Introduction

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In this publication is assembled a set of 14 papers from the presentations at a meeting of the Marine Studies Group of the Geological Society, held on the 29th and 30th January 1986. The papers cover various aspects of the geophysics, sedimentology, geochemistry and geotechnics of abyssal-plain sediments.

Abyssal plains are among the least studied areas of the earth's surface. They are poorly preserved in the sedimentary record because they tend to be consumed by subduction in the long term. They were not recognized as distinct physiographic features of the present sea-floor until the late 1940s, and systematic investigations of relatively few examples have been made. During the late 1970s an international research programme began to examine selected areas of the N Atlantic and Pacific Ocean seabeds to assess the feasibility of disposal of radioactive waste in deep-sea sediments. This work was coordinated through the Seabed Working Group of the Nuclear Energy Agency (OECD, 1984). The considerations of sea-floor properties required for such studies (Laine *et al.* 1983; Searle 1984) had the result that some of the N Atlantic study areas were in abyssal plains. The availability of new geological information from this programme provided the impetus for convening this meeting, but the papers are not restricted to those deriving from such studies.

The first paper by Pilkey sets the scene by summarizing the sedimentological work which has been carried out at Duke University on 13 abyssal plains. 12 factors controlling the formation and development of abyssal plains are discussed. The paper by Kuijpers *et al.* tackles the difficult problem of estimating accumulation rates in the Nares Abyssal Plain, where the sediments consist of pelagic and turbiditic clays containing little calcium carbonate and few dateable fossils. Ledbetter & Klaus show that sediments are supplied to the Argentine Basin by down-slope processes but can be picked up by bottom currents and redistributed. The Argentine Abyssal Plain thus consists of areas of coarse terrigenous sediments and areas of mud-waves. In this, the Argentine Abyssal Plain contrasts sharply with the Madeira Abyssal Plain (in the Cape Verde Basin) which is dominated by the input of fine-grained turbidites.

Kidd *et al.* show the regional picture of parts of the Cape Verde Basin using GLORIA sonographs, and Searle describes in detail the characteristics of the 'Great Meteor East' (GME) area. This area lies in the centre of the Madeira Abyssal Plain and, as a result of the activities of the Seabed Working Group, is probably the most extensively surveyed area of abyssal plain in the world's ocean. This volume contains several papers relating to the GME area.

The distribution of individual turbidites and entry points of the turbidity currents into the GME area is discussed by Weaver & Rothwell. Williams describes fault structures which are common in the sediments of part of the area, and proposes a model in which differential compaction initiates the faults which may then act as seals to pore-water flow, leading to normal or reverse directions of throw. Huggett, in a novel approach, shows how the turbidite sediments on the plain can be identified on the basis of macrofaunal feeding and burrowing traces from seabed photographs.

Papers by Shephard *et al.* and Schultheiss & Noel concentrate on geotechnical properties of abyssal-plain sediments. The former paper describes the geotechnical properties of sediments from the Nares Abyssal Plain, and the latter discusses conflicting evidence of pore-water flow through the GME sediments derived from temperature and pressure measurements. The heat-flow data suggest large downward advection, whereas the pore-pressure data suggest at most a small downward movement.

The paper by de Lange *et al.* demonstrates by compositional arguments that the turbidites emplaced on the Madeira Abyssal Plain have at least three distinct sources. Few previous geochemical studies have contrasted the conditions developed in sediment columns containing abyssal-plain turbidites with those which would otherwise obtain in the pelagics of deep basins (Wilson *et al.* 1985). The papers by Jarvis & Higgs and Thomson *et al.* illustrate that the importation of labile organic carbon with turbidites has consequences for the redox status, sediment colour and post-depositional redistribution of several elements. (A recent edition of *Marine Geology* (Vol. 68, 1985) contains further papers on the contrasts between turbidites and other sediment types in the Venezuela Basin.) The final paper by Heggie *et al.* compares estimates by different methods of the amount of organic carbon oxidation in the sediments of the Hatteras Abyssal Plain and its environs. It is suggested in this paper that dissolved organic compounds may be more important than previously appreciated.

To place the papers of this Special Publication in context we present below a brief history of research into abyssal plains and an account of their distribution in the oceans. The abyssal plains discussed here form a very small proportion of those listed in Table 1, and are limited almost exclusively to the Atlantic Ocean. This reflects in part the relative inaccessibility of the abyssal plains in high latitudes, and the impetus for research in specific abyssal plains given by the Seabed Working Group's research programme relating to the feasibility of radioactive waste disposal in the deep ocean.

History of research

Before the late 1920s bathymetric data were collected by discontinuous soundings using lines lowered to the seabed. These were never taken in sufficient numbers to enable the detailed physiography of the world's oceans to be delineated, although maps such as those by Murray & Renard (1891) and Thoulet (1904) did outline other major features such as the edge of the continental shelves and the Mid-Atlantic Ridge. During the 1920s acoustic sounding equipment was developed which could be operated much more rapidly than the sounding lines, thus enabling the Meteor expedition of 1925–1927 to take soundings every 20 min on E–W Atlantic transects. Maps produced from these techniques (Maurer & Stocks 1933; Stocks & Wust 1935) show clearly the major Atlantic basins, but the depth precision of these early instruments was not sufficient to reveal the flat featureless floors of the basins, now known as abyssal plains. As the equipment became more refined the depth precision became greater and the profiling became continuous. The accumulation of such data allowed accurate and detailed maps to be drawn of large areas of the ocean-floor and consequently features such as the abyssal plains could be recognized. Tolstoy & Ewing (1949) identified the first abyssal plain to the S of Newfoundland—now known as the Sohm Abyssal Plain. Following this discovery many other examples were found in all the oceans (Heezen *et al.* 1954, 1959; Koczy 1954; Menard 1955; Hurley 1960; Heezen & Laughton 1963).

The first cores taken from abyssal plains revealed sediments containing sands, often with displaced shallow-water foraminifera (Locher 1954; Phleger 1954) and it became evident that abyssal plains were formed by the infilling of basins, and other deep areas of the ocean-floor, by turbidity currents (Heezen *et al.* 1951; Heezen & Laughton 1963). As a result of this infilling, all depressions in the seabed become flattened, and, although there may be a small regional slope, undulations in the seabed of more than a few metres are rare. This serves to distinguish abyssal plains from other relatively flat areas of seabed, such as the central parts of the Pacific, which have been termed 'archipelagic aprons' by Menard (1958).

One early study of sediments on an abyssal plain was by Belderson & Laughton (1966), who obtained a series of sediment cores from the Madcap area of the Cape Verde Basin which contained turbidites, some with coarse bases, that could be correlated across distances of over 65 km. They recognized colour sequences within individual turbidites but did not investigate the geochemical processes responsible. Later studies by Horn *et al.* (1971) and Horn *et al.* (1972) revealed the importance of turbidity currents in forming abyssal plains in the Atlantic, Pacific and Mediterranean regions. These workers also showed how turbidity-current entry points into abyssal plains could be identified by grain-size analyses, with the coarsest sizes lying most proximally. Recently, the distribution and thicknesses of individual turbidites have been mapped between closely spaced cores on several Atlantic abyssal plains (Bennetts & Pilkey 1976; Ditty *et al.* 1977; Elmore *et al.* 1979; Schorsch 1980; van Tassell 1981; Weaver & Rothwell 1987). Ultimately, these studies should help to elucidate characteristics of the turbidity currents, such as their velocity, density and rates of settling.

One feature which has emerged from studying individual turbidites is the very large volume of material which can be involved in a single flow. Elmore *et al.* (1979) estimated the volume of the Black Shell turbidite on the Hatteras Abyssal Plain as over 100 km^3, and Weaver & Rothwell (1987) estimate a volume of over 120 km^3 for the *f* turbidite on the Madeira Abyssal Plain. Such volumes are comparable with those calculated for the sediment slides and debris flows along the NW African margin (Embley 1982), one of which (the Saharan slide) travelled in the direction of the Madeira Abyssal Plain, reaching almost to the plain–lower rise boundary (Simm & Kidd 1983/84). It is possible that in some cases slides, debris flows and turbidites may be generated as part of the same event. The initiation of the turbidity currents reaching the Madeira Abyssal Plain has been linked to sea-level changes associated with ice advances and retreats (Weaver & Kuijpers 1983), and similar explanations have been invoked for turbidites in the southern Brazil Basin (Johnson & Rasmussen 1984). Weaver *et al.* (1986) speculated that the Madeira Abyssal Plain was initiated by the onset of major glaciation in the late Miocene, and that this abyssal plain, at least, is a relatively recent feature.

Distribution of abyssal plains

Abyssal plains were defined by Heezen *et al.* (1954) as 'areas of the deep ocean floor in which the ocean bottom is flat and the slope of the bottom is less than 1:000'. The flat seabed is produced by the ponding of transported sediments beyond the bases of slopes, which causes an infilling of the deeper areas between abyssal hills. The hills gradually become submerged as the area of the plain extends, although few plains have become so mature as to have no protruding hills left. With the exception of trenches, abyssal plains often form the deepest parts of the oceans, and in the Atlantic the largest abyssal plains are located between the base of the continental rise and the distal parts of the Mid-Atlantic Ridge, or other topographic highs such as the Madeira–Tore rise.

Approximately 75 abyssal plains have been identified in the world's oceans (Fig. 1, Table 1). This list excludes the flat areas on the floors of trenches and the flat areas on shelves such as are found off California, as well as the numerous areas of ponded turbidites which occur in very localized basins throughout the oceans. Emery (1960) named flat areas of seabed in shallow water as 'basin plains', although later workers have used this term interchangeably with abyssal plains. An indication is given in Table 1 of the area occupied by each abyssal plain, but it should be recognized that such estimates are subject to considerable uncertainty. Errors can be caused by inadequate mapping, especially since some of the largest abyssal plains occur in the less-well-known Antarctic Ocean. Other errors occur in defining the boundaries of the features, and they can only be resolved by detailed studies of each abyssal plain. The Cape Verde Abyssal Plain, which lies to the S of the Madeira Abyssal Plain, for example, was shown by detailed studies (Auffret *et al.* 1984; Kidd & Searle 1984) to have more of the character of the lower continental rise than of an abyssal plain *sensu stricto*. It is therefore omitted from our table.

The distribution of abyssal plains is not uniform, with the Pacific, for example, having a total of seven and the Atlantic having 29. The comparatively small Arctic Ocean has 10 abyssal plains, and the Caribbean four. Abyssal plains develop preferentially on sea-floor which can receive a large sediment input from a nearby continental shelf or upper rise. They are thus precluded from forming adjacent to margins bounded by trenches, the situation common around most of the Pacific. In the N Pacific the only true abyssal plains have formed in the NE, to the N of the Mendocino Fracture Zone. In this area sediment supply from N America has infilled much of the trench, thus allowing sediment to cross the trench axis and pond in the areas of the Tufts and Cascadia Abyssal Plains. Rivers

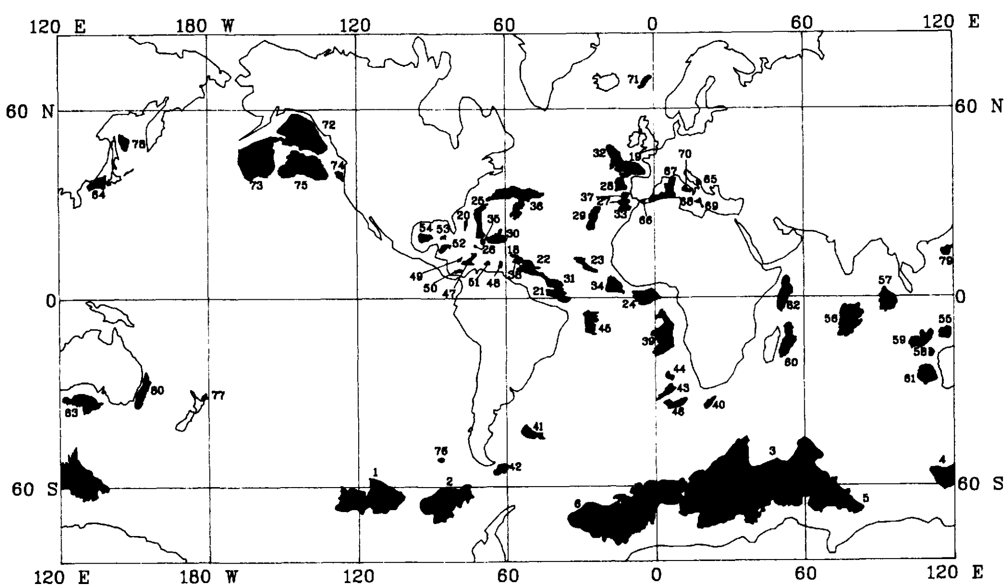

FIG. 1. Distribution of abyssal plains in the world's oceans (see Fig. 2 for Arctic abyssal plains). The key to the numbers is given in Table 1.

TABLE 1. *List of named abyssal plains by ocean with approximate locations and areas*

	Lat	Long	Area (km^2)
Antarctic			
1 Amundsen	63°S	128°W	570 000
2 Bellinghausen	65°S	90°W	385 000
3 Enderby	60°S	35°E	3 703 000
4 South Indian	58°S	125°E	865 000
5 Valdivia	62°S	68°E	420 000
6 Weddell	65°S	20°W	1 298 000
Arctic			
7 Barents	85°N	40°E	870
8 Boreas	77°N	1°E	1 100
9 Canada	76°N	150°W	8 700
10 Chukchi	77°N	172°W	1 700
11 Dumshaf	70°N	5°E	9 000
12 Fletcher	87°N	180°W	110
13 Greenland	75°N	3°W	4 200
14 Mendeleyev	81°N	170°W	1 500
15 Northwind	76°N	161°W	1 400
16 Pole	88°N	90°E	360
17 Wrangel	82°N	177°E	1 800
Atlantic (N)			
18 Barracuda	17°N	56°W	34 000
19 Biscay	45°N	7°W	268 000
20 Blake Bahama	28°N	76°W	54 000
21 Ceara	1°N	38°W	303 000
22 Demerara	10°N	48°W	380 000
23 Gambia	12°N	28°W	175 000
24 Guinea	1°N	3°W	508 000
25 Hatteras	31°N	71°W	460 000
26 Hispaniola	20°N	71°W	11 000
27 Horseshoe	36°N	12°W	36 000
28 Iberian	44°N	14°W	107 000
29 Madeira	32°N	21°W	54 000
30 Nares	23°N	63°W	338 000
31 Para	6°N	41°W	215 000
32 Porcupine	49°N	16°W	165 000
33 Seine	34°N	12°W	63 000
34 Sierra Leone	5°N	17°W	368 000
35 Silver	22°N	69°W	71 000
36 Sohm	36°N	55°W	309 000
37 Tagus	37°N	12°W	41 000
38 Vidal	15°N	55°W	39 000
Atlantic (S)			
39 Angola	15°S	2°E	1 001 000
40 Aghulas	46°S	23°E	52 000
41 Argentine	47°S	50°W	140 000
42 Burdwood	54°S	62°W	66 000
43 Cape	35°S	6°E	104 000
44 Namibia	31°S	5°E	53 000
45 Pernambuco	7°S	27°W	393 000
46 Town	39°S	11°E	136 000
Caribbean			
47 Colombian	13°N	76°W	168 000
48 Grenada	13°N	62°W	42 000
49 Jamaican	15°N	79°W	42 000
50 Panama	11°N	79°W	93 000
51 Venezuela	14°N	67°W	75 000
52 Yucatan	20°N	85°W	75 000
Gulf of Mexico			
53 Florida	25°N	86°W	18 000
54 Sigsbee	23°N	93°W	135 000
Indian			
55 N Australian	14°S	117°E	196 000
56 Mid Indian	4°S	82°E	1 025 000
57 Cocos	3°S	93°E	536 000
58 Cuvier	22°S	111°E	45 000
59 Gascoyne	16°S	110°E	430 000
60 Mascarene	19°S	52°E	496 000
61 Perth	28°S	110°E	398 000
62 Somali	1°N	51°E	542 000
63 S Australian	37°S	130°E	436 000
Japanese Sea			
64 Japan	41°N	135°E	160 000
Mediterranean			
65 Adriatic	42°N	18°E	13 000
66 Alboran	36°N	4°W	2600
67 Balearic	40°N	6°E	238 000
68 Sicilia	36°N	18°E	17 000
69 Sidra	34°N	19°E	3800
70 Tyrrherian	40°N	12°E	30 000
North Sea			
71 Norway	65°N	4°W	19 000
Pacific (N)			
72 Alaska	55°N	143°W	718 000
73 Aleutian	49°N	160°W	988 000
74 Cascadia	47°N	127°W	35 000
75 Tufts	47°N	140°W	793 000
Pacific (S)			
76 Mornington	54°S	86°W	9200
77 Raukumara	36°S	179°E	21 000
Sea of Okhotsk			
78 Okhotsk	52°N	149°E	76 000
S China Sea			
79 S China Sea	17°N	117°E	129 000
Tasman Sea			
80 Tasman	34°S	153°E	303 000

draining into the Atlantic from the large drainage area of N America have supplied enough sediment to form the very large Hatteras and Sohm Abyssal Plains, with Nares Abyssal Plain receiving its sediment via an overflow channel (the Vema Gap) from the Hatteras Abyssal Plain (Tucholke 1980). In the eastern Atlantic there is a series of abyssal plains forming an almost unbroken chain from 50°N to 30°N. In the S Atlantic abyssal plains are less frequent (Fig. 1). Emery & Uchupi (1984) estimated that abyssal plains in the Atlantic Ocean occupy one-seventh of the area of all physiographic units that are due to sedimentary processes.

In the polar regions abyssal plains are common, with 10 in the Arctic Ocean (Fig. 2) and six

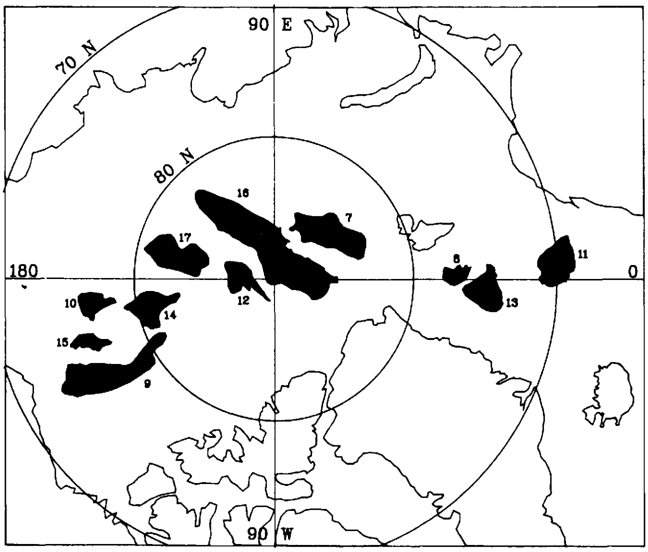

FIG. 2. Distribution of abyssal plains in the Arctic Ocean. The key to the numbers is given in Table 1.

surrounding the Antarctic continent. Sediment supply is high in these areas owing to ice erosion on the adjacent continents and the absence of trenches. The largest abyssal plains of all are those surrounding the Antarctic continent, with the Enderby Abyssal Plain occupying an area of 3.7×10^6 km^2, three times larger than the second largest Weddell Abyssal Plain. These vast abyssal plains off the Antarctic continent have been able to form because of the absence of trenches and the prolonged erosion of the Antarctic continent by ice (Vanney & Johnson 1976).

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