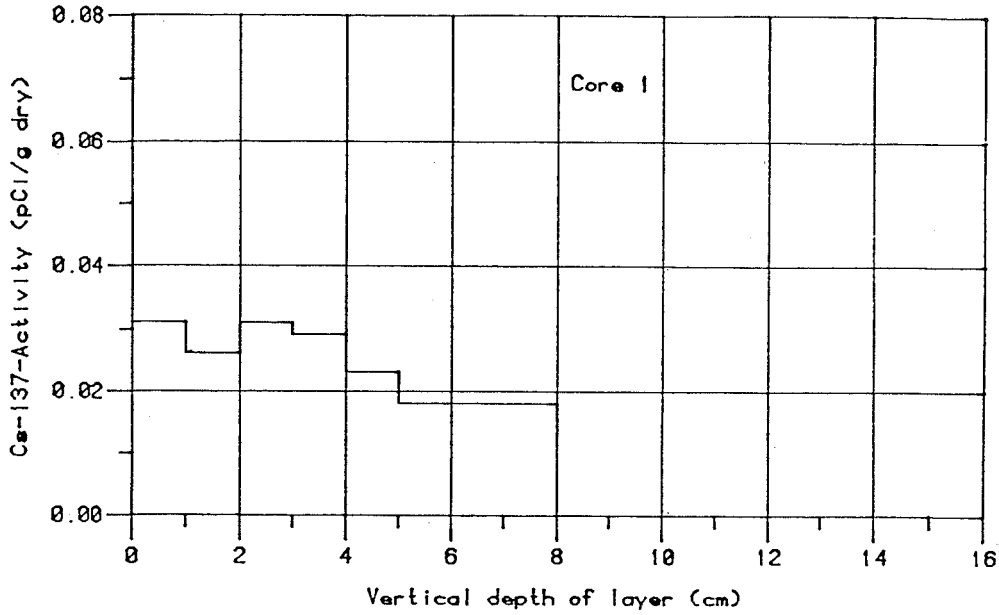


Figure 10.1 Study areas in the north-east Atlantic. A is the dumping site, B is the present dumping site, and C and II are the sites chosen for comparison purposes.



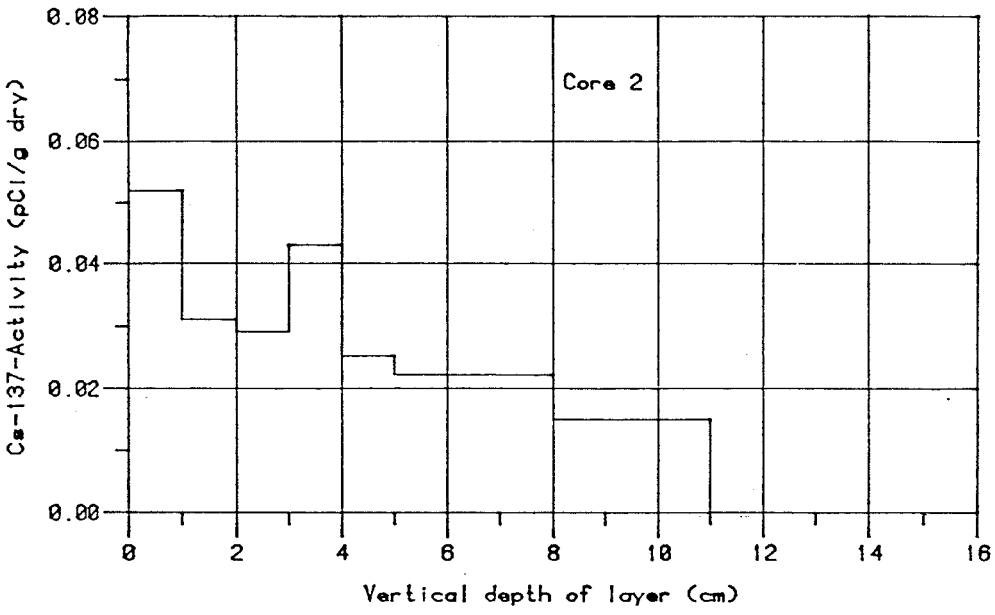
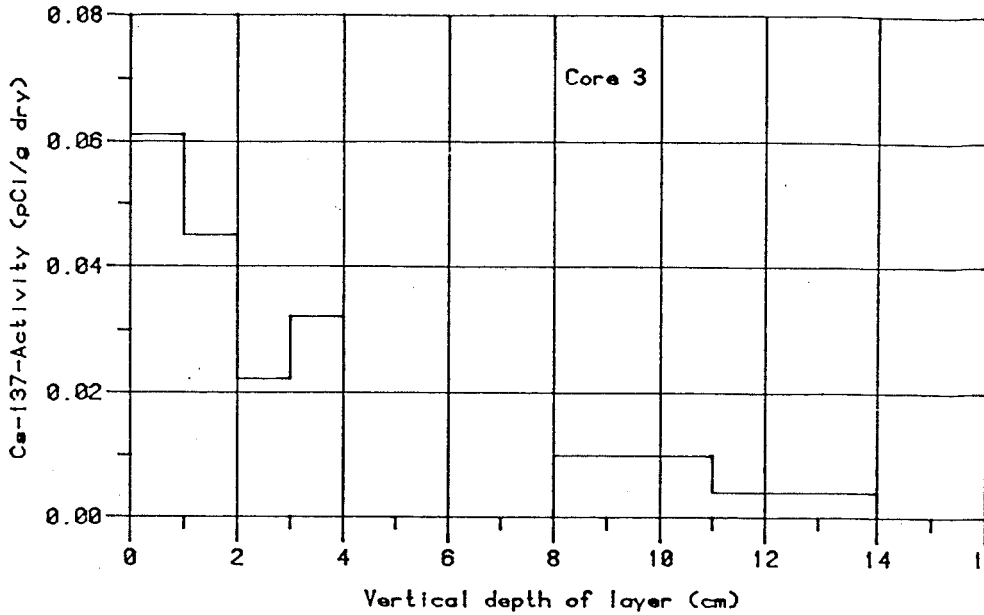


Figure 10.2 Vertical profiles of the Cs-137 activity in sediment cores 1 and 2, site B.



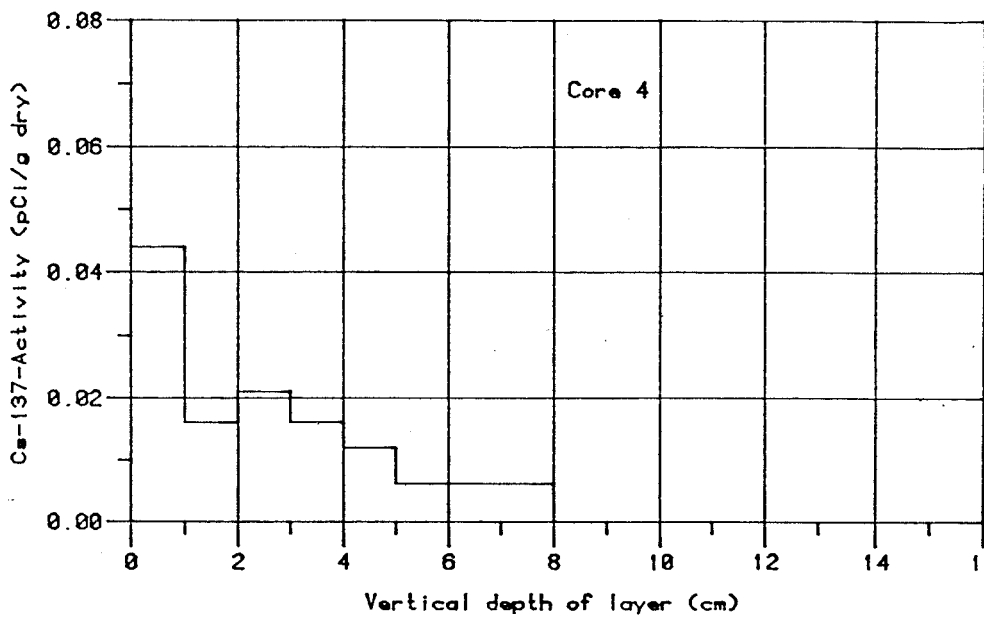


Figure 10.3 Vertical profiles of the Cs-137 activity in sediment cores 3 at site B and 4 at site C.

Chapter 11

ADSORPTION AND GEOCHEMICAL PARTITIONING OF LONG-LIVED RADIONUCLIDES ON DUMPSITE SEDIMENTS

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Interaction of long-lived radionuclides with NEA dumpsite and other marine sediments

Several series of laboratory experiments have been completed to determine the rate and the extent of uptake of transuranic and other long-lived radionuclides from sea water onto suspended sediments. Equilibrium Kd values have been determined during these experiments and the desorption of these radionuclides from sediments into sea water has been studied. So far the behaviour of Pu (both as III + IV and V + VI oxidation states), Am Np, Cf, and Tc (both as VII and lower oxidation states) has been investigated, and will be extended in the near future to include Cm. The experimental studies have made use of photon emitting isotopes of these elements, including the first application of Neptunium-235 for aquatic radioecological studies. The work has involved the use of sediments from the NEA north-east Atlantic dumpsite, the central Pacific sub-seabed study site, the proposed Japanese dumpsite (NW Pacific) and other locations.

The results indicate that for Pu, Am and Cf the equilibrium Kd values measured by batch techniques with NEA dumpsite sediments (46°02'N, 16°55'W) are in the range 10^4 to 10^5. The adsorption Kd values for Pu are independent of the oxidation state(s) of the Pu introduced into the experiments. Neptunium equilibrium Kd values are lower, being in the range 10^2 to 10^3, and it is interesting to note that there is a linear relationship between the Np Kd values at equilibrium and the calcium carbonate content of the deep-sea sediments studied thus far (Fowler and Aston, 1982).

In addition to studies on the uptake of transuranic radionuclides onto dumpsite sediments, the Kd equilibrium values have also been measured for Tc in the pertechnetate and 'lower oxidation' forms. The preliminary results indicate that Kd values for this element with the dumpsite sediment are very low, e.g. 10^0 to 10^1, and that retention of

this element by the sediments can be expected to be low (Fowler et al., in press). Also, the stability of the 'lower oxidation state' form of Tc is low and in normal oxygenated sea water oxidation to the Tc (VII) state is very rapid (< 1 hour). Thus, the occurrence of lower Tc oxidation states in oxidised surface sediments at the dumpsite is not very likely.

Although the primary aim of the batch adsorption experiments has been to determine the equilibrium Kd values for various radionuclides, the experiments have been used for two other purposes. First, the rates of radionuclide adsorption onto the sediments have been measured. These rates of uptake are fast, equilibrium values being reached in terms of hours or tens of hours. Second, the contaminated sediments obtained from Kd experiments have been used to examine the desorption of the radionuclides on their introduction into uncontaminated sea water. Preliminary results indicate that the transuranic radionuclides are not easily desorbed at all, and in most experiments the losses from sediment are within the experimental errors. However, unlike the transuranics, Tc is easily desorbed from sediments (Fowler et al., in press).

Geochemical partitioning of long-lived radionuclides in NEA dumpsite and other sediments

Methods in the literature for studying the partitioning of trace elements between different geochemical phases in marine sediments have been systematically evaluated. A sequential extraction procedure has been adopted and used to study the geochemical partitioning of stable elements and the radionuclides of transuranic elements in the sediments discussed above. The aim of the sequential extraction procedure is to specify, in at least a semi-quantitative fashion, the distribution of the transuranic elements in geochemically defined compartments of the sediments. In the sequential extraction procedure developed, four compartments are recognised:

1. Associated with the 'exchangeable or easily leached' fraction.

2. Associated with the 'oxidisable organic matter' fraction.

3. Associated with the 'reducible Fe/Mn non-detrital' fraction.

4. Associated with the 'resistant' fraction.

The methodology and preliminary results of these experiments will be published in due course, but the data base is incomplete at present. It can be stated, however, that significant differences between the distributions of transuranics adsorbed onto the sediments are emerging.

Action

The Geochemistry Working Group of the NEA Coordinated Research and Environmental Surveillance Programme recommends that partitioning of long-lived radionuclides in sediments should continue to be studied.

Acknowledgements

The author wishes to thank Mr R. Wilke, Brookhaven National Laboratory, for his assistance in the 1981 sample collections during the Biogas XI cruise. This work was supported by the Office of Radiation Programs, United States Environmental Protection Agency (DOE-EPA interagency agreement #AD89F00070).

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Chapter 12

BIOLOGICAL STUDIES

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12.1 Introduction

Marine organisms are not uniformly distributed throughout the oceans; both their diversity and abundance varies in space and with time. In the open ocean, away from the continental shelves, the maximum depth to which sunlight penetrates at a sufficient intensity for photosynthetic processes to occur is about 150 to 200 m. This upper layer of the ocean is therefore termed the photic, or epipelagic, zone. The limit of solar light penetration in the clearest oceanic waters is about 1000 m and this underlying, mesopelagic, zone contains its own representative fauna of organisms which migrate upwards to feed in the epipelagic zone, plus a large range of predators.

Below 1000 m, in the bathypelagic zone, the biomass is much depleted, consisting largely of organisms which are coprophagous - feeding on the faecal pellets arising from the overlying waters - and of carnivores. The density of the biomass in the water column continues to decrease with increasing depth and becomes very low indeed below 2500 m. It increases again, however, in the body of water overlying the sea bed. The fauna of the sea bed itself is collectively termed the benthos, and the water overlying it is termed the benthopelagic zone.

The faunal composition of the benthopelagic zone varies with the depth of overlying water. On the upper continental slopes, to a depth of some 1000 m, the benthopelagic fauna mixes with that of the mesopelagic to some extent, and benthopelagic fish are most abundant in the 200 to 2000 m depth zone. Macrourid (rat-tail) fish are prominent members of this slope fauna, both in numbers and in species. Below 2000 m however, away from the continental slopes, both the benthopelagic and benthic fauna become increasingly depleted.

Fish species, both pelagic and benthopelagic, display discrete limits of vertical distribution and it is generally observed that the

younger fish occupy the more shallow waters within any one species' range. Little is known about the life histories of deep sea fish but some inferences can be drawn from the morphology of adult fish and their eggs. Many teleost (bony) fish produce buoyant eggs and this applies to the majority of macrourids. It is also known that eels, notacanths and halosaurs have leptocephalus larval stages which live near the surface. It therefore appears that as these fish mature into adults they move into deeper waters. This is not the case for all families of fish; the ophidioids, for example, have benthic larvae and often retain their eggs to develop inside the adult. Similarly the cartilagenous fish (rays, sharks and chimaeras) produce eggs which develop at depth and some of these species, too, are 'live-bearers'.

In view of the limited depth ranges of different species it is obvious that, in studying the possible transfer of radionuclides along deep-sea pathways, the species which are analysed should be accurately identified. For example, within the genus Coryphaenoides, three species frequently taken in the north-eastern Atlantic are Coryphaenoides rupestris, which is not found at depths greater than 2000 m, Coryphaenoides guentheri, which occurs between 1100 and 2800 m, and Coryphaenoides (Nematonurus) armatus which is only taken from depths greater than about 2400 m (Merrett, pers. comm.). The last of these has been caught in the NEA dumpsite area.

12.2 Concentrations of radionuclides in biological materials

Samples of biological material caught within the existing dump site have been analysed for a number of radionuclides. The most extensive surveys have been made by Feldt et al. (1981) in June/July 1979 and April/May 1980. Samples were taken from the existing dumpsite, a previous dumpsite (14-15°W, 42-43°N) and from a site further west (approximately 19°W, 43°N). Planktonic organisms were taken from the upper water column using a modified Isaac-Kidd mid-water trawl (mesh size 405 μm); benthic organisms, and benthopelagic organisms, were obtained by Agassiz trawl and a 'deep-sea closing net'. The three categories of samples obtained - designated plankton, nekton and benthic organisms - actually consisted of whole animal, mixed species and these were analysed by gamma-ray spectrometry. The samples were also analysed for ^{90}Sr following chemical separation.

A wide range of radionuclides was observed in all of the mixed-species samples and the authors concluded that such radionuclides were either naturally occurring or derived from fallout, there being no significant difference in the concentrations obtained at the three sites. Material from one individual species, however - a sea anemone (Chitonanthus abyssorum) - was available from a 1966 cruise to the old dumpsite. Analyses of this species indicated that its concentrations of ^{90}Sr and ^{137}Cs were higher in 1980 than those obtained previously, and were higher than those obtained in 1980 at the other two sites. The authors therefore concluded that the elevated levels in the sea anemone samples at the old dumpsite were the result of drum-leakage.

Samples of the deep-sea fish Coryphaenoides armatus have also been obtained from the existing dumpsite using baited traps, and muscle tissue from individual specimens have been analysed for ^{137}Cs following chemical separation of the element (Mitchell and Pentreath, 1982). The results are given in Table 12.1. Although the number of samples analysed is not large, the ^{137}Cs concentrations in the dumpsite fish do not appear to be significantly different from those of specimens of the same species caught at other locations in the north-east Atlantic. Indeed their concentrations are similar to those of Icelandic cod (Hunt, 1981). It is not possible to state categorically that all of the ^{137}Cs observed in the dumpsite fish arises from fallout, but it is equally difficult to apportion any fraction of it to the dumped waste. Further recent data on radionuclides in north-east Atlantic biological samples are given by Noshkin (Chapter 13).

The consumption of fish caught, at depth, within the dumpsite is possibly the most direct pathway for radionuclide transfer to man which could reasonably be envisaged, and ^{137}Cs is the fission product nuclide most likely to be accumulated by fish (Pentreath, 1977). Commercial fishing does not take place at depths in excess of 1800 m and adult Coryphaenoides armatus only occur at depths well in excess of this. Nevertheless, it has been estimated that, even if this species from within the dumpsite were to be consumed continually at a rate of 0.5 kg per day, the ^{137}Cs content would only deliver 0.014% of the ICRP-recommended dose equivalent limit for members of the public (Mitchell and Pentreath, 1982). And even this ^{137}Cs may be entirely derived from fallout.

12.3 Radiation effects on the dumpsite fauna

It is commonly assumed that the deep-sea fauna, being highly specialised and adapted to an essentially constant environment, devoid of daily and seasonal fluctuations, would be particularly vulnerable to any external perturbating effect. Recent attempts to define the deep seas radiation environment, however, have indicated that the dose rates experienced by the fauna from both external and internal sources is of the same order as those experienced by shallow water species (Pentreath et al., 1980; Woodhead and Pentreath, 1983). The most important contributor to the absorbed dose rate appears to be the naturally-occurring ^{210}Po which accumulates in the tissues of the marine fauna. As a prerequisite to considering any adverse effects resulting from very slight increases in the radiation field, therefore, it is desirable to obtain further data on the concentrations, and range of concentrations, of ^{210}Po in deep-sea organisms.

A number of fish, caught near the sea bed in different areas of the north-east Atlantic, by various methods by MAFF and by the Institute of Oceanographic Sciences, have been analysed for ^{210}Po. The data obtained to date are shown in Figures 12.1, 12.2 and 12.3 for muscle, liver and gonad tissue respectively. As can be seen, these preliminary results suggest that the ^{210}Po concentrations, and thus the dose rates arising from them, show no consistent change with increasing depth. For example the Coryphaenoides rupestris and Coryphaenoides armatus ^{210}Po concentrations in muscle and gonad tissue are similar

even though the two species are separated by more than 3 km in depth. The Coryphaenoides guentheri values are greater than those of either of the other two species of this genus and may be related to feeding habits rather than to depth. It is also important to note that a considerable range of ^{210}Po values exists within each species and therefore the resulting absorbed dose rates must be far from constant for any one population, and probably far from constant for an individual fish.

In addition to the fish, deep-sea amphipods (Eurythenes gryllus) caught within the dump site have also been analysed for ^{210}Po (Pentreath et al., 1980). A number of invertebrate species taken in shallower waters (~ 2000 m) to the west of the UK by the Scottish Marine Biological Association at regular intervals are also being analysed to see if there is any evidence for seasonal variations in their ^{210}Po content.

12.4 Future modelling requirements

With regard to sea dumping, as in all waste disposal practices, it is necessary to consider the dose to man in terms of the dose limits recommended for members of the public as well as the collective dose commitment for the purposes of optimization. For the former, calculations may be made on the assumptions of real or potential pathways leading to the exposure of discrete groups of the population, and for the latter the dose to the total population from all pathways needs to be assessed. In order to make these dose assessments, therefore, different approaches to the transport of radionuclides from the deep sea to man need to be made.

12.4.1 Dose-limit (critical group) calculations

It has already been stated that the most direct transfer of radionuclides to man which could be envisaged is that of the direct consumption of fish caught, at depth, within the dumpsite. Calculations based on this assumption, and measured data, were cited above, but although such a calculation is readily made it should be related to the probability of it occurring and the acceptability of it recurring. In practice such an event might actually have a high probability of occurring once (a gastronomically inquisitive deep sea oceanographer?) but a very low probability of being sustained.

Similar calculations could be made using concentration factors and predicted water concentrations within the dumpsite; but again the question arises as to what consumption rates and critical group sizes it was reasonable to envisage and, from the physical oceanographic point of view, what volume of water would have a reasonably constant concentration of nuclides with different half-lives.

A more realistic assumption is that any exposure resulting from ingestion will arise from food species caught in coastal waters. This is because, as stated above, marine organisms are not uniformly distributed throughout the oceans. By far the greatest abundance occurs in

waters of less than 1000 m depth, and most of the world's fishing catch is sustained in waters of less than 200 m depth. In order to demonstrate that dose limits will not be exceeded, therefore, two basic assumptions need to be made depending on whether (a) the pathways originate, and are confined to, shallow (coastal) waters or (b) the pathways originate in the deep sea. For (a) the models which need to be, and are being, developed are those of physical oceanography which predict the water concentrations in shallow waters. The biological modelling need is for better concentration factor data for marine organisms, with an emphasis on the mean and range - or a statistical property of the mean value - which could be adopted for a certain class of marine foodstuff.

With regard to (b), in a previous document (MAFF, 1980) it had been suggested that some form of modelling could be carried out to represent the transfer of a radionuclude along a food chain, from the dumpsite, to man. The basis of such a model assumes that the turnover of an element in an aquatic organism may be represented by a simple expression such that the amount within the organism at time t (Q_t) can be described by

$$\frac{dQ_t}{dt} = I_q - kQ_t \qquad (12.1)$$

where I_q is the rate of intake per unit time and k is an excretion coefficient. I_q will be a function of the varying concentrations in the water, the food, the rate of feeding, and the fractions of an element present in the water and food which are actually absorbed. In addition, k will be affected, as also will I_q, by temperature, body size, growth rates and so on.

It is frequently observed that some form of steady state body burden (Q_{ss}) is achieved when all of the various biological parameters, and the water concentration, are held constant. Thus

$$Q_t = Q_{ss}(1-e^{-kt}) \qquad (12.2)$$

and the average input (I_q) is therefore equivalent to the value of kQ_{ss}.

With radionuclides the physical decay rate (λ) has also to be taken into account. Thus

$$\frac{dQ_t}{dt} = I_q - (k+\lambda)Q_t \qquad (12.3)$$

and therefore

$$Q_t = \frac{I_q}{k+\lambda}(1-e^{-(k+\lambda)t}) \qquad (12.4)$$

When Q_t or Q_{ss} is expressed per unit weight (i.e. as a concentration) and this, in turn, is related to the concentration in the water, as a concentration factor, the values obtained will clearly depend on whether or not the concentration of the radionuclide in sea water is maintained at a constant level. Where it is, an equation of the general form of equation (12.4) is applicable (substituting values of body burden for concentration factor units) and this may be the most relevant expression to use in a model which calculates a constant radionuclide concentration in an area of water around the dumped waste as a result of a given dumping rate. Where the concentration in the water is reduced solely by physical decay, an equation of the general form of equation (12.2) is more applicable because the decay constant cancels out. This is the form of equation usually used in controlled aquarium experiments to study the accumulation of radionuclides by aquatic organisms from water (Pentreath, 1975). In practice, however, the water concentration will decrease more rapidly than the value of λ alone because of the turnover of the ambient water mass and the removal of the radionuclide from the water column.

One of the concerns expressed with regard to deep-sea dumping centres on the possibility of a radionuclide being concentrated by successive links in the food chain. The extent to which this can be envisaged depends, amongst other things, on whether or not the radionuclide is derived from uptake from water or from food. For marine fish, the majority of radionuclides studied indicate that food is the more important pathway (Pentreath, 1977) although in some instances, as for ^{137}Cs accumulated by plaice (Jefferies and Hewett, 1971; Pentreath and Jefferies, 1971), the direct input from water appears to account for a substantial fraction of the body burden. In the case of Pu, laboratory experiments - again with plaice - could only demonstrate direct uptake from water (Pentreath, 1978). Attempts have also been made to relate, in a simple way, the relationships of biological half-time, steady-state concentrations, and the rates of intake from food and water (Preston, Jefferies and Pentreath, 1972). These calculations implied that where concentrations of, for example, transition elements in fish are high relative to those of the water, and the biological half-life is short, not only does the main route of intake need to be from food but, even at high assimilation rates, the concentrations in the food must be greater than those of the fish.

Assuming that, for food chain modelling purposes, intake arises only from food, then equation (12.3) can be expressed as

$$\frac{dQ_t^F}{dt} = I_q^F - (k+\lambda)\, Q_t^F \qquad (12.5)$$

(where the superscript F indicates food pathway only) and thus at steady state, where intake equals excretion,

$$I_q^F = (k+\lambda)\, Q_{ss}^F \qquad (12.6)$$

The intake from food is complicated by the fact that food is consumed for both maintenance and growth, the former being dependent upon the actual body size of the predator at any one time. Nevertheless, in its simplest form intake from food can be represented by

$$I_q^F = C^{fo} \; r \; f \qquad (12.7)$$

where C^{fo} = concentration in food,

r = rate of food intake,

and f = fraction of radionuclide absorbed/assimilated.

The transfer of radionuclides from one link in the food chain to the next is usually expressed in terms of the relative concentrations at each link. Thus if the concentration in the predator is expressed as C^{pd} then

$$f \; C^{fo} \; r' = (k+\lambda) \; C^{pd} \qquad (12.8)$$

where r' = weight of food eaten per unit weight of fish.

The relative concentrations of the radionuclide in predator and prey (C^{pd}/C^{fo}), represented as a transfer factor (T^F) can then be summarized as

$$T^F = \frac{f \; r'}{(k+\lambda)} \qquad (12.9)$$

Such an expression does simplify calculations of the magnitude of possible food chain transfers, but more importantly it puts limits on the values likely to be obtained, and highlights those factors for which data are most needed. Multi-step food chain transfers ($T_1 \rightarrow T_2 \rightarrow T_n$) could be calculated, including branching chains. For preliminary purposes, values for r', f and k derived from coastal water studies would have to be used. Examples are given in Figures 12.4 and 12.5. Attempts are currently being made to put limits on the value of r' by using the relative concentrations of ^{210}Po observed in the stomach contents and tissues of deep sea fish, assuming an f value of 1 and the fact that the rate of intake of ^{210}Po has to be sufficient to sustain a given body burden, or concentration, against the rate of physical decay of the nuclide if it is not supported by ^{210}Pb. If an f value of 1 were to be used throughout, it clearly puts limits on the overall model and places the emphasis on the relative rates of feeding and the effective half-life (resulting from both λ and k) for increases in concentration along the food chain to occur. Again biological excretion rates (k) have only been derived from coastal water studies, but as it is generally observed that larger animals have longer biological half-lives, and that this can be represented by a power law in relation to the size of the animal (Pentreath, 1977), suitable adjustments could be made working backwards from coastal waters to the deep sea.

It is important to note, however, that such a transfer-factor model approach (a) ignores input from water at different links in the

food chain, and (b) assumes that a discrete food-chain pathway leads back to the first link in the chain. The input from water, at each link, could if necessary be allowed for by adjusting equation (12.9) such that

$$T = \frac{f\, r' + w'}{(k+\lambda)} \qquad (12.10)$$

where w' represents the input from water per unit weight of animal and the assumption that the k value represents the turnover of the total body burden regardless of route of intake; T represents the relative concentration of predator and prey, regardless of route of intake. It should be noted, however, that the advantage of ignoring input from water is that it eliminates the need to take into account the gradation of water concentrations through which the food chain operates. If there was no water concentration gradient it would be simpler to apply a relevant concentration factor to the last step in the food chain!

With regard to the discrete nature of the pathway, this again would make such a model a limiting case. In reality it is unlikely in the extreme that a top predator, in the fishable (< 1000 m depth) sea areas would only consume prey which, in turn, only consumed prey which, by successive mono-phagous habits led to the consumption of fauna which lived in the dumpsite. A dilution effect would therefore serve to decrease the concentration at the upper ends of the food chain because of the consumption of prey arising from waters with different radionuclide concentrations. The extent to which this would alter the calculations depends, inevitably, on the radionuclide concentration gradient arising within the water column from the physical oceanographic model. The effect could be allowed for, perhaps, by a function which was reciprocal to depth, or to population density. But from the radiological protection point of view it is not, in any case, the concentration in an individual animal which is important, but the average concentration likely to obtain. Because the diluting effect of eating prey not contaminated from the disposal area may be expected to increase along the food chain, the average concentration in a species ($\bar{C}$) at any link in the food chain could be related to the appropriate transfer factor and the probability (p) of contaminated prey being eaten. Thus the average concentration at trophic level n, assuming intake from food only, could be estimated by

$$\bar{C}_n^F = C_o^{fo}\left[T_1^F\, p_1\, T_2^F\, p_2 \ldots . T_n^F\, p_n\right] \qquad (12.11)$$

where C_o^{fo} is the concentration in the food species at the base of the food chain in the area of the waste. The values initially attributed to p could be 1.0 at the first link, 0.3 at the second, 0.1 at the third and so on. Adjustments would also have to be made to allow for the consumption of the whole animal, or part of the animal, and the relative concentrations in the different fractions. As in food chain modelling generally, over-simplified models are clearly unrealistic but often serve to highlight major features, whereas highly intricate food web models more closely simulate the real world in structure but have a very large number of transfer functions in them which cannot possibly be determined directly, or otherwise verified.

Finally it needs to be borne in mind that any discrete food-chain pathway model to a real or hypothetical critical group needs to be considered in conjunction with pathways which originate in coastal waters only. Such pathways are, in any event, more likely because of current fishing techniques and because the highest concentration factors are frequently those of algae and shellfish (molluscs and crustaceans) which are only harvested from shallow waters. Thus a soluble radionuclide, which is highly accumulated by an alga or invertebrate, is more likely to represent a potential critical pathway to man than a food chain link direct to the dump site, even though the former originates in the coastal water zone.

12.4.2 Collective dose commitment and mass transfer calculations

Because the distribution of marine organisms is far from homogeneous, the collective dose commitment for ingestion pathways will arise primarily from food taken in coastal water areas and at depths of less than 200 m. Data on the quantities of fish, shellfish, seaweed - indeed on all aquatic organisms normally eaten in significant quantities - are supplied by the FAO fisheries statistics volumes, the most recent of which is that for 1980 (FAO, 1981). Although these data are given in relation to different sea areas, they are not given in relation to depth of capture; this, however, can be estimated by reference to normal fish catching practices for the majority of species consumed. At present the north-east Atlantic supplies almost 20% of the total world's fish and invertebrate catches; in 1980 it was 1.2×10^7 t out of a total of 6.4×10^7 t (FAO, 1981).

A further aspect to be considered is that of the total quantities likely to be landed in the future. It is generally assumed that the total sustainable fish yield is of the order of 10^8 t a^{-1}. More difficult to assess is the future consumption of benthic algae, cephalopods and krill.

The human population size is not required in order to make a collective dose commitment calculation for ingestion pathways; it is derived from the fact that x Bq kg^{-1} multiplied by the total kg consumed will result in a man-Sv value for each radionuclide. There is also some merit in being able to derive a dose equivalent commitment, which is the integration of the per caput dose equivalent rate, from a given source as a function of time. Although such a calculation is not often made, it does allow the estimation of a maximum annual, per caput, dose equivalent at some time in the future. This can then be compared with a value derived from any other source of exposure - background, or another waste disposal practice - so that suitable comparisons can be made.

In contrast to the transfer of radionuclides along discrete food chains, concern is also expressed as to the possibility of biological processes accelerating, or short-circuiting, the mass transfer of radionuclides into surface or coastal waters. A number of hypothetical mechanisms were mentioned in the MAFF Internal Report No. 7. Since this publication three brief attempts have been made to compare the magnitude of such hypothetical transfer rates in comparison with those

due to water movement alone (NEA/SWG, 1980; Anon., 1981, 1982). All three have concluded that water transport processes are more important, by some 3 to 6 orders of magnitude, than potential biological pathways from the deep sea to the surface. In one of them, however, (Anon., 1982) it was evident that biological/biochemical processes may not, in fact, be insignificant in actually retarding the transfer of radionuclides from the deep sea to surface waters, from which they could be transferred to man. This model consisted of a simple 6-box ocean volume model. Considerable improvement in assessing the extent to which biogeochemical processes retard, or otherwise alter, the transfer of radionuclides dumped in the ocean could be made by more realistic box models. For example, in a vertical plane the divisions should more accurately represent the biomass distribution as described in 12.1 with divisions at 200, 1000, 2500 m plus one at 100 m above the sea bed at 4500 m. The boxes need also to reflect the changes in water depth beween the dumpsite and the coast. In view of the above calculations such modelling may seem to be superfluous, but this approach has two distinct advantages: firstly, if sea-disposal options are to be compared with land-disposal options, then the models used should represent as accurately as possible the most likely consequences, and a retardation of the return of radionuclides back to man should not be excluded; and secondly it would be possible to simulate the effects of changes in biomass which could occur at some time in the future - such as the eutrophication of coastal waters leading to changes in primary productivity, changes in upwelling, and so on.

12.4.3 Dose-to-fauna models

With regard to the potential impact to increased radiation exposure, it is important to realise that two different sets of information are required: the first of these is an estimation of the dose rates which could be sustained as a result of waste emplacement in the deep ocean; such estimates can be modelled with some degree of accuracy. The second set is that of a knowledge of the effects of such dose rates, and it must be accepted that it would be exceedingly difficult, and expensive, to obtain such a data set; although some information is forthcoming on the radiosensitivity of deep-sea bacteria. It should also be noted that the dose rate limits used in radiation protection standards for man relate to the individual. It is probably impractical to recommend dose limits for individuals of the marine fauna and flora because any deleterious effects of irradiation on them is only likely to be considered at the population level. In fact population dose limits are no longer recommended by the ICRP for human populations and it is difficult to see how they could possibly be considered for organisms other than man. There is, nevertheless, an approach which it is advantageous to pursue, and that is to consider the potential deleterious effects in terms which relate the dose rates to be expected from waste disposal to the range of dose rates which already obtain as a result of background radiation - excluding fallout.

Dosimetry models for a wide range of marine organisms have already been derived (IAEA, 1976; Woodhead, 1979). Such models could, however, be developed further, particularly with regard to dose rates sustained by individual organs of large fauna such as fish. It would also be

useful to develop an approach along the lines of that discussed by Woodhead and Pentreath (1982) in relation to the feasibility of the disposal of high level waste on the sea bed. Such a model could also be combined with dose-field calculations around drums, and in relation to possible areas of contaminated sediment arising from the release of radionuclides.

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Table 12.1 Caesium-137 in the deep-sea fish Coryphaenoides (Nematonurus) armatus in the north-east Atlantic Ocean, June 1980

Station number, location and depth	Whole-body weight (kg)	^{137}Cs, Bq kg^{-1} (wet) in muscle*
91 52°30'N 17°43'W (4046 m)	1.44	0.29 ± 0.02
	1.20# 1.91	0.36 ± 0.03
	2.09# 1.07	0.38 ± 0.05
184 47°39'N 10°00'W (3926 m)	1.79	0.16 ± 0.03
139 46°00'N 17°23'W (4729 m) NEA Dumpsite	1.44	0.22 ± 0.03
	1.30	0.47 ± 0.04
	1.76	0.28 ± 0.04
	2.09	0.46 ± 0.06
	1.19	0.16 ± 0.03
	1.73	0.29 ± 0.04
	2.06	0.31 ± 0.04

* Errors quoted are ± 1 σ propagated counting error
# Samples bulked for analysis

From Mitchell and Pentreath (1982)

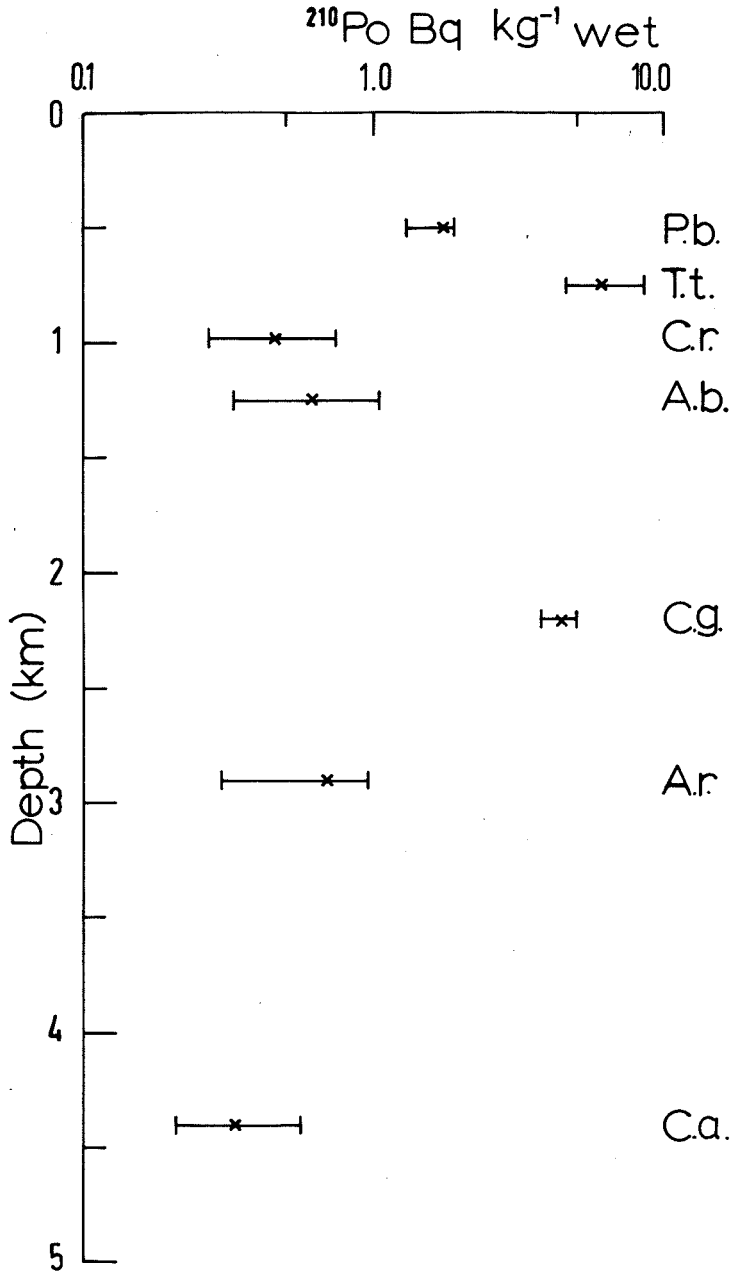

Figure 12.1 Concentrations, mean and range, of ^{210}Po (Bq kg^{-1} wet) in the muscle tissues of deep sea fish in relation to depth of capture. P.b., Phycis blennoides (n=6); T.t., Trachyrhynchus trachyrincus (n=6); C.r., Coryphaenoides rupestris (n=6); A.b., Alepocephalus bairdii (n=6); C.g., Coryphaenoides guentheri (n=2); A.r., Antimora rostrata (n=4); C.a., Coryphaenoides armatus (n=9).

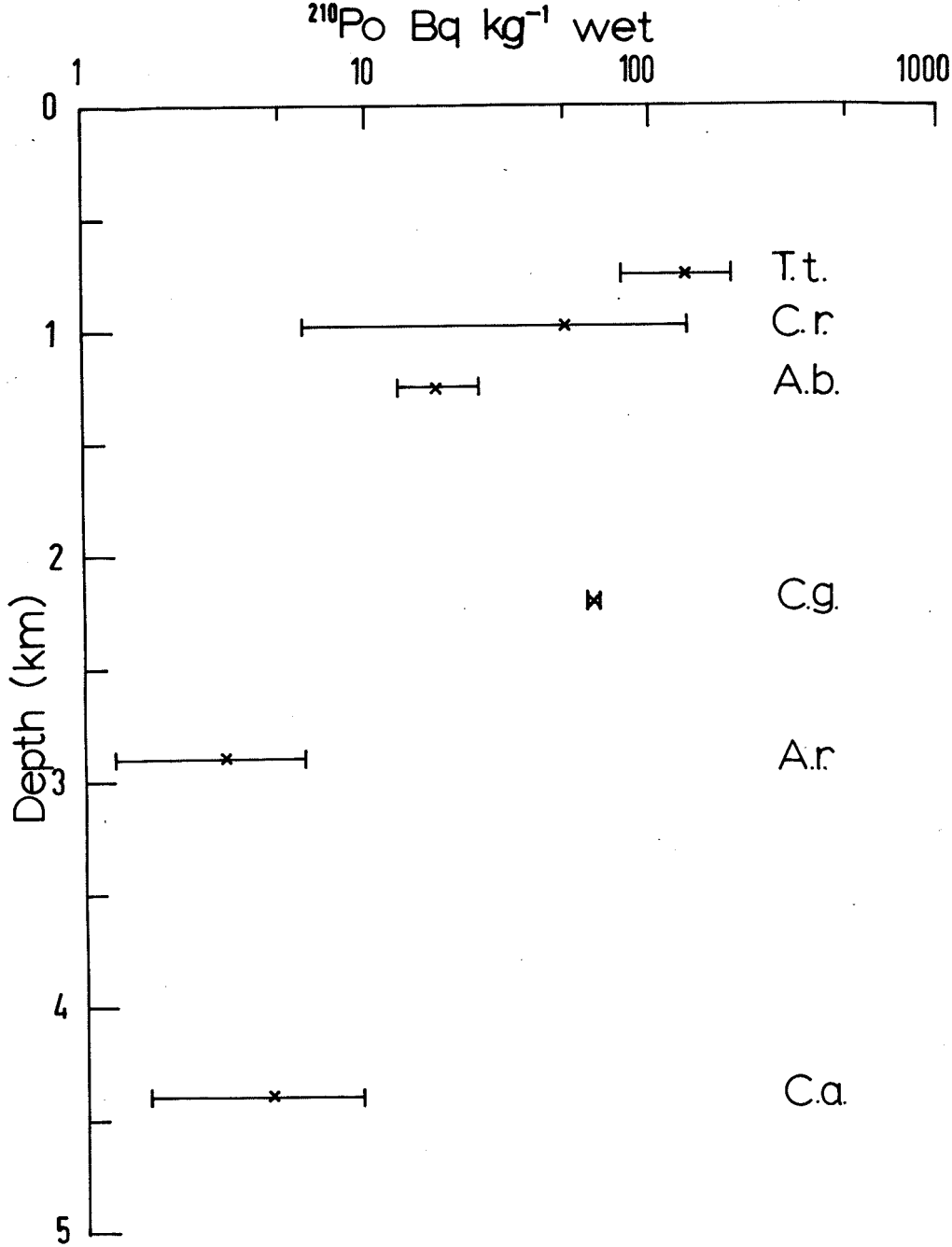

Figure 12.2 Concentrations, mean and range, of ^{210}Po (Bq kg^{-1} wet) in the livers of deep sea fish in relation to depth of capture. T.t., Trachyrhynchus trachyrincus (n=6); C.r. Coryphaenoides rupestris (n=6); A.b., Alepocephalus bairdii (n=6); C.g., Coryphaenoides guentheri (n=2); A.r., Antimora rostrata (n=4); C.a., Coryphaenoides armatus (n=9).

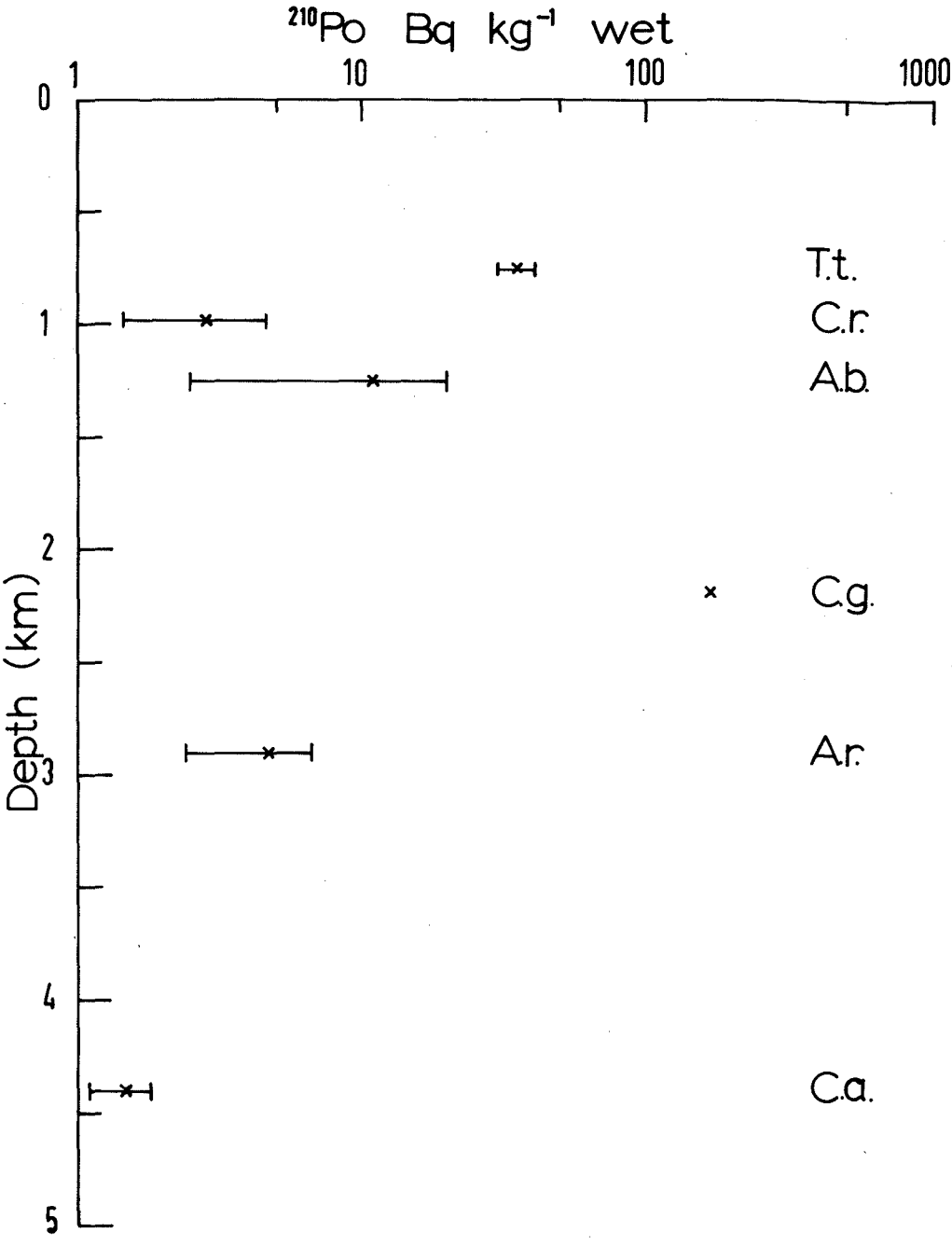

Figure 12.3 Concentrations, mean and range, of ^{210}Po (Bq kg^{-1} wet) in gonad tissue of deep sea fish in relation to depth of capture. T.t., Trachyrhynchus trachyrincus (n=4); C.r., Coryphaenoides rupestris (n=6); A.b., Alepocephalus bairdii (n=6); C.g., Coryphaenoides guentheri (n=1); A.r., Antimora rostrata (n=4); C.a., Corphaenoides armatus (n=9).

	T_1	T_2	T_3	T_4
r'	0.05	0.05	0.05	0.05
f	0.4	0.3	0.2	0.1
k	0.025	0.01	0.005	0.0025
T^F	0.8	1.5	2.0	2.0

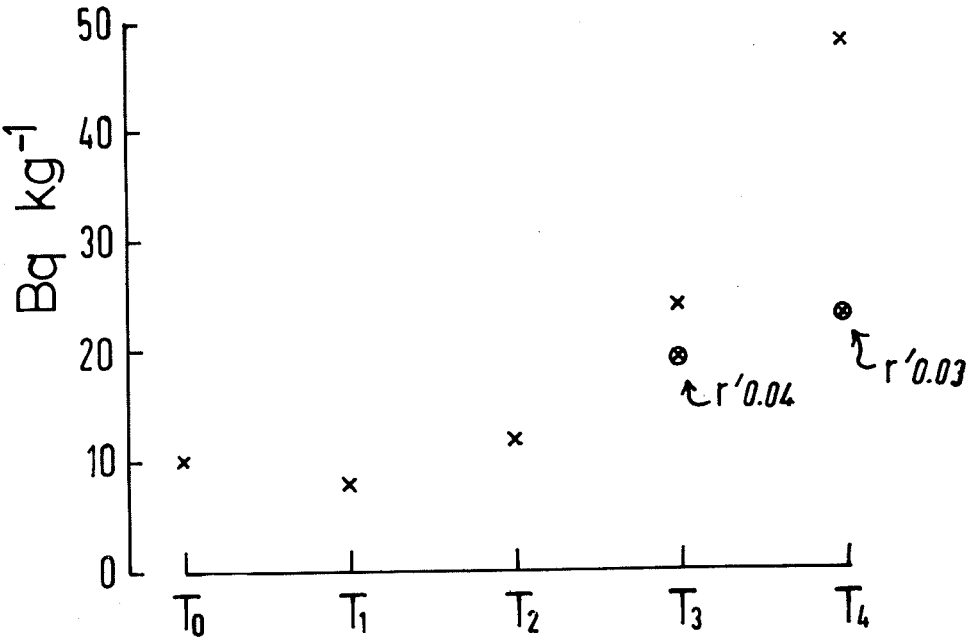

Figure 12.4 Hypothetical transfer of ^{137}Cs along a food chain, starting at 10 Bq kg^{-1}, in which the feeding rate (r') is 5% body weight per day at each link, the fraction absorbed (f) steadily decreases, and the excretion rates also decrease (equivalent to biological half-times of 28, 69, 139 and 277 days respectively). Also shown is the effect of reducing the feeding rates at the penultimate and ultimate links to 4% and 3% of body weight per day respectively.

	T_1	T_2	T_3	T_4
r'	0.05	0.05	0.05	0.05
f	0.4	0.1	0.04	0.0001
k	0.025	0.006	0.002	0.00015
T	0.80	0.83	1.00	0.033

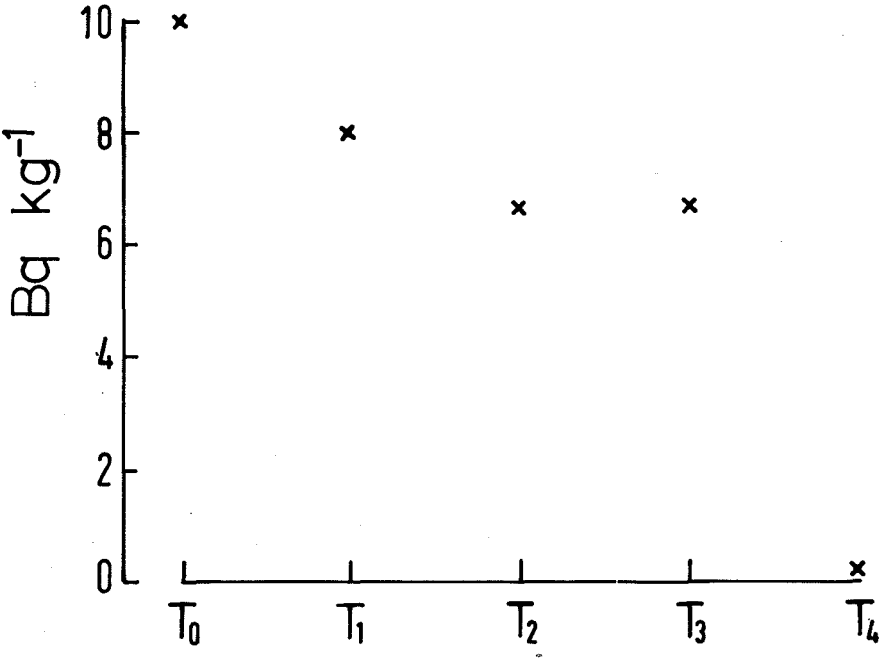

Figure 12.5 Hypothetical transfer of ^{239}Pu along a food chain, starting at 10 Bq kg^{-1}, in which the feeding rate (r') is 5% body weight per day at each link, the fraction absorbed decreases markedly although the excretion rates also decrease (equivalent to biological half-times of 28, 116, 347 and 4620 days respectively).

Chapter 13

FALLOUT CONCENTRATIONS IN SEDIMENTS AND SOME BIOTA FROM REGIONS OF THE NORTH-EAST ATLANTIC

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Sediment and some organisms were collected east of the Nuclear Energy Agency (NEA) dumpsite in the Bay of Biscay during 1981. Samples from these collections are being analysed for several radionuclides derived from global fallout. The concentrations measured in the abyssal sediments and organisms should be characteristic of current northern mid-latitude fallout background levels that could be used for baseline comparisons in comparable samples near the NEA dump site.

Sediment

Two 7.6 cm diameter sub-cores were removed from each of two consecutively sampled box-core samples from 4100 m at 47°35'N 9°41'W.

These cores were obtained for radionuclide analysis during the Biogas XI cruise to the Bay of Biscay during September 1981 on the research vessel N.O. JEAN CHARCOT. The sub-cores were frozen in the vertical position and returned to the Lawrence Livermore National Laboratory (LLNL) for processing. We sectioned 2 cm thick intervals (to a 12 cm depth) from the frozen core. A circular disk measuring 26.4 cm^2 was removed from the central portion of each section. This was retained as the sample and the outer 1 cm thick annulus was discarded. Results for $^{239+240}Pu$ concentrations in the sections of the duplicate sub-cores from the replicate box cores are shown in Table 13.1.

Differences are evident in the concentrations in the upper sections of the replicate cores, which are larger than one would attribute simply to analytical uncertainty. For example, a subsurface maximum is detected in the 2 to 4 cm section of sub-core 212-1 at a concentration of 6.3 fCi cm^{-3}. In the second sub-core from the same box core (212-2), the maximum concentration is still evident in the 2 to 4 cm

section but with 40% less $^{239+240}Pu$. Both profiles differ from the $^{239+240}Pu$ vertical profiles in sub-cores 221-3 and 4 from the replicate box core. The causes for these differences are not apparent from the results thus far available. It is therefore unproductive to interpret the changes in $^{239+240}Pu$ concentrations vs depth in the sediment from this region of the Atlantic.

Inventories of $^{239+240}Pu$ in the sediment columns are shown along with the ^{137}Cs inventory and ^{238}Pu and ^{241}Am ratios determined to date (Table 13.2). The inventory of $^{239+240}Pu$ computed for each of the four cores falls within a narrow range of 0.26 to 0.34 mCi km^{-2}. Using the Pu particle sinking model developed from results derived during the late 1960s (Noshkin and Bowen, 1973), it was predicted that by the end of 1980 the fallout Pu inventory in marine sediments within the 40°N to 50°N latitude band from overlying water depths of 4000 to 5000 m should range between 0.3 and 0.7 mCi km^{-2}. The current average inventory (0.29 ± 0.3 mCi km^{-2}) of fallout $^{239+240}Pu$ measured falls at the low end of the predicted range. With some degree of confidence it is estimated that current $^{239+240}Pu$ fallout background levels in sediments in the NEA dumpsite should range between 0.3 and 0.7 mCi km^{-2}.

In nine different depth sections thus far analysed from the four cores, the mean ^{241}Am to $^{239+240}Pu$ ratio is found to be 0.47 ± 0.09. These sediments show an enrichment of ^{241}Am relative to $^{239+240}Pu$ over that expected if the ratio were characteristic of the northern latitude fallout value of 0.2 to 0.3. This higher ratio, however, is within the range of ratios presently detected in western Atlantic sediments at 38°N latitude from overlying water depths of 2800 m (Bowen and Livingston, 1981) and somewhat less than the mean previously reported in sediments from the Mediterranean (Livingston and Bowen, 1976). This is but another example to show that there is geochemical fractionation among these two transuranics in the marine environment and could result, in this region of the Atlantic, from either more rapid sedimentation of ^{241}Am relative to $^{239+240}Pu$ to deep-water bottom sediments or more rapid mobilization of $^{239+240}Pu$ from the bottom sediments to the bottom water.

The ^{137}Cs inventory in the single core analysed falls within the range of fallout concentrations previously determined in North Atlantic cores sampled between 1974 and 1977 from 2000 to 4000 m (Bowen and Livingston, 1981).

The concentrations of $^{239+240}Pu$, ^{241}Am, and ^{137}Cs detected are probably typical for bottom sediments at depths of 4000 to 4500 m in the north Atlantic between 40°N and 50°N latitude. These values can be used with some degree of confidence to estimate background levels anticipated within the NEA dumpsite.

Fish

Radionuclide concentrations detected in tissues of deep-living fish collected in traps from 2100 m at 47°33'N 8°35'W are shown in Table 13.3. Immediately after sampling the fish were frozen and

returned to LLNL for analysis. Unfortunately the sample size was too small to do a detailed analysis of specific organs and tissues and also, because of the small sample size, many radionuclides of interest were below our detection limits. The ^{90}Sr, for example, was not detected at concentrations above 1 to 8 pCi kg^{-1} wet weight in muscle or eviscerated whole fish (muscle, bone and skin). The ^{137}Cs and $^{239+240}Pu$ were identified above our respective detection limits of 0.39 ± 0.17 and 0.012 ± 0.005 pCi per sample in only a few samples.

The average fallout ^{137}Cs concentration in the different species of eviscerated whole fish (muscle, bone and skin) was 5.1 ± 2.2 pCi kg^{-1} wet weight (0.19 ± 0.08 Bq kg^{-1}). This is in general agreement with concentrations recently measured in other deep-living fish from the north-east Atlantic. For example, 9.3 ± 2.2 pCi kg^{-1} wet weight was the average concentration reported in black scabbard (Aphanopus carbo) caught off Madeira Island at depths of 1800 to 2000 m in 1979 (Ortins de Bettencourt et al., 1980). Mitchell and Pentreath (1982) report on the ^{137}Cs levels in the muscle of Coryphaenoides armatus collected from locations within and outside the NEA dumpsite: within the site the average concentration was 0.31 ± 0.12 Bq kg^{-1} and at the remote sites the average value was 0.30 ± 0.10 Bq kg^{-1}. It would be difficult to conclude from the concentrations alone that any of the ^{137}Cs currently found in deep-living fish near the NEA dumpsite orginates from any source other than global fallout.

The ^{241}Am levels exceeded those of $^{239+240}Pu$ in three of four fish analysed whereas in the environment (using the sediment values as examples), $^{239+240}Pu$ exceeds ^{241}Am levels. This enrichment of ^{241}Am was completely unexpected based on our own analysis of fish from the Pacific where $^{239+240}Pu$ always exceeded ^{241}Am levels in all tissues analysed (Noshkin et al., 1981a, b). However, this enrichment has been noted in a number of marine organisms including fishes from the north-east Irish Sea (Pentreath, et al., 1980). Note that in the eel-like fish the $^{239+240}Pu$ concentrations exceed the levels of ^{241}Am.

These results show there is no consistent trend to suggest ^{241}Am is more or less biologically available than Pu to all deep-sea fishes. Identification of the gut contents of the different fish are also provided in Table 13.3. The last meal of the Macruridae was from the water column while the Coryphaenoides sp. and the Antimora sp. were feeding on the bottom. If these are the normal feeding habits of these fishes during their lifetime, it is observed that higher ^{241}Am body burdens were detected in bottom-feeding fish than in fish feeding in the water column. Similar relationships have been observed among fish and feeding habits from Pacific atolls (Noshkin et al., 1981). Fallout levels of the transuranics are very low in the tissues of deep-sea fish and large samples will be required in the future for accurate assessment of the concentration levels in species from within and outside the NEA dumpsite.

Acknowledgements

The author wishes to thank Mr R. Wilke, Brookhaven National Laboratory, for his assistance in the 1981 sample collections during the Biogas XI cruise. This work was supported by the Office of Radiation Programs, United States Environmental Protection Agency (DOE-EPA interagency agreement #AD89F00070).

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Table 13.1 Concentrations of $^{239+240}Pu$ in sections of cores from the northeast Atlantic (47°35'N 9°41'W, 4100 m)

Depth increment (cm)	Section dry weight (g)	$^{239+240}Pu$ (fCi cm^{-3})	Section dry weight (g)	$^{239+240}Pu$ (fCi cm^{-3})
	KG 212-1		KG 212-2	
0-2	39.6	2.78 (9)	28.6	3.30 (7)
2-4	34.7	6.3 (6)	31.9	3.99 (6)
4-6	37.2	4.3 (7)	34.8	3.42 (6)
6-8	38.5	0.73(15)	36.1	0.96(13)
8-10	39.5	0.15(50)	38.5	0.73(16)
10-12	46.4	<0.2	40.2	0.38(20)
12-16	88.9	<0.04	88.6	0.11(70)
	KG 221-3		KG 221-4	
0-2	26.3	3.98 (6)	41.2	6.86 (5)
2-4	33.6	2.48 (7)	32.7	3.47 (8)
4-6	33.7	4.08 (5)	35.2	1.6 (10)
6-8	41.4	2.51 (6)	37.5	1.98 (9)
8-10	39.8	0.98(17)	32.3	2.39 (8)
10-12	37.6	0.21(33)	30.6	0.64(12)
12-16	87.1	0.08(53)	81.6	0.03(45)

Note: Area of each section is 26.4 cm^2

Values in parentheses are the 1σ counting error expressed as the percent of value listed.

Table 13.2 Radionuclide sediment inventory

Radionuclide	KG 212-1	KG 212-2	KG 221-3	KG 221-4
$^{239+240}Pu$ (mCi km^{-2})	0.29	0.26	0.28	0.34
^{137}Cs (mCi km^{-2})	4.1	-	-	-
	Mean			
$^{241}Am/^{239+240}Pu$	(9 sections) 0.47 ± 0.09			
$^{238}Pu/^{239+240}Pu$	(9 sections) 0.06 ± 0.03			

Table 13.3 Radionuclide concentrations in fish samples from Charcot-Biogia XI cruise Bay of Biscay (northeast Atlantic) in 1981, Station 1 (47°33'N 8°35'W, 2100 m)

Specimen	#	Dry weight (g)	Dry / wet wt ratio	Radionuclide concentrations pCi kg^{-1} wet weight			
				$^{239+240}Pu$	^{241}Am	^{137}Cs	^{90}Sr
Coryphaenoides sp.	3						
Muscle		9.8	0.194	<0.07	0.4 (30)	< 5	<3
Viscera		3.4	0.215	2.4 (16)	9.5 (10)	<19	<9
Antimora sp.	1						
Eviscerated whole		21.8	0.191	<0.12	0.4 (28)	6 (25)	<8
Viscera		6.5	0.325	<0.14	7.8 (10)	< 7	<7
Macruridae	1						
Eviscerated whole		31.5	0.169	<0.04	0.009(50)	6.7(38)	<2
Viscera		2.9	0.171	0.6 (45)	1.2 (25)	<34	<8
Eel-like fish	3						
Eviscerated whole		58.1	0.311	0.09(45)	0.01 (60)	2.5(40)	<1
Viscera		6.7	0.209	0.9 (40)	<0.6	<10	<4

Note: Values in parentheses are the 1σ counting error expressed as the percent of value listed.

Gut contents:
Coryphaenoids sp. - polycheate remains and parts of crustacea
Antimora sp. - polycheate remains and sediment
Macruridae - crustacea parts and fish remains
eel-like fish - unidentified remains

Viscera sample includes gut contents, gills, liver, and gastrointestinal tract.

Eviscerated whole sample includes muscle, bone, and skin.

Chapter 14

ISOPYCNAL TOPOGRAPHY

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As work needs to be done to move a parcel of water of one density to a position in the water column where it could mix with a parcel of water of a different density, a reasonable assumption is that mixing and motion in the deep ocean occur primarily along surfaces coinciding with those of constant potential density. An investigation of the variation in depth of these surfaces (isopycnals) will help in understanding how water masses mix in the deep ocean and, in particular, how radioactivity released from a bottom source might spread though the ocean basin.

Published reviews (Reid, 1981) reveal that isopycnal surfaces can differ quite markedly from isobaric (level) surfaces, particularly in polar regions. Figure 14.1, taken from Reid (1981), shows the depth in hectometres of the surface which is defined by σ_2 = 37.00 below 1500 m, σ_1 = 32.47 between 1500 m and 500 m and σ_0 = 27.845 above 500 m. This surface reaches a depth of approximately 2200 m in the region of the NEA low-level dumpsite but rises to less than 100 m near Antarctica and actually outcrops the surface in the Norwegian and Greenland seas. It should be noted that in the Pacific ocean this surface is generally deeper than in the Atlantic ocean.

A closer look at the North-east Atlantic basin, Figure 14.2, confirms the trend of the isopycnals to become shallower in the north and west of the region, confirming the distribution shown in Figure 14.1. Figure 14.2 shows that the depth of the surface σ_4 = 45.88 is over 3000 m in the area of the NEA low-level dumpsite, but this rises to less than 1800 m near 60°N. The slope can perhaps be more clearly seen in Figure 14.3 which shows a meridional section along the centre of the eastern Atlantic basin from 56°S to 59°N west of Hatton Bank which has been constructed from GEOSECS data (Painbridge, 1976), IGY data (Fuglister, 1960) and some recent unpublished MAFF data. The depths of the neutral surfaces (isopycnals) have been calculated using the method of Ivers (1975) and quite steep slopes are revealed at the poleward limits of the transect especially in the south.

Even though water may be thought to move and mix preferentially along isopycnal surfaces, it does not mean that the distribution of a property on that surface will be uniform, but instead will reflect the sources and sinks for that property. This can be seen in Figure 14.4 which shows the salinity on the surface defined above and in Figure 14.1. The high salinity tongue from the Mediterranean Sea is clearly visible with values in excess of 35.05^0/oo on this surface, whereas further south the salinity drops to 34.48^0/oo.

Action

Clearly what is missing from the above discussion is the behaviour of the isopycnal surface (σ_4 = 45.92) which intersects the bottom at the low-level dumpsite. The GEOSECS data (plate 29 in Bainbridge, 1976) reveals that σ_4 = 45.92 appears to come very close to the surface (less than 50 m) at 60°S. What is needed is a map of the depth of this surface and the distribution of natural tracers on this surface so that more can be learnt about possible preferential mixing paths from the dumpsite.

Prof. J. L. Reid has mapped this surface for the Pacific Ocean and has offered to do the same for the Atlantic ocean using his existing data set which MAFF has acquired with the intention of adding more recent North-east Atlantic data. A second iteration of the Atlantic ocean map will need to be done later with the revised data set.

References

Bainbridge, A. E., 1976. GEOSECS Atlantic Expedition, Volume 2, Sections and Profiles. US Government Printing Office, Washington DC 20402 (Stock No. 038-000-00435-2).

Fuglister, F. C., 1960. Atlantic Ocean Atlas. Woods Hole Oceanographic Institution, Woods Hole, Mass.

Ivers, D. W., 1975. The circulation in the northern Atlantic, with especial reference to the Labrador Sea. PhD Thesis. University of California, San Diego.

Reid, J. L., 1981. On the mid-depth circulation of the world ocean. Chapter 3, In: Evolution of Physical Oceanography, Warren B. A. and Wunsch, C. (Eds). MIT Press, Cambridge, Mass. and London.

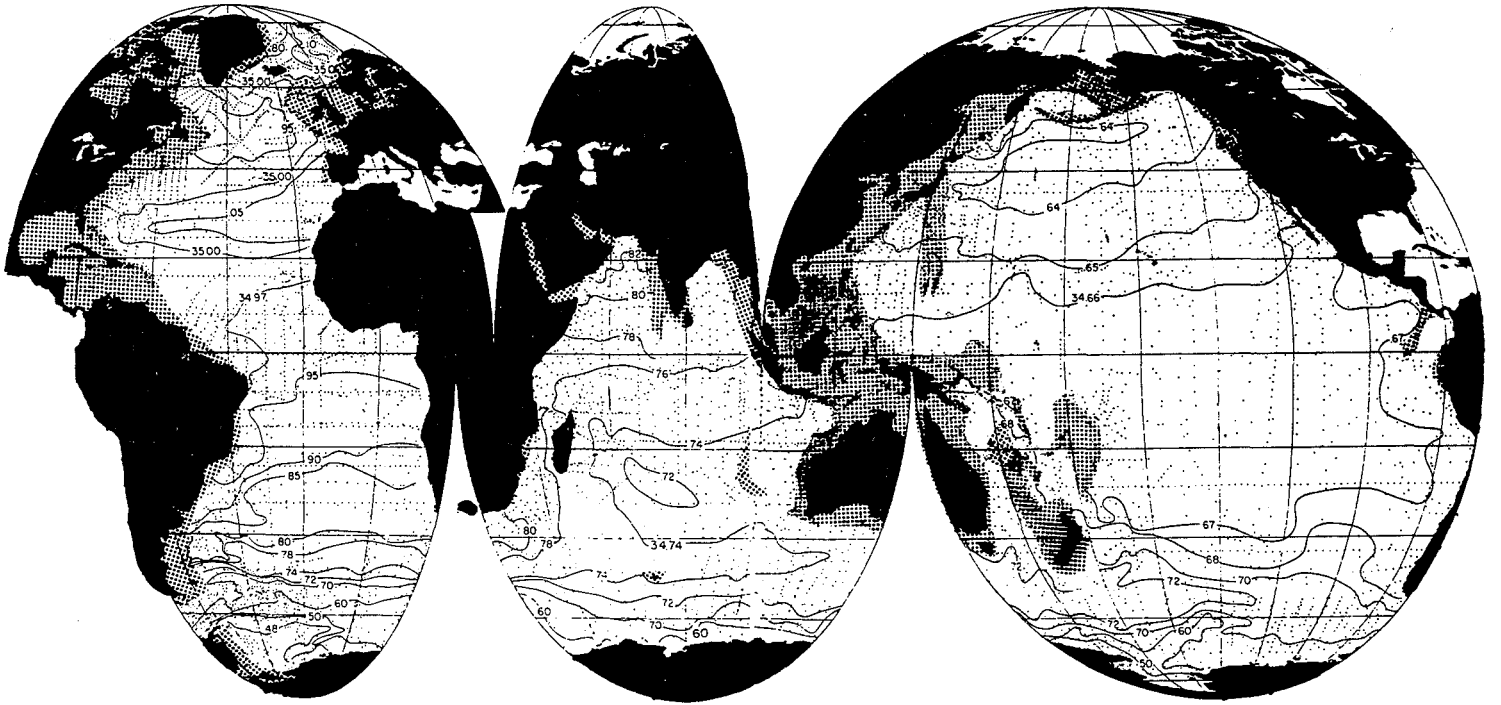

Figure 14.1 Depth (hm) of the isopycnal defined by σ_2 = 37.00 below 1500 m, σ_1 = 32.47 between 1500 m and 500 m and σ_0 = 27.845 above 500 m. In the shaded areas all water is less dense than the isopycnal chosen. The isopycnal outcrops around the hatched area in the Norwegian-Greenland Sea (from Reid, 1981).

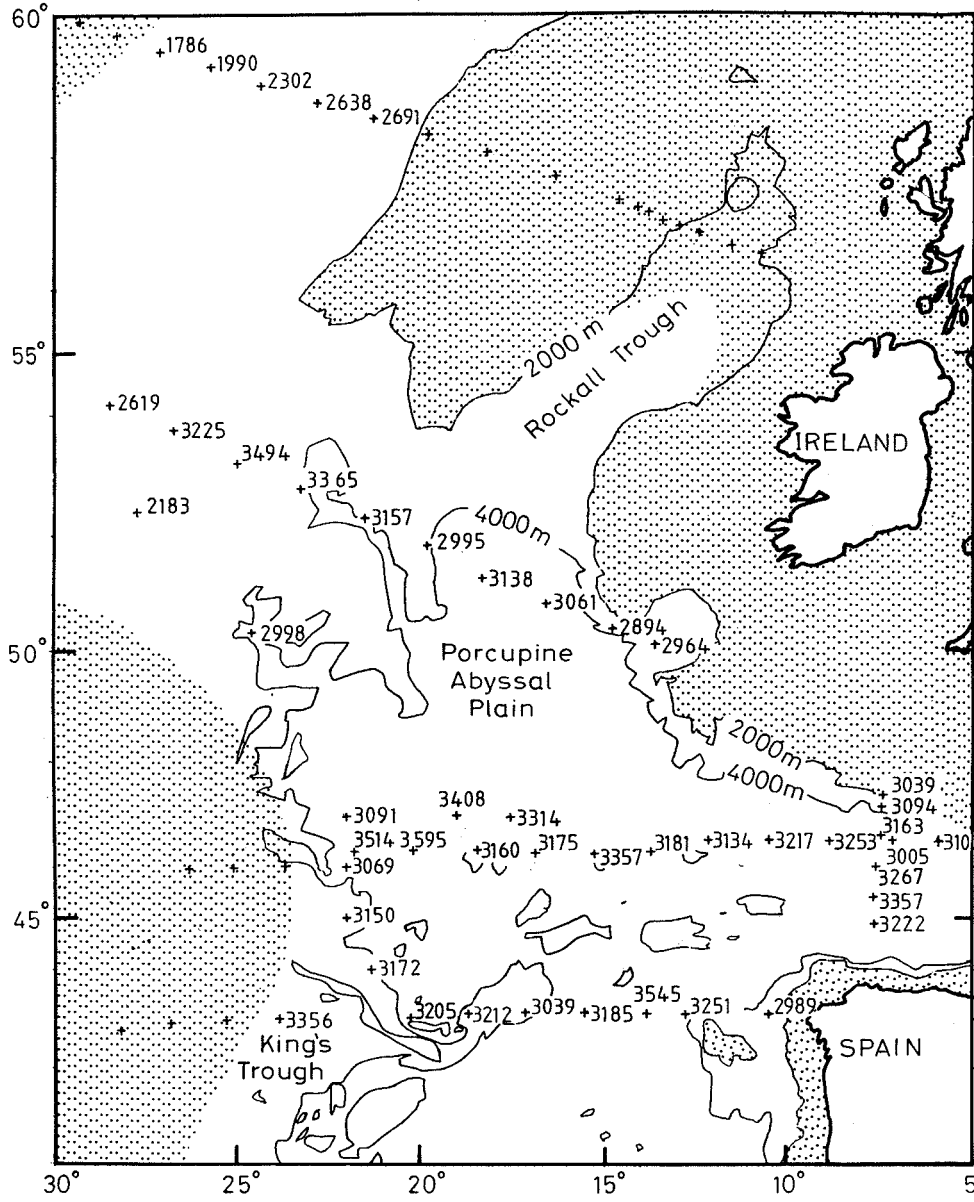

Figure 14.2 Depth (m) of σ_4 = 45.88 from hydrographic data for the north-east Atlantic.

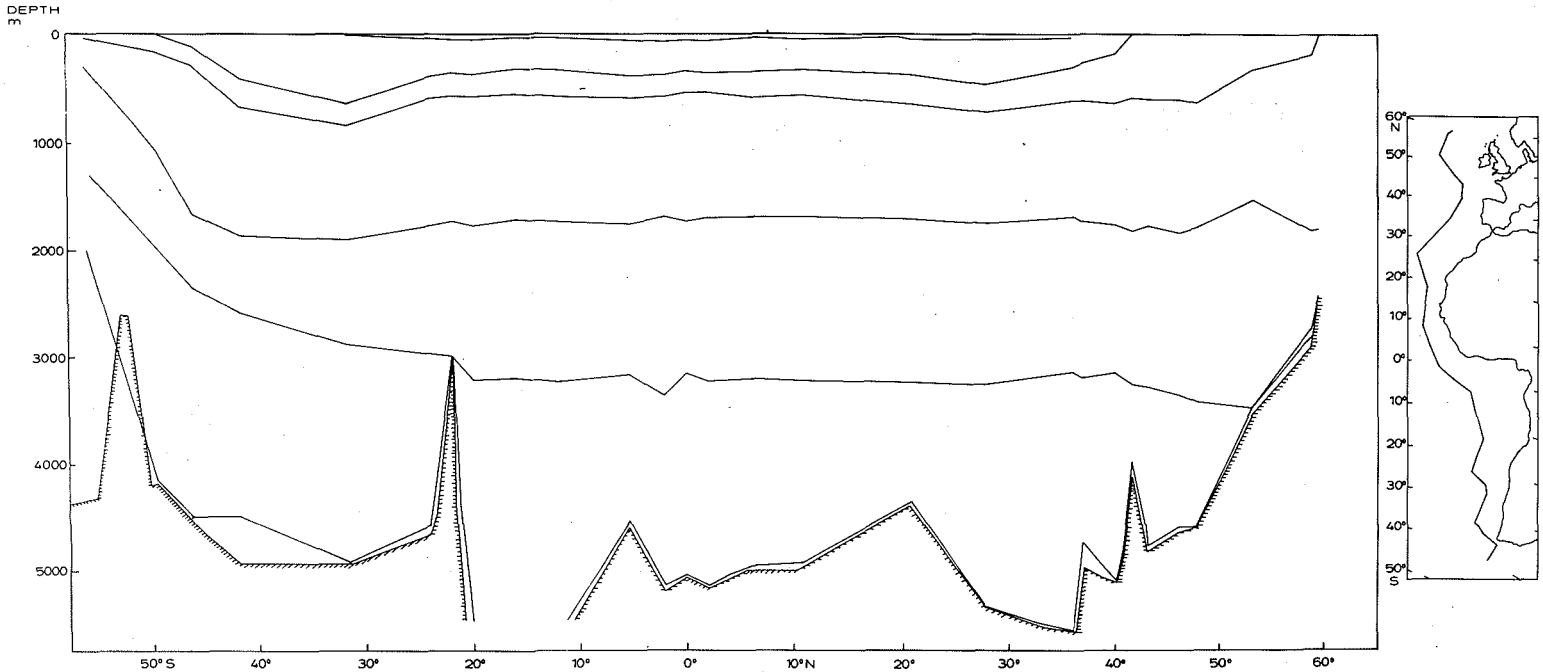

Figure 14.3 Some neutral surfaces for the eastern Atlantic from 56°S to 59°N.

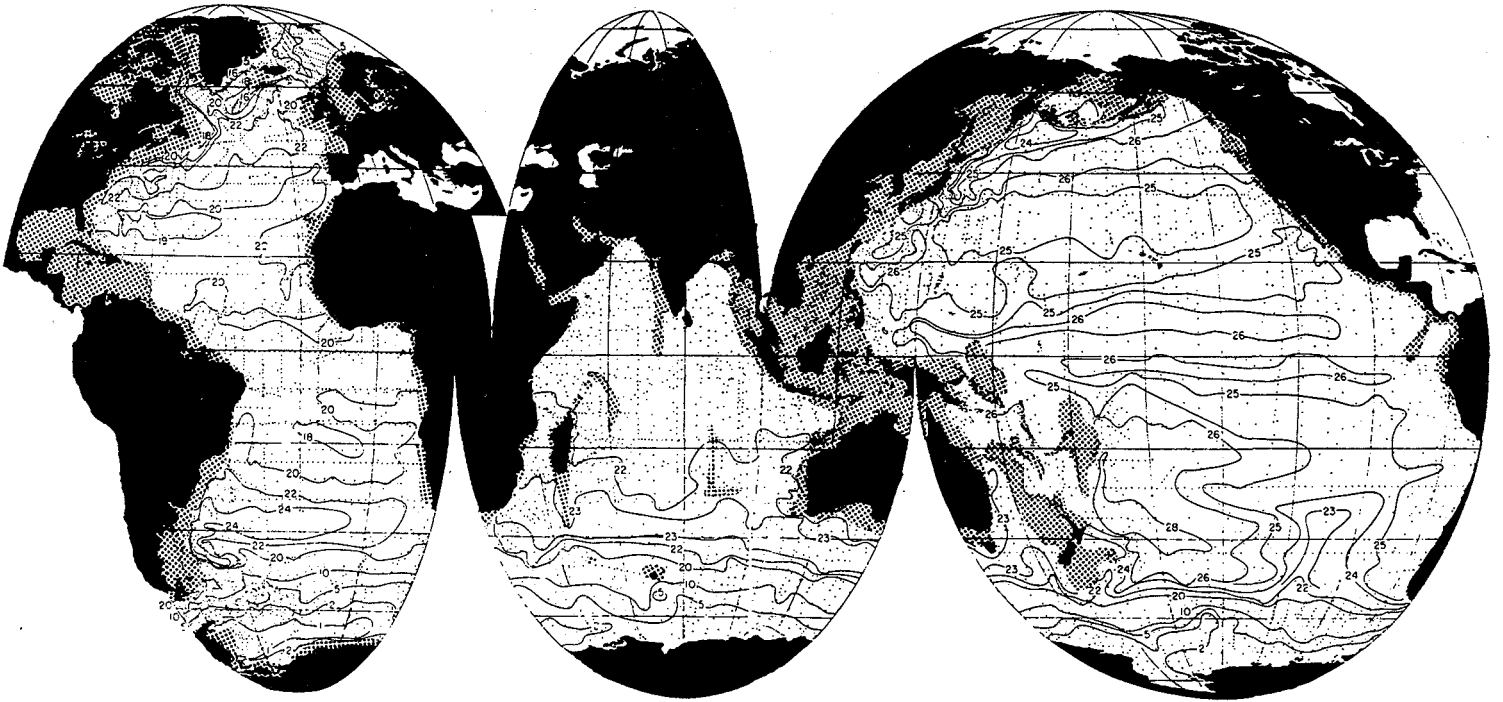

Figure 14.4 Distribution of salinity ($^0/oo$) on surface shown in Figure 14.1.

Chapter 15

WINDSTRESS AND STRATIFICATION

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Windstress and stratification are probably the least relevant parameters to be included here. However they justify a brief mention through their combined role in the input of eddy kinetic energy to abyssal depth (see Chapter 5), and some measure of wind strength is also of possible relevance to the dumping operation.

Figure 15.1 plots individual values of the 0-300 m temperature difference (°C) from bathythermograph observations at OWS ROMEO close to the NEA site (47°N 17°W), from February 1977 to September 1980, using data supplied by l'Etablissement Principal du Service Hydrographique et Oceanographique de la Marine (EPSHOM).

For the same period are shown the daily mean values of windstress at OWS ROMEO (N m^{-2}) calculated from individual windstress estimates using the quadratic windstress law with variable drag coefficient of Heaps (1965). The drag coefficient (c) varies as follows for different windspeed (w) intervals:

$$c \times 10^3 = \begin{cases} 0.565 & \text{for } w \leq 5 \text{ m s}^{-1} \\ -0.12 + 0.137\, w & \text{for } 5 < w \leq 19.22 \text{ m s}^{-1} \\ 2.513 & \text{for } w > 19.22 \text{ m s}^{-1} \end{cases}$$

Action Nil

Reference

Heaps, N. S., 1965. Storm surges on the continental shelf. Phil. Trans. R. Soc. (A) 257, 351-383.

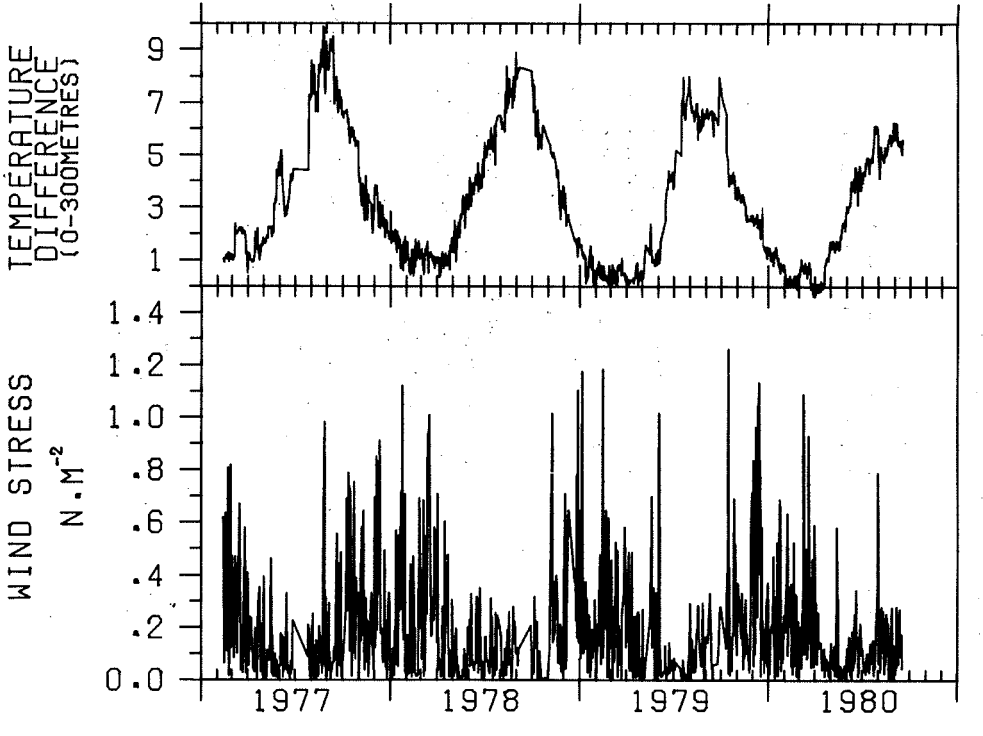

Figure 15.1 A plot of the temperature difference in the top 300 m of the water column from XBT observations and a plot of the windstress derived from observations at OWS ROMEO from February 1977 to September 1980.