COMMISSION OF THE EUROPEAN COMMUNITIES

environment and quality of life

ENVIRONMENTAL ASPECTS OF OFFSHORE MINERAL PRODUCTION IN THE EUROPEAN ECONOMIC COMMUNITY

Volume I: Technical

Prepared by
François J. LAMPIETTI

Environment and Consumer Protection Service

1978

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CHAPTER 1

INTRODUCTION

1.1 PURPOSE

This study intends to provide the Environment and Consumer Protection Service of the European Economic Community (EEC) with technical information and opinions to help make judgments about the environmental aspects of mineral production offshore.

According to the terms of reference (Appendix A), this study intends:

1. To describe offshore mineral resources, their magnitude, and their future importance — both in general and in the EEC in particular.
2. To describe the technologies for finding (exploration) and exploiting offshore mineral resources.
3. To comment on the environmental aspects of mineral production offshore, i.e., the possible stresses, the risks of their occurrence and the methods and techniques of prevention and control of environmental damage.
4. To compare the legal and institutional measures for the protection of the environment from offshore mineral production worldwide and in particular in the EEC countries.

1.2 DEFINITIONS

The word environment as used herein refers to the physical elements, the air, water, and seabed of the offshore regions. Indirectly, it also includes the living resources of the flora and fauna together with the recreational amenities of the seas and coasts.

The term mineral is widely used to describe all lifeless substances. Within the so-called extractive industries,a distinction is made between the oil industry and the minerals or mining industry. In this text this difference will be reflected by the use of petroleum and natural gas in contrast with the term hard minerals. Other definitions are introduced throughout the text.

Although no academic rigor is intended,a word of caution is sounded against "buzzwords" such as environmental impact, technology assessment, and many such others in much of the current literature. These buzzwords embody specific concepts which are discussed under the appropriate chapter headings, but this report is not an application of any of them.

Vague definitions have so plagued many recent arguments concerning mineral resource availability and scarcity that a special nomenclature is also introduced where such terms are used.

1.3 SCOPE AND VIEWPOINT

The study was conducted over a period of about eight months. It consists mainly of a critical appraisal of some of the vast quantity of material available on offshore oil and gas, on minerals, on pollution in general and on the North Sea in particular. This has been done from a viewpoint biased against neither technology nor against the environment.

Because much of the material on offshore mineral production assumes a considerable technical background, this text has been oriented toward the average reader with suggestions for more specialized reading for those who are interested. Thus many simplifications and descriptions of a fairly elementary kind have been introduced for the sake of clarity.

Much of the literature consulted is highly detached from the human element,and to offset this, descriptions of human functions, careers and operations have been introduced wherever possible.

Finally, it is important to observe that, in addition to the vast mass of material already in existence, there is an even greater amount steadily being generated from all sides at technical conferences and special meetings and by professional societies and environmental interest groups, etc. It is difficult to be original in such an environment, and some of the things said here may appear elsewhere in similar form.

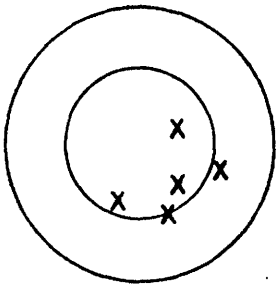
Although the emphasis is primarily technical, the subject has been approached from two points of view:

1. The interaction in time of technology with the environment. Interaction is gradually reached by describing the resources, the environment, and the technologies. Extrapolations in time range from the near future to the distant future (25 years).

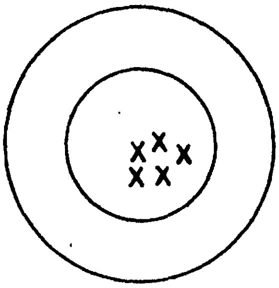
2. Its social aspects. These are covered in a highly subjective manner under a general chapter on mineral production regimes. Although no apology is intended, the reader is reminded that no legal or sociological rigor is claimed for this part of the text.

An explanation may be needed concerning the approach employed to cite numeric quantities in the following text. For example, the statement "The average world offshore oil production in 1975 was 9, 215, 673 barrels per day" has no greater meaning or value to the reader than "The average world offshore oil production in 1975 was of the order of 10 mill. bbls. per day." The former number embodies an unwarranted precision if not accompanied by explanations of how it was calculated, over how many days, and with what level of precision (e.g., is it an average over the year? If so, what were the highest and lowest daily productions? Were the rates measured to the nearest barrel?). By comparison, the later number conveys more directly the order of magnitude.

Precision, therefore, should not be confused with accuracy, and the reader is reminded of the familiar target analogy:



reasonably
accurate



precisely
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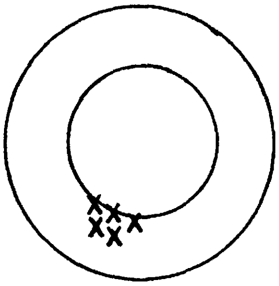


precise but
inaccurate

1.4 REFERENCES

The references in this study are arranged according to the main divisions in each chapter where they appear in alphabetical order at the end. Additional sources of information are cited together with those which are referenced in the text. Much of the current information pertaining to resources and mining appears in journals, often in news items or editorial comments and cannot always be assigned to a specific author. Such references are also placed at the end of each main section.

1.4.1 Abbreviations and Acronyms

(a) Abbreviations

bbls/day	barrels per day
^oC	degrees centigrade (Celsius)
cm	centimeters
cu.	cubic
CH_4	methane
dwt	dead weight tons
ft	feet
Hm	mean wave height

hr	hour
Hs	significant wave height
hz	hertz (1 cycle per second)
km	kilometers
km^2	square kilometers
m	meter
max	maximum
mcfd	million cubic feet per day
met. tons	metric tons
$miles^2$	square miles
n	nautical
pa	per annum
ppm	parts per million
sec	second
shp	shaft horse power
ton	short tons (2000 lb)
yr	year
$x\ 10^6$	million
$x\ 10^9$	billion
$x\ 10^{12}$	trillion

(b) List of Acronyms Used in the Text

BOP	Blowout Preventer
CA	Certifying Authority
CRISTAL	Contract Regarding an Interium Supplement to Tanker Liability for Oil Pollution. 1969.
CS	Certification Society
DP	Dynamic Positioning
GERTH	Groupement Europeen de Recherches Techniques sur les Hydrocarbures
GESAMP	Group of Experts on Scientific Aspects of Marine Pollution

IGOSS	Integrated Global Ocean Station System
LOS	Law of the Sea
MARMAP	Marine Resources Monitoring and Prediction Program
NSESG	North Sea Environmental Study Group
NSOSG	North Sea Oceanographic Study Group
OCS	Outer Continental Shelf Lands Act 1953
OPOL	Offshore Pollution Liability Agreement 1973
SBM	Single Buoy Mooring
SCUBA	Self-Contained Underwater Breathing Apparatus
SDC	Submersible Diving Chamber
SPC	Conference on Safety and Pollution Standards in the Development of Northwestern European Offshore Mineral Resources.1973
SPM	Single Point Mooring
TFL	Through Flow Line
TOVALOP	The Tanker Owners Voluntary Agreement Concerning Liability for Oil Pollution.1969
TUP	Transfer Under Pressure

A list of organizations concerned with aspects of the offshore environment and offshore technology is supplied at the end of each chapter.

1.4.2 Conversion Factors

Table 1-1. Conversion factors.

APPROXIMATE CONVERSION FACTORS FOR CRUDE OIL*

INTO	Metric Tons	Long Tons	Short Tons	Barrels	Kilolitres (cub. meters)	1,000 Gallons (Imp.)	1,000 Gallons (U.S.)
FROM	MULTIPLY BY						
Metric Tons	1	0·984	1·102	7·33	1·16	0·256	0·308
Long Tons	1·016	1	1·120	7·45	1·18	0·261	0·313
Short Tons	0·907	0·893	1	6·65	1·05	0·233	0·279
Barrels	0·136	0·134	0·150	1	0·159	0·035	0·042
Kiloliters (cub. meters)	0·863	0·849	0·951	6·29	1	0·220	0·264
1,000 Gallons (Imp.)	3·91	3·83	4·29	28·6	4·55	1	1·201
1,000 Gallons (U.S.)	3·25	3·19	3·58	23·8	3·79	0·833	1

TO CONVERT	FROM			
	Barrels to Metric Tons	Metric Tons to Barrels	Barrels/Day to Tons/Year	Tons/Year to Barrels/Day
	MULTIPLY BY			
Crude Oil*	0·136	7·33	49·8	0·0201
Motor Spirit	0·118	8·45	43·2	0·0232
Kerosine	0·128	7·80	46·8	0·0214
Gas/Diesel	0·133	7·50	48·7	0·0205
Fuel Oil	0·149	6·70	54·5	0·0184

***Based on world average gravity (excluding Natural Gas Liquids)**

Length

1 meter (m) = 3.28 feet (ft)

1 kilometer (km) = 1000 m
= 3280 ft
= 0.62 mile (mi)

statute mile (mi) = 5280 ft = 1.60 km

nautical mile (n mi) = 6000 ft = 1.83 km

Area

1 square meter (m^2) = 10.76 square feet (ft^2)

1 square kilometer (km^2) = 1,000,000 m^2

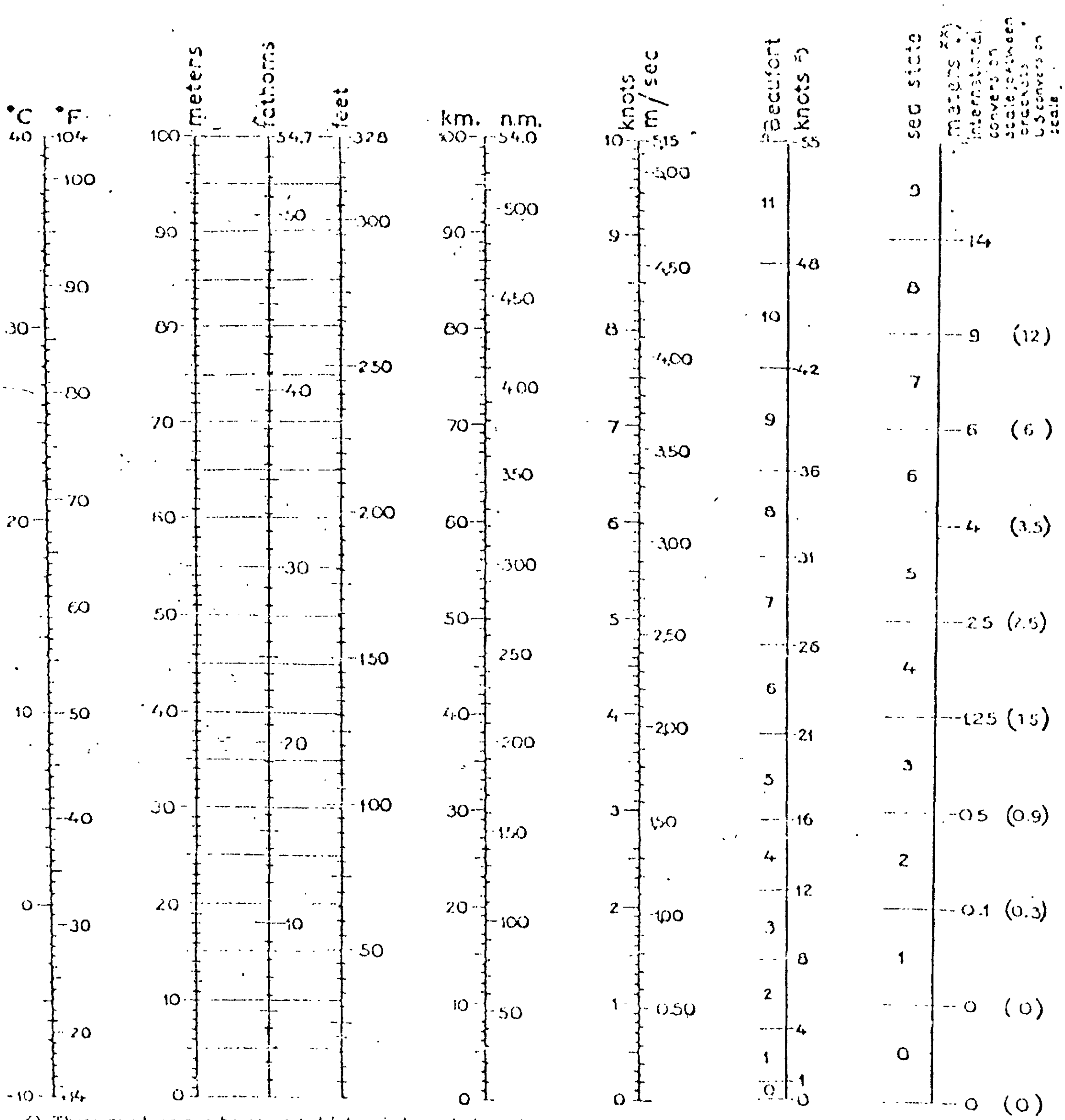
1 km^2 = 0.386 mi^2

1 mi^2 = 2.56 km^2

Volume

1 cubic meter (cu m) = 35.3 cu ft

1 cubic yard = 0.76 cu m



X) These numbers can be converted into wind speeds in meters per second according to the "Maritime" conversion scale

XX) Vertical distance from wave crest to trough

Source: Netherlands Hydrographer

Figure 1-1. Conversion table, offshore environment.

CHAPTER 2

OFFSHORE MINERAL RESOURCES

CONTENTS

CHAPTER 2

OFFSHORE MINERAL RESOURCES

This chapter is intended to situate and describe the EEC offshore lands and their mineral resources for the reader who is not already familiar with the numerous publications on the subject. The chapter begins with some definitions.

2.1 TERMINOLOGY

Minerals lie dormant in nature until they are discovered. Most mineral deposits are unique concentrations of minerals distinct from their surrounding materials. Their availability to man is contingent upon a technology for extraction. Known resources, exploitable within a particular price-technology framework, are called reserves. Undiscovered resources can, after discovery, become either reserves or remain as subeconomic or marginal resources. The terminology introduced recently in the United States will be used for convenience in this text and is summarized in Figures 2-1 and 2-2 (McKelvey, 1972; NAS, 1975).

2.1.1 Resources and Reserves

Many mineral occurrences are still on the border between resources and reserves and are shifted back and forth between the two. The reasons for exploiting a mineral resource change with time and socioeconomic factors which are peculiar to each mineral. The unit value and accessibility of a mineral deposit, cost, public acceptability and personnel safety, among others, are such factors.

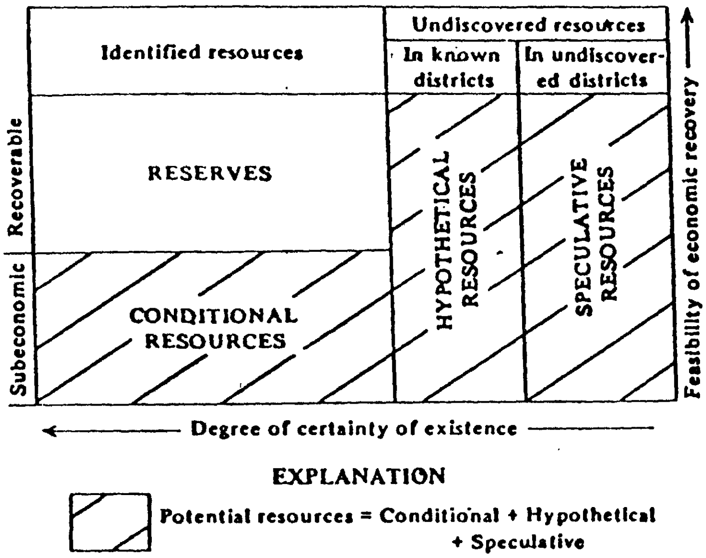


Figure 2-1. Classification of mineral resources (according to USGS, 1973, p. 820).

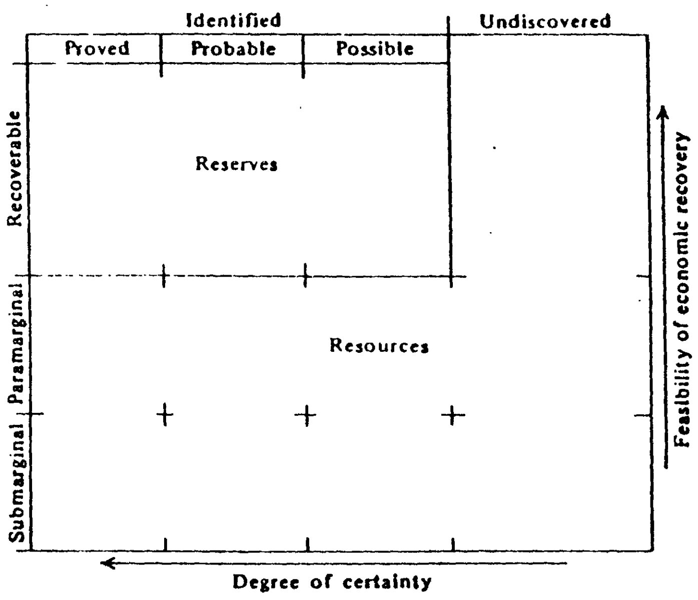


Figure 2-2. Classification of mineral resources (according to McKelvey, 1972).

The recent public controversy concerning the abundance and scarcity of minerals has introduced confusion between reserves and resources. One view is that new resources can be virtually created by technological innovation from lower grade minerals or less accessible mineral deposits. These can include both identified and undiscovered resources which new technology makes accessible or exploitable. Resources of offshore regions are a case in point.

Resource inventories are a necessary first step in planning and policy considerations toward minerals. Various methodologies have been conceived (Brink, 1971; Harris, 1973) for estimating the resource endowment of particular regions for inventory purposes.

The most important aspect of resources is the feasibility of economic recovery. This is particularly critical to offshore petroleum. Its future price per barrel influences the development of new technology. Occasionally, new technological developments (breakthroughs) make economic recovery (i.e., at lower cost) feasible without change in price. Taking the North Sea as an example, a drop in the price of oil could severely cut back present plans for exploitation by making them unprofitable. Theoretically, all earth resources are finite, and their need by man will motivate the development of new technologies for their economic recovery.

2.1.2 Reserve Estimates

Estimation of mineral reserves is a judgmental process requiring sampling data. The exact size of a particular mineral deposit can only be known after it has been totally exploited. Industrial terminology still includes proven, probable and possible reserves. These distinctions tend to be replaced by numerical probability estimates or confidence levels. The quantity of sampling information determines the accuracy with which the size of a discovered reserve-in-place can be calculated. The accuracy desired is a function of the cost of sampling. For example, one petroleum drill hole may constitute a discovery and several a field, but the size of the reserve-in-place may still not be known with a confidence level greater than ± 25%. The quantity of exploitable reserves in a mineral deposit depends on the judgments which are made about its rate of extraction using a particular technology. This rate determines the estimated life of the reserves.

Estimates of the size of the undiscovered reserves, although important, are highly judgmental and can only be of an order of magnitude.

Few of the published sources of data on mineral resources offer any clarifications on the accuracy of reserve estimates. However, it can safely be assumed that they are generally conservative in order to allow a safe margin of error for the reasons outlined above.

2.2 THE OFFSHORE LANDS OF THE EEC

2.2.1 The Offshore Limits of the EEC

Throughout the text, the EEC offshore areas are those shown in Figure 2-3. Including the median-line boundaries and the treaties in existence (the 1958, 200-meter depth Continental Shelf Treaty) or under discussion (200-nautical-mile economic zone), the offshore areas under the jurisdiction of the EEC member nations (excluding offshore Greenland) total approximately 800, 000 square miles (2, 050, 00 square kilometers) (Table 2-1). Greenland offshore areas to a depth of 3000 feet (1000 meters) would add approximately 100, 000 square miles (260, 000 square kilometers). Thus, the total EEC offshore area, including Greenland, would be equivalent to roughly 55% of the outer continental shelf of the United States, as defined by Geer (1976). The North Sea alone, to the 62° parallel, covers an estimated 200, 000 square miles (530, 000 square kilometers) of which some

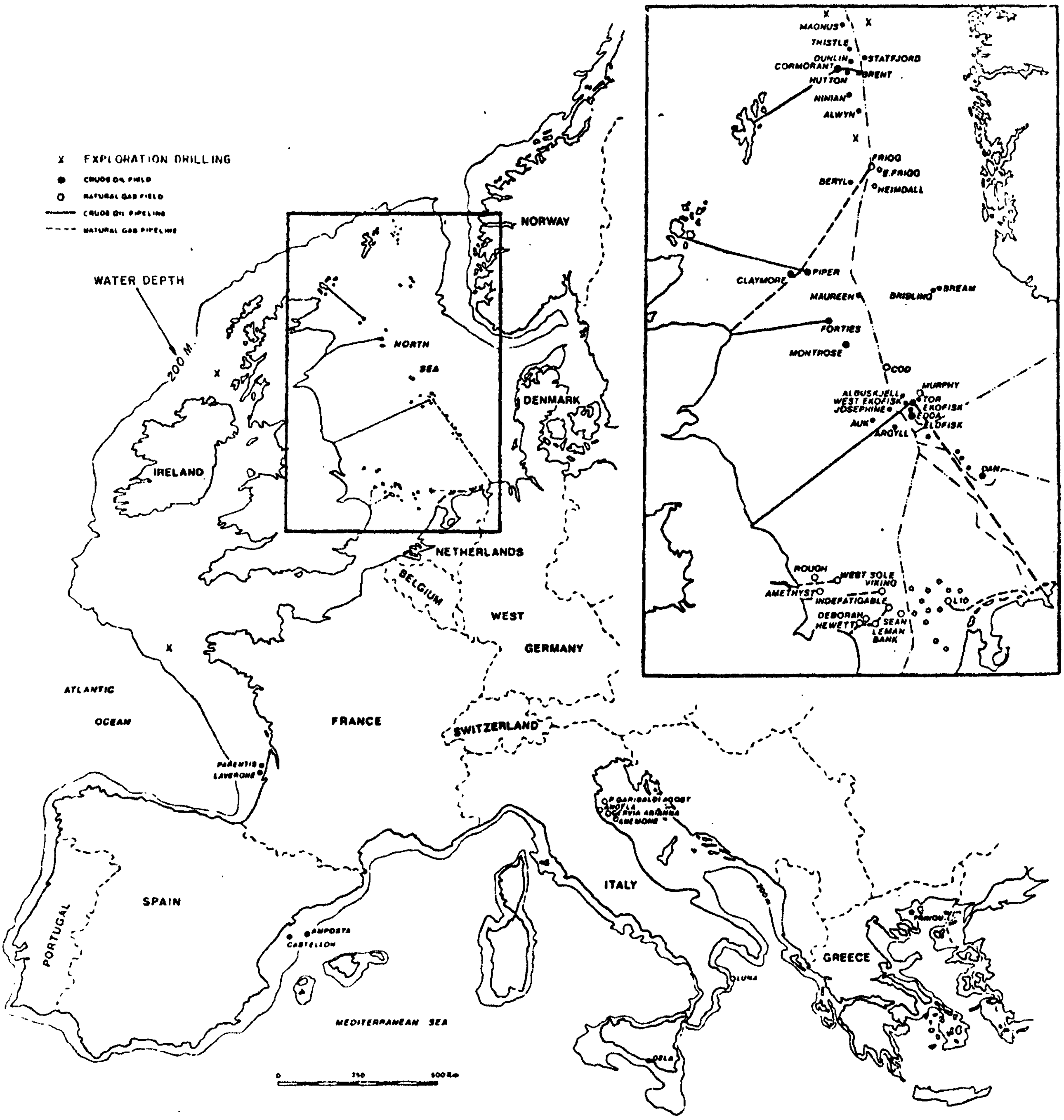


Figure 2-3. Offshore oil and gas fields (from Oil and Gas Yearbook, 1975-1976, p. 342).

150, 000 square miles (400, 000 square kilometers) presently belong to EEC nations[1]. Norwegian waters, fixed by treaty, add up to 51, 000 square miles (131, 000 square kilometers).

Table 2-1. Estimated offshore areas of EEC nations[2] (refer to Figure 2-3).

	North Sea		North Atlantic		Mediterranean	
	approx. area		approx. area		approx. area	
	sq. mi (thousands)	sq. km	sq. mi (thousands)	sq. km	sq. mi (thousands)	sq. km
United Kingdom	95	244	96	250		
Netherlands	22	56				
Denmark	22	56	100	260		
West Germany	14	36				
Belgium	1. 5	4				
France	1. 5	4	170	440	70	180
Italy					200	520
Eire (Ireland)			40	100		
Total	156	400	406	1050	270	700

2. 2. 2 Offshore Regions

Due to obvious physical and geological differences, the total offshore area may be divided into regions. These are described below in order of their importance to present offshore mineral extraction.

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[1] Territorial control of the sea was determined by the Geneva Convention of 1958 in the Law of the Sea. This was superseded by the Continental Shelf Act of 1964 and subsequent Continental Shelf (Designation of Additional Areas) Orders in 1965, 1968 and 1971 (MacGregor, 1975).

[2] Including those parts of the Baltic, Baffin and Adriatic Seas belonging to member nations.

A. The North Sea

The North Sea dates mainly from the early Tertiary period (70 million years ago). It is a shallow sea with an average overall depth of 300 feet (90 meters), ranging from depths of over 600 feet (200 meters) in the north to only 100 feet (30 meters) in the shallow southern basins.

Recent exploration has shown that the geological structure (Figure 2-4) consists of deep, linear, sediment-filled troughs up to 30 miles (50 kilometers) wide and 200 miles (320 kilometers) long, separated by uplifted fault-bounded platforms of continental crust (Naylor and Mounteney, 1975). The central North Sea graben system, which is almost 750 miles (1200 kilometers) long, has a trough-like structure. At the southern end, this trough opens out to embrace two large shallow basins, the Anglo-Dutch Basin and the Northwest German Basin. The trough and basins are infilled with sediments over 3000 feet (900 meters) thick. Much of the commercial oil and gas found in the North Sea has been associated with these thick deposits (Figure 2-4).

The distribution of oil and gas reservoirs is by no means uniform. Within the trough system several provinces, each with a different potential for hydrocarbon accumulations, can be identified. The distribution of these hydrocarbons is largely controlled by sediments older than the Tertiary, which extend as far back as the Carboniferous period (350 million years ago).

For descriptive purposes, the North Sea can be considered in three major commercial areas: first, the southern Anglo-Dutch and the Northwest German Basins, where large reserves of gas have been found in the Permian sandstones; second, the Central Graben in the central North Sea, which includes the huge Ekofisk complex of oil and gas on the median line between British and Norwegian waters[1]; and third, the Viking Graben east

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[1] Other fields in this basin are the Dan field with reservoirs in upper Cretaceous Danian chalk, the Auk and Argyll fields on older Permian levels and the Forties and Montrose reservoirs in sandstones of the Paleocene. Field depths vary from 3000 to 12, 000 feet (910 to 3700 meters).

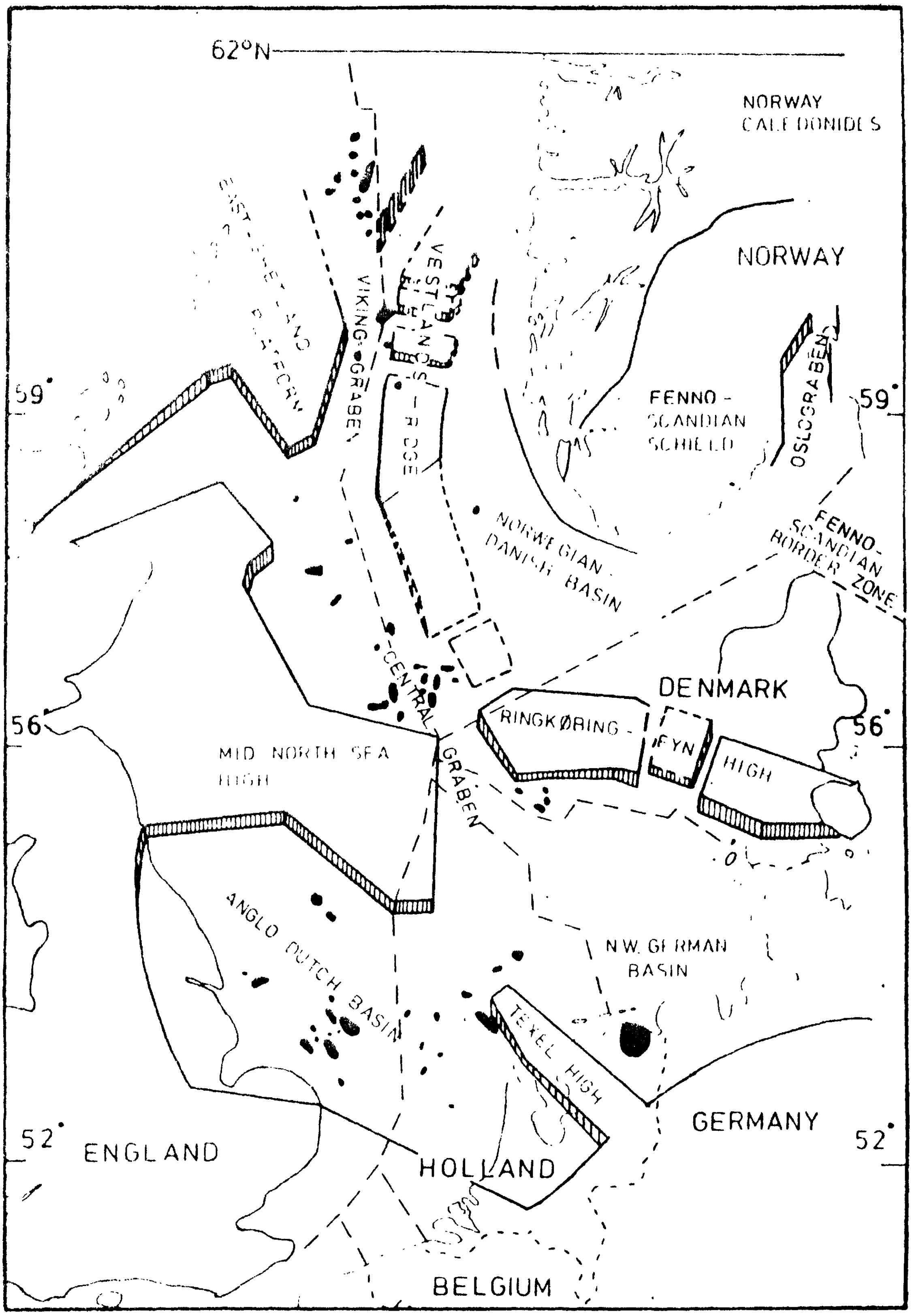

Figure 2-4. Major geological structural elements of the North Sea (Ronnevik et al., 1975, p. 12).

of the Shetland Platform at the northern end of the central trough, which is currently providing the richest yields with oil and gas accumulations at several levels.[1]

B. The North Atlantic

Between 200 and 300 million years ago, there was a creeping separation of the continental blocks of Europe and North America. Tensional stresses in the crust of the North Atlantic Basin gave rise to a series of ridges and fault-bounded troughs. The continental shelves of Western Europe and Greenland were separated by a ridge-like fragment of continental crust called the Rockall Plateau.

The North Atlantic can be divided in four main provinces: 1) the Rockall Plateau and Faroe Rise; 2) the Greenland Basin; 3) the Rockall Trough and Faroe-Shetland Channel; and, 4) the Bay of Biscay (Figure 2-5).

1. The Rockall Plateau and Faroe Rise are well defined shoal areas 300 miles (480 kilometers) west of Scotland (Naylor and Mounteney, 1975). The plateau is thought to be composed of metamorphosed pre-Cambrian basement rocks and perhaps of more recent volcanics that are unlikely to be suitable for the formation or storage of hydrocarbons.

2. Little is known about the Greenland Basin west of the plateau. The Greenland margin is much less accessible, and the major part is ice-covered, even in the summer months (Talwani and Eldholm, 1974), but it is thought to be similar to the plateau.

3. The Rockall Trough and Faroe-Shetland Channel, 100 miles (160 kilometers) north and west of Scotland, are extensions of formations presently being explored for oil at shallow depths, approximately 3000 feet (1000 meters) in the North Sea. There are extensive deposits of sedimentary

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[1] The Cormorant, Brent, Dunlin and Hutton holdings are under 6000-foot-thick sections and date from the Triassic period (Brennand and Siri, 1975).

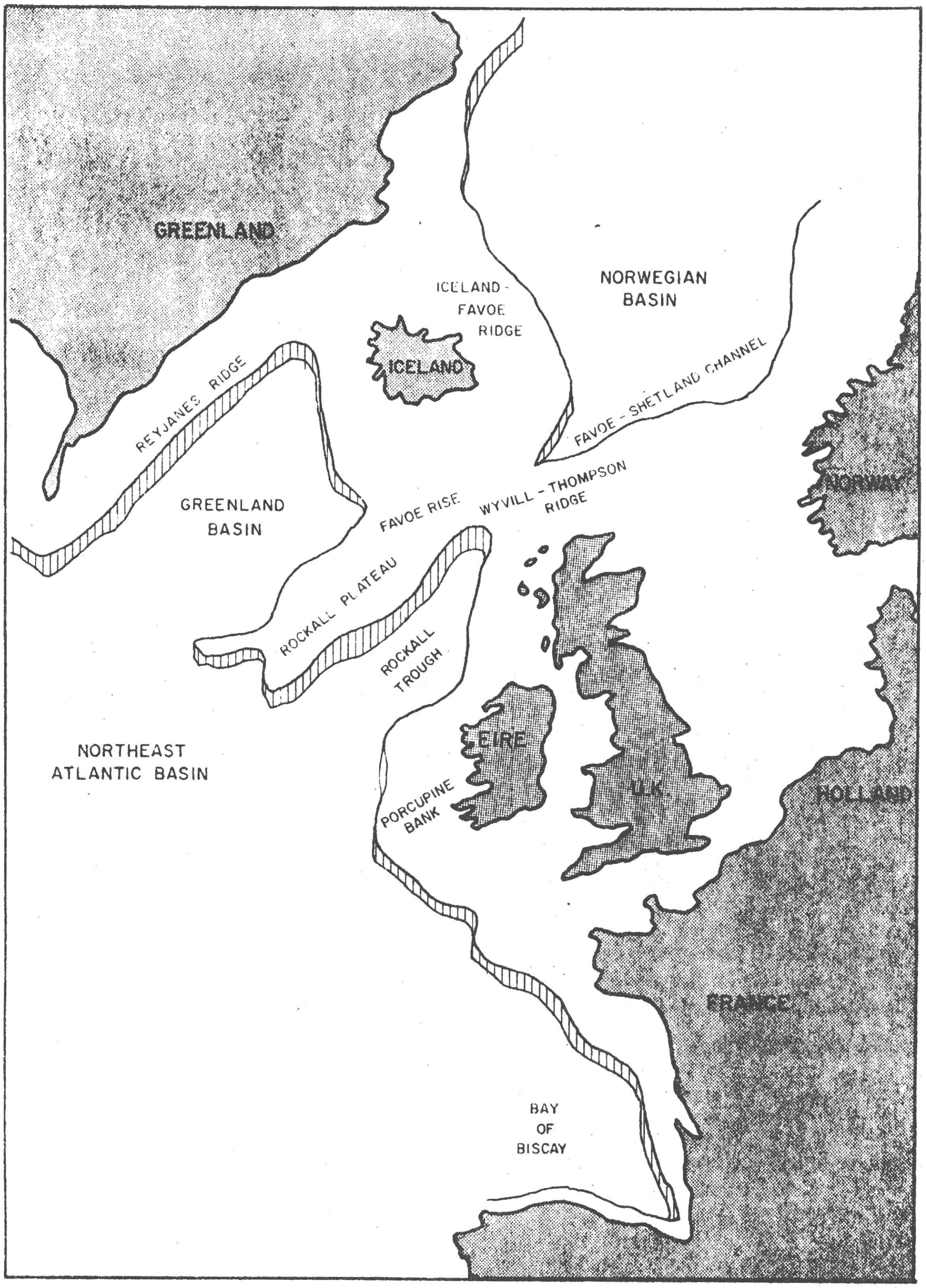

Figure 2-5. Sea floor of the North Atlantic.

rocks, roughly horizontally bedded to a depth of 10, 000 feet (3000 meters), which may prove to contain large resources of oil and gas (Whitbread, 1974). The oldest sediments identified on the floor of the trough are of upper Cretaceous age, but the down-faulted basin structure could have collected sediments from earlier Mesozoic and Paleozoic periods.

4. The Bay of Biscay lies to the south of the Western Approaches Basin and the English Channel. The channel is a synclinal trough made up of a series of basins filled with Jurassic, Cretaceous and Tertiary deposits with some Carboniferous coal-bearing measures. South of the Armorican Massif of Brittany, the channel opens out into the Bay of Biscay. The continental shelf around the bay narrows from a gently sloping 100-mile- (160-kilometer-) wide platform, south of Brittany, to a steep-sided shelf with water depths over 650 feet (200 meters) in the southeast corner of the bay, at the Franco-Spanish border. The steep sides plunge down to the Atlantic basin — 11,000-feet (3400-meters) deep. The same sedimentary structure is apparent in the Bay of Biscay as in the channel area. Oil is being sought in the Mer D'Iroise west of Brittany, which indicates these sediments could reveal further valuable reservoirs (Le Nouvel Economiste, 1975, No. 2, p. 94).

C. The Mediterranean Sea

The Mediterranean Sea is connected to the Atlantic by the narrow Strait of Gibraltar and is almost an enclosed sea with an area of well over 1 million square miles (2, 600, 000 square kilometers). Its main east and west basins are divided by the Straits of Sicily and Messina.

In the eastern basin only the Adriatic Sea, which includes some of the territorial waters of Italy, is of interest to this study. It has an area of 52, 000 square miles (135, 000 square kilometers) and has a maximum depth of 4000 feet (1200 meters) at its southeastern end. The north and central Adriatic is shallower with depths less than 650 feet (200 meters) (Carter et al., 1971). Structurally, the Adriatic is a synclinal zone extending the onshore trend of the Po Valley, where gas occurs in the formations of the

Tertiary age. Offshore, the gas fields of Ravenna and Mazo, in Pliocene sandstones, were discovered in 1969 (Tiratsoo, 1973).

The complex western basin of the Mediterranean is divided into two smaller basins, the Balearic and the Tyrrhenian, which are surrounded by narrow continental platforms. The Balearic Sea, to the west of Sardinia, is a broad flat abyssal plain with depths between 8900 and 9500 feet (2700 and 2900 meters) and covers an area of 92, 000 square miles (240, 000 square kilometers). In the Tyrrhenian Sea, depths range from 10, 000 feet (3000 meters) in the center of the basin to less than 650 feet (200 meters) in the north (Figure 2-6).

Geologically, the Balearic and Tyrrhenian Sea floor is a complex series of alpine folds (Burollet, 1969) and crystalline massifs. To the west, these seas are almost an oceanic trough with a thin sediment cover cut by numerous salt domes, which are targets as potential petroleum reservoirs (Deltar, 1973). Sicily is the one area where small reserves of oil have been found at Ragun and Gela (Tiratsoo, 1973)[1]. French petroleum companies have been holding offshore petroleum exploration permits in the deeper waters of the Mediterranean since 1972.

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[1] The Gela field yielded 4 x 10^6 barrels (550, 000 metric tons) of oil in 1974.

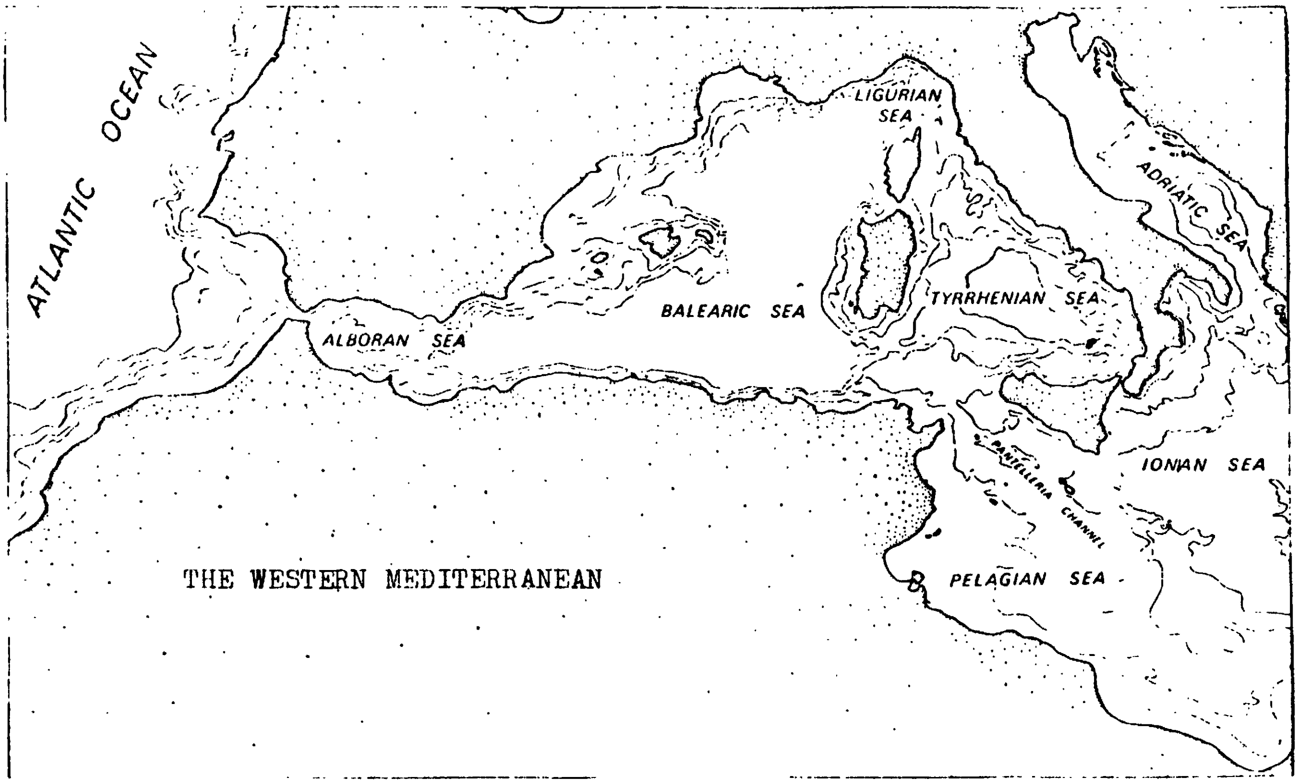

Figure 2-6. Western Mediterranean Sea and Atlantic Ocean.

2.3 OFFSHORE PETROLEUM AND NATURAL GAS

2.3.1 Natural Hydrocarbon Fluids

Reservoir rocks contain various mixtures of natural hydrocarbon fluids, principally oil (petroleum) and natural gas.

The term oil refers broadly to a liquid mixture of natural hydrocarbons found within the pore spaces of certain rocks. Oil varies in specific gravity and composition from one location to another. Impurities may be present: the most conspicuous of these is sulphur, but small amounts of other non-hydrocarbons may also be associated (AGA, 1975, p. 13).

Natural gas is a mixture of hydrocarbon compounds and small quantities of various nonhydrocarbons existing in the gaseous phase or in solution with oil in natural underground reservoirs. The principal hydrocarbons usually contained in the mixture are methane, ethane, propane, butanes and pentanes, and typical nonhydrocarbon gases which may be contained in reservoir natural gas are carbon dioxide, helium, hydrogen sulphide, nitrogen, etc. (AGA, 1975, p. 98).

A condensate or natural gas liquid (NGL) refers to hydrocarbons which are in the gaseous state under reservoir conditions and which become liquid in passage up to the surface due to the reduced pressure conditions (Crook, 1975, p. 47).

2.3.2 Reserves and Undiscovered Potential — World Picture

A. Reserves

The total world proven reserves are estimated to be approximately 660 x 10^9 barrels (90 x 10^9 metric tons) of which 25% lie in offshore fields. The average rate of discovery of oil this century has been 18 x 10^9 barrels per annum (2.5 x 10^9 metric tons) (Waters, 1974), and the annual production rate is a little over 20 x 10^9 barrels per annum (2.7 x 10^9 metric tons).

Estimates of the world's undiscovered oil resources vary with the organizations which make them. The picture may be complicated further if it is not clear whether the figures refer to the total resources or the potential recoverable resources (oil fields have a recovery factor as low as 20% of the oil in place). Estimates of the world's total undiscovered resources in place made in recent years vary from 1250 to 2290 x 10^9 barrels (170 to 310 x 10^9 metric tons), according to a survey by Warman (1972), who sees the recoverable fraction as 1600 to 1800 x 10^9 barrels (220 to 245 x 10^9 metric tons). Among the more recent estimates of undiscovered oil are those of Odell (1974)[1] at 4000 x 10^9 barrels (550 x 10^9

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[1] Odell based his predictions on statistical, economic extrapolation from existing trends rather than the conventional assessment of geological evidence.

metric tons) and of Moody (1975)[1] at 963 x 10^9 barrels (130 x 10^9 metric tons).

The world's natural gas reserves are at present roughly 7, 500, 000 x 10^9 cubic feet (210, 000 x 10^9 cubic meters) with an estimated future potential of 5, 080, 000 x 10^9 cubic feet (144, 000 x 10^9 cubic meters) (anonymous source).

B. Offshore

Although offshore reserves are only some 165 x 10^9 barrels (22.4 x 10^9 metric tons), the continental margins, rich in sediments localized in troughs, show every indication of containing oil and gas in substantial quantities. The deeper ocean slopes may have equally rich reservoirs, but there has not been extensive exploratory drilling yet due to the absence of proven techniques for producing oil if it were found; these areas are likely to be opened up in the future (NAS, 1975). McCaslan (1975) estimates that 98% of ultimately recoverable offshore petroleum will be found in water depths of less than 650 feet (200 meters) as shown in Figure 2-7.

The total undiscovered offshore oil resources of the world could be as high as 1950 x 10^9 barrels (270 x 10^9 metric tons) (Weeks, 1973, 1974, and quoted in NAS, 1975). The estimates of Moody (1975), shown below, are rather more conservative (Table 2-2).

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[1] These estimates include those made by Weeks (1973 and 1974). In the development of a methodology for estimating future reserves, a great debt is owed to H. M. King (NAS-COMRATE, 1975) and to the contributions of J. D. Moody (1970).

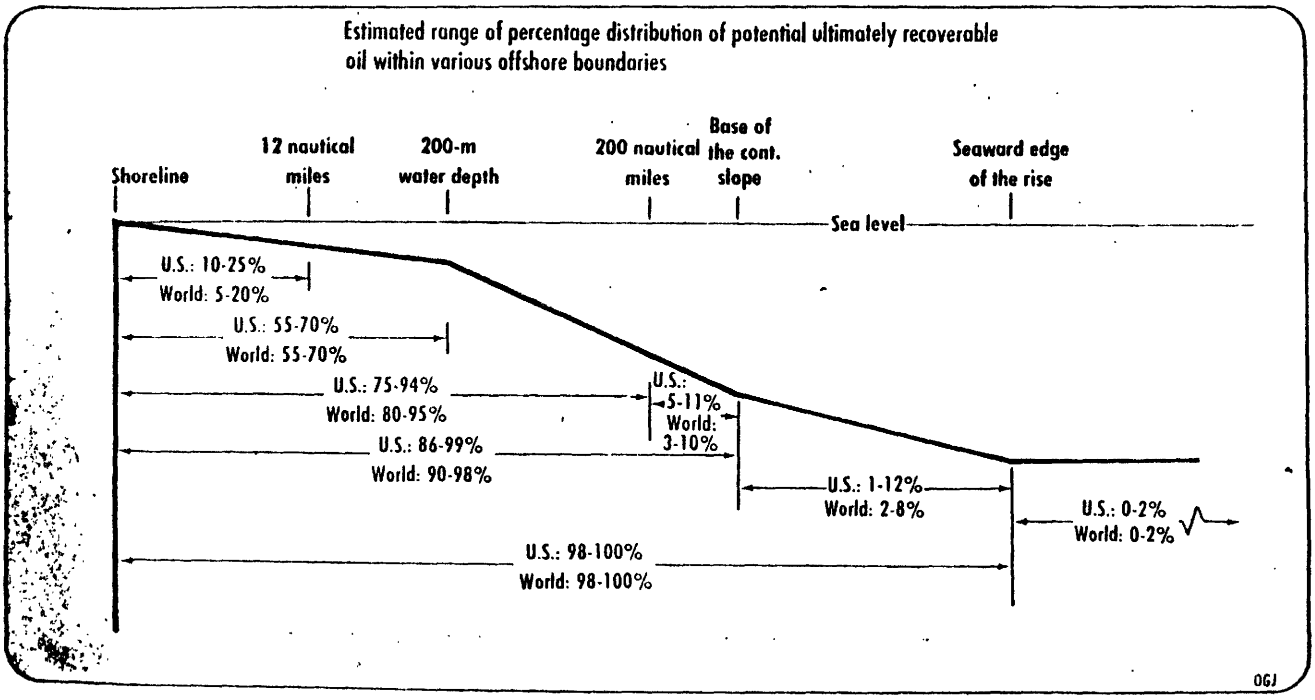

Figure 2-7. Offshore petroleum resources (from Oil and Gas Journal, May 5, 1975, p. 226).

Table 2-2. Estimated undiscovered resources of oil (C. F. Moody, Petroleum Economist, 1975).

	barrels of oil	metric tons of oil
World	963×10^9	131×10^9
World offshore	378×10^9	52×10^9
EEC	45×10^9	6×10^9
North Sea	30×10^9	4×10^9

In conclusion, with rates of increase in present annual production (20×10^9 barrels per year), there are less than 30 years of world production foreseeable from existing reserves. Undiscovered resources may add another 50 years. It appears that more than half of future production would be offshore.

2.3.3 EEC Reserves and Undiscovered Potential

A. Reserves

The present reserves picture for the EEC is shown in Table 2-3.

Table 2-3. EEC 1975 oil and gas reserves (from International Petroleum Encyclopedia, 1975).

COUNTRY	OIL		GAS	
	10^6 barrels	% offshore	10^9 cu ft	% offshore
Denmark	247	16%	500	5%
Italy	750	5%	12,000	15%
France	142	—	5,800	—
Netherlands	250	—	94,800	35%
West Germany	550	—	11,473	10%
United Kingdom	15,700	80%	50,000	90%
Belgium	—	—	—	—

The North Sea alone had reserves estimated in 1975 to be 18.5 to 19.5 x 10^9 barrels (2.5 to 2.7 x 10^9 metric tons). Within this area, five fields (Forties, Brent, Piper, Auk and the Ekofisk field in the Norwegian sector) had proven reserves of 6.3 x 10^9 barrels (0.9 x 10^9 metric tons) (White et al., 1974, p. 55). Gas reserves are currently estimated at between 47,000 x 10^9 cubic feet (1330 x 10^9 cubic meters) (MacKay, 1975, p. 59) and 55,000 x 10^9 cubic feet (1560 x 10^9 cubic meters) (OECD, 1974, Vol. 11, p. 139). The current reserves of the North Sea are outlined in more detail in Table 2-4.

B. Undiscovered Potential

The NAS-COMRATE (1975) report puts the undiscovered oil potential of Western Europe (Spain, Portugal, France, West Germany and Italy) at 15 x 10^9 barrels (2 x 10^9 metric tons) and the undiscovered potential

Table 2-4. North Sea fields (from Offshore Services, October 1975, p. 35).

Field Name	*Water Depth*	*Est. Reserves*	*Est. Prod. (max.)*	*Comments*
Alwyn	418ft	500m bbls		
Andrew	330ft	300m bbls		
Argyll	250ft	100m bbls	45 000 b/d	
Auk	280ft	150m bbls	40 000 b/d	
Beryl	384ft	800m bbls: 0.4 x 10^{12}cu.ft	120 000 b/d	
Brae	335ft			
Bream	300ft	130m bbls		
Brent	445ft	2000m bbls: 0.7 x 10^{12}cu.ft	500 000 b/d	
Brisling	300ft	150m bbls		
Bruce		Condensate		Uncommercial
Claymore	375ft	700m bbls	200 000 b/d	
Cod	230ft			
Cormorant	500ft	400m bbls	100 000 b/d	
Crawford				
Dan	136ft	30m bbls	8000 b/d	
Dunlin	500ft	1250m bbls	200 000 b/d	
Ekofisk complex:				
Albuskjell	230ft	600m bbls: 1.7 x 10^{12}cu.ft	800 000 b/d 1200 mcfd	
Edda		100m bbls: 0.2 x 10^{12}cu.ft		
Ekofisk		1234m bbls: 3.7 x 10^{12}cu.ft		
W. Ekofisk		524m bbls: 2.6 x 10^{12}cu.ft		
Eldfisk		380m bbls: 1.6 x 10^{12}cu.ft		
E. Eldfisk				
Tor		150m bbls: 0.5 x 10^{12}cu.ft		
N.W. Tor		100m bbls		
S.E. Tor		23m bbls		
Flyndre		200m bbls		
E.&N.E. Frigg	340ft	5 x 10^{12}cu.ft	430 mcfd	
Forties	400ft	2000m bbls	400 000 b/d	
Frigg	310ft	12 x 10^{12}cu.ft	1205 mcfd	60%N 40%UK
Heather	470ft	500m bbls		
Heimdall	395ft	2.5 x 10^{12}cu.ft	220 mcfd	
Hutton	491ft	800m bbls	200 000 b/d	
Josephine	238ft			Uncommercial
Lomond	120ft	80m bbls: 0.8 x 10^{12}cu.ft		
Magnus	600ft	700m bbls		
Maureen	300ft	300m bbls		
Montrose	196ft	500m bbls	50 000 b/d	
Ninian	450ft	1100m bbls (?)	200 000 b/d (?)	
Odin	340ft	1.5 x 10^{12}cu.ft	150 mcfd	
Piper	475ft	800m bbls	240 000 b/d	
Statfjord	470ft	3000m bbls: 3.5 x 10^{12}cu.ft		10-15% reserves in UK
Tern		300m bbls		
Thistle	530ft	800m bbls	200 000 b/d	
		200m bbls		
		200m bbls		
		1.0 x 10^{12}cu.ft		
		1.0 x 10^{12}cu.ft		
		Condensate		Uncommercial
	380ft	400m bbls		
	—			
		60m bbls: 0.8 x 10^{12}cu.ft		
	490ft			

of the North Sea (including the United Kingdom, Eire, Norway, Belgium, Denmark and the Netherlands) at 35 x 10^9 barrels (5 x 10^9 metric tons), indicating a combined oil potential for the EEC countries of approximately 47 to 48 x 10^9 barrels (6.6 to 6.8 x 10^9 metric tons).

The same source estimates the gas potential for the EEC, exclusive of the North Sea, as 61,000 x 10^9 cubic feet (1700 x 10^9 cubic meters) and for the North Sea a further potential of 175,000 x 10^9 cubic feet (5000 x 10^9 cubic meters) – a total potential of 236,000 x 10^9 cubic feet (6700 x 10^9 cubic meters). The United Kingdom Department of Energy predicts reserves of over 27 x 10^{12} cubic feet (760 x 10^9 cubic meters) in the United Kingdom sector of the North Sea (1975), and total North Sea reserves have been estimated at 47 to 55 x 10^{12} cubic feet (1.4 to 1.6 x 10^{12} cubic meters) (Table 2-5) (also see Section 2.3.2).

Clearly, the offshore areas, particularly the North Sea, offer the greatest prospects. Estimates put forward by the oil companies indicate the North Sea undiscovered potential to be 44 to 50 x 10^9 barrels (6 to 7 metric tons).[1] The OECD (1974) is likewise optimistic concerning the importance of offshore areas, predicting that 60% of the total proved, possible, and probable gas reserves of the EEC lie offshore in the North Sea, the Adriatic, the coast of Sicily, the Mediterranean south of France, where a number of salt dome structures have been identified by geophysicists in water 10,000-feet (3000-meters) deep (Burollet, 1969), along the Atlantic coast west of Brittany, and on the Rockall Plateau (UN Economic and Social Council, 1971). Additional potential exists in Greenland, where the first awards for oil and gas exploration were made in 1975 (Oil and Gas Journal, May 5, 1975).

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[1] The estimates of Odell (1974) of North Sea undiscovered resources are ambitiously set at 79 to 138 x 10^9 barrels (11 to 19 x 10^9 metric tons).

Table 2-5. Estimated United Kingdom North Sea gas reserves (remaining in known discoveries, December 31, 1974) (from United Kingdom, Department of Energy, 1975, p. 12).

	Totals in trillion (10^{12}) cubic feet			
	Proven	Probable	Possible	Total
Southern Basin Fields presently being produced or under contract to British Gas	18.2	1.1	1.5	20.8
Other discoveries to be commercial but not yet covered by British Gas contract	2.8	0.1	0.2	3.1
Other discoveries which may become commercial	—	1.2	1.4	2.6
Total Southern Basin	21.0	2.4	3.1	26.5
Northern Basin Under contract to British Gas	2.9	0.3	—	3.2
Other significant gas discoveries (including gas in gas-condensate finds)	—	4.3	4.5	8.8
Gas associated with oil discoveries	3.0	2.5	0.4	5.9
Total Northern Basin	5.9	7.1	4.9	17.9
Total United Kingdom North Sea	26.9	9.5	8.0	44.4

2.3.4 Unconventional Offshore Resources

Hydrocarbon resources in this category may have an important future role to play. At present, they are not exploited because of economic or technical limitations.

Clathrates are oil-like accumulations of crystallized gas. Found in the sediments at the foot of continental slopes, these ice-like molecules could receive considerable attention in the future if methods are found to extract them from the sediments (Kaplan – NAS-COMRATE, Meeting of 11-13 June 1973).

Oil shales occur in sedimentary basins onshore and offshore. They constitute a possible energy resource intermediate between oil and coal. There are extensive oil shale deposits in the world, and the process for extracting oil has been known for over a century, but problems of mining the shale and disposing of waste has made shale oil extraction uneconomic. Should oil prices continue to rise, shale oils will assume greater importance (OECD, 1975). Tar sands in sedimentary basins are also a potentially major hydrocarbon resource of the future. The total world resources are only incompletely known but only one-tenth of tar sands are recoverable with present technology (NAS, 1975, pp. 94 and 97).

2.4 OFFSHORE MINERALS

Extensive information on offshore minerals may be found in Mero (1965) and Cruikshank et al. (1973).

2.4.1 Definitions

Worldwide offshore minerals belong to three categories, depending on the materials with which they are found associated:

1. Minerals on or near the seabed are generally called detrital because they have resisted abrasion and destruction while being transported in geological time. Detrital minerals concentrated in economic quantities are called placers. Familiar placer minerals include tin, gold, zircon, platinum, diamonds, sand and gravel, the titanium minerals ilmenite and rutile, and monazite.

Also found on the seabed are chemically precipitated deposits of calcium carbonate (oolites) and of phosphates (phosphorite).[1]

To become economically useful, minerals on the seabed must be separated from valueless materials, such as silt or sand, found associated with them.

2. Minerals in veins or seams consolidated within hard rock may lie several hundred to several thousand feet below the seabed. Most known minerals can theoretically exist in this manner, but few have yet been found offshore. The most significant are coal, iron, sulphur, potash, salt and tin.

3. Some chemicals dissolved in seawater, including bromine, potassium, magnesium compounds, salt, heavy water, and fresh water, are commercially recoverable. Other chemical elements, such as gold, are present in small quantities not economically recoverable (UN Economic and Social Council, 1971; Fossett, 1970; Mining Annual Review, June 1975).

2.4.2 World Production Data

Table 2-6. Estimated 1974-1975 world offshore production of hard minerals (indicating principal source areas).

	Units	Quantity	U. S. dollar value millions	EEC Share %
Seabed Minerals				
Sand and Gravel (UK)	short tons	13×10^6	40×10^6	95-98%
Tin metal (Southeast Asia)	short tons	15, 000	90×10^6	1%
Shell (U.S.)	short tons	10×10^6	20×10^6	0

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[1] Although manganese nodules are a valuable resource of nickel, copper and manganese, they are not discussed here because they occur in much deeper ocean basins.

Table 2-6. (continued)

	Units	Quantity	U. S. dollar value millions	EEC Share %
Seabed Minerals (continued)				
Aragonite (Bahamas)	short tons	500, 000	?	0
Minerals below Seabed				
Coal (UK and Japan)	short tons	$5\text{-}10 \times 10^6$	$25\text{-}50 \times 10^6$	70%
Potash (UK)	short tons	400, 000	20×10^6	100%
Sulphur-Frasch (U. S.)	short tons	4×10^6	$150\text{-}200 \times 10^6$	0
Chemicals from Seawater				
Magnesium (U. S.)	short tons	125, 000	100×10^6	0
Magnesium Compounds	short tons	250, 000	25×10^6	25%
Bromine and bitterns	short tons	100, 000	50×10^6	0
	Total Value		$500\text{-}550 \times 10^6$	

2.4.3 EEC Offshore Minerals

A. On or Near the Shallow Seabed

In the UK detrital tin deposits have been located off St. Agnes, Cornwall, mainly in drowned stream channels in 25 to 50 feet of water. St. Ives and Mounts Bay have also been dredge-sampled in an attempt to evaluate such deposits. In 1973, 151 tons of tin concentrate were produced from a through-put of over 14, 000 tons of tailings and beach sand (Mining Statistical Yearbook, 1976).

Economic deposits of zircon and associated heavy minerals may be present off the east coast of the United Kingdom at Spurn Head and the Dogger Bank (UN Economic and Social Council, 1971).

Sand and gravel deposits are found in abundance on the continental shelves and are exploited in shallow water (100 feet) areas around the United Kingdom (NOAA, 1971), Denmark and France. Most extensive dredging has occurred in the United Kingdom where offshore production is approximately 11% of the annual production of 120 x 10^6 tons. Offshore sand and gravel deposits are increasing in demand by the expanding construction industries of the EEC,and future exploitation is likely to be considerable (Archer, 1973).[1]

B. Below the Seabed

Coal seams 1000 and 2000 feet below seabed level are extensively mined under the sea off the coast of Northumberland and to a lesser extent off the coast of Kent and Scotland in the United Kingdom (Figure 2-8). The National Coal Board (NCB) of the United Kingdom estimates that a further 550 x 10^6 tons of coal can be mined by existing methods under the North Sea and that larger reserves of coal extending offshore are not accessible from land at this time. At present production rates of approximately 100 x 10^6 tons per year, United Kingdom coal resources would be sufficient for approximately 100 years.[2]

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[1] Sand and gravel deposits should not contain more than 40% sand and not more than 5% of silt and shells. The sodium chloride content of the washed gravel should be less than 0. 1% if it is to be of commercial value in the construction industry.

[2] In 1972-1973, the total United Kingdom coal production was 140 x 10^6 tons. The underground deep-mine production was 130 x 10^6 tons. The amount mined under the sea was not reported separately. In 1973-1974, total production dropped to 107 x 10^6 tons because of industrial disputes (Energy, HMSO, 1974).

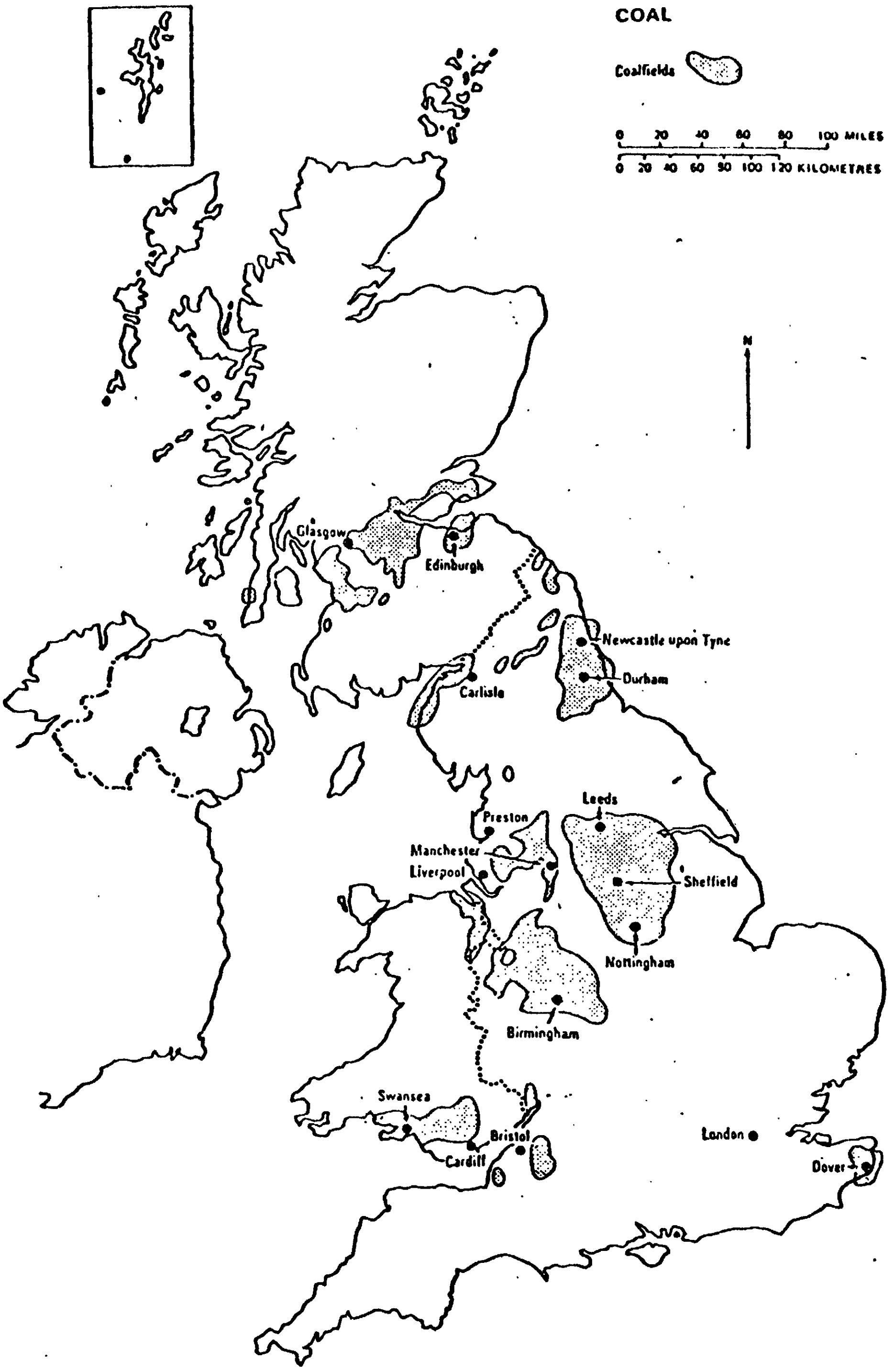

Figure 2-8. Location of coal fields in the United Kingdom (from Energy, HMSO, 1974, p. 7).

Potash beds occur under the sea near Whitby in Yorkshire. Extraction by underground mining is currently aimed at the rate of 1.0 x 10^6 feet per year (304,000 meters per year) 4000 feet below ground. These beds may extend farther under the North Sea in the Zechstein Basin. On the west coast, anhydrite is mined in Cumbria and may extend under the Irish Sea.

In offshore EEC areas, undiscovered resources may include tin lodes off Cornwall. (The largest mine in Cornwall, at Pendeen near St. Ives, was recently extended under the sea to the old Levant mine.) Tin may also be found in similar geological structures off the Brittany coast. Metallic sulphide veins may exist off the coast of Sardinia; sulphur may be found in association with salt domes off the Mediterranean south coast of France; and geothermal energy near Sicily and southern Italy. As technology develops, these resources may be found and exploited.

C. Minerals Dissolved in Seawater

Extraction of magnesia from seawater, rather than from the conventional land sources, is now widely favored. In 1969, the first United Kingdom plant for the extraction of magnesium compounds from seawater was built at Hartlepool. The annual production rate at Hartlepool is 254,000 tons, and it takes approximately 1.5 tons of dolomite and 75,000 gallons of water (350 tons) to produce 1 ton of magnesia (Archer in Goldberg ed., 1974). Other plants are under consideration in the Mediterranean.

Small plants exist in France, Italy and the United Kingdom both for the desalinization of seawater and for the extraction of sea salt. Such plants are of only local importance.

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2.5.2 Organizations

No attempt has been made to list all the government departments, educational establishments, institutes, or private agencies which contribute in some way to the offshore field. Such a task would be impossible. Some of the organizations named below can provide further information:

AAPG	American Association of Petroleum Geologists
ASTEM	Association Scientifique et Technologique pour l'Exploitation des Mers. France.
API	American Petroleum Institute. Washington, D. C.
CNEXO	Committe National pour l'Exploitation des Oceans. France. Also, Committe d'Etudes Marines.
CNRS	Centre de Recherches Scientifiques. France.
DOE	Department of Energy. United Kingdom.
ICES	International Council for Exploration of the Sea.
IFP	Institut Francais du Petrole, Paris.
IGS	Institute of Geological Sciences. United Kingdom.
IP	Institute of Petroleum in London.
	Ministerialrat Bundesministerium fur Furschung and Technologie. West Germany.
NAS	National Academy of Sciences – Committee on Mineral Resources and the Environment. Washington, D. C.
	Netherlands Mining Institute.
OECD	Organization for Economic Cooperation and Development.
UN	United Nations.
USBM	United States Bureau of Mines. Washington, D. C.
USGS	United States Geological Survey.

CHAPTER 3

THE OFFSHORE ENVIRONMENT

CONTENTS

CHAPTER 3

THE OFFSHORE ENVIRONMENT

The offshore environment covers 70% of the earth's surface. It has a multidimensional character — it is the fragile habitat of seabirds, fish and plankton, but to man it can be hostile and unpredictable, endangering vessels and slowly wearing away his workings. The purpose of this chapter is first, to describe the natural forces which are at work in the offshore environment, where minerals are found and exploited, and, second, to briefly summarize the expanding technology of oceanographic measurements.

Random natural processes are continuously at work in the offshore environment. These processes are still not fully understood because of:

1. the range of scales on which they operate.
2. their many interrelationships.
3. their dynamic and discontinuous character.

Oceanography, the science of the offshore environment, embraces many disciplines: meteorology, physics, geology, and the specialized aspects of marine biology. It is a science still mainly observational and without laws to firmly predict the behavior of the processes at work.

Offshore technology uses the scientific knowledge of the environment to design safe and reliable marine systems.

3.1 THE ENVIRONMENT OF OFFSHORE MINERALS

The continuous disturbances of the masses of air, water, and sand in the offshore environment are due to exchanges of energy. These exchanges result in the forces which shape coastlines, fish, birds, and sea mammals, as well as ships, production platforms and submarines. It is convenient to refer to a region as a high or low energy environment depending on the intensities of energy exchanges which typify that region.

3.1.1 The Air

Many ocean processes orginate from changes in temperature and pressure in the air masses circulating over the oceans and continents of the world. The circulation of these air masses produces winds. At sea, winds range from highly variable and localized turbulence to major storms and gales on the regional scale. It is now possible to achieve some degree of accuracy in forecasting storms from pressure data, but the maximum storm or the maximum disturbance within a single storm are still not fully predictable.

The drag force of wind against a ship or a fixed structure during its service must be anticipated accurately before its construction. This drag force increases with the square of the wind speed.

Ice and snow add weight to the surfaces on which they lie. Ice clings and grows with sea spray[1] and increases the surface exposed to the wind.

Air and sea temperature differences cause expansion and contraction of materials, resulting in stresses.

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[1] Accretions of ice on the rigging of ships have been seen to grow 3-14 inches (7-35 centimeters) in a few hours in the North Sea.

3.1.2 The Air-Sea Interface

The sea surface is always rising and falling with the tides and undulating with waves. The wind friction against the water surface makes waves, but the way in which wind energy is imparted to the waves still is not well explained. Although the water is not transported by waves in the open ocean, wave shapes themselves may travel long distances. Traveling from a distant source across an open ocean, the wave shape gradually purifies itself to become a swell. Wave shapes passing a point are described by their height (the vertical distance between crest and trough) and their zero crossing period (the time interval between two crests passing the same point) (Shepard, 1973).

No two waves are alike in height or period. A wave spectrum describes a family of wave heights and periods generated by a given wind force for a particular duration of time. For a region, it is possible with adequate data to describe the wave spectra or regime over a period of years and to estimate the largest wave that can be expected in 50 or 100 years; but, it is not possible to predict when that wave will occur. Waves can develop to a great height in storm conditions and can achieve tremendous destructive power. There are reliable reports of waves of over 100 feet (30 meters) having been observed.[1] The destructive power of storm waves is likewise supported by many accounts.[2]

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[1] The S. S. Ramapo observed a wave of 112 feet (34 meters) in the Pacific Ocean in 1933 (Bascom, 1964, p. 58). A more dramatic sighting by the lightkeeper of the light at Trinidad Head, California, was of a wave that was as high as the light itself, some 195 feet (60 meters) above sea level (Bascom, 1964, p. 238).

[2] The breakwater at Wick Bay, north Scotland, was destroyed by a tremendous storm in 1872. Stevenson's historic account describes the way in which huge blocks of masonry weighing from 80 tons to an incredible 1350 tons were carried from the breakwater into the harbor (Bascom, 1964, pp. 421-423).

During a violent storm, there may be a noticeable rise in sea level along a coast: this is known as a storm tide or surge. This rise in water level is the result of differences in air pressure over the sea and land. Near shore winds propel large waves across shoaling water, forcing their steep breaking crests so hard after one another that surface water cannot be returned seaward along the bottom and the piling water floods the coast.[1]

Knowledge of waves is critical to marine design in several ways. The passage of a wave by a fixed object, such as piling, has four effects:

1. increasing the water level causes increased buoyancy.
2. flow back and forth results in drag forces.
3. by breaking against piling, the wave tends to push it over.
4. the frequent mixing of oxygen and water in the splash zone is highly corrosive.

The response of floating objects, such as ships or production platforms, to waves is somewhat different from fixed objects. The floating object may roll from side to side and may also heave up and down. It may, depending on its shape and mass, move in harmony with the waves or remain stationary.

The sea surface and the water beneath, through which light penetrates, are the habitat of marine life. Despite the turbulent forces involved, there is a great variety of ingeniously shaped, intricately adapted, interdependent organisms actively reproducing and seeking nourishment near the air-sea interface.

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[1] A famous example of a storm surge was the Galveston, Texas, flood of 1900. In 1953, a storm surge swept waters down the North Sea and breached the Dutch coast dikes, flooding 800, 000 acres (Bascom, 1964, p. 78).

3.1.3 The Water Column

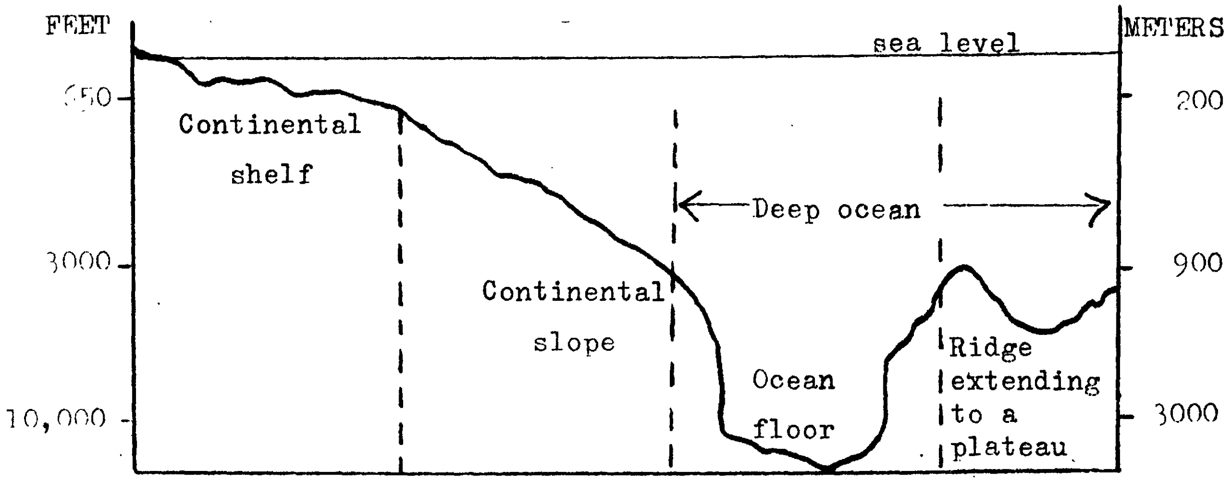
As in the other parts of the offshore environment, water masses below the surface are constantly in motion. Currents flow in the sea exchanging and transporting heat, chemicals and nutrients along the way; their speed and direction change vertically and laterally with the seasons, the days, the tides, and the hours.

Pressure is the only near static force in the marine environment, being always directly proportional to the height of the water column which itself only changes with the tides.

When man enters the marine environment, organisms colonize his structures. Such colonization is described by the unfortunate term of fouling. Organisms clinging to a surface increase its drag resistance to currents and may weaken its resistance to corrosion.

3.1.4 The Sea Floor

Each sea floor region has a characteristic topography, sediment cover, and its flora and fauna. According to established nomenclature, the sea floor is given different names as it slopes seaward as shown in Figure 3-1. The sea floor is relevant to marine technology in two main respects: sedimentary processes and as the habitat of marine fauna.



(vertical scale exaggerated)

Figure 3-1. Zones of the sea floor.

Sea floor sedimentary processes vary with the zones. In shallower water, coarse sediments such as sand are involved (McCave, 1973), and finer sediments are generally found farther from shore. Moving sand banks change the depths of the continental shelf areas. In the North Sea, for example, sand shifts along the sea floor in great, dune-like waves. The speed and direction of this movement are related to the strength of the ocean currents. However, sand ridges do occur in areas with weak currents which suggests they were formed under more turbulent conditions in a former era (Stride, 1973).

On the continental slope, turbidity currents drive huge masses of sediment which periodically tumble, avalanche-like, down to the abyssal plains of the deep ocean, devastating everything in their path (Shepard, 1973). Sea floor sediments can become impregnated with foreign substances and can be either vectors or repositories for pollutants.

The flora and fauna of the sea floor vary with temperature, current velocity, depth (temperature, light and pressure change with depth) and the availability of nutrients. The most familiar organisms live on, or are spawned on, the shallow seabed. Plankton and benthos (bottom organisms) are the start of the sea food chain and feed the great shoals of fish[1] that populate the continental margins (Fraser, 1973). The shallow seabed is also the home of many mollusks and crustaceans such as crab, shrimp and lobster, and the oyster, mussel and cockle (Korringa, 1973; Cushing, 1973). Plant life of the seabed, rich and varied, is often of economic importance to man — some species of seaweed are gathered for food fertilizer and for the extraction of iodine.

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[1] It is useful to distinguish between pelagic fish such as herring, mackerel, pilchard and sprat which only spawn on the sea bottom, and demersal fish such as cod, haddock, rays, plaice, sole, turbot and whiting which live and feed on or near the sea bottom (Sibthorp, 1975. See also Brodie, 1972).

3.1.5 Below the Seabed

Below the few feet in which organisms make their habitat, the seabed is a mostly inert environment. Its relevance is associated with the presence of freshwater aquifers, of minerals, and of formations which are as important to the foundations and safety of offshore structures as soils to buildings on land. The homogeneity and strength of the clays and sands are an integral part of the offshore environmental information necessary to design a sea floor supported structure (Bynum and Lovie, 1974; Wilson, 1975).

3.1.6 Life

Marine ecology is the study of the habitats of creatures within the marine environment. Marine life is intricately specialized, and its finely balanced adaptation to environmental processes is less than fully understood. For this study of offshore mineral production, only the broadest aspects of life in the marine environment can be taken into account.

One such aspect is the productivity of a zone which expresses quantity of biomass (biological material) per unit volume of the region (Cushing, 1973). Another is the maximum sustainable yield or level at which a natural living resource, such as fish, may be regularly harvested without impairing the productivity of a region or its ability to replenish itself.

For centuries, man has looked to the sea for part of his food supply. Just over 50% of seafood comes from only 0.1% of the ocean — not because of any difficulties involved in fishing in deep waters but because the most prolific fishing areas are in the shallow seas of the continental margins (Korringa, 1973).

Man is only just becoming aware of the results of his over zealous fishing of the oceans.[1] One method of preserving fish stocks is to establish

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[1] Cod and herring catches should be about half the present level if stocks are not to be fished out (Sibthorp, 1975, p. 16).

fish farms for spawning fish (Milne, 1972). Sheltered coastal and estuarine areas (if there is no danger of pollution) provide breeding grounds for fish and cultivation grounds for shellfish.

Sea birds make their nesting place along the coasts in marshy areas or on cliff faces (Evans, 1971). Great river delta areas, such as the Rhone, the Rhine and the Po, and esturine areas such as the Wash, are the breeding and nesting grounds of ducks. Cliffs in Scotland and Brittany provide nesting places for gulls, puffins and terns (Nye et.al., 1971). Open sea diving birds, chiefly the auk and the seaduck, are species vulnerable to floating oil.

3.2 ENVIRONMENTAL MEASUREMENTS

The quantification of environmental processes necessary to serve offshore technology and to assess possible environmental damage demands more and better oceanographic measurements. These measurements require sensors and instruments to collect data. The art of making instruments, of placing them effectively to obtain data, and of interpreting data is critical to understanding environmental processes correctly.

3.2.1 Environmental Measurement Technology

1. Sensors are devices which respond to a natural process in some measurable fashion. There are sensors of wind velocity (anemometers), of current velocities and direction (current meters), of air temperature and humidity (dew point hygrometers), of sea floor shear strength, of wave height and period, and of tide levels. A sensor is designed for measurements at a predetermined level of accuracy and sensitivity over a period of time in one location.

2. Measurement requirements. The scale of the process investigated and the cost of measurements constrain the acquisition of environmental data. Ocean current data collected at one point may not be reasonably expected to be representative of conditions 300 feet (100 meters) below or 1.5 miles (2 kilometers) to the side. Similarly, a satellite photograph of the cloud pattern over a whole ocean basin may provide broad information on the wind circulation but will not give the maximum wind load at a particular location. Nor will placing an anemometer there for a few months, or even a full year, give a wholly representative picture of what wind speed is likely to be for several years in succession (Beckwith, 1975).

For most environmental measurements, statistical concepts of sampling in space and time are essential to obtain reliable estimates of average and extreme phenomena. The design of measurement programs at sea requires the careful selection of a number of sampling locations. In the open ocean, the emplacement and maintenance of a sensor may require elaborate support — this may be a ship remaining on station or an autonomous buoy recording data in place and telemetering it to shore.

During the design of offshore mineral exploitation projects, judgments must be made whether existing data are adequate to estimate the largest possible wave, the highest wind gust, and the maximum current velocity, or whether new data must be collected (Pitt, 1974). When new data are needed, the scale of the offshore mineral targets and of regional environmental concern dictates that multiple measurements must be made by sensors deployed over vast areas for several years to provide an accurate synoptic picture of the processes at work. The costs and the degree of organization required to successfully carry out such measurements call for the resources of multinational bodies (Mallery, 1975).

3. Interpretation. The ultimate value of all environmental measurements lies in their interpretation, which, if successfully done, can serve to forecast future events. The quality of forecasts of conditions in the open ocean has greatly improved in the recent past. For a particular storm, it is now possible to make reasonable predictions of waves and wind conditions up to 36 hours in advance (Hull and Austin, 1974). The prediction of the likely frequency and intensity of storms for a whole year is much more difficult because data have not yet been accumulated for long enough times.

Hindcasting is the technique of reconstructing wave climates from past atmospheric pressure data (Cardone and Pierson, 1975). The calibration of hindcasts against observed historical wave data provides a basis for forecasting. The prediction of the highest wave for a region and for a given span of time is much more controversial. Such predictions depend on the interpretation of phenomena such as storm tides, observed indirectly, usually at locations remote from the point of interest.

3.2.2 Baseline Studies and Monitoring

A baseline is intended to be a reference mark from which ecological and environmental changes may be measured at any subsequent time in a given region. In principle, any measurable parameter such as the biomass per unit volume or the oil content of seawater could be sampled to establish a baseline at any time prior to the installation of an offshore project. However, there is difficulty in selecting the criteria for establishing a baseline since the baseline measurements are themselves dependent on the sampling process. For example, it would be pointless for obvious reasons to establish a baseline of the North Sea herring population by recording the size of catch of herring during any particular set of years. Usually, the time span of the measurements is too short and results in a high level of variance. Monitoring is the process of environmental measurement to test whether certain parameters remain within baseline criteria. Despite the foregoing limitations on baselines, the value of monitoring to environmental protection cannot be denied.

3.2.3 Future

The future technology of environmental measurements offshore will have a critical influence on the preservation of the environment and on the compromises between the cost of environmental protection and the benefits derived from it.

For minerals and petroleum exploitation, the following developments are needed:

1. Improvement of sensors for monitoring petroleum and its derivatives. The availability of reliable sensors for continuous monitoring of hydrocarbon discharges would enable greater ease of compliance and observation.

2. Large scale regional networks of sensors placed to provide a continuous synoptic picture of wind and sea conditions. Much progress has already been achieved in the North Sea with the work currently in progress and planned by the North Sea Oceanographic Study Committee (NSOSC), the United Kingdom Offshore Operators Association (UKOOA) Oceanographic Committee, the Cooperative European Oceanographic Data Collection (COST 43) cooperative European venture for establishing a grid of telemetering data buoys by 1980 and the recently formed Oil Industry International Exploration and Production Forum (E and P Forum) for consultation with the United Nations and other organizations (Mallery, 1975). This work is primarily oriented toward the collection of physical environmental parameters (winds, waves and currents). The development of more reliable automatic wave and current sensors which can telemeter standardized data would be very valuable to such programs.

3. Improved theoretical understanding of wave and current processes in high energy regions will benefit both safety and cost aspects of offshore structures, and, as more data accumulates, more reliable and accurate predictions and forecasting will be possible.

3.2.4 Personnel

The safety and working conditions of oceanographic scientists, engineers, technicians and seamen engaged in making environmental measurements have received very little attention. Working for long hours at sea on small vessels, these men provide the measurements and forecasts vital to the whole offshore industry.

3.3 OFFSHORE ENVIRONMENTAL REGIONS OF THE EEC AND THEIR RELEVANCE

In this section, the salient environmental aspects and related human activities of the offshore regions of the EEC are briefly reviewed. For environmental purposes, there would be good reason to compile an atlas of the various EEC offshore regions. For this study, three have been identified: the North Sea, the North Atlantic, and the Mediterranean.

3.3.1 The North Sea

The North Sea is a high energy environment — only in the North Atlantic are more extreme conditions encountered. The North Sea lies between the continental and Atlantic air masses. In winter frontal depressions, moving and deepening over the North Atlantic, fill the area. The average temperature through the year is approximately 17°C, ranging from as low as -10°C to over 30°C in the summer when stable anticyclonic spells can lead to occasional periods of fine weather (Hohn, 1971). Frontal conditions give rise to rain in all seasons of the year. Storms and gales in the winter months lead to wind gusts of over 90 miles per hour (145 kilometers per hour) and high waves. (An extensive description of the North Sea environment may be found in Goldberg (1972). In Sibthorp (1975), data on uses and fisheries are given.)

Difficulties in estimating maximum probable wind speeds over the North Sea arise from the lack of records (Department of Energy, 1974). Maximum storm conditions are extrapolated from past storm tide records. In the winter of 1971-1972, wave heights of 60 feet (18 meters) were recorded in the Frigg field, of 80 feet (24 meters) in Ekofisk and 95 feet (29 meters) in the Brent field. The bulk of present wave data is from visual observation, and confidence levels for wave height and period estimates are low. There is a similar lack of adequate measurements or understanding of near-surface sea currents. Seabed topography is poorly charted at the precision necessary to safely locate offshore installations. Dune like waves of 50 feet (15 meters) in height and many uncharted wrecks on the seabed add to the problems. (ICES, 1969; Hill in Goldberg, 1972; McGregor-Hutcheson and Hogg, 1975, pp. 16-26.)

In 1967, seven oil companies (Amoco, BP, Burmah, Conoco, Mobil, Shell, and Total) with the assistance of the United Kingdom Institute of Oceanographic Science and the MAFF Fisheries Laboratory, Lowestoft, formed the North Sea Environmental Study Group (NSESG) which collected data from December 1967 to April 1971 from six points in the North Sea.[1] A very abbreviated summary of the data collected by the NSESG follows (Mallery, 1975):

Wind

Southern North Sea

Maximum 1 hour mean = 55 knots
Maximum gust = 73 knots

Northern North Sea

Maximum 1 hour mean = 66 knots
Maximum gust = 91 knots

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[1] Four southern North Sea gas platforms were instrumented, plus Staflo, a semisubmersible operating off Scotland. Also the M. V. Famita, a rescue vessel.

Waves[1]

Southern North Sea

Maximum predicted H_s = 16.9 feet
Maximum predicted H_m (3 hours) = 32.9 feet

Northern North Sea

Maximum predicted H_s = 40.4 feet
Maximum predicted H_m (3 hours) = 74.4 feet

Currents

Southern North Sea

Maximum measured current 3.03 knots (n. miles per hour)

Northern North Sea

Maximum measured current 1.02 knots

Some problems were experienced which highlighted the need to improve instrument reliability for wave and current measurements. Difficulties were also encountered in using rigs and structures as data collection points when they are dedicated to hydrocarbon exploration and production and not to weather measurement. In 1972, the UKOOA and the Government formed the North Sea Oceanograph Study Group (NSOSG). NSOSG and the Institute of Oceanographic Sciences use a chartered ship as a data collection center in the North Sea. Real-time weather reports are sent from the ship every three hours (Mallery, 1975).

Biologically, the North Sea is an area of high productivity resulting in an active tradition of fishing (Cole and Holden, 1971). In 1971, the North Sea landed catch was some 16 x 10^6 tons[2] of fish from 11 principal species. Other North Sea users are having an increasing effect on the fishing industry in three main ways:

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[1] H_s = significant wave height; H_m = mean wave height.
[2] Twenty percent of total world catch.

1. Quantities of waste and industrial and military debris have been dumped in the North Sea so that some areas are now said to be untrawlable (FAO, 1970; Shelton, 1971; ICES, 1969).

2. So far, the ever increasing number of rigs and platforms in fishing areas has not led to any serious conflict, but fishermen dislike the additional hazards.[1] Oil developments have resulted in competition for harbor facilities in major fishing ports, such as Aberdeen.

3. Varieties of industrial pollutants enter the North Sea carried by rivers or transported through the air from the industrial complexes of the adjacent countries.

The North Sea is a major shipping route. The shipping passages, particularly in the narrow English Channel, are officially described as difficult (North Sea Pilot). These difficulties consist of:

1. Numerous migrating sandbanks making water depth charts unreliable.

2. Strong tidal streams.

3. Restricted visibility. This is caused by the low coast line, and fog and mist at certain times of the year.

4. Congested shipping lanes close together.

The coastal amenities of the North Sea are not highly developed (Sibthorp, 1975, p. 57). There are resorts on the North Sea coasts of Holland and East Denmark. Wild life reserves and protected coastal scenic

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[1] One major fear the trawlermen of the North Sea had was their responsibility if heavy trawl boards damaged oil or gas pipelines. However, it was conclusively demonstrated that the newly formulated concrete lagging of these pipes could withstand repeated collision with the trawl boards without any damage.

areas are of special importance in the North Sea states.[1] Sailing is also a growing recreational activity in the Frisian Islands and the Norfolk coast.

3.3.2 The North Atlantic

The North Atlantic is the highest energy environment of the offshore EEC, but conditions become milder southward to the Bay of Biscay. The quality of environmental data is poorer than for the North Sea. Two weather ships, one west of the Shetlands and the other in the Celtic Sea, provide meteorological and oceanographic measurements and weather reports.

Cold currents from the north meet warmer currents from the Caribbean in the seas south of Greenland. The area is described as the greatest birthplace of storms on earth, where the "frequency and violence of frontal activity are unsurpassed" (Arctic Pilot, Vol. II). The seas are exceptionally wild and stormy. Strong winds, rain and fog are associated with the frontal activity.

The Greenland seas are ice-bound through most of the year. Great ice islands and icebergs move in the strong currents and are a menace to shipping, even with advanced modern radar navigation. In years when the seaward extension of solid ice is less, more icebergs are detached and drift in the current. The western coast of Britain is ice free even in winter due to the warm currents (the North Atlantic Drift).

The western coasts of the British Isles and the Atlantic coast of France are also influenced by the more stable anticyclonic continental pressure which brings cold clear days in winter and warm, fine summer spells. The Bay of Biscay can experience severe storms with strong gusts of wind and high waves.

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[1] Some coastal areas have been made into nature reserves or national parks. There are six in the United Kingdom, three in Denmark, two in Belgium, and five in the Netherlands (Sibthorp, 1975, p. 57).

The North Atlantic is also a commercial fishing area, although not as important as the North Sea. Large fleets of deep sea vessels fish the great banks off Iceland and may follow the shoals of fish as far west as Newfoundland. Many nations fish these waters including the Russians, Japanese, Norwegians, and British. The large coastal fishing fleets of France and Britain vie with each other in the channel area and Bay of Biscay. The coastal areas of France are important oyster cultivation grounds.

The main commercial shipping routes of the North Atlantic are somewhat south of Greenland because of the dangerous ice conditions of those waters. The North Atlantic also has extensive military uses, mostly by ships and submarines of the naval powers.

The recreational uses of the North Atlantic are limited to the coastal areas of France, Eire and the southern United Kingdom, where extensive crowds visit the beach resorts during the summer months.

3.3.3 The Mediterranean

The Mediterranean, an almost totally enclosed sea with about one-third of its water being lost by evaporation, is replenished by river water. This restriction in the supply of new ocean water makes the Mediterranean particularly vulnerable to pollution. It is probably one of the more polluted seas in the world today. Operational or accidental releases of oil, widespread discharges of untreated sewage, of industrial effluents and of chemical fertilizers washed into the sea by rivers, all contribute to the pollution level. The offshore areas of the EEC in the Mediterranean include the Adriatic and the Balearic - Tyrrhenian basin. The Mediterranean is a low-energy environment. The wave climate is mild. Tidal influence is small, and winds are variable. Gales may occur in the winter months, and there are, on average, 15 to 20 days a year when violent thunderstorms occur (Mediterranean Pilot, Vol. II and III). Current circulation is not well known, especially in the offshore deepwater column.

In the Mediterranean, the fishing industry is on a small localized scale, such as the tuna fishing industry of Sardinia. Probably, the most outstanding use of the Mediterranean this century is as a recreation area. Coastal resorts in France, Italy, Tunisia and the islands of Corsica and Sardinia attract numerous tourists from all parts of Europe.

For centuries the Mediterranean has been one of the world's major transport routes (Bascom, 1976), and navigational use includes large tonnages of cargo, passenger traffic, and numerous ferries. The world's main naval powers have many active vessels in the Mediterranean.

3.4 ORGANIZATIONS CONCERNED WITH THE EEC OFFSHORE ENVIRONMENT

This section lists some of the organizations currently involved with the offshore physical and biological environment, particularly in the EEC. The distinction between public and private bodies made below is somewhat arbitrary.

3.4.1 International

The abbreviated name or acronym is followed by the country of location of the headquarters.

Public

CEPEM	European Center for Marine Environment Problems (France)
CNEXO	Centre National pour l'Exploitation des Oceans (France)
COST 43	Cooperative European Oceanographic Data Collection (United Kingdom)
COWAR	Scientific Committee on Water Research (France)

Public (continued)

E&P Forum	Oil Industry International Exploration and Production Forum (1974)
Eurocean	European Oceanic Organization (Monaco)
FAO	United Kingdom Food and Agricultural Organization (Geneva)
IAWPR	International Association on Water Pollution Research (South Africa)
ICES	International Council for the Exploration of the Sea
ICSU	International Council for Scientific Unions (France)
IHO	International Hydrographv Association (France)
IMCO	Intergovernmental Consultive Organization, a United Nations Organization (United Kingdom)
IOC	International Oceanographic Commission (France)
MAMBO	Mediterranean Association for Marine Biology and Oceanology (Italy)
Met. Office	Meteorological Office. London (United Kingdom)
NSESG	North Sea Environmental Study Group (United Kingdom)
NSOSC	North Sea Oceanographic Study Committee (United Kingdom)
NSHC	North Sea Hydrographic Commission
SCOR	Scientific Committee on Ocean Research (UNESCO, Geneva)

Private

IABO	International Association for Biological Oceanography (Denmark)
IAPSO	International Association for the Physical Sciences of the Ocean (United States)
IME	Institute of Marine Engineers (United Kingdom)
IOI	International Ocean Institute (United States)
IO	Institute of Oceanography (United Kingdom)

Private (continued)

IOS	Institute of Oceanographic Science (United States)
MTS	Marine Technology Association (United States)
SUT	Society for Underwater Technology (United Kingdom)

3.4.2 National

ASTEM	Association Scientifique et Technologique pour l'Exploration des Mers (France)
Bureau...	Bureau de Recherches Geologiques et Mineres (France)
CEASM	Centre d'Etudes et d'Action Sociales Maritimes (France)
CNR	Consiglio Nazionale delle Richerche (Italy)
Danish...	Danish Fishery and Marine Research (Denmark)
GESMA	Groupe d'Etudes sous Marines de l'Atlantique (France)
Laboratoire...	Laboratoire d'Oceanographie Physique du Musee Nationale d'Histoire Naturelle (France)
Instituti...	Instituti Talassografici e Limnologici (Italy)
Institut...	Institut Royal de Sciences Naturelles (Belgium)
Ministerialrat...	Ministerialrat Bundesministerium fur Furschung und Technologies (West Germany)
Netherlands...	Netherlands Industrial Council for Oceanography
Seakeeping...	Seakeeping Laboratory Netherlands
WFA	White Fish Association (United Kingdom)
Wirtschafts...	Wirtschaftsreinigung Industrielle Meerestechnik (West Germany)

Environmental Groups

British Trust for Ornithology (United Kingdom)

Conservation Society (United Kingdom)

Danish Union for Conservation of Nature (Denmark)

Institute for Environmental Education (Netherlands)

Nature Conservation Council (United Kingdom)

Environmental Groups (continued)

Nature Conservancy Board (United Kingdom)

Netherlands Society for the Protection of Birds

Netherlands Commission for International Nature Protection

Royal Society for the Protection of Birds (United Kingdom)

Society for the Prevention of Environmental Pollution (Netherlands)

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CHAPTER 4

OFFSHORE MINERAL PRODUCTION TECHNOLOGY (OMPT)

CONTENTS

CHAPTER 4

OFFSHORE MINERAL PRODUCTION TECHNOLOGY (OMPT)

4.1 INTRODUCTION

This chapter serves to identify and describe the technologies for producing offshore minerals and to evaluate the future importance of these technologies. Since most nonmilitary offshore technology is being related to the production of hydrocarbons and to their transportation, more emphasis is placed on petroleum technology.

4.1.1 What is OMPT?

Offshore Mineral Production Technology (OMPT) includes the interrelated structures, machinery, vessels, crafts, materials, tools, practices, communications and ideas employed by men for the purpose of extracting minerals from the offshore environment.

To describe offshore technology, it is necessary to understand its language and its habitat, which originate with the oil industry in the United States.

4.1.2 Designing for the Offshore Environment

The first offshore engineers simply extended onshore operations to relatively short, safe distances offshore in a clement environment. This was easily accomplished for petroleum in the Gulf of Mexico or for tin mining in Thailand at the turn of the century. In the 19th Century, one engineer usually designed and supervised a whole project. Today, teams of specialized engineers collaborate on solving problems such as: how to reenter a drill hole on the seabed; how to drill from a floating vessel without anchoring; and what kind of floating platform would experience minimum motion in a high sea.

The answers to these problems emerge from the design process which combines imagination, computation, drawing and testing before the problem is considered solved.

The cost of materials and operations compel engineers to optimize and to economize. Over-estimation by one foot of the height of the maximum wave which can hit an offshore structure during its lifetime can cost several million dollars in extra materials. Under-estimation can cost several million dollars in repairs or damage.

Most new designs are motivated by economics — a higher profit. Fewer are motivated by safety or environmental considerations. All designers implicity and explicitly seek an adequate margin of safety[1] (a safety factor). In some situations safety factors cannot be calculated in advance. For example, a steel weld depends essentially on the skill of a welder and on the post-weld inspection (Section 5. 1).

4. 1. 3 The Evolution of Technology

It is only recently that technologies have become objects of study in themselves (Spangler, 1970). The systematic appraisal of the socioeconomic and environmental consequences of technology is the discipline called technology assessment (OTA, 1975; Kash et. al., 1973). Technology evolves under various constraints and follows familiar s-shaped growth and decay curves (there are many examples in railroads, coal mining and aviation). Technology forecasting attempts to project the future trends of this evolution (NAS-NRC, 1971).

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[1] Both extreme and routine conditions must be considered, i. e., the impact of the highest wave expected in the highest predicted storm in 100 years, plus the daily impact of many smaller waves at random intervals.

Many parameters would need to be quantitatively evaluated to forecast where offshore technology is going under the influence of higher oil prices. For example, the historical evolution of fixed petroleum production platforms toward deeper water is a familiar image, but the successful development of underwater oil well completion techniques competing as a substitute technology may eliminate platforms in a few years.

A forecast of OMPT in the year 1985 or 2000 would need to consider energy demand, material supply, alternative materials, and many other factors beyond the scope of this study. However, some restricted technological predictions will be advanced under the headings which follow.

4.2 PETROLEUM AND NATURAL GAS TECHNOLOGY

Two separate phases must be considered: the search for hydrocarbons or exploration phase, and the recovery and distribution of oil and gas to shore or production phase.

4.2.1 Exploration

Exploration for petroleum and natural gas comprises two techniques:

1. Indirect techniques to reduce large geologically favorable areas to smaller targets. These do not actually involve drilling deep into the seabed to test formations. They begin with geological interpretation and are followed by airborne or shipborne geophysical and geochemical investigations.

2. Direct techniques to determine whether the targets contain oil. This involves the testing of virgin rock formations several thousand feet below the seabed. This is called wildcat or exploration drilling. Once a strike or discovery is made, additional wells are drilled to delimit the oil reservoir; this is called development drilling.

Favorable geological areas can be several tens of thousands of square miles in area; targets can cover several tens of square miles (Table 4-1).

Table 4-1. Sizes of some North Sea oil and gas fields (from Goldberg, 1973, p. 458; Forages, No. 70, IFP, 1976).

Oil Fields	Area (km)	Thickness (m)
Ekofisk West	4 x 4	180
Tor	7 x 4	—
Eldfisk	14 x 4	—
Albvskjell	20 x 5	—
Gas Fields	**Miles**	**Reserves ($m^3 \times 10^9$)**
West Sole	12 x 3	30
Leman	18 x 5	330
Indefatigable	10 x 5	225
Hewett	18 x 3	112

The exploration technologies described in this section are:

A. Geophysical surveys
B. Drilling equipment
C. Drilling platforms and ships
D. Offshore drilling procedures

A. Geophysical Surveys

The most prevalent technique is shipborne seismic reflection. Acoustic waves are transmitted to the seabed and through the rock layers beneath by low frequency (≤ 100 Hz) sound sources[1] which emit enough

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[1] Acoustic energy travels at velocities proportional to the densities of different rock layers. Energy is also reflected back from the different rock layers to the sea surface, where it is detected by sensors called hydrophones. Hydrophones are trailed behind the survey ship. One line may trail out for as much as two miles behind the ship.

energy to reach rock layers 10,000 to 15,000 feet (3000 to 4500 meters) deep. Dynamite, which was used in the past, has now been replaced by gas guns or vibrators[1] (Gaskell, 1973) (Figure 4-1).

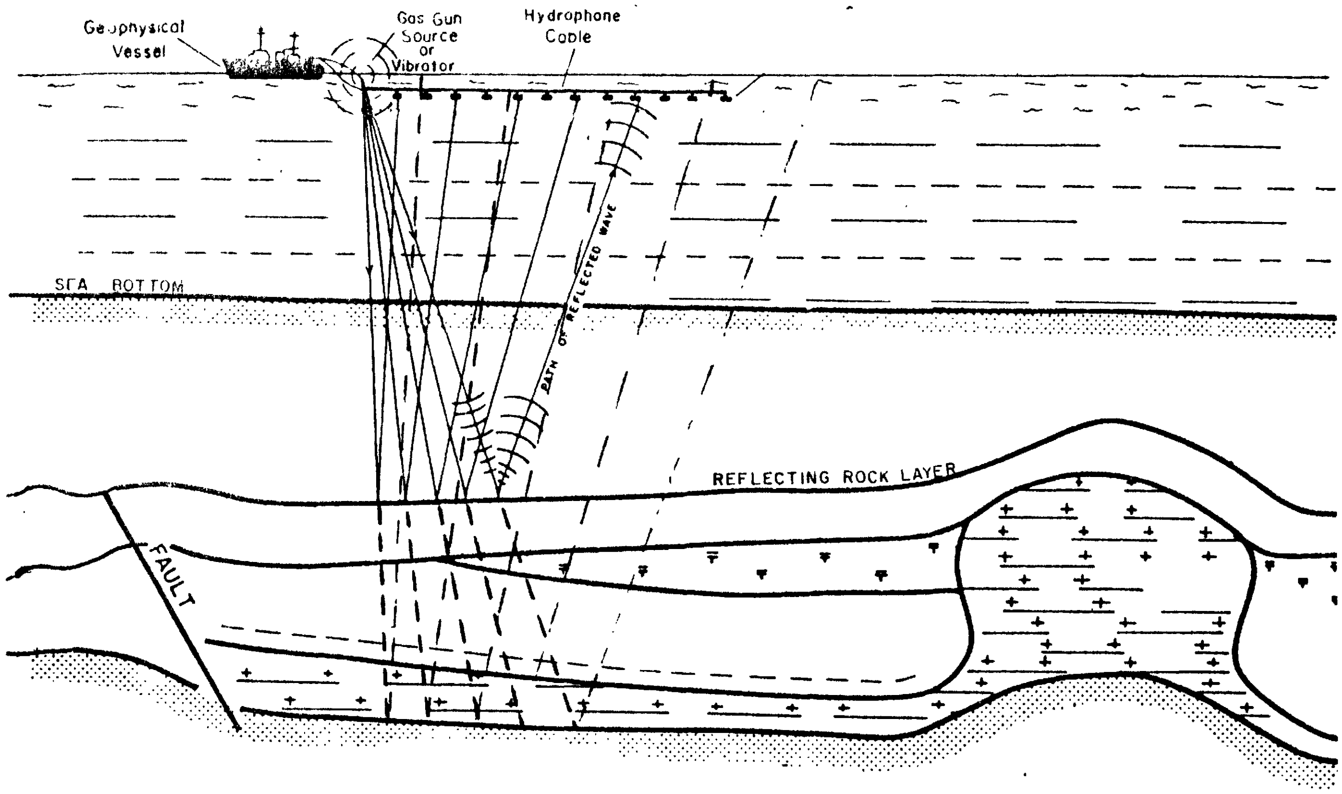

Figure 4-1. Marine seismic surveying of the ocean subbottom.

Geophysical vessels conducting surveys travel at speeds of 4 to 6 knots depending on sea conditions and the number of turns they are required to make in a survey pattern. Accurate positioning by satellite or electromagnetic signals is essential. Line density for reconnaissance may be 2 line-miles per square mile and more for close definition. Shipborne

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[1] In a gas gun an explosion of gas takes place inside a rubber sleeve. In a vibrator a piece of metal is made to vibrate mechanically.

geophysical instruments include gravimeters (for detecting salt domes) and magnetometers (for detecting igneous rocks. These can also be flown over an area of interest). Shipborne geochemical instruments which sometimes accompany geophysical surveys are called sniffers. They are used to continuously detect minute traces of hydrocarbons which may have leaked naturally into seawater from the sea floor.

Before further exploration decisions are made,[1] geophysicists interpret seismic results from analog seismic profiles, or cross sections. Recently, the treatment and interpretation of the amplitudes of seismic waves has led to the bright-spot technique which gives the geophysicist a very high assurance of the presence of natural gas.

B. Drilling Equipment

The basic principle of oil well drilling is to rotate a cutting tool (the bit) under pressure while removing the rock cuttings. The drill pipe is a hollow steel shaft which is rotated at 50-100 rpm to turn the drilling bit several thousand feet below the derrick in which it hangs. When one considers that oil drilling has reached 30, 000 feet and is contemplated to 45,000 feet, it is an extraordinary kind of remote-control operation. There are many kinds and sizes of drill pipe which make up a drill string and numerous different shapes of drilling bits with tungsten carbide tips or diamond inserts. Pressure is applied on the bit by special heavy pipes above the bit called drill collars. The driller on the rig floor controls this weight on the bit by letting out more or less of the drill collars to rest it. Drill holes are lined with a concentric large diameter steel pipe (the casing) which insulates the hole from and is cemented to the wall rock.

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[1] The decision to drill is not taken lightly since it calls for the expenditure of up to several million dollars with a chance of about 1 in 7 of finding oil or gas. Contractors may charge $25, 000 to $50, 000 per day for a drilling unit, and the cost to the operator may be twice that.

Drilling mud is a fluid circulated by high pressure pumps down the hollow drill pipe, around the bit and back up outside the drill pipe. It fulfills two critical functions in drilling:

1. It provides hydrostatic pressure to contain the formation pressure due to natural gas and forms a cake, sealing the walls of the drill hole before casing is introduced.

2. By its flow and density, it removes the rock cuttings.

Drilling mud is carefully controlled by the addition of chemicals and additives to provide correct properties of specific gravity, viscosity, sealing and gelling capability. Drilling mud is usually a water mixture of clay and other minerals or of high density material (barite). The high density is critical for restraining blowouts, i.e., gas under high pressure, being released uncontrollably from the formation breached by the bit (Crook, 1975, pp. 85-86). Mud control is an essential part of the art of oil drilling. The objective is to keep the hole full of mud at all possible times. It consists of careful adjustments of mud density and manipulations of mud in and out of the hole when other operations such as tripping pipe, setting and cementing casing, or formation testing are required (Crockford et al., 1975).

Monitoring drilling mud is a surprisingly primitive process given its importance. The monitoring activities are: volume control to detect losses or dangerous rises in level in the mud tanks, the so-called well kick which can be the start of a blowout; detection of the presence of gas; and monitoring of density.

Drilling is the crucial moment in exploration. Many variations on the simple principles outlined above make up the vast field of drilling technology.

C. Drilling Platforms and Ships

Offshore drilling takes place from fixed or floating platforms or ships (Figure 4-2). Today, there are some 450 offshore drilling rigs in the world.[1] They fall into three categories:

1. Jackups and submersibles — 48%
2. Drilling ships — 22%
3. Semisubmersibles — 30%

For any exploration assignment, the platform most suited to the drilling environment will be selected (Laborde, 1975). In making this decision, water depths and sea conditions are crucial factors since once a well is spudded in (when the drilling bit starts making the hole), it is normal for the platform to remain on station for several months. An offshore drilling rig, of whatever kind, is a complex industrial plant valued at $30 million to $60 million (more than a 747 jet aircraft), employing about 100 men and costing some $2000 to $4000 per hour of operation in 1975.

1. Jackups. This type of drilling barge lowers legs onto the seabed and then raises itself up on these legs to make a stable drilling platform above the surface of the ocean (Figure 4-3). Jackups operate in water depths up to 300 feet (90 meters) and construction costs are lower than for ships or semisubmersibles. Jackups have significant stability during well-testing. The blowout preventer is located on the platform, where it is easily accessible for surveillance and repair.

A critical period for a jackup drilling rig is when the rig is under tow to and from a drilling station. At this time, it is most sensitive to weather conditions. During long tows, the legs are partly cut off to ensure hull stability; during short tows, the legs are raised rather than cut off. In terms

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[1] In 1959, there was only one floating platform capable of drilling for oil offshore in the United States, and this was the barge CUSS 1. Other offshore wells were drilled from fixed jackup platforms. Of the 450 offshore rigs, 300 are operating units, and 150 are planned or under construction (Ocean Industry, January 1976; September 1975).

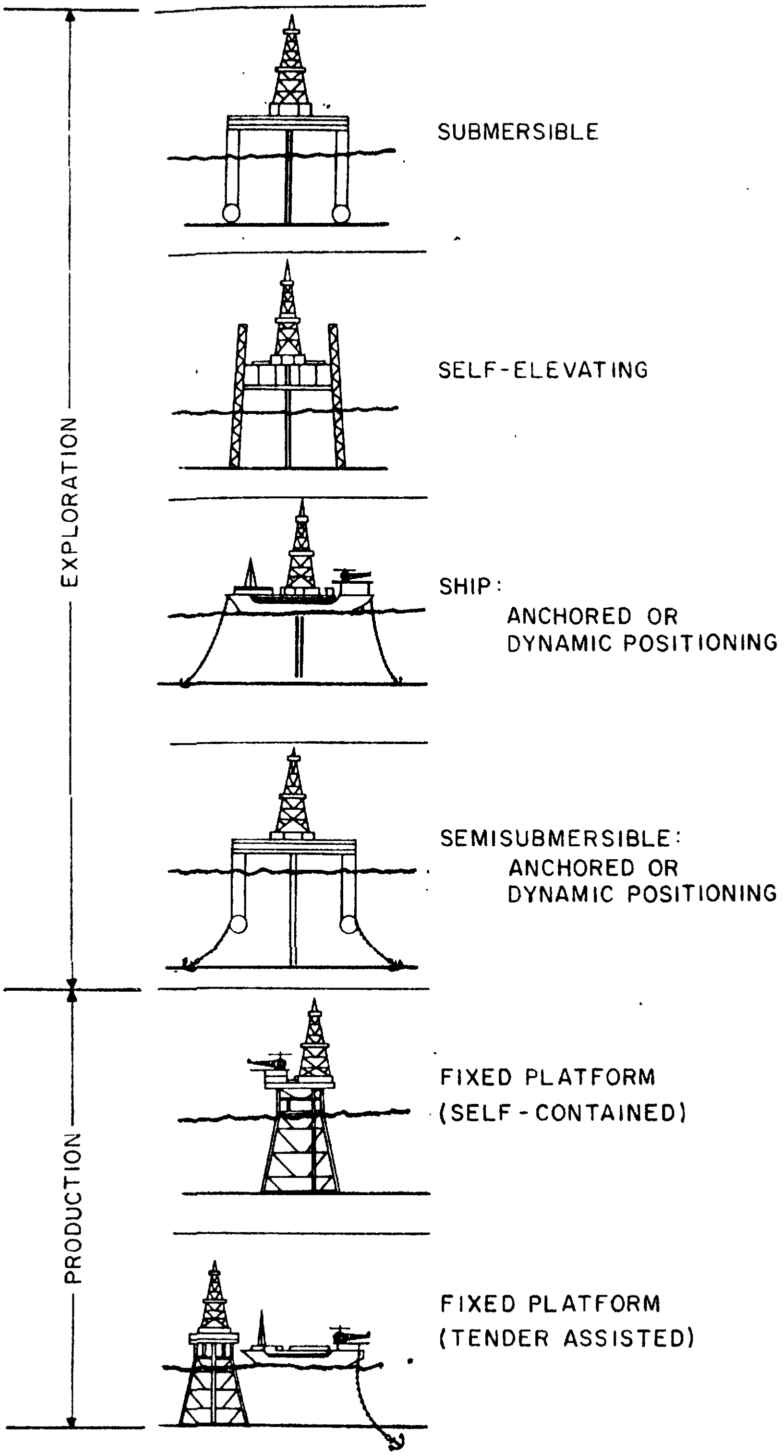

Figure 4-2. Examples of exploration and production platforms (from Grande Encyclopedie Alpha de la Mer, p. 1523).

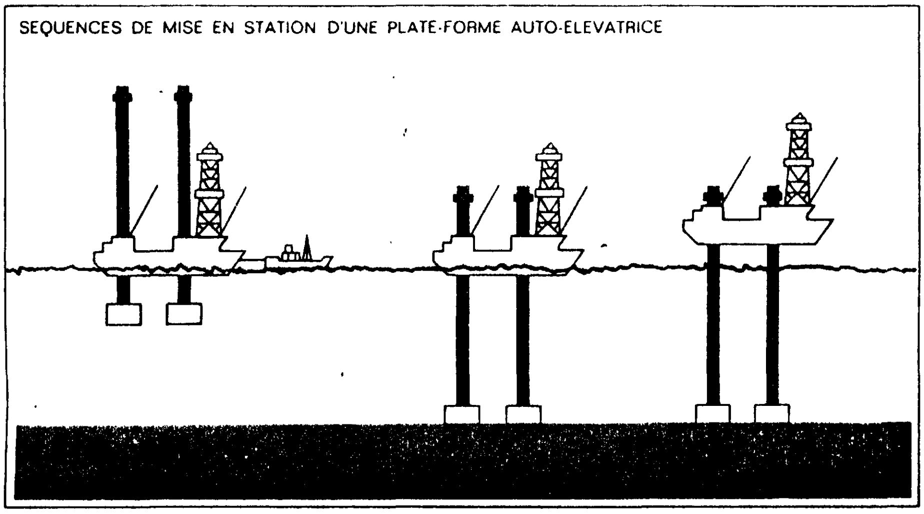

Figure 4-3. Jackup drilling platform (from Grande Encyclopedie Alpha de la Mer, p. 1523).

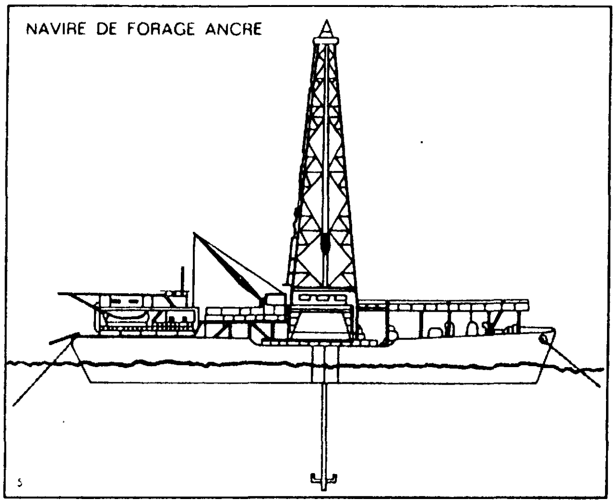

Figure 4-4. Anchored drilling ship (from Grande Encyclopedie Alpha de la Mer, p. 1523).

of efficiency, jackups are marginally more efficient than semisubmersibles, actually drilling about 50% of the time compared with 45% for semisubmersibles[1] (Bynum and Lovie, 1974). There will be 18 jackups operating in the North Sea by 1976 in comparison with 71 semisubmersibles.

To offset some of the limitations of jackups, a new generation of offshore mobile drilling units has been designed for water depths to 430 feet (130 meters). The new design uses computer analytical techniques to provide high safety factors against overturning. Another innovative design is the mobile monopod, a gravity-base, multiservice jackup for exploration, drilling and production in water depths to 450 feet (140 meters). A single jackup leg connects the upper hull (quarters and drilling equipment) to the lower hull, which provides crude oil storage capacity of 220, 000 barrels (30, 000 metric tons)[2] (Bynum and Lovie, 1974).

2. Drilling Ships. These ships, equipped with a complete drilling rig, have greater mobility than jackups for operating in water depths of 300 to 3000 feet (100 to 1000 meters) (Figure 4-4). Drill ships have a structural opening amidships below the derrick, called a center well, through which the drill pipe and other equipment are lowered (Crook, 1975, p. 56).[3] Drill ships must be kept within a specific radius of a point above the drill hole or excessive bending stresses will be sustained by the drill pipe. Dynamic positioning (DP) or anchoring controls the position of the drilling ship. For DP, propellers, installed in the bow and stern of the ship, are

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[1] Despite the stability and efficiency of the jackup, more semisubmersibles are used in the North Sea because of the great water depths. Of the 135 offshore units now under construction for delivery in 1977, over half (72) are semisubmersibles.

[2] With added safeguards against uncontrolled flooding, the monopod is designed to accommodate almost any North Sea condition.

[3] Today, there are 162 drilling ships and barges in operation and 30 under construction worldwide. They have many different characteristics. Barges have no propulsion or dynamic positioning.

centrally and automatically controlled to deliver counteracting thrusts to keep the ship within its required radius of the drill hole.[1]

Whether a drill ship is dynamically positioned or anchored to the sea floor, it is still subject to five types of motion in response to the movement of the waves. These motions are critical to the drill pipe. Roll and pitch tend to bend it; heave (vertical motion) sends down longitudinal stress waves; and surge and sway tend to displace it. Various antiroll stabilizers and heave-compensating devices have been designed to decouple the drill pipe from the ship and to prevent damaging fatigue stresses from accumulating.

The SEDCO 470 is an example of a modern drill ship:

> "SEDCO is 470 feet long and has a 22-foot diameter center well. She is capable of traversing any ocean propelled at a maximum speed of 14 knots by twin screws driven by electric motors. A dynamic positioning system consisting of twelve thrusters (DC motors with a total of 9600 shaft horse power) and associated control equipment maintains position during offshore drilling operations. The crew accommodation (for up to 121 men) and navigation spaces are located forward, while the generation and propulsion machinery and heliport are located aft. Drilling equipment, machinery, stores and supplies are located amidships.
>
> The SEDCO 470 is designed to operate at a draft of 20 to 24 feet (6 to 7 meters) and survive 100 knot winds and associated waves. Its storage capacity permits drilling for 90 days on the open sea without support. The dynamic positioning system will hold location in water depths of up to 3000 feet (900 meters) while drilling to depths of 15, 000 feet (4, 600 meters), and will also maintain drilling operations in a 30-knot wind gusting to 50 knots, 15-foot (5-meter) waves and a 3-knot current." (Offshore Engineer, 1975).

3. Semisubmersibles. These floating structures have a platform deck supported by columns connected to large, underwater, hull-shaped buoyancy chambers (Figure 4-5) (Harris, 1972, p. 31). Semisubmersibles

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[1] The deeper the water, the greater the radius of ship movement.

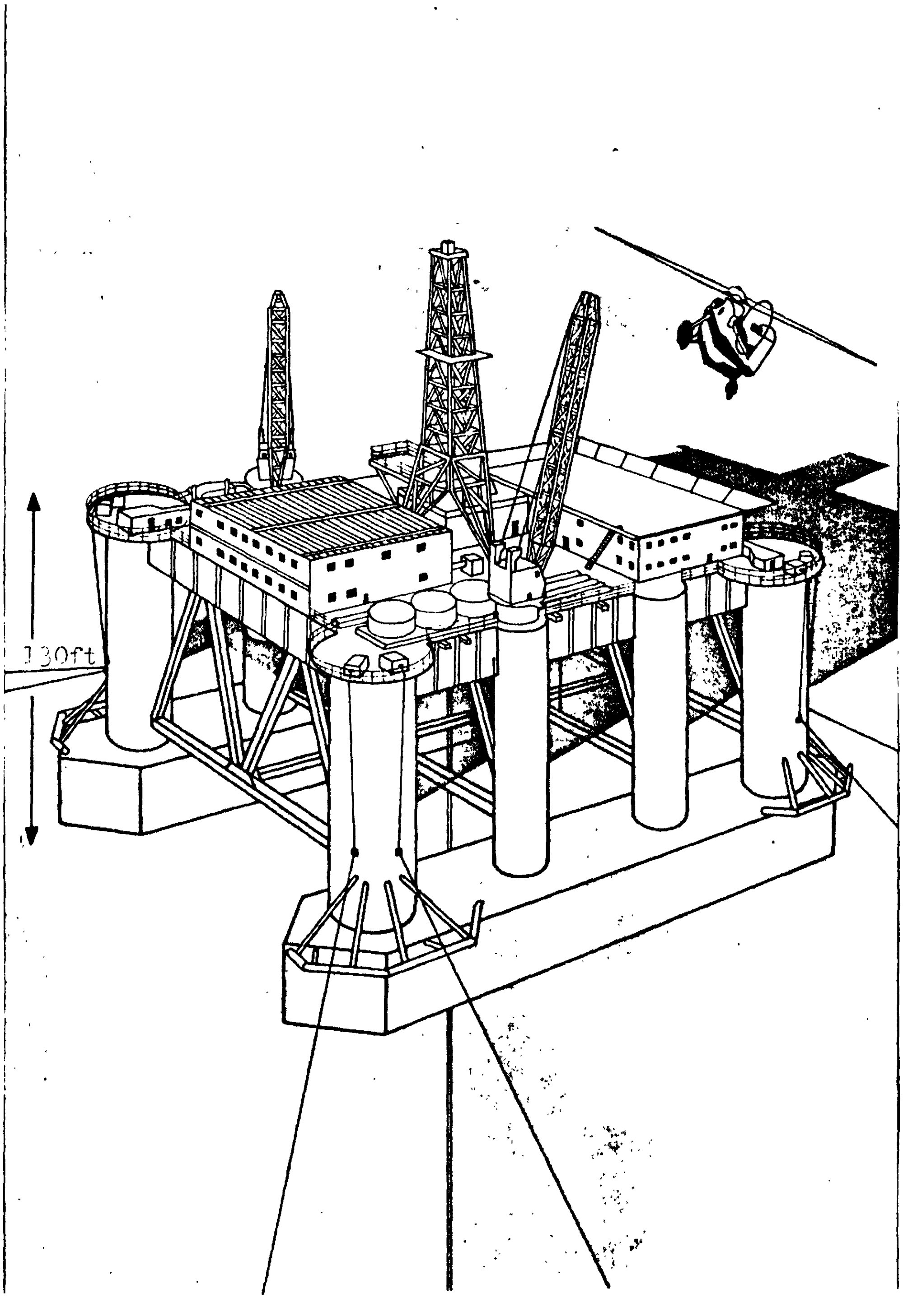

Figure 4-5. Semisubmersible drilling rig (from Design, 296, August 1973, p. 33).

can operate in water depths of over 1,250 feet (380 meters) and drill to 25,000 feet (7,600 meters) (Bynum and Lovie, 1974). The water plane area of the columns is much less than for a ship, giving the semisubmersible a very long heave period and less roll and pitch. Semisubmersibles are better suited than jackups or drill ships to drill in the deep water, high energy environment of the North Sea (Hammett, 1975).

There are over 75 different kinds of semisubmersibles operating today. Some are self-propelled, while others are towed to their stations. Most semisubmersibles are anchored, but dynamic positioning is being installed in newer designs. The SEDCO X-700 is typical of semisubmersible rigs active in EEC waters:

> "It is a rectangular, column-stabilized mobile drilling unit. The main deck is supported by four 30-foot (10-meter) columns and four 18-foot (6-meter) intermediate columns. The drilling rig is in the center of the deck area which also houses crew quarters, equipment, storage areas and work shops. The lower hull contains cement and mud storage areas, pump rooms ballast compartments and space for propulsion equipment. SEDCO 700 has increased structural redundancy to survive 120-foot (36-meter) maximum wave conditions. It is self-propelled and operates in water depths of 1250 feet (380 meters) and has a drilling capacity of 25,000 feet (7,600 meters)." (Petroleum Engineer, April 1971)

D. Offshore Drilling Procedures

This is identical to land drilling (Section 4.2.1B, above) except for the need to connect the well entrance at the sea floor to the rig on the sea surface (Figure 4-6). This is accomplished with a riser pipe. The riser pipe is kept under variable tension on the ship to compensate for the ship's horizontal excursions. When the bit is changed, the riser pipe serves as a passage to return the bit to the bottom of the hole. It also serves as a conduit for the return of drilling mud.

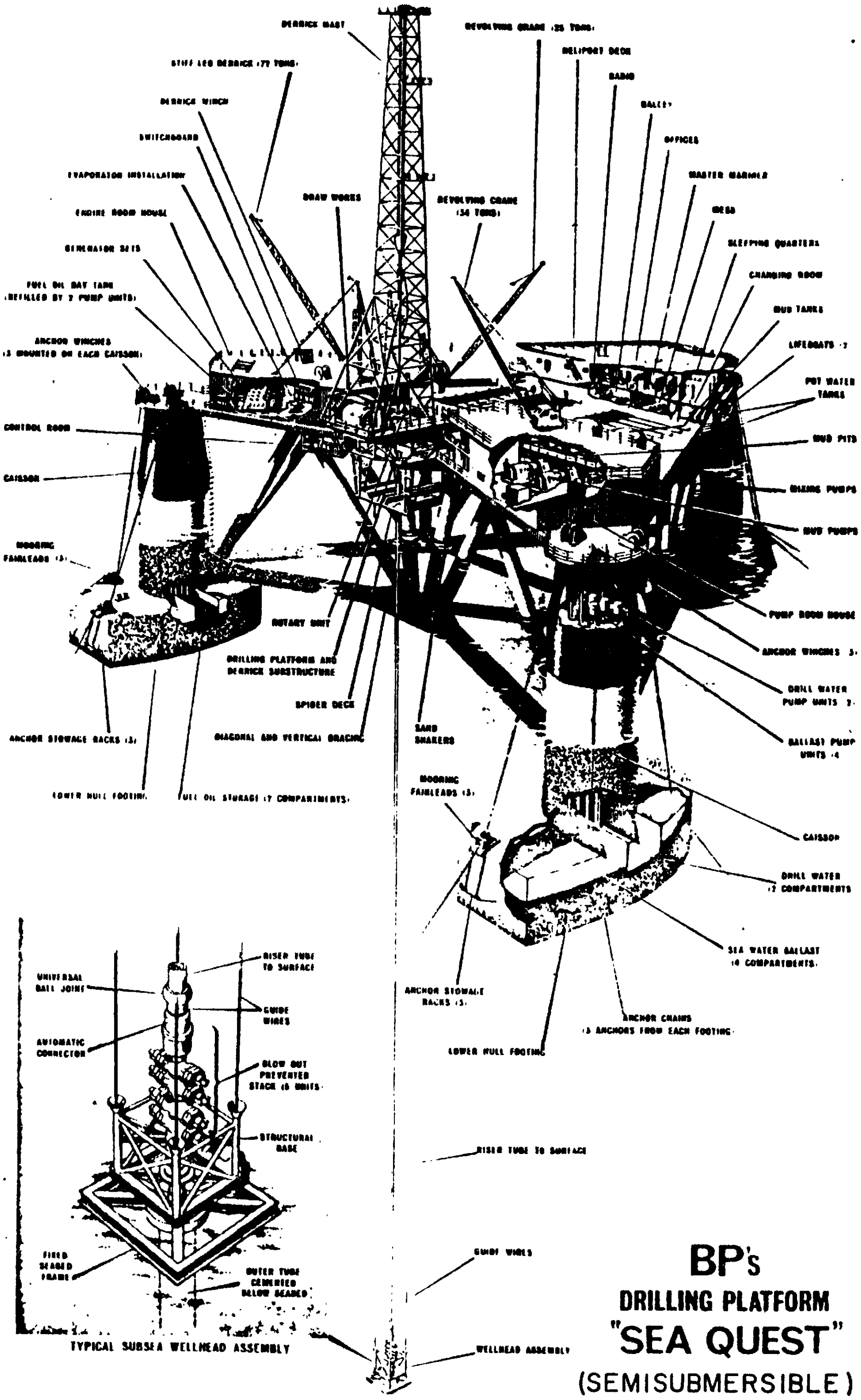

Figure 4-6. Offshore drilling platform (from Offshore Fixed Structures, SUT, 1974, p. 35).

If drilling could be done with seawater alone and the cuttings pushed onto the sea floor, the riser could be dispensed with. Various techniques of hole re-entry have been perfected; for example, on drill ships with dynamic positioning, acoustic ranging devices can be used to return the drilling bit to a funnel-shaped orifice at the hole entrance.

At the foot of the riser pipe, the blowout preventers (BOPs) are installed. BOPs are hydraulic rams designed to seal off the well by choking off any gas attempting to rush out of the hole (Figure 4-7).

A rotary drilling bit will penetrate approximately 5 to 10 feet (1.5 to 3 meters) of rock per hour and wear out after 20 to 40 hours depending on the hardness of the rock formations encountered. Each time the bit is worn out, the whole drill string must be pulled out, the bit changed and returned into the hole. This whole process is called a round trip. High speed modern draw-works have hoisting rates to 10 feet per second (3 meters per second), but a round trip from 10,000 feet (3,000 meters) may still require 6 to 8 hours to uncouple and store away pipe sections on the way up, and to handle and couple them on the way down. Pipe handling on the floor of the rig is still fairly laborious, requiring roughnecks (the rig floor crew) with physical stamina and coordination. On drill ships, the drill pipe sections are racked horizontally and conveyed automatically to a vertical position in the derrick.

When hydrocarbons are encountered, the phase called formation testing begins. This is small-scale petroleum and gas production on an experimental basis and exposes the rig to risks of blowouts. After an exploration drilling program is completed and while the next phase is being planned, a well is abandoned by plugging the hole entrance with cement.

Offshore exploration drilling for petroleum has been advancing steadily into deep water. By 1975, the maximum drilling water depth was in 2,300 feet (700 meters) off the coast of West Africa.

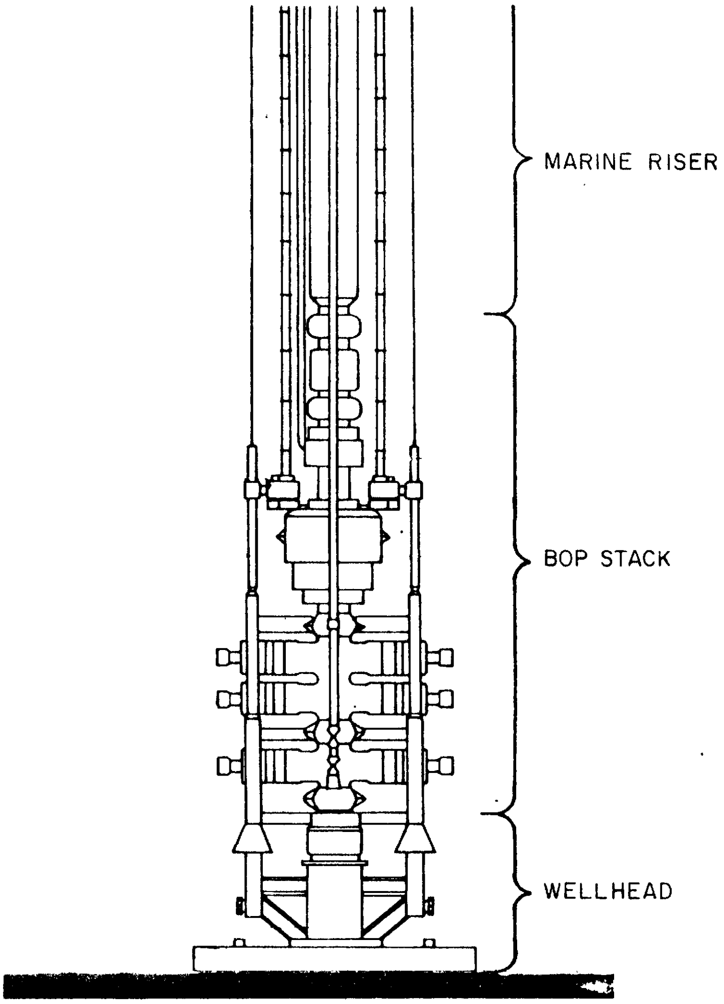

Figure 4-7. Subsea wellhead and blowout preventer (BOP) stack (from Gande Encyclopedie Alpha de la Mer, p. 1527).

In 1975, the deepest water depth and formation exploration well drilled in any offshore location was 22, 840 feet (7, 000 meters), and the deepest production well was 18, 948 feet (5, 800 meters).[1] Noncommercial offshore drilling by oil technology methods has been done in water depths of 11, 000 feet (3,350 meters) in 1961 by CUSS 1 (phase I of the Mohole Project) and, subsequently, by Glomar Challenger for the scientific program JOIDES in depths to 18, 000 feet.

4. 2. 2 Production

After oil or gas is discovered, data must be collected by further drilling to determine the size of the field and the reservoir characteristics. A complex decision-making, design and planning activity culminates in production and delivery of oil to market. The objectives of production are profit. Time and regulations are constraints. The production installations of offshore oil fields in the North Sea (Figures 4-8, 4-9 and 4-10) each cost several hundred million dollars. They include many wells controlled by production platforms connected by flowlines to storage tanks and loading buoys or pipelines. Gas may be flared or sent to shore by pipeline.

The following aspects of production will be considered:

A. Well completion
B. Production systems
   1. Platforms
   2. Subsea production
C. Transportation systems
   1. Pipelines
   2. Single buoy mooring systems and undersea storage
D. Ancillary operations
   1. Construction
   2. Diving and submersibles
   3. Onshore support

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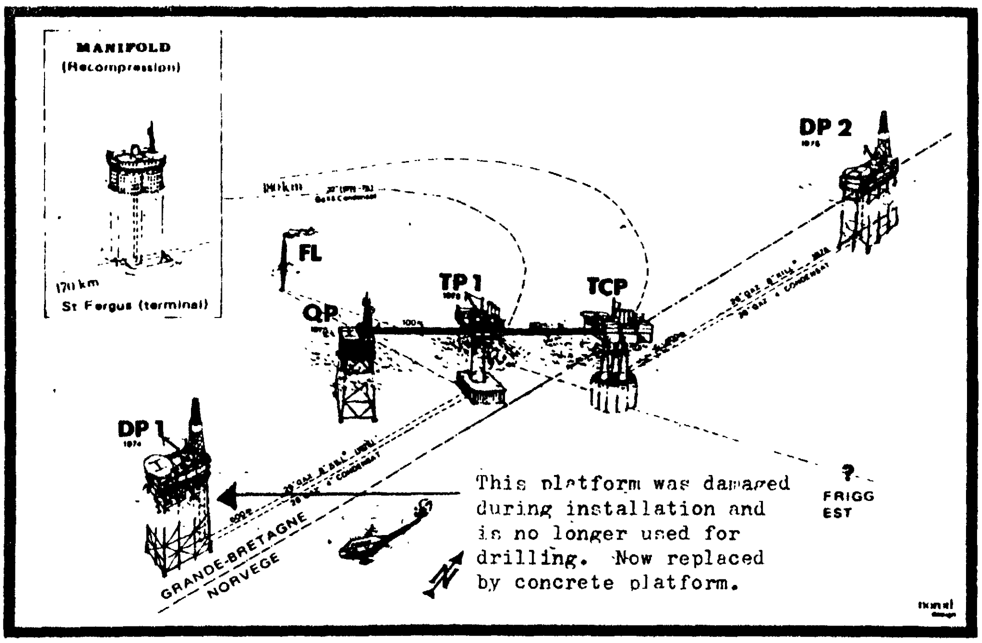
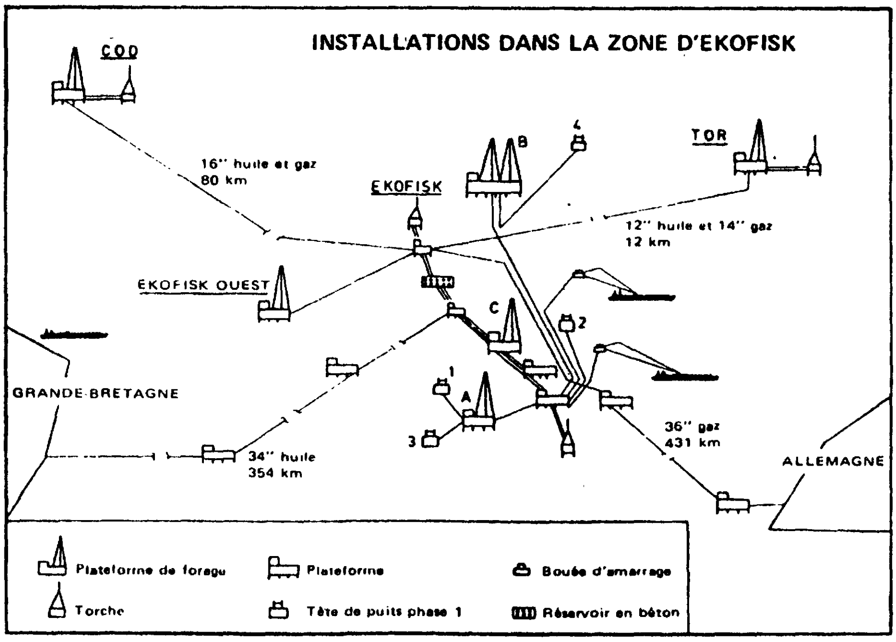
[1] Water depths plus formation depths.



This platform was damaged during installation and is no longer used for drilling. Now replaced by concrete platform.

* Kill : conduite pour "tuer" les puits à distance.

Figure 4-8. Frigg gas field plan for 1974-1978 in the North Sea. Target production is 1, 250 million cubic feet per day and condensate.



Installations permanentes dans la zone d'Ekofisk au cours de la phase 3. Puits à forer pour production et injection de gaz Plateforme A, 9 puits – Plateforme B, 17 puits – Plateforme C, 4 puits + 8 puits d'injection de gaz – Ekofisk ouest, 10 puits – Tor, 15 puits – Cod, 6 puits.

Figure 4-9. Ekofisk pipeline and production complex in the North Sea. Target production is 800, 000 barrels per day and 1, 200 million cubic feet per day (from Sondages Actualities, IFP, No. 61, August 1975).

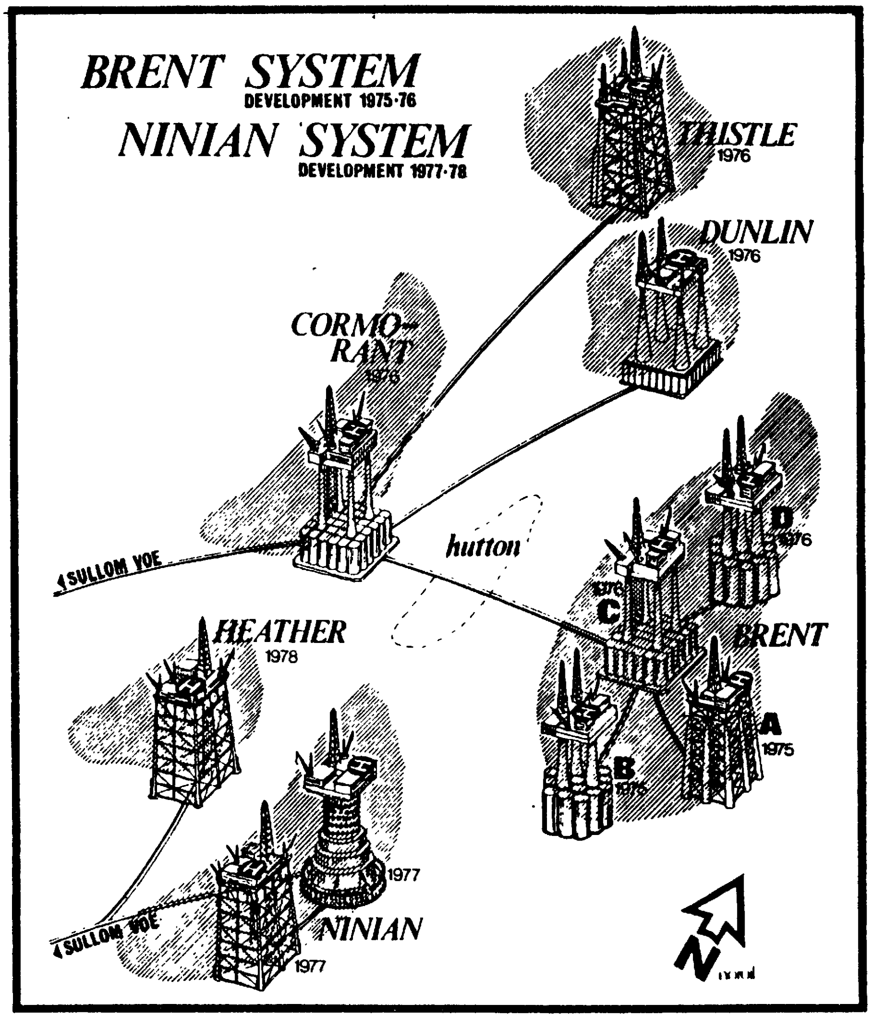


Figure 4-10. Brent and Ninian oil field systems in the North Sea (from Sondages Actualities, IFP, No. 60, July 1975). Target production is 700, 000 barrels per day.

A. Well Completion

The various activities required to transform a well into a producer of oil and gas are designated within the industry by the terms development and completion. The design of petroleum production systems begins with decisions by the reservoir engineers on well spacing, size of casing, type of well head, downhole tubing, and decisions on the treatment of the rock formation[1] required for optimum production. The term wellhead refers to the mechanical assembly at the entrance of a drill hole below which casing hangs and above which the Christmas tree and separation equipment are located (Figure 4-11).

The Christmas tree (Figure 4-12) is the assembly of valves and fittings (Crook, 1975, p. 45) through which the fluids (oil, gas and water) pass to reach the separation and metering equipment prior to transportation. Usually brines and sand may be entrained with the oil and gas. Sand is potentially dangerous to all mechanical equipment, valves, and seals so that every effort is made to prevent its flow into the well.

Decisions are made on the number of wells to be completed, on the flow rate of each well and on the particular market where the oil will be sold. These decisions depend on the size of the oil or gas reserves and the formation characteristics (pressure) of the production zones. Single well flow rates may reach up to 800 barrels per hour (110 metric tons per hour) from a single well. For whole fields in the North Sea, typical production rates will range from 40, 000 to 500, 000 barrels per day (5, 400 to 68, 000 metric tons per day). At $10 per barrel, this represents $400, 000 to

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[1] Many specialized techniques are used during the life of the field:

1. Acidizing the formation using acid to enlarge the pore openings.
2. Fracturing in order to increase yield and permeability.
3. Pressurizing the gas cap or the water to ensure a steady flow of oil and gas from the rockwall into the well.

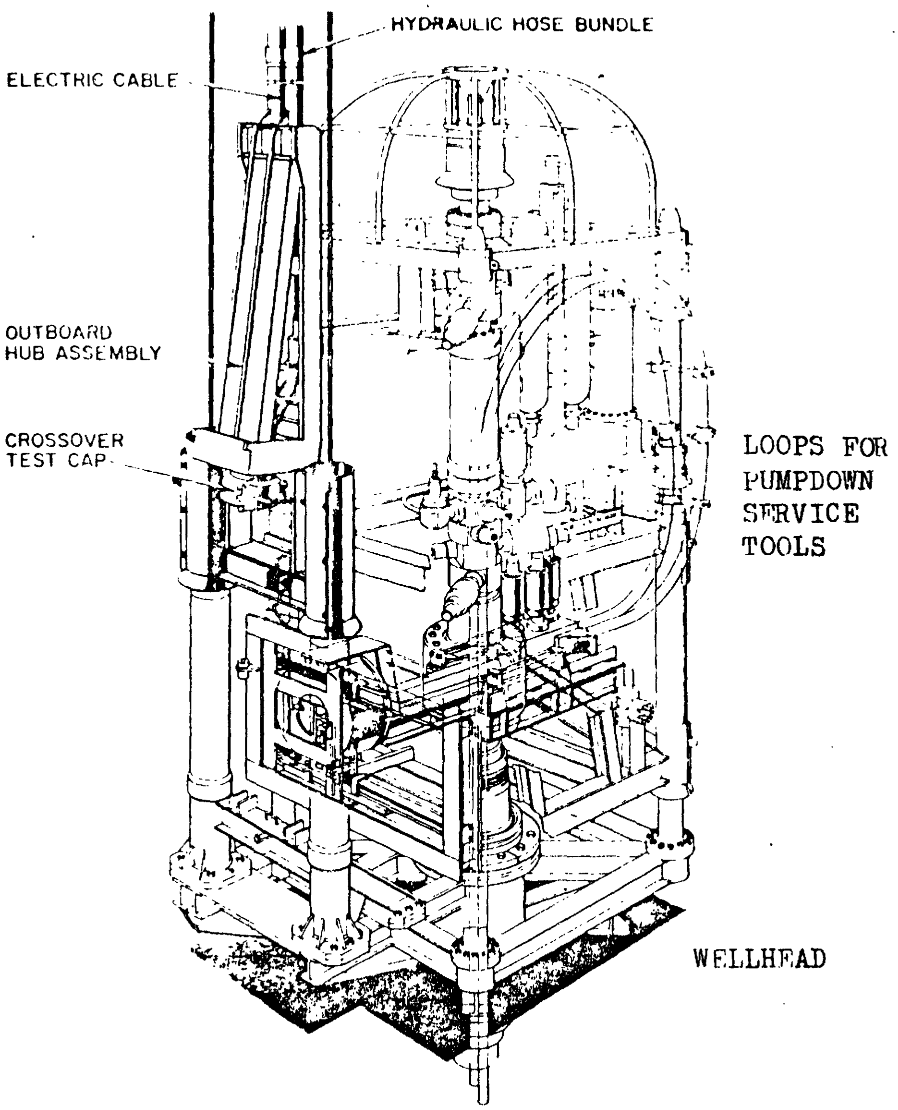

Figure 4-11. Through Flow Line (TFL) subsea Christmas tree (from Forage, IFP, No. 70, March 1976, p. 62).

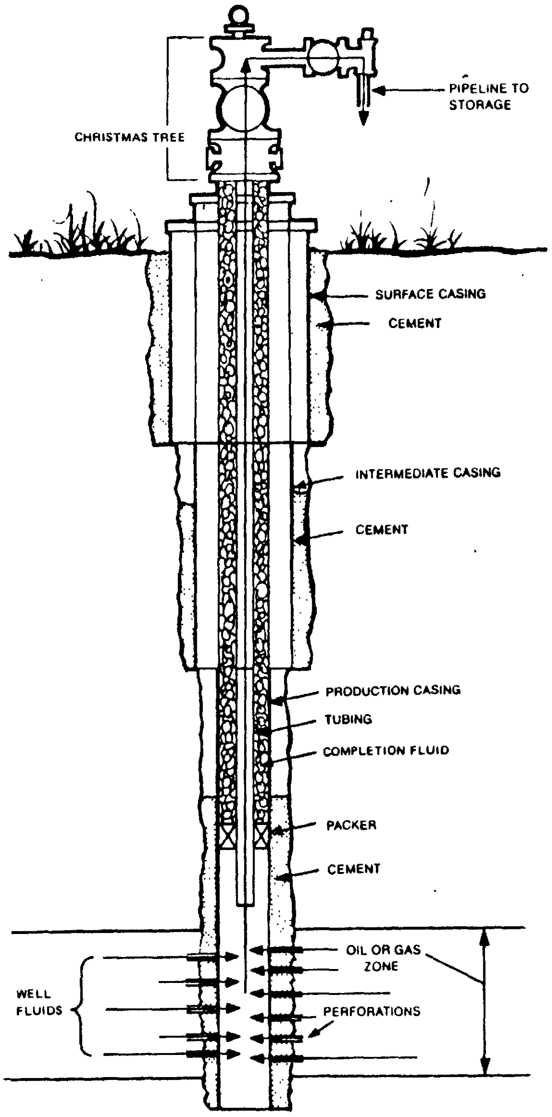

Figure 4-12. Completed onshore well with casing, tubing and Christmas tree (from Oil Spill Prevention: A Primer, Am. P. I. Publication 4225, p. 11).

\$ 5, 000, 000 per day or \$ 150 x 10^6 to \$ 1, 800 x 10^6 per year. The routing of oil from the well presents many choices between alternative techniques which in turn depend on water depth, oceanographic conditions, sea floor sediment properties and distance to the shore. Present technology favors placing the wellhead on a platform above water, but much thought is being given to placing it on the seabed (subsea completion).

B. Production Systems

1. Platforms

Production platforms positioned over the offshore field are usually trusses of large steel columns supported on tubular piling legs deeply embedded into the sea floor[1] (Figures 4-13 and 4-14). They are difficult to implant in the seabed, and their long, complicated installation operation may be made hazardous and costly by wind, wave and current conditions. The function of the platforms is to drill, equip and complete the wells needed to bring the field into production. As many as 40 production wells are aimed from one platform at various angles toward the production strata of the field several thousand feet below the sea floor. Platforms are like autonomous factories, employing as many as 100 men. With auxiliary facilities (pipelines, etc.), they represent a capital investment of \$ 75, 000, 000 to \$ 150, 000, 000; require power plants of up to 10, 000 horsepower and produce an annual revenue of the order of \$ 100, 000, 000 to \$ 1, 000, 000, 000.

In the North Sea Forties Field, four fixed platforms are being built for use in water depths of 350 feet to 420 feet (110 to 140 meters). Each platform will support 27 wells producing a total of 100, 000 to 125, 000 barrels per day (17, 000 metric tons per day) (Walker, 1975).

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[1] The steel fixed platforms are the descendants of the simple wooden structures erected in the 1920s and 1930s in Lake Maracaibo, Venezuela.

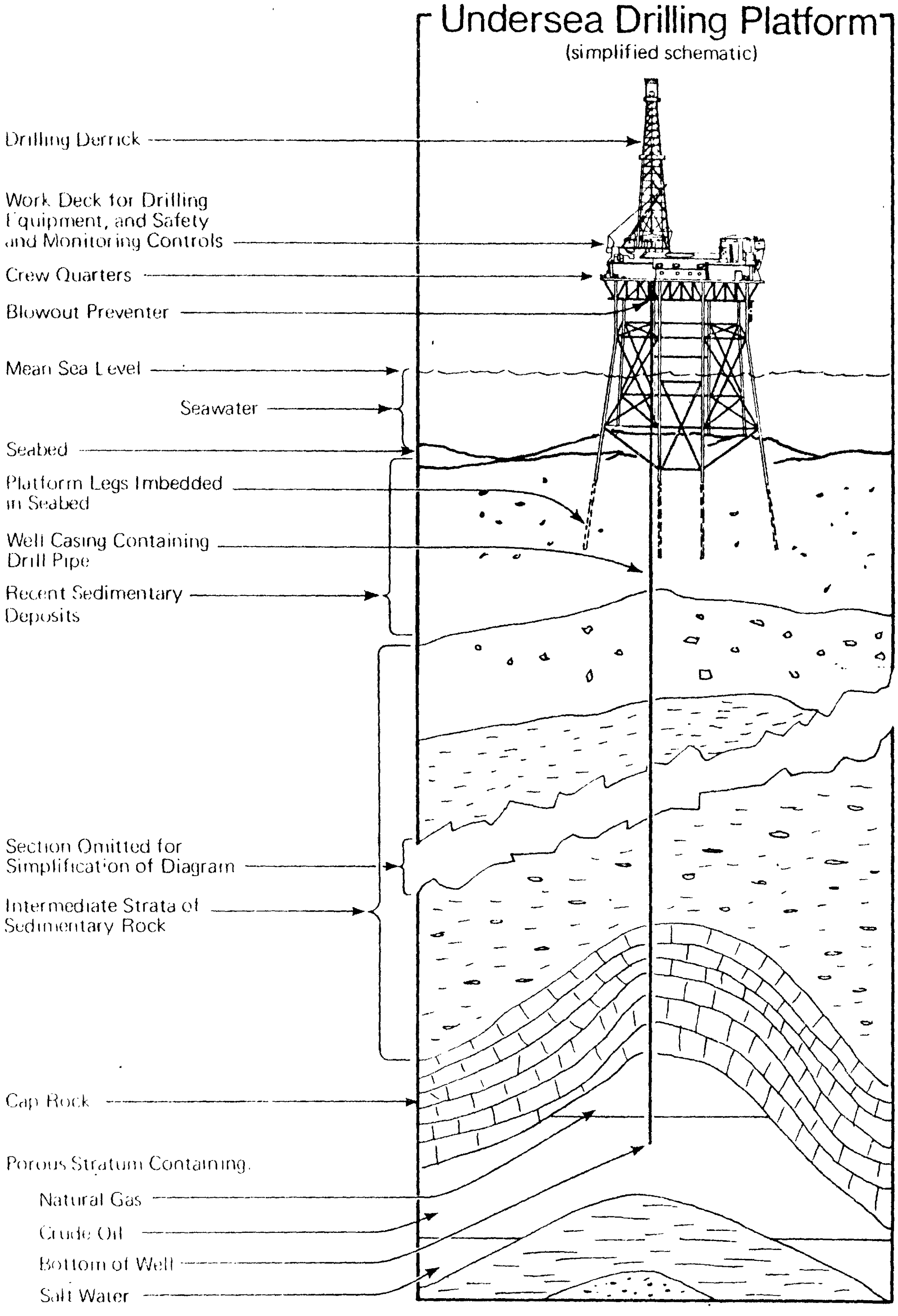
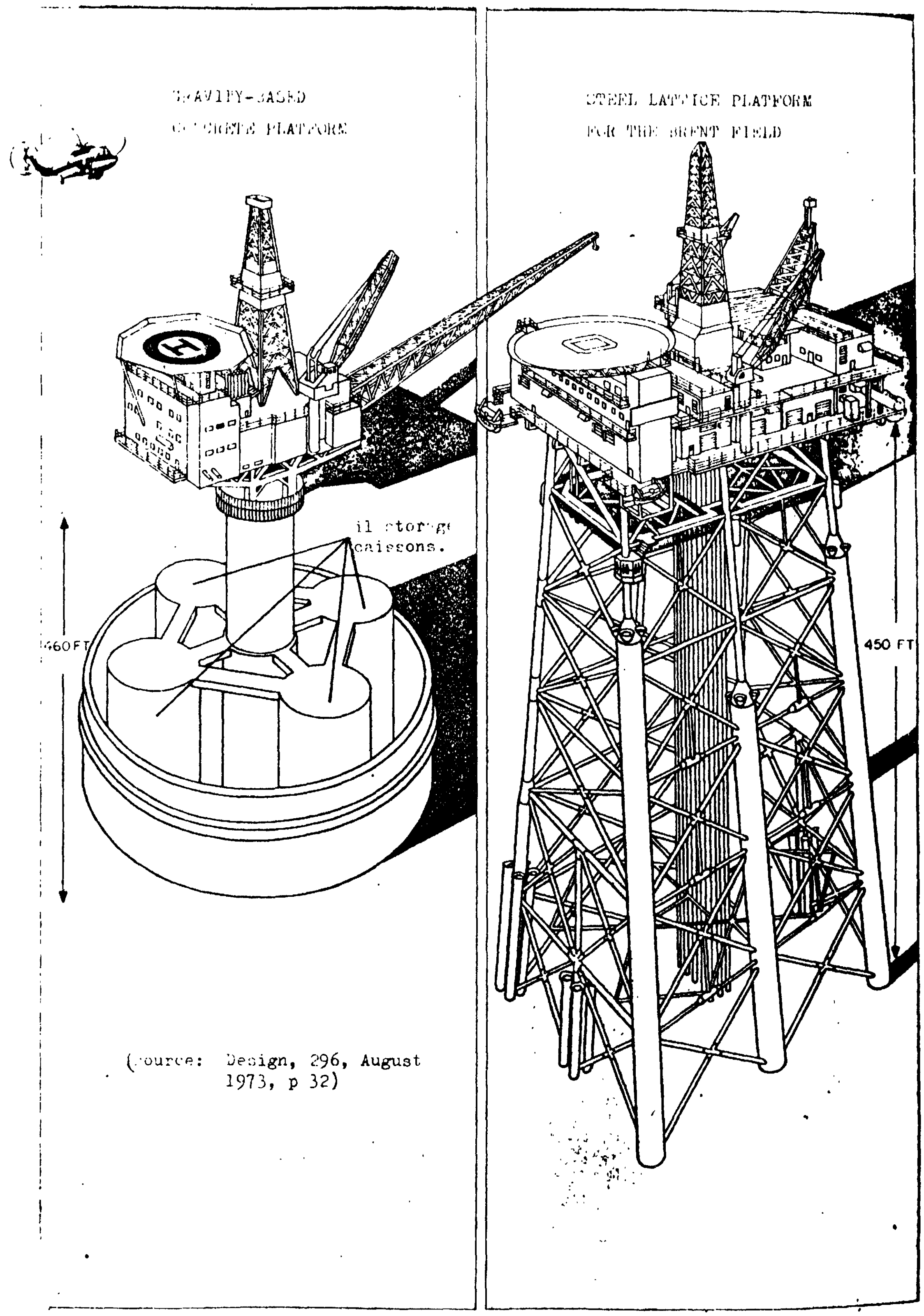


Figure 4-13. Undersea drilling platform, simplified schematic (from Undersea Drilling, API, p. 7).



(Source: Design, 296, August
1973, p 32)

Figure 4-14. Production platforms (from Design, 296, August 1973, p. 32).

In the Ekofisk field (Figure 4-9), 17 production wells are already producing (in 1975) 190, 000 to 200, 000 barrels per day (27, 000 metric tons) and 40 more wells are planned (Jobin, 1975).[1] In California, Exxon is reportedly planning a structure with an ultimate capacity for 28 wells which will exploit a reservoir with an area of 1800 acres (6 square kilometers) at a maximum rate of 75, 000 barrels per day (10, 300 metric tons per day) of oil and 38 x 10^6 cubic feet (1. 1 x 10^6 cubic meters) of gas. The structure will be 940 feet (290 meters) high and stand in 850 feet (260 meters) of water.

The offshore production platform in the deepest water at the present time is in the BP Highland 1, which lies in 416 feet (130 meters) on the Forties field in the United Kingdom sector of the North Sea (Offshore, June 20, 1975).

A new design, the gravity structure (Figure 4-15), has been conceived for the North Sea. It is fully prefabricated of reinforced concrete at a sheltered site near the shore. During calm weather, the platforms are towed to a production site and sunk into position on the sea floor, where they rest passively under their own weight without the need of pilings. This is the first major recent innovation in fixed-platform subtechnology. It features a new material (reinforced concrete), new emplacement operations, and new bottom support concepts (Figure 4-15).

Mobil's Condeep A, one of the first concrete platforms in the North Sea, was emplaced on the Beryl field in August 1975. The Condeep measures 500 feet (150 meters) from sea floor to rig floor. The base consists of 19 cylindrical concrete cells, which hold the necessary ballast and serve as storage tanks for oil with a capacity of 1. 5 x 10^6 barrels (205, 000 metric tons). The cells support three reinforced concrete towers capped by the platform deck and equipment, which are thus protected from wind and waves.

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[1] In the Brent field are similar platforms with a production capacity of 100, 000 barrels per day (14, 000 metric tons per day) (Williams, 1975).

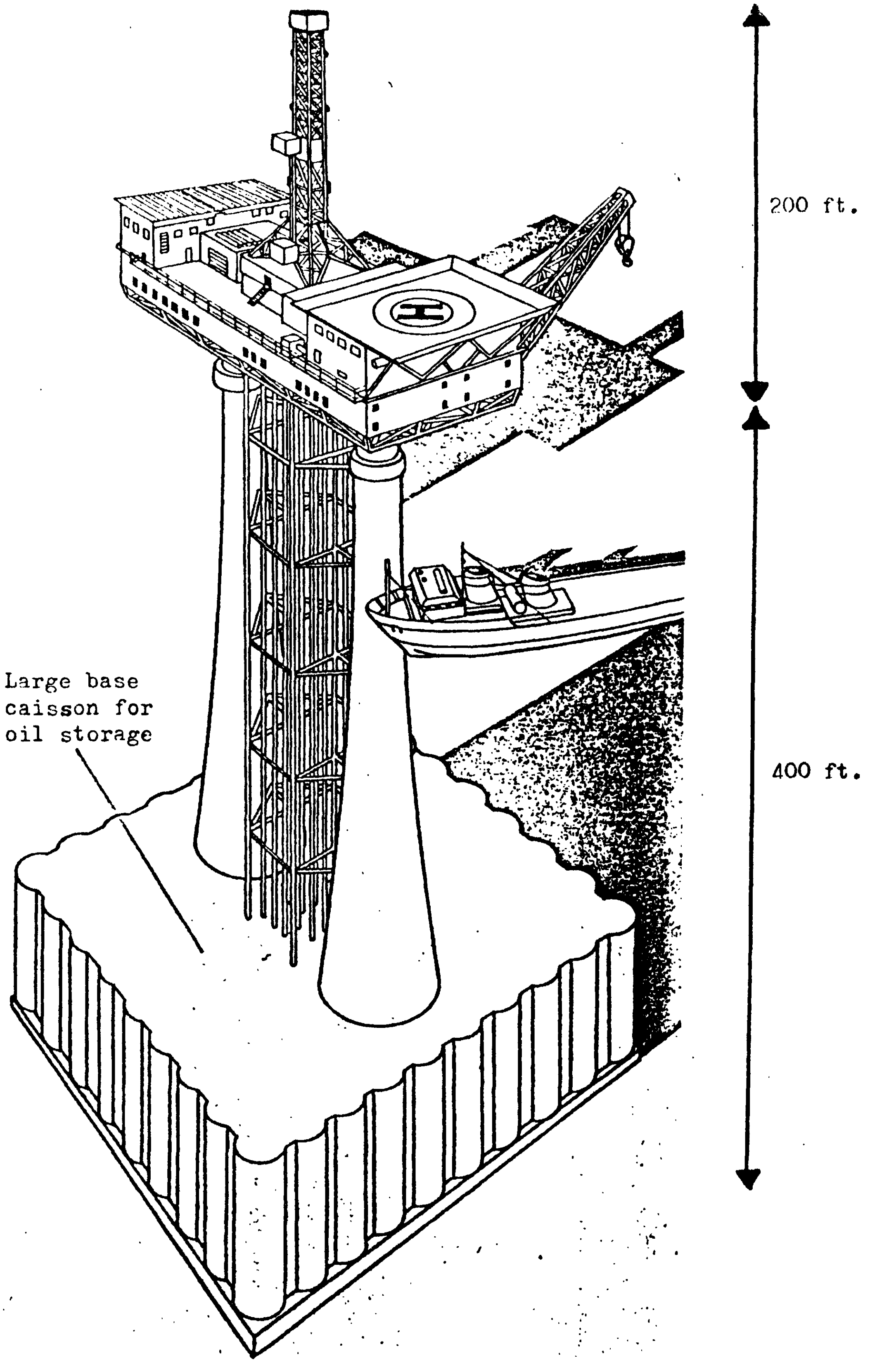

Figure 4-15. Concrete gravity platform (supports all production functions, drilling, living quarters and separation equipment) (from Design 296, August 1973, p. 33).

To prevent the seabed material under the platform from being eroded by the bottom currents, special spoilers have been built into the concrete base to dissipate the flow of these currents, and skirts protrude 10 feet (3 meters) below the edge of the base into the sea floor sediments[1] (Offshore, November 1975).

Accommodations for up to 120 men are provided on Condeep. It has a capacity for 40 wells, and the peak oil production rate will be approximately 300, 000 barrels per day (41, 000 metric tons per day). A Condeep-type platform was also successfully landed on the Brent field in August 1975. This platform was in a water depth of 420 feet (140 meters) and has a production capacity of 100, 000 barrels per day (13, 700 metric tons per day) (Allcock, 1975) (Figure 4-15).

2. Subsea Completion

The technique of placing the wellhead on the sea floor is referred to as subsea completion or subsea production. After subsea completion, the drilling platform or vessel is removed from the site and the well is produced by remote control (Figure 4-16). All further servicing and maintenance operations (workover techniques) during the life of the well are performed by lowering equipment from a special ship positioned or anchored above the well (Stone, 1975). Although some 250 subsea completions have been reported to be operational worldwide (Ocean Industry, 1975), only 20 to 25 have been proven in deep water (Chateau, 1976).[2]

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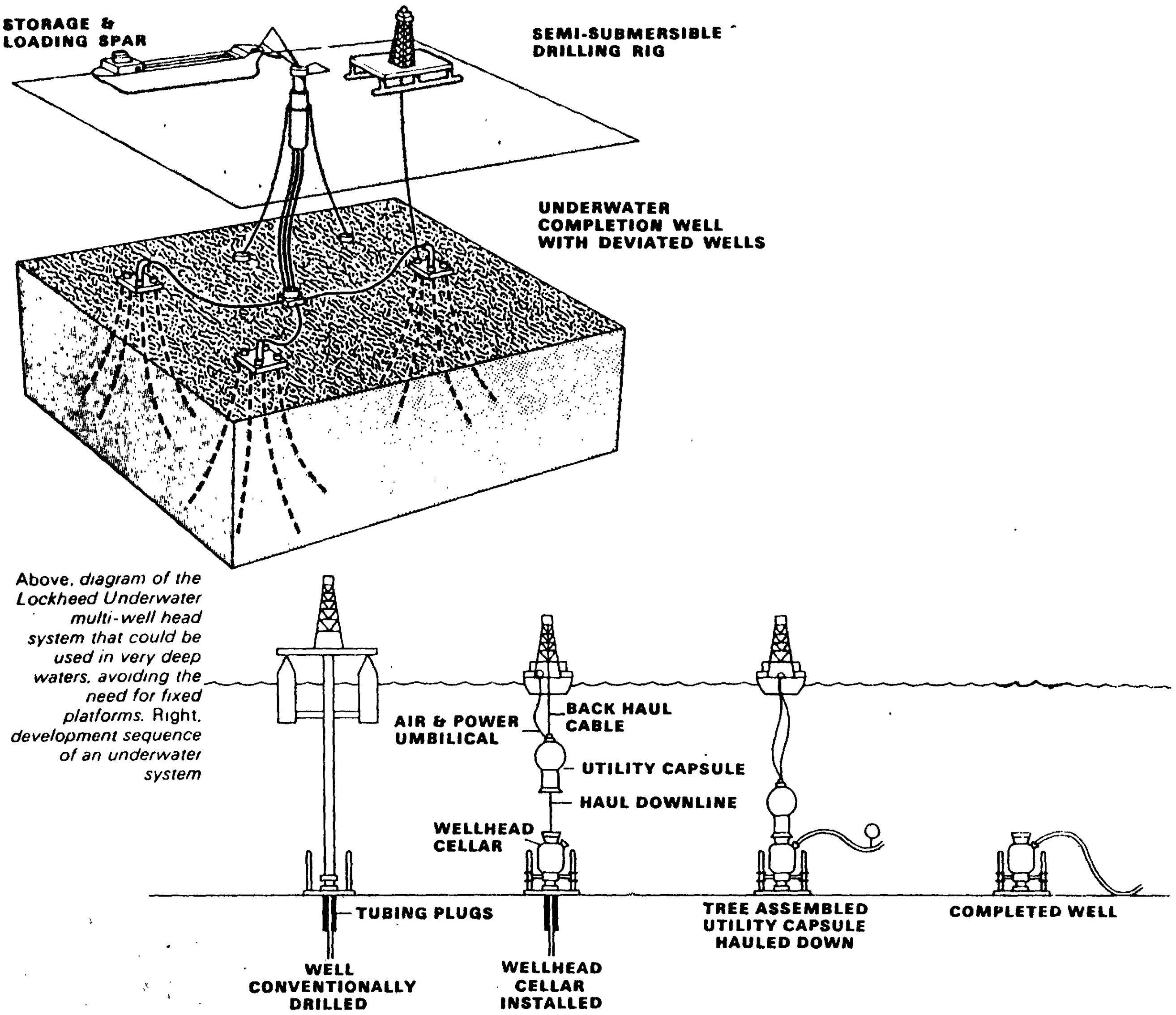
[1] The latest concrete offshore gravity structures are in some way reverting to the designs of the first stone English lighthouses of the 18th Century. The first Eddystone lighthouse, built on a rock islet 14 miles from Plymouth, was lost (with its builders and designers aboard) in a great storm in November 1703. In 1759, a new tower was completed, built of stone in the tappering shape of an oak tree trunk (parabolic curve) to a height of approximately 190 feet (60 meters) above sea level. This tower successfully withstood the elements until 1882, when it was replaced by a new structure on an adjacent shoal. The rock ledge on which it had stood had become so eroded by the sea as to undermine the structure (Panell, 1964).

[2] Oral communication.



Above, *diagram of the Lockheed Underwater multi-well head system that could be used in very deep waters, avoiding the need for fixed platforms.* Right, *development sequence of an underwater system*

Figure 4-16. Subsea completion technique (from Design, 296, August 1973, p. 39).

Two types of subsea production completion systems are being developed: an enclosed atmospheric pressure system and a wet-tree system.

In the atmospheric pressure system, a water tight enclosure insulates the conventional surface-type Christmas tree, manifold and wellhead equipment from the outside marine environment. Crews are transfered to the enclosure from submersible personnel transfer capsules or submarines to perform any operations as if on the surface. This system presents the advantage of utilizing conventional surface equipment which is protected from corrosion. Operators require a minor amount of specialized training. Water depths are limited to about 1500 feet (500 meters), but difficulties of access can arise in case of accidents.

The wet-tree type of system is exposed to the marine environment. Its operation is either by remote control, by robot devices or by specialized submarines. The production equipment must be redesigned for this environment, particularly with regard to pressure and corrosion.

Easy access of the equipment from the outside and absence of depth limitation compensate for the necessity of developing new techniques and new equipment. Both types of undersea wellhead can be installed either alone, as single well completions, or in multiple well clusters. Both types of wellhead, as presently configured, protrude above the sea floor, which presents the risk that they may be torn off or damaged by ship anchors. A new approach is being developed by placing the wellhead below the mud line (sea floor).

Subsea completions are more costly than wells grouped on a platform. However, being relatively fast to install, they can serve to bring a field into production more rapidly.

In the North Sea, four subsea wellheads have been installed in Ekofisk and four in Argyll. A single wellhead[1] designed to produce 8000 barrels per day and installed on the Beryl field in 385 feet (120 meters) of water in 1975 is giving some operating problems.

C. Transportation Systems

There are two major alternatives to transporting oil to shore: pipeline and tankers.

1. Pipelines

Laying a pipeline from shore to a particular production field is a complex exercise (Figure 4-17). Today, large diameter pipes (32-36 inches, 81-91 centimeters, inside diameter) are laid in the North Sea to depths of 500 feet (150 meters). The Ekofisk to Teeside pipeline, for example, is 220 miles long (350 kilometers) and has a diameter of 34 inches (86 centimeters) (Shaub, 1975). Vessels such as the Viking Piper, a semi-submersible lay barge, have been designed to lay 42-inch (107-centimeter) diameter pipe at depths of 1200 feet (370 meters). A pipeline is to be laid from the Frigg and Heimdal fields to Norway across the 600-foot-deep Norwegian trench (Oil and Gas Journal, Jan. 12, 1976). Table 4-2 shows the capacity of different pipelines.

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[1] This subsea production unit weighs approximately 50 tons (45 metric tons) and consists of two major systems: a master valve assembly (MVA) and a production control assembly (PCA). The MVA roughly fulfills the function of the Christmas tree and contains the tubing flowline valves.

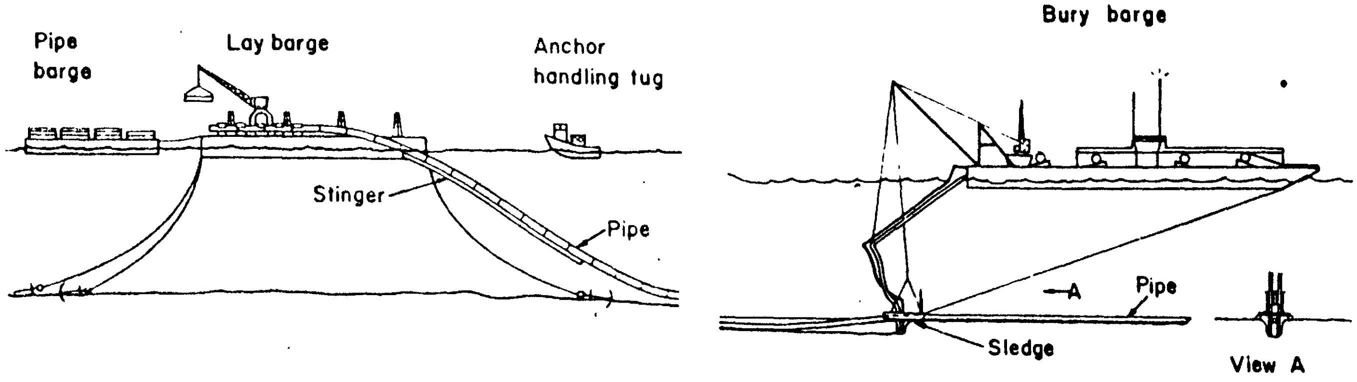

Figure 4-17. Pipe laying operations (from Williams, 1972, p. 39).

Table 4-2. Pipeline flow rates (from Larmine, 1975).

Pipe diameter (inches)	Metric tons per year (x 10^6)	Barrels per day (x 10^3)	Approximate pump station spacing (miles)
6	0.4-0.7	8-14	30-80
8	0.7-1.3	14-26	
10	1.3-2.5	26-50	
12	2.0-4.1	40-82	40-100
16	4.1-8.0	82-160	
20	4.0-13.0	80-260	
24	12.0-18.0	240-360	
26	15.0-25.0	300-502	60-200
36	20.0-40.0	400-800	
40	25.0-45.0	502-1080	
48	30.0-100.0	600-2000	

Offshore pipelines are different from those laid on land. They are designed to withstand greater pressures, corrosion and the difficulties in laying, linking, welding and repairing in deep water. Recent achievements in pipe laying have been made possible because of the production of high quality steel pipe, new fabrication yards for pipe (Ewing, 1976), the use of hyperbaric welding techniques and of underwater connections (Lallier, 1975).

By the end of 1974, a total of 347 miles (560 kilometers) of pipeline were in use in the North Sea, and 592 miles (950 kilometers) had been laid ready for use. In 1975, 496 miles (800 kilometers) were laid, mostly in water 350-450 feet deep (Figures 4-8, 4-9 and 4-10). It is estimated that in the next three to four years large diameter pipe will continue to be laid in the North Sea at the rate of 370 to 500 miles (600 to 800 kilometers) per year (Ewing, 1976). In 1975, there were 11 lay barges present in the North Sea. It is necessary to bury the pipeline in the seabed (this regulation mainly applies to the North Sea). Burial is done by submersible jetsleds towed by the bury barge, which follows the lay barge (Figure 4-17). The jetsled straddles the pipeline, blasting a trench beneath the pipe with water jets. This trench may be up to 7 feet (2 meters) deep (Wilson, 1975). The lay barges must be carefully anchored during the pipe-laying operation, and calm weather conditions are desirable (Bynum and Rapp, 1975). Semisubmersible lay barges are large vessels carrying up to 350 men.[1] Pipe laying is personnel-intensive, making extensive use of divers to inspect connections and to assist operations (Wilson, 1975).

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[1] Lay barges can cost up to $250, 000 per day in operation.

2. Single Buoy Mooring Systems and Undersea Storage

The other commercially viable method of bringing oil ashore is by tanker. One loading system in worldwide operation being used in the North Sea is the Single Buoy Mooring (SBM) (Figure 4-18). The SBM is designed to have the capability to moor tankers up to 100, 000 dead weight tons. The buoy or loading-spar is anchored on site with several anchors.[1] SBMs are already operating in the Ekofisk, Argyll and Dan fields in the North Sea (Hazzard, 1975). When the tanker is moored to the SBM,flexible hoses are connected to transfer oil from the undersea storage tank. In the Ekofisk field, the undersea concrete storage tank has a capacity equivalent to three days production. The tanker capacity selected at Argyll for a production rate of 50,000 barrels per day was 200, 000 barrels or 30, 000 dead weight tons (Williams, 1975). At present, the SBM systems are limited to water depths of not more than 300 feet (100 meters) because of the weight and handling problems of the anchor chains. Tankers cannot moor or load and vacate the berth in difficult weather conditions because of the manual assistance required in hose-handling operations.

D. Ancillary Operations

Although oil production requires many support operations, three are discussed here: construction, diving and onshore support.

1. Construction

The installation of equipment on the seabed near offshore platforms has led to the development of special multipurpose work boats (Figure 4-19). The placement of multihundred ton packages[2] on Ekofisk 1, for example, was accomplished by a derrick barge with a capacity of 1600 tons.

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[1] A related system is the single point mooring (SPM), where the buoy is attached to one point on the seabed.

[2] Packages designate modular units prefabricated onshore and lifted in place during installation.

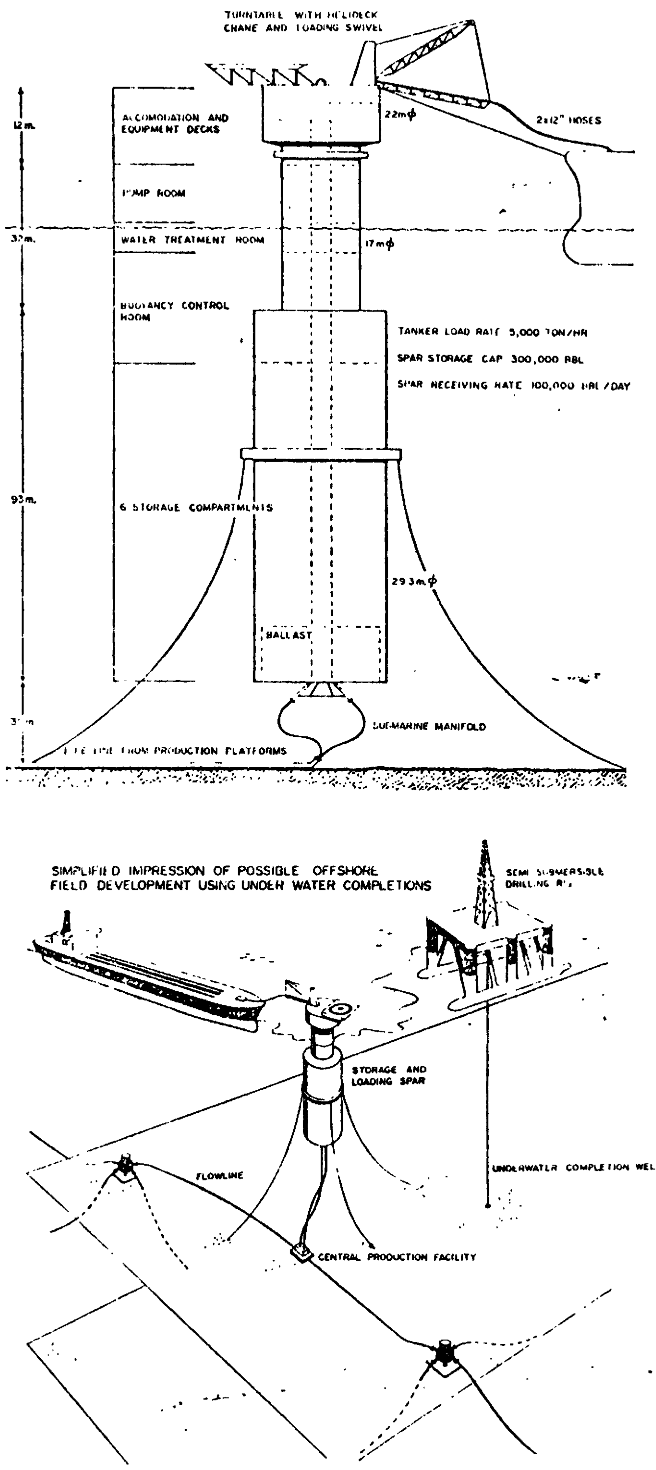

Figure 4-18. Single buoy mooring (SBM) and undersea storage tank (from Baxendall, 1974, pp. 27-28).

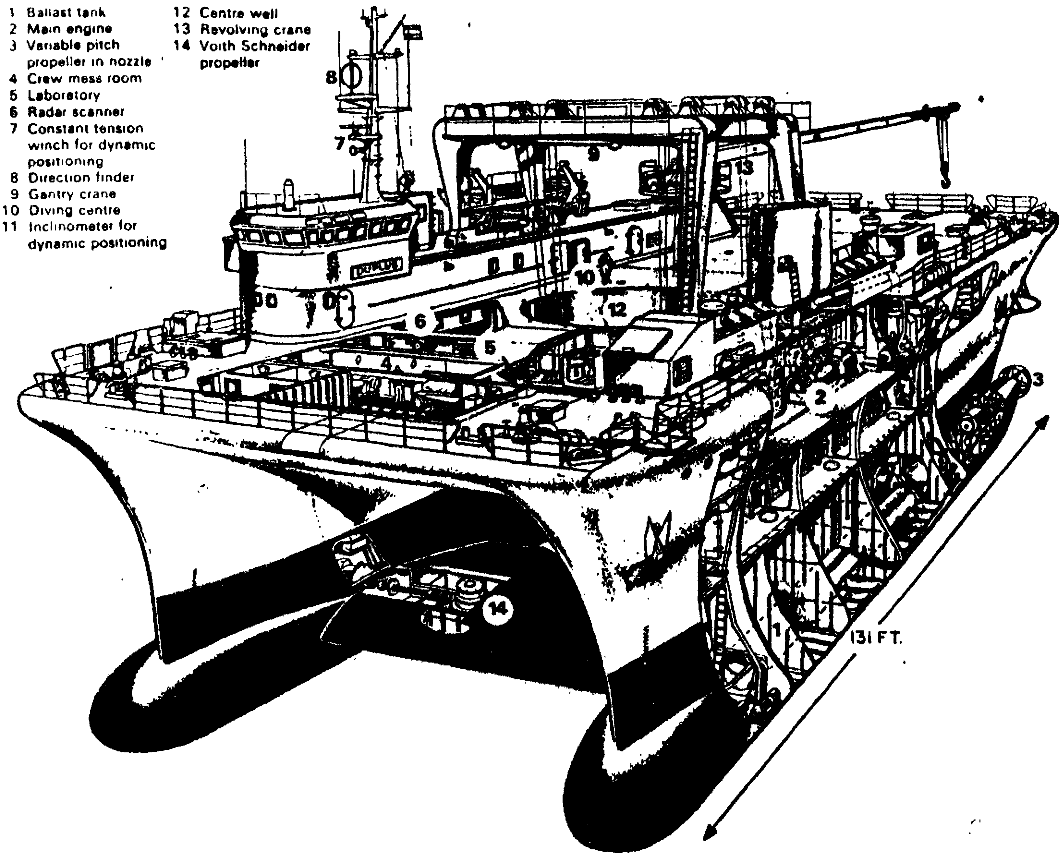

Figure 4-19. General purpose work vessel under evaluation for support services in the North Sea (from Design, 296, August 1973, p. 45).

Accurate positioning of the barge is essential, and every anchor has to be positioned by survey. One system using satellite fixes claimed to provide a precision within ± 10 meters.

It is easy to visualize the many complex scheduling, coordination and erection operations required during the construction of offshore installation. Construction is personnel-intensive and calls for the skills of riggers, welders and divers to perform many nonroutine, hazardous tasks.

2. Diving and Submersibles

Diving methods employed in offshore fields vary according to the nature of the work, the depth of the water, and the required bottom time. Self-contained underwater breathing apparatus (SCUBA) equipment is used at moderate depths (less than 100 feet) for dives of short duration under good visibility (such as inspection in daylight hours only). Compressed-air diving with face masks or lightweight helmets is used extensively to depths of approximately 150 feet (45 meters). Surface-to-surface helium/oxygen diving is used in depths of 150 to 300 feet (45 to 90 meters). Much of the danger has been eliminated in this method of diving by providing an open-bottom bell at the work site. The transfer under pressure (TUP) method is usually employed for deep helium/oxygen dives of short duration. With the TUP method, two divers are usually lowered to the work site in a submersible diving chamber (SDC). The chamber is pressurized to the work site depth pressure, and one man leaves the chamber to perform the work task while the other tends him.

In conventional surface-to-surface diving, without using a bell, the diver decompresses during his ascent. Decompression allows the gases, forced into solution in the body tissues, to escape without forming bubbles in the blood stream which would cause decompression sickness (bends). In the saturation diving technique, the divers are sealed on shipboard in a SDC pressurized to the depth pressure of their work. After some 12 hours at a given pressure, the body is saturated, and the divers may be lowered to and from the job site in a SDC. The main object of saturation diving is to eliminate decompression after each and every dive. The length of time the diver may spend working at depth is limited only by his physical endurance (Morrisey, 1975).

The deepest commercial saturation diving in 1975 was 325 meters (about 1000 feet) off Labrador. The record depth for diving under simulated conditions (SDC pressurized at the surface) is currently about 2000 feet. Despite the many advances in diving physiology, divers remain critically dependent on artificial light for visibility and on their life-support systems.

A submersible is a diving vehicle dependent upon surface support (Ballard and Emery, 1970). The tasks of submersibles can be classified into three major categories: intervention, observation and surveying (Oldaker, 1975).

Submarines are important to the pipeline fleet. They may be used to chart the pipeline route and to carry out inspection of and repairs to the pipeline, thus eliminating the need for divers. At the Shell Development Laboratory in Houston, seven companies are participating in a major project to develop a submersible pipeline repair vehicle guided by sonar, video and other sensors to carry out all aspects of repair (Oil and Gas Journal, May 1975).

3. Onshore Support

Offshore activities need many services from the land (Table 4-3). Vast amounts of consumables and materials such as mud, cement, lubricants, pipe sections, food and spare parts must be ferried to the offshore installations. Special supply boats operate on a 24-hour basis from the nearest service ports. In the North Sea at Aberdeen, for example, £2 million have been invested in improving quayside facilities for supply boats. Thirty vessels may be in the harbor at any one time, and there will be up to 70 movements a day. Crews for the offshore installations must also be ferried

Table 4-3. Onshore services needed by offshore installations (from Williams, 1972, p. 41).

Services	Equipment and Materials	Contracts
Supply Boats	Steel Plate	Onshore Structure Fabrication
Helicopter and Aircraft	Steel Tubulars	Onshore Process Facilities Fabrication
Catering	Pressure Vessels	Pipe Coating
Telecommunications	Pipe Fittings and Valves	Offshore Structure Installation
Diving	Compressors and Pumps	Offshore Process Hook Up
Survey (Seabed Mapping, Soil Testing, Etc.)	Engines, Motors, and Turbines	Submarine Pipe Laying
Offshore Painting	Instruments and Control Gears	Pipeline Burial
Engineering Consultancy	Electrical and Telecoms	Onshore Construction
Mechanical Repair	Oil Well Equipment	Bases, Terminals and Offices
Structural Repair	Mud Chemicals and Cement	Floating Drilling
Onshore Workshop	Fuel and Lubricants	Platform Drilling
Corrosion Protection	Fire/Safety Equipment	Diving
After Sales (For Equipment)		Submarine OPS

to and from their tours of duty; helicopters are used for passenger transport (Magnuson, 1974).

The fabrication yards for the construction of offshore installations are a vital aspect of onshore support. For the new gravity-based concrete platforms, sheltered coastal sites with water depths of 600 feet (200 meters) are necessary. Such sites are more common on the west coast of Scotland or in Norway. Shallower water sites accommodate steel platforms (jackets) which are usually assembled on their sides and towed out to the offshore site, where they are tilted and sunk into position.

Oil refineries require extensive flat sites with a good water supply and access to a deepwater terminal for the loading and unloading of oil (Sibthorp, 1975, pp. 44-49). The onshore infrastructure requirements of offshore oil have been the subject of many prior inquiries (McKay, 1975, pp. 145-152; Gaskin, 1974, p. 90; White et al., 1973, p. 100; McGregor-Hutcheson and Hogg, 1975). The current refinery capacity of the EEC member countries is of the order of 16, 000 million barrels per day (Table 4-4).

Table 4-4. Refining capacity of EEC countries (from International Petroleum Encyclopedia, 1975).

Country	Thousands of barrels per day
Belgium	867
Denmark	220
France	3342
Italy	3953
Netherlands	1841
United Kingdom	2783
West Germany	2987

4.2.3 The Magnitude of the Technology

A. Exploration

In 1975, worldwide exploration involved some 300 rigs, each drilling approximately 2 to 4 wells per year (International Petroleum Encyclopedia, 1975). In 1974, a total of 100 wells were started or drilled in the United Kingdom sector of the North Sea by 39 rigs working a total of 25[1] rig years. This was an increase from 61 exploration wells drilled in 1973

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[1] Rig year is unit of working time; other time is standby time.

by 25 rigs spending 13 rig years (Department of Energy, 1975). To date, there have been some 550 exploration wells and 250 production wells drilled for oil and gas in the North Sea. Table 4-5 lists the number of exploration wells drilled by EEC countries in 1974.

Table 4-5. Offshore exploration results in EEC countries for 1974 (from Offshore, June 20, 1975).

Country	Development Wells	Wildcat Wells	Total Wells	Gas Producers	Oil Producers	Dry Holes
Denmark			2			2
France		1	1			1
West Germany			4			
Ireland		5	5			
Italy	17	13	30	16	1	13
Netherlands	9	17	26	9		17
United Kingdom	56(35)[1]	65	121	23	46	52
Adjacent Countries						
Norway	16	20	36			
Sweden		3	3		1	
Portugal		3	3			3
Spain		4	4			4

For 1974, assuming an average daily cost of $50, 000 per offshore rig,[2] the order of magnitude of annual exploration expenditures for the United Kingdom sector of the North Sea would have been $500 million.

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[1] There is some debate concerning development wells and hence no actual agreement concerning the number of wells.

[2] Daily rates vary from $25, 000 to $50, 000, depending on the configuration, but the assumption attempts to allow for geophysical surveys and other prior expenses.

For 1975, an estimated 35 to 45 rigs were expected to spend some 30 rig years of activity on exploration drilling in the United Kingdom sector. In 1976, for the North Sea countries, the following are reportedly planned as shown below:

Table 4-6. Projected exploration in the North Sea for 1976 (from International Petroleum Encyclopedia, 1975; Offshore, June 1975).

Country Sector	Number of Wells
United Kingdom (west of Shetland and west of Wales)	120 - 140
Norway (including north of 62°)	36 - 40
West Germany	20 - 22
Netherlands	26 - 36
TOTAL	202 - 238

For 1976, by interpolating from past statistics, it can be expected that the following numbers of wells will be drilled:

Celtic Sea	8 - 15
West of France	1 - 4
Mediterranean (France and Italy)	17 - 20

B. Production

In 1975, world offshore production was of the order of 10 million barrels per day (500 x 10^6 metric tons per year) from some 18, 000 offshore wells. The main producing countries are listed in Table 4-7.

Table 4-7. Major countries of offshore oil production in 1974 (from Oil and Gas Journal, May 1975).

Country	Barrels Per Day
Venezuela	2, 700, 000
Saudia Arabia	2, 000, 000
United States (Gulf and California)	1, 700, 000
Other Near East	2, 000, 000
EEC	10, 000
Norway	25, 000
Others	800, 000
TOTAL	9, 235,000

Worldwide offshore oil production is projected to increase at a rate of 5 to 10% per year. North Sea offshore oil production in 1975 was approximately as shown in Table 4-8.

Table 4-8. North Sea offshore oil production in 1975 (from IPF, 1976).

Area	Barrels Per Day	Metric Tons Per Year
Norway (Ekofisk)	190, 000	9, 350, 000
United Kingdom Sector	25, 000	1, 100, 000
TOTAL	215, 000	10,450, 000

The range of offshore production estimated for future years in the United Kingdom sector of the North Sea is shown in Figure 4-20 and recent forecasts, based on present reserves and undiscovered potential, estimate that an average of 730 to 1100 x 10^6 barrels per year (100 to 150 x 10^6 metric tons per year) (United Kingdom Department of Energy, 1975) or approximately 2 to 3 x 10^6 barrels per day will be produced during the years 1980 to 1990.

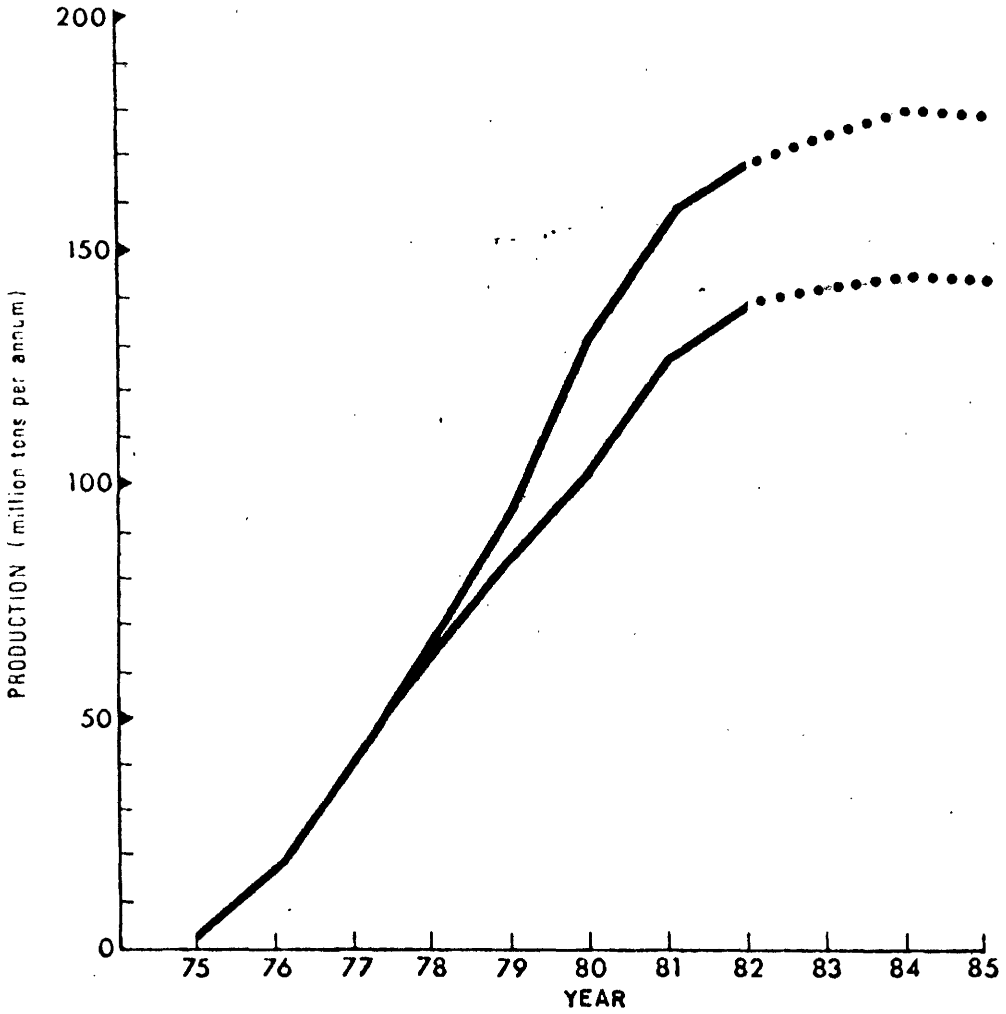

Figure 4-20. Forecast range of oil production 1975-1985 (including production from existing and future discoveries in presently designated areas of the United Kingdom Continental Shelf) (from United Kingdom Department of Energy, 1975, p. 16).

For the total of the North Sea, future oil production is currently projected as indicated in Table 4-9. It is estimated that this production would originate from to 50 to 80 platforms each manned by some 100 men.

If these projections are valid, it can be seen that the North Sea alone is expected to overtake the current offshore production of Venezuela and the United States combined by 1980-1982.

Table 4-9. Forecast range of oil production in the North Sea for 1976-1986 (from Energy Prospects to 1985, Offshore Journal, 1975).

Year	10^6 Barrels Per Day	10^6 Metric Tons Per Year
1976	0.8	38
1978	2.3	114
1980	4.1	207
1982	4.7	240
1984	4.9	245
1986	5.0-5.1	250-255

World gas production is currently 17 x 10^{12} cubic feet per day (478 x 10^9 cubic meters per day). North Sea production is approximately 3.6 x 10^9 cubic feet per day (0.1 x 10^9 cubic meters per day) from 23 existing wells and may even be 15 to 20 x 10^9 cubic feet per day (420 to 560 x 10^6 cubic meters per day) by 1980.

4.2.4 Personnel of Offshore Mineral Production Technology

The human activities in offshore oil technology are still moderately labor-intensive, especially in the production and construction phases. Many human operators perform many individual coordinated tasks from handling drill pipe to turning valves. Some of these tasks affect the safety of others, and all of them ultimately affect the environment. This subject, which has not received much public attention, is also discussed in Chapter 5.

For the whole of the North Sea, the present total number of men working offshore is in the order of 8,000 to 10,000.[1] As exploration and production increase, it is possible that the number may reach 10,000 to 15,000 by 1980-1985 (Table 4-10). These men are roughnecks, drillers, toolpushers and superintendents, sailors and riggers, cooks and stewards, mud engineers

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[1] In 1974, it was estimated that about 4000 men were on offshore platforms in the United Kingdom sector of the North Sea (UK Department of Energy, 1975). Others would be on construction and pipe-laying barges, supply vessels, etc.

and corrosion engineers, welders, divers, crane operators, drilling engineers and logging service engineers, helicopter pilots and supply boat captains, and many others (Figure 4-21). (There are very few, if any, women aboard drilling rigs.) Most of the men work a twelve-hour day in the open. The tour of duty is usually two weeks on, one week off. When they are off duty, the men are flown back to their homes. They are mostly young and highly paid. They wear special clothing but receive little formal training. They have a high level of mobility between the companies in the industry.

Table 4-10. Time span of an offshore oil field (1 billion barrels recoverable and 250,000 barrels per day capacity) (from Williams, 1972, p. 41).

	EXPLORATION	CONSTRUCTION	PRODUCTION		
	SURVEYS 2000 TO 4000 km. EXPLORATION/ APPRAISAL DRILLING 5 TO 30 WELLS	PLANNING / DESIGN CONSTRUCTION OF PRODUCTION FACILITIES DRILLING OF PRODUCTION WELLS CONSTRUCTION OF TRANSPORT FACILITIES	BUILD UP 3-5 YEARS	PLATEAU 5 YEARS	DECLINE 8-10 YEARS
TIME	2-6 YEARS	5-6 YEARS	16-20 YEARS		
DIRECT EMPLOYMENT	200-400 MEN	1000-2000 MEN	300-400 MEN		
CAPITAL INVESTMENT	£10-£60 MILLION	£250 MILLION	£50-£100 (MILLION) DEPENDENT ON TYPE OF SECONDARY RECOVERY SCHEME /OTHER OPERATIONS NECESSARY		
OPERATING EXPENDITURE			£250-£300 (MILLION)		

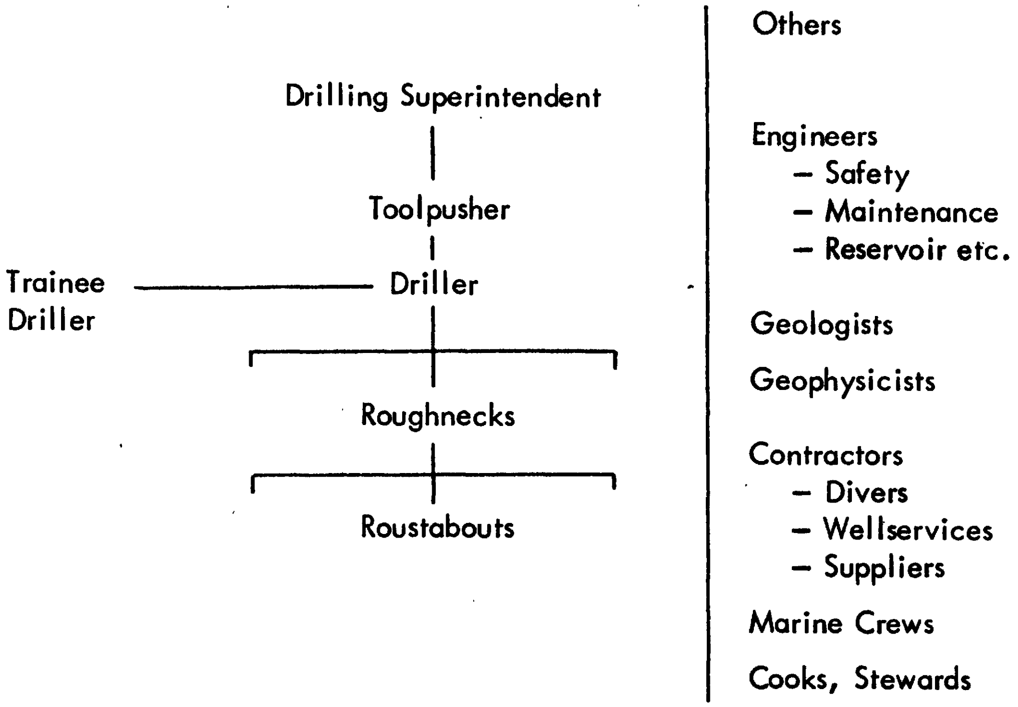

Figure 4-21. Organization of drilling rig personnel (from Crook, 1975, p. 61).

4.2.5 The Future

Three aspects of future offshore petroleum technology will be considered below: exploration, production and transportation.

A. Exploration

Considerable resources have been and are deployed by the oil industry in attempting to devise new drilling methods (OECD, 1974). Some of the industry's critics, however, believe that this has not been enough and that research has been improperly motivated (Spangler, 1970; Kash et al., 1973). Some obvious goals for research might be to eliminate the need to change drilling bits so frequently or to put less reliance on the mud system.

It is likely that future improvements in drilling technology will continue to be based on greater computer manipulation of data. This will result in quantitative improvements of physical hardware and in more automation, but there is little prospect of any truly dramatic qualitative change in drilling technology in the foreseeable future.

Some new exploration technology concepts which have been proposed are summarized below:

Surveys

Higher speed surveys by hydrofoil and hovercraft.	Not successful. Higher speed creates noise in the hydrophones towed behind the vessel.
Geophysical satellites to yield magnetic data.	May be of use in large scale geophysical exploration.
Imagery satellites, "Landsaterts."	Not directly usable for exploration for hydrocarbons, but weather and sea patterns recorded on the image may be of considerable value.
Geophysical bright-spot technique.	May permit the identification of gas reservoirs on geophysical records.

Drilling

Replace drilling pipe by an armored hose which can be reeled in, thus saving valuable trip time.	Neither this nor full automation of pipe handling in the derrick have been widely attempted.
New designs for bits which can be lowered and removed inside the drill pipe.	This has not proved reliable.
New principles of rock breaking using flames and high pressure water jets.	Tested in the laboratory but not found to be adequate substitute for drilling bits currently in use.
Drilling mud compositions have become more versatile to meet down-hole conditions.	Mud circulation system itself remains primitive.

Few new developments have taken place in human engineering of oil drilling operations, but this seems a promising direction for innovation and automation. Sophisticated sensors and remote control techniques of the kind widespread in the aircraft and nuclear reactor industries can only be adapted with difficulty to a technology as primitive as drilling. Attempts to transfer technology from other sectors do not gain ready acceptance because of cost limitations and mistrust of new concepts.

The most obvious trend in the offshore exploration industry will continue to be improvements in platform design, allowing safer and more efficient drilling in rougher and deeper waters (Ocean Industry, September 1975).[1]

New deepwater riser pipe designs incorporating lighter and stronger materials are being investigated to support exploration in 3000-foot (1000-meter) depths. The capabilities exist to go deeper, but the technology for completing wells and producing petroleum from these depths has not been tested. However, it is highly probable that exploration drilling will begin in the Mediterranean in water depths of 7500 to 9000 feet (2500 to 3000 meters) by 1978 and that production will be attempted by 1985, if petroleum is found.

Petroleum exploration drilling, offshore trends and space events are summarized in Table 4-11.

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[1] Successful tests of tension-leg platforms may permit drilling in water depths of 3000 feet (1000 meters) and more with less motion and at less cost. Other designs are also being model-tested for use in arctic waters; they look like armored islands and are designed to withstand ice impact (Offshore, November 1975).

Table 4-11. Historical exploration drilling events.

Year	Oil Drilling Offshore Water Depths (feet)	Land Drilling (feet)	Aerospace	Other Water Depths (feet)
1930	0-25			Beebe Bathyscaphe (?)
1940	25-50	15, 000	V-2 Rocket	
1950	100 (jackup)	20, 000 28, 000	X-15 Flight	Bathyscaphe TRIESTE 26, 000
1960				
1964	semisub. in 300		Man in space	CUSS 1 dynamic positioning and drilling in 11, 000
1970				
1971	1300		Land on moon	JOIDES-CHALLENGER dynamic positioning and drilling in 18, 000
1975	2300	31, 000		

B. Production

In the future, offshore oil production technology will take two major alternative directions: systems with wellheads above water (surface production system) and systems with wellheads below the water (seabed production systems).

Surface systems will be located on platforms implanted in the seabed, resting on the seabed or floating and anchored. By 1980, one source estimates that between 50 and 80 platforms will be installed in the North Sea. Of the existing 27 platforms now on order, 12 are seabed supported, concrete gravity-type units designed for water depths between 300 feet (100 meters) and 500 feet (150 meters). Several concrete bottom-supported structures and a variety of hybrid steel-concrete concepts are being designed for 1000-foot (300-meter) depths (World Oil, 1975). Articulated buoyant structures attached to the sea floor and combining drilling, production, and oil storage are now being designed for 1200-foot (365-meter) water depths (Adye, 1973). A scale model of a compliant 1500-foot (460-meter) steel tower is now being tested (Ocean Industry). It is unlikely that seabed supported platforms would exceed 1500-foot depths.

Successful recent model tests of a tension-leg surface floating platform indicate a capability to perform in depths of 3000 feet (1000 meters) (Ocean Industry, 1975). Research engineers generally consider 10, 000 feet (3000 meters) as their logical objective for 1985 if oil is found in the deeper water of the Mediterranean. Several floating spar-buoy concepts are also being considered. For all these floating, moored platforms, new longer flexible riser pipes connected to the seabed (Hueze, 1975) and new anchoring arrays for minimal lateral displacement will have to be provided.

Seabed production systems will continue to receive more attention because they offer several advantages (Section 4. 2. 2B) including rapid production of a field. The concept of a subsea wellhead entirely below the mud line is being developed (Offshore Services, July 1975). Subsea completion technology in deeper water will be paced by the development of reliable remote control techniques, submersible work chambers, and advanced diver support systems (Ocean Industry, 1975). All deepwater production operations will need more reliable automation techniques and remote controlled manipulators. The employment of divers and submersibles will continue for shallower water (< 600 feet) tasks, but it is difficult to see their continued justification in deeper water in view of safety hazards. Promising new developments include an anthropomorphic, one-atmosphere diving suit that is essentially a man-shaped submarine;[1] and sensing and telemetering of diver physiological responses.

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[1] Currently operating at 450 feet (140 meters) in the North Sea but designed to dive to 1500 feet (460 meters), this diving suit presents disadvantages in comparison with submarines.

C. Transportation

Pipelines will continue to be the principal means of transporting oil to shore. Tanker loading from single point moorings (SPMs) connected to undersea storage tanks will frequently be used for deeper water. Floating SPAR buoys, which combine oil storage with low motion characteristics, will gain more acceptance in deeper quieter waters such as the Mediterranean (CFP Total Documentary Film). Improvements in tanker mooring and loading methods in rough sea conditions will be sought to reduce down time. For the North Sea, new interconnected pipeline grids, similar to onshore gas utilities, will be considered. Pipeline technology is not as advanced as production platform concepts for deep water. There are still major problems in laying lengths of pipeline shorter than the water depth and in joining pipelines in deep water.

New developments may also be possible in processing offshore oil. Whole petro-chemical plants, either floating or on artificial islands, have been conceived in the past and will come up again as possible alternatives to shore-based plants (Ocean Industry, 1975; Offshore Technology Conference, 1975).

4.3 HARD MINERAL TECHNOLOGY

Except in very deep ocean water, the worldwide production of hard minerals involves three distinct kinds of technologies which are neither advanced nor very large when compared to petroleum technology. They are: dredging and related methods of excavation of the seabed; mining of minerals below the seabed by underground excavation and tunnelling; and solution mining such as in the FRASCH process for sulphur. It is expected that these technologies will acquire greater importance between 1985 and 2000.

4.3.1 The Magnitude of Industry

The relative importance of the three technologies can be approximated from the estimated value of the minerals they produce annually. Large volumes of dredged seabed material, excavated for harbor or pipeline construction, are not valued as mineral. Table 4-12 lists the values of minerals recovered by each technology.

Table 4-12. Estimated value of hard minerals recovered by type of technology (see table in Section 2.4).

Technology	Dredging	Underground Mining	Solution Mining
Value	U.S. dollars	U.S. dollars	U.S. dollars
Source			
Southeast Asia	90×10^6 (Tin)		
Europe	35×10^6 (Sand and Gravel)	20×10^6 (Potash)	
United States	(Oyster shells)		(Sulphur, Gulf of Mexico)
Other	(Oyster shells, Iceland)	(Coal, Japan)	

The exploitation of hard minerals is preceded by prospecting or exploration, which is a subtechnology in its own right, just as in the petroleum industry. The total worldwide annual expenditures for this activity are highly variable from year to year. For example, in the mid-1960s offshore exploration for sand and gravel, diamonds, tin and gold on the continental shelves, when combined, amounted to between $5 million and $10 million annually. It is much less today because the interest of industry has shifted to manganese nodules in the deep ocean. In any case, it is considerably smaller than exploration for petroleum.

4.3.2 Mineral Exploration

Mineral exploration, like oil exploration, is a game of chance against nature – the object being to gradually reduce the odds by reducing the size of the area in which a target is found.

In 1975, the offshore techniques of exploration for minerals, in water depths between 15 feet (5 meters) and 1500 feet (500 meters), included geophysical methods to locate the target and sampling techniques to identify the minerals and their value. Exploration requires a support vessel and a positioning method.

A. Geophysics

Geophysical methods for hard mineral exploration are generally similar to those employed by the petroleum industry (Section 4.2.1) but on a smaller scale since the targets sought are generally smaller and nearer the seabed. They include:

1. The echo-sounder to measure sea floor topography.
2. The continuous seismic reflection system[1] with hydrophones trailed behind the moving vessel which pick up signals generated by an acoustic source[2] to investigate ancient river channels or contacts between hard and soft rock formations.
3. Other geophysical techniques include magnetic and gravity measurements.

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[1] Refraction, unlike in petroleum exploration, is seldom used to locate minerals.

[2] Explosives are not used any longer.

4. Two visual methods of undersea mineral exploration are side scan sonar and underwater television. Side scan sonar emits and records pulses of high frequency acoustic energy laterally from a "fish" towed a small distance above the seabed to obtain a facsimile image of topography and obstacles. It has a range of 1600 feet (500 meters) on either side of the path travelled by the fish. With a powerful light, underwater television gives a close-up visual display in real time of seabed objects such as phosphorite nodules.

B. Sampling

There are many varieties of mechanical sampling devices for minerals (Cruikshank, 1974). The purpose of these devices is to cut, remove and bring back material from the seabed. Some are also used for soil and foundation studies in civil engineering (Figure 4-22).

Drilling is done by driving pipes from ships or platforms on the sea surface or by lowering fully automated, remotely controlled drilling machines onto the seabed to take a continuous sample (core). Most core samples are cylindrical and not more than a few inches in diameter. When several cubic meters of sample (bulk sample) are required, as in the case of sand and gravel or diamond prospecting, the seabed material is pumped up by air-lifting or jet-lifting. Mechanical vibratory samplers can cut core samples up to 30 inches (76 centimeters) in diameter. In Southeast Asia, BANKA and BECKER drills drive 4- to 6-inch (10- to 15-centimeter) pipes into the sea for tin sampling.

From 1965 to 1974, diamonds were sampled off southwest Africa from a 200-foot (60-meter) ship, the Rockeater, which had four-anchor mooring assisted by an orientable stern propeller. Through a center well in the ship, a 30-inch (76-centimeter) diameter pipe could be lowered to cut the sea floor gravels by a reciprocating action. A jet-pump lifted the gravels

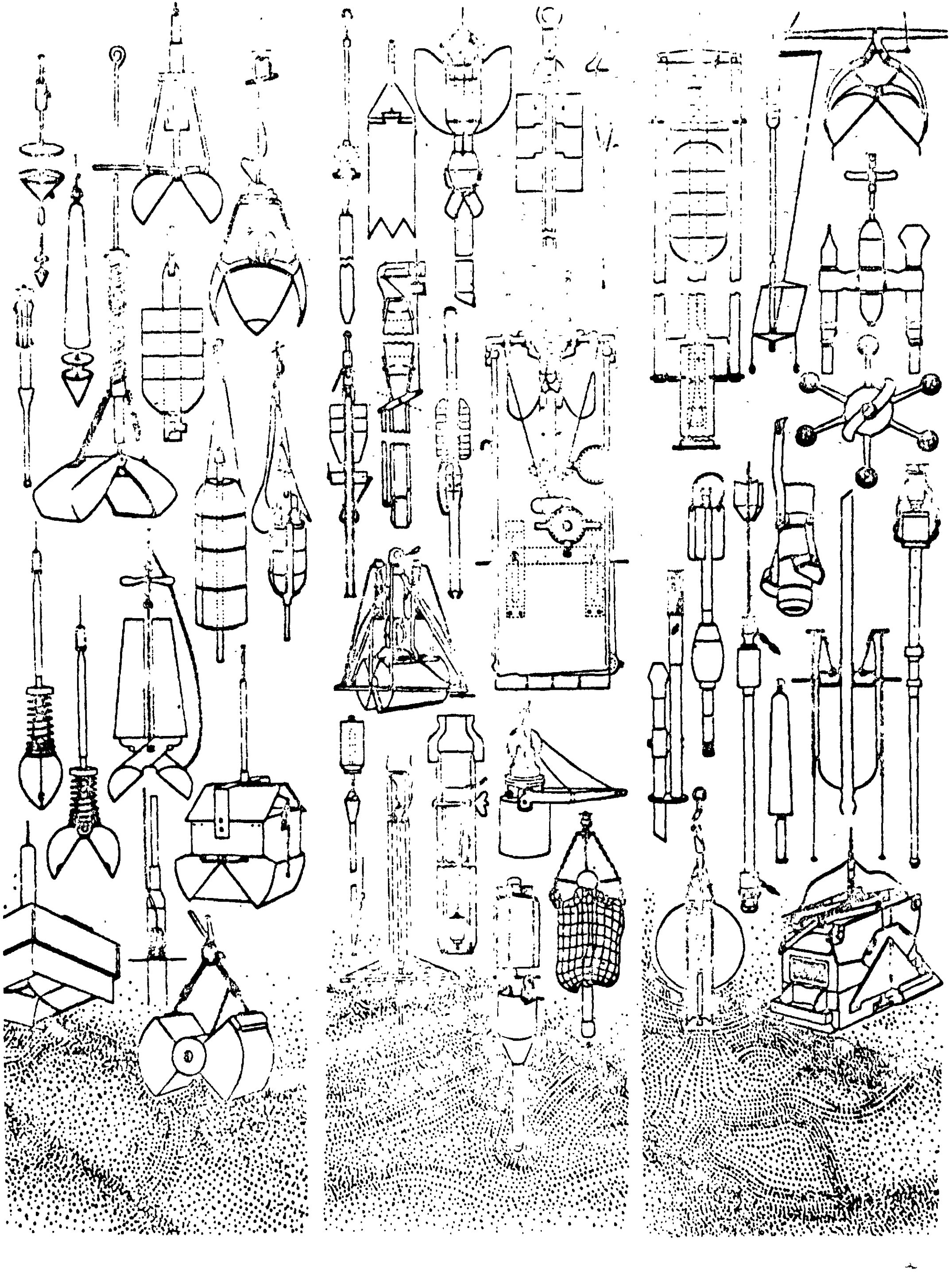

Figure 4-22. Equipment used for sea floor sampling (from Kazmitcheff and Lekime, 1972, p. 131).

to a ship-board processing plant. In the North Sea, sand and gravel deposits are sampled by submerging a 30-inch (76-centimeter) diameter caisson (the Amdrill), which cuts into the seabed with water jets. This sample is then recovered by pumping.

Manned submersibles have not been widely used for mineral sampling as their costs have been too great.

4.3.3 Mineral Production Techniques

This section describes the main production techniques including: dredging and seabed techniques; ship-board mineral processing; mining below the seabed; and solution mining.

A. Dredging and Seabed Techniques

Dredges, working in ponds or rivers, have mined tin and gold for nearly a hundred years. Dredgers have removed sand and silt drifting into harbor entrances for centuries. Dredging is a method of excavating and lifting seabed material on a more or less continuous basis (Figure 4-23). Most dredges are floating vessels, as shown in Figure 4-24. There are three kinds of dredges: bucket line, cutter suction and hopper dredges.

A typical bucket dredge mining offshore in Southeast Asia for tin is shown in Figure 4-25. These dredges are currently excavating and processing 250, 000 to 500, 000 cubic yards (190, 000 to 380, 000 cubic meters) per month of tin-bearing sand and gravel from depths of 100 to 130 feet (30 to 40 meters) below sea level 5 to 10 miles (8 to 16 kilometers) from shore. The most serious operating limitation and cause of downtime for offshore bucket dredges is due to long-period wave motion (swell). This causes heaving and pitching of the hull, resulting in bumping of the lower end of the ladder (lower tumbler) against the seabed with the risk of damage or slipping off of the bucket chain. In consequence, bucket line dredges have never been used in high energy offshore environments.

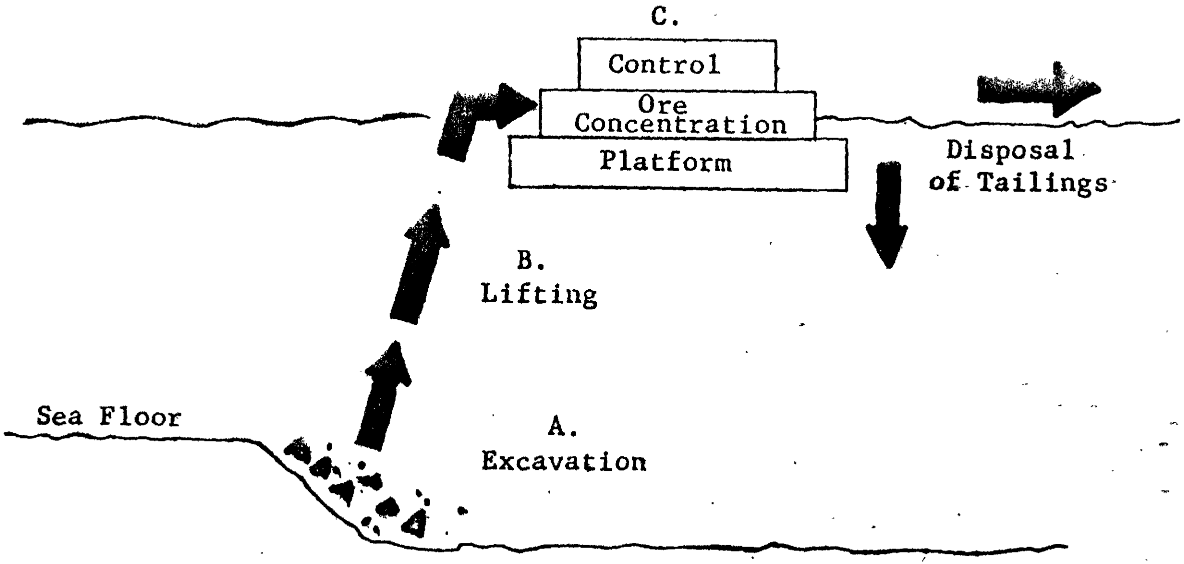

Figure 4-23. Typical components and functions of a floating dredging system (from OSE, 1971, Vol. 1, p. 157).

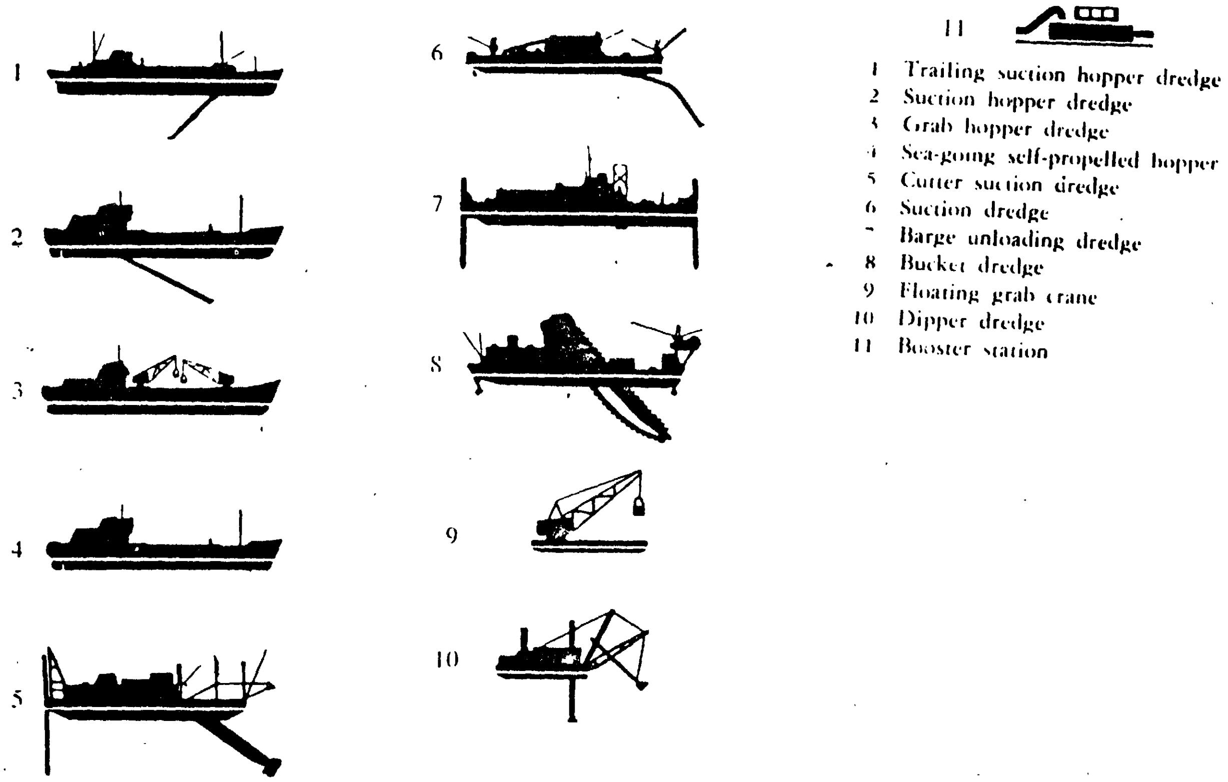

Figure 4-24. Examples of dredges (from World Dredging and Marine Construction, January 1975, Vol. 11, No. 2).

The schematic arrangement of a cutter suction dredge is shown in Figure 4-26. Cutter suction dredges are also not widely used in high energy offshore environments because of the possible risk of damage to the ladder due to wave motion. Nevertheless, two kinds of suction dredges, with modified ladders, were recovering tin ore from shallow sand and gravel off the west coast of Thailand until recently. The seabed material is excavated in a dilute water mixture by the combined action of the cutter head and the suction lift of the pump. This takes place at rates between several hundred to several thousand cubic yards per hour. Many suction dredges are employed for civil engineering works in sheltered coastal or esturine areas (Herbich, 1975).

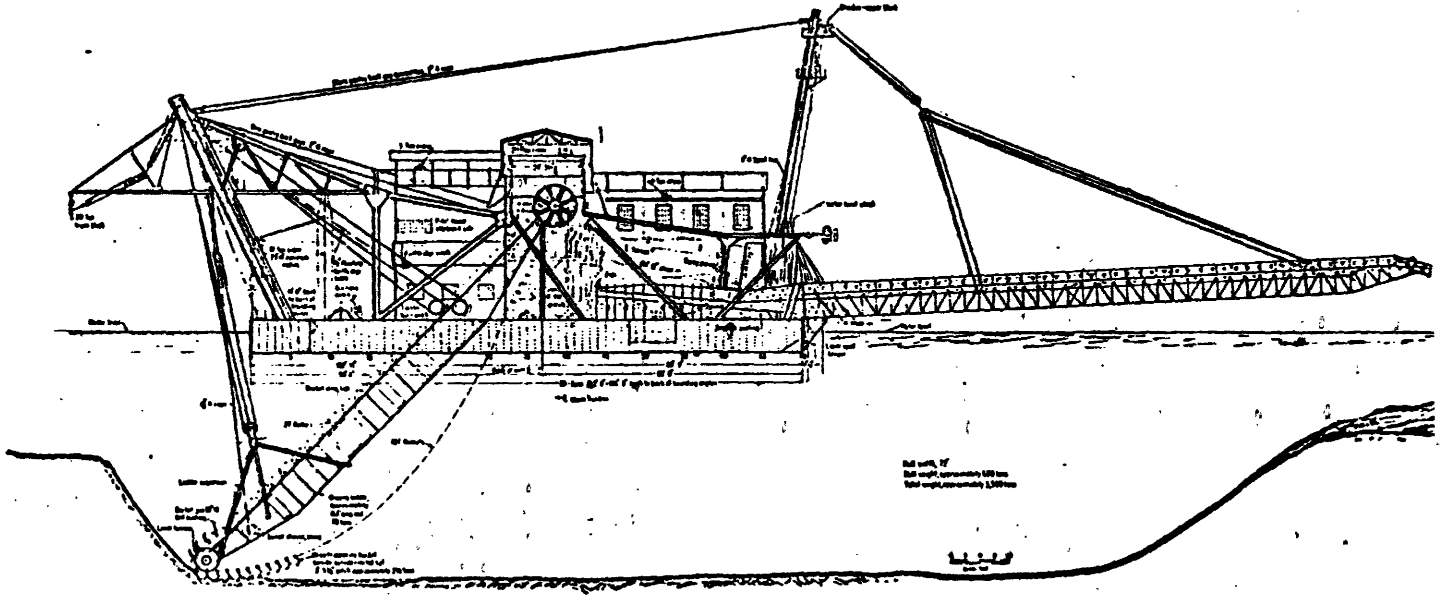

Figure 4-25. Typical bucket dredge (from OSE, 1971, Vol. 1, p. 163).

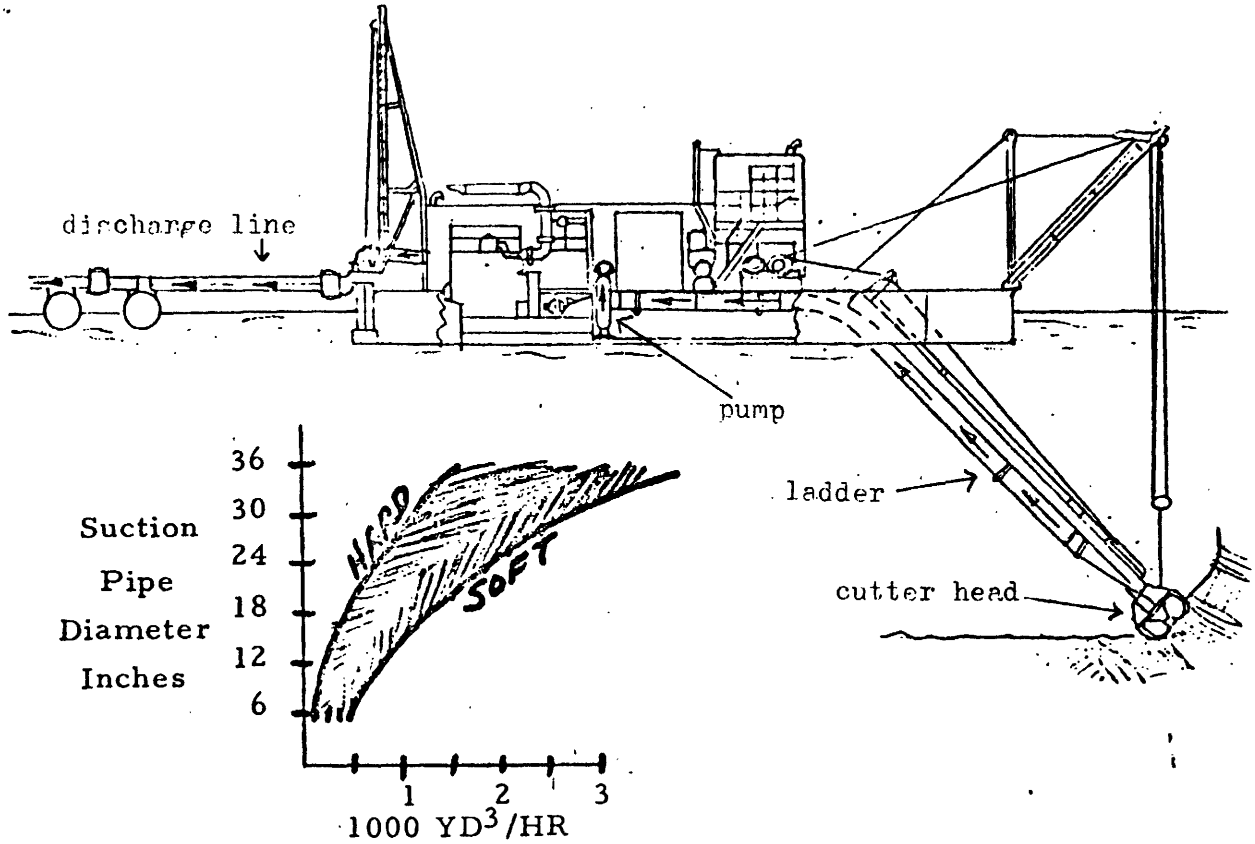

Figure 4-26. Arrangement of cutter suction dredge (from OSE, 1971, Vol. 1, p. 165).

The configuration of a hopper dredge is shown in Figure 4-27. The hoppers are cargo tanks where the wet material is dewatered and stored for transportation to shore (Pohlke, 1974). Hopper dredges, with capacities of 300 to 7000 tons, operate in the United Kingdom sand and gravel mining areas of the North Sea (Hess, 1971). Large hopper dredges, with capacities up to 10,000 tons, maintain the harbor entrances on the Dutch coast. A suction head is either trailed along the seabed, with the vessel under way at low speed, or is implanted into the sea floor with the vessel at anchor. In the first instance, the suction head at the end of the trailing arm acts rather like a vacuum cleaner which creates a long furrow. In the second instance, it excavates a series of cones. In the process of dewatering the material for storage in the hoppers, quantities of fine silt may be brought into suspension

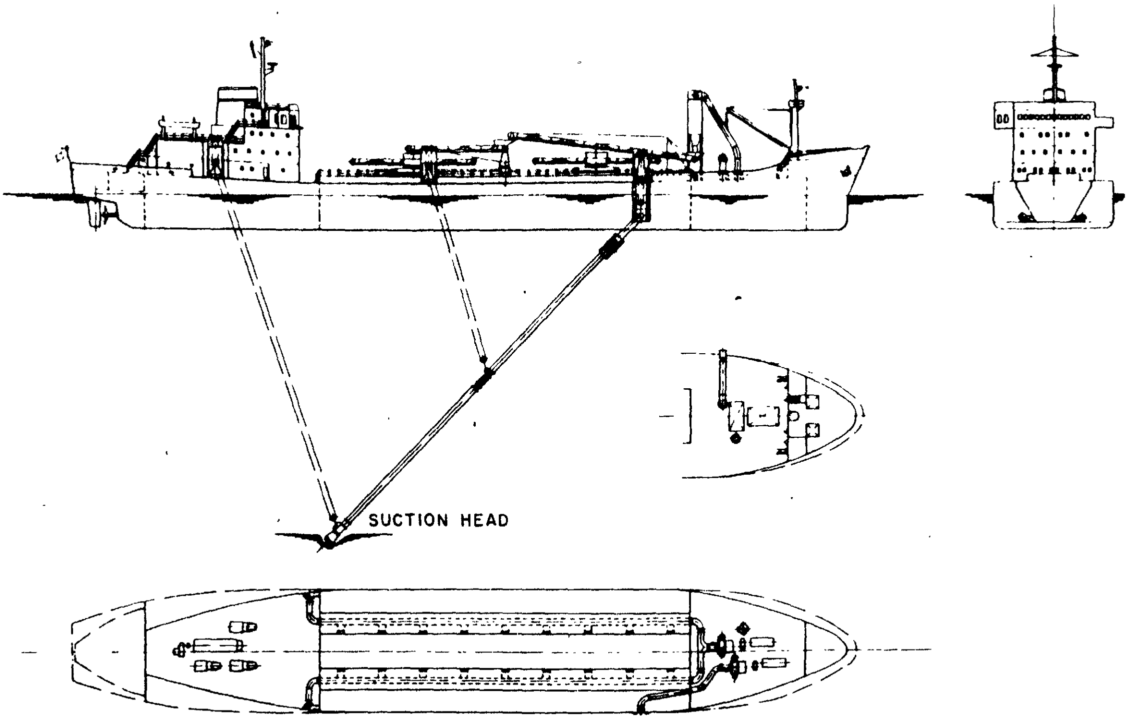

Figure 4-27. Gravel hopper dredge with unloading equipment (from Proceedings of World Dredging Conference, 1974, p. 352).

and discharged overboard with the water. The result is often a yellowish plume of silt which trails conspicuously behind the dredge. Screening of sand and gravel may also be done at sea with the rejection of coarse material.

Between 1965 and 1970, diamonds were dredged by suction from the seabed off the coast of southwest Africa (the Sea Diamond Operation of CMD-de Beers). Between 10,000 and 15,000 tons of sand and gravel were pumped daily, screened, processed and the heavier concentrate sorted for diamonds aboard the barge Pomona (Nesbitt, 1967). This operation was terminated in 1970, reportedly because it was costing more than the value of the diamonds recovered.

B. Shipboard Mineral Processing

In an offshore floating mining system, the seabed material is processed to separate the valuable minerals from the worthless waste. This waste fraction (tailings) must be disposed away from the system without risking that it may be rehandled. Being heavy, sand and gravel, gold, tin and rutile, and similar materials are easy to separate from waste by simple gravity-separation techniques.

The general configuration of gravity-processing plants is shown in Figure 4-28.

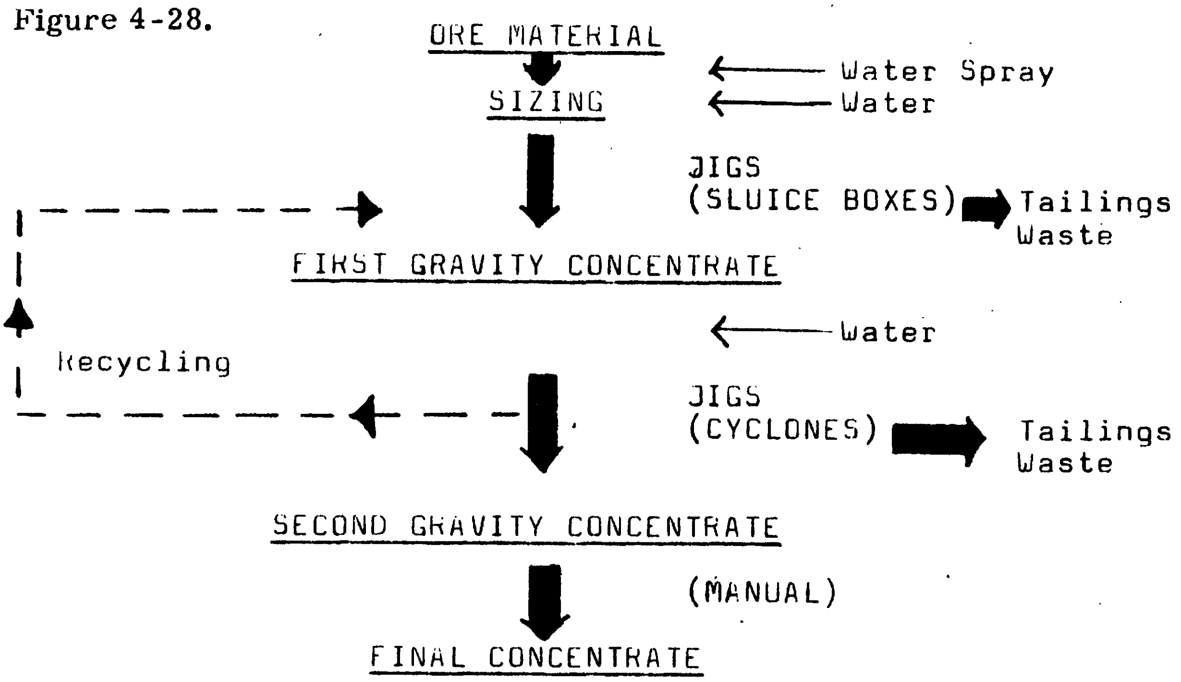

Figure 4-28. Gravity-processing plant.

All separation processes require an abundance of water but introduce no foreign matter in the material processed. In the United Kingdom, the hopper dredge El Flamingo (7000 tons) is equipped with a highly automated shipboard treatment plant, capable of producing a wide range of washed and sized aggregate products at sea. This plant includes vibrating screens, hydrocyclones, conveyor belts and bucket elevators (Hess, 1971).

C. Mining Below the Seabed

Mining under the seabed is done by conventional rock-breaking techniques. Some countries produce significant quantities of coal, iron ore, tin, gold, potash and limestone from mines deep under the seabed. Today, these mines are short distances from the coast, well within territorial waters. In the future, their relevance to offshore mineral production will increase as technology enables mining to proceed farther offshore, or from artificial islands.

Most mines were started near the water, where outcrops of ore were exposed on the surface. Later, they were extended under the sea when land reserves were depleted. This kind of undersea mining was done with techniques identical to those used on land. Some problems later incurred by these mines resulted from not planning specifically for a submarine environment.

Today, the technology of underground hardrock mining includes the following methods:

Room and Pillar

This technique is used to mine flat-lying, massive deposits such as coal or salt. The deposit is laid off on a grid system, and miners proceed to excavate certain areas, or rooms, while leaving other rock behind as pillars to support the roof of the mine. The resulting pattern is likely to resemble a chess board with alternate squares left as pillars.

Longwall

This method is used to mine flat-lying, massive deposits of soft material such as coal. A wall of coal, sometimes measuring over 1, 000 feet long, is mined with machines which move across the width of the wall and scrape the coal from the face onto a conveyor. The unique feature of the system is that virtually all of the coal from a seam is mined out. The roof is allowed to collapse a short distance behind the working face so as to close the void resulting from the removal of the coal. This controlled caving eliminates the support problem of other methods but may cause subsidence of the sea floor above the mine. If fractures develop from this subsidence, inundation may result.

Shrink Stoping

This method is used in steeply dipping, narrow deposits, such as base metal veins. The ore in the roof, or back, is drilled from below and then blasted. The broken rubble forms the floor for the next overhead drilling operation. Since rock volume expands after blasting, some of the broken ore must be drawn off from below after each blast so as to provide working room for the next cycle. The broken ore provides support for the walls of the stope until the stope has been completely worked out. All of the broken ore is then removed, leaving an open, unsupported void where ore had previously existed.

Several underground hardrock mines deserve a brief mention. At the Seafield Colliery, [1] in Scotland, longwall mining is producing about 5, 000 tons per day of coal from levels as much as 1900 feet (580 meters) below the Firth of Forth. At the Boulby Mine in Yorkshire, potash is mined by the room and pillar method toward a target of 1 million tons per year from shore-based workings with reserves extending under the sea. The Levant Mine in Cornwall produces tin from workings 2000 feet (610 meters) below sea level that extend seaward for more than a mile. It is possible that flooding of the mine in the past was the result of workings coming to close to the seabed. In Japan, until recently collieries under the sea accounted for 30% of the country's coal production. Access was by artificial islands located in water depths of about 50 feet (15 meters) and constructed with

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[1] At the nearby Culross Colliery, coal has been mined under the sea since the early 17th Century, C. F. J. U. NEF, The Rise of the British Coal Industry, 2 Vols., London, 1932.

rubble, masonry and steel piling to support the shaft entrances and other surface workings of the mines (Figure 4-29).

D. Solution Mining

At present, offshore solution mining applies mainly to the recovery of sulphur. In the future it may apply to geothermal power, to underground coal gasification, and to base metal recovery from rock fractured by massive explosions.

To date, the FRASCH solution process has produced some 300 million tons of sulphur from 35 mines located both on and offshore in Texas, Louisiana and Mexico. Solution mining of brines, and experimentally, of potash, has been tried in Canada and the United Kingdom. Excavation of underground chambers for storage or waste disposal has been successfully completed in many areas by solution. Today, at the Old Reliable Mine in Arizona, disseminated copper is recovered at the rate of 3000 tons per year by apraying acid solution on rock which has been fractured by a massive underground blast.

FRASCH Process

At the Grand Isle[1] and Caminida mines in the Gulf of Mexico, sulphur occurs in the cap rock of salt domes at depths of 1000 to 2500 feet (300 to 760 meters) below sea level. The sulphur, found in formations several hundred feet thick covering up to 2000 acres (8 kilometers^2), was discovered when drilling for oil. The FRASCH process takes advantage of the low melting point of sulphur and of its insolubility and immiscibility with water. Water, heated under pressure above the melting point (138°F) of the sulphur, is injected down pipes drilled into the sulphur formation. The heat melts the

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[1] Production at the Grand Isle Mine is of the order of 1 million tons annually.

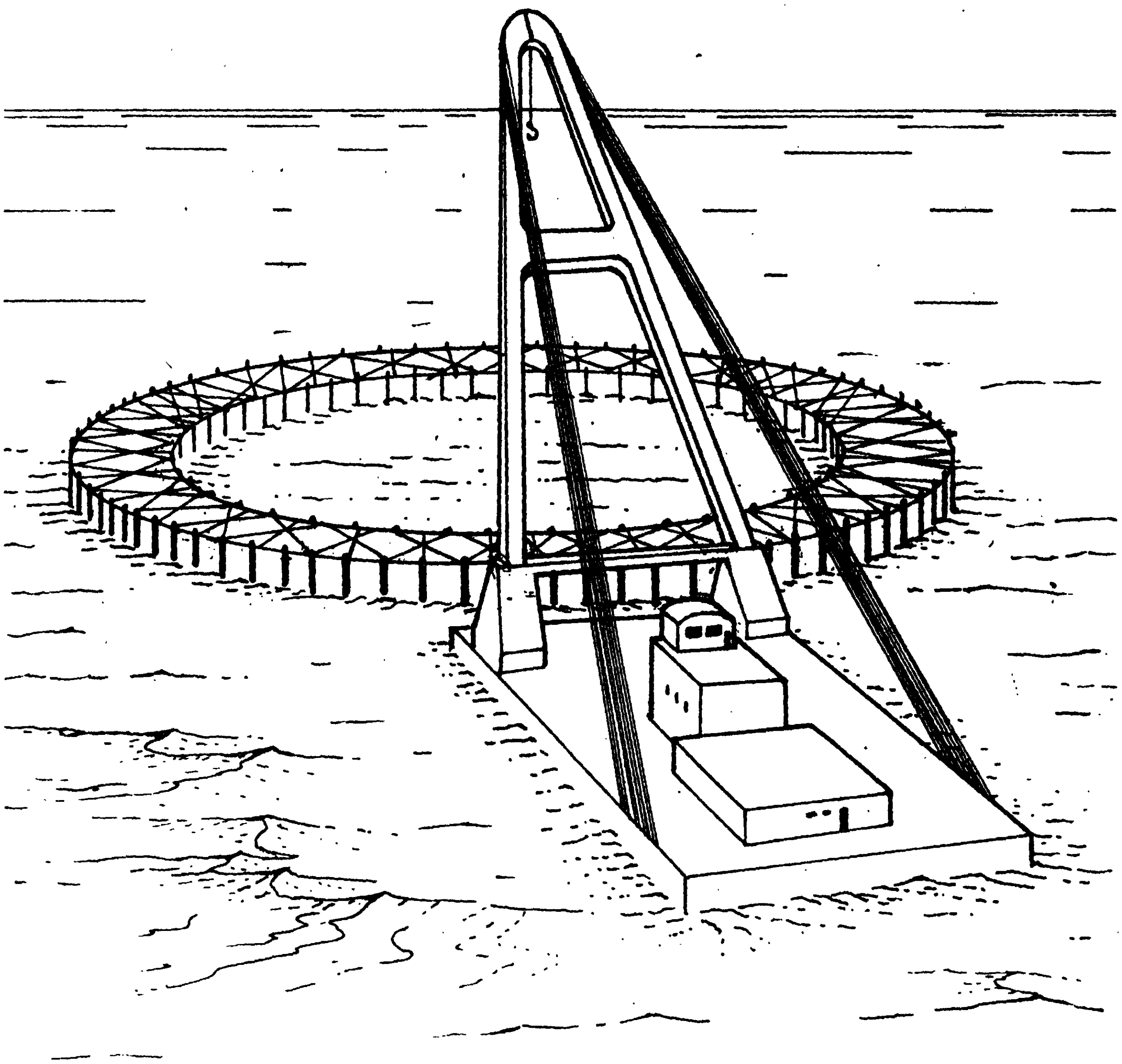

Figure 4-29. Miike Colliery in Ariake Bay, Japan, an artificial island standing in 50 feet of water (from Economics of Offshore Mining, Ocean Mining, Inc., 1971, Vol. 1, p. 108).

sulphur which then flows up in concentric pipes to the surface, where it is recovered (Spangler, 1970; Mining Handbook, 1973).

The techniques of well completion and formation treatment for sulphur mining are closely associated with those of the petroleum industry. The solution aspect requires considerable quantities of water and energy to heat the water. For a sulphur mine, which produces 1000 tons of sulphur per day, between 1 and 15 million gallons of water and between 3 and 45 million cubic feet per day of gas are required. Seawater is usable but requires special treatment to control corrosion.

When the hot yellow sulphur reaches the surface, it is sprayed into a storage pile where it crystallizes into red sulphur. Fixed platforms are used to drill from and to control production offshore. Thus far, water depths have been relatively shallow. Disposal of the solution water, which usually contains dissolved impurities including H_2S, requires special attention to prevent contamination of the adjacent environment. As in other kinds of underground mining, removal of sulphur at depths gradually causes subsidence of the overlying formations. This can eventually propagate to the land surface or to the seabed.

4.3.4 Human and Social Aspects of Offshore Mining

The human aspects of the offshore minerals industry are less well defined and specialized than in offshore petroleum. Few groups, except in some sand and gravel mining companies in the United Kingdom, devote themselves exclusively to the offshore. Personnel are consequently interchangeable with land assignments.

The people involved in the sand and gravel industry, by professional categories, include surveyors, geophysicists, seamen, dredge captains, engineers and occasionally divers.

The occupational categories of undersea hardrock mines are similar to those of shore-based underground mines.

4.3.5 Future Technology

If demand for material continues at its present rate in our society, there will be in the future considerable expansion of offshore mineral production. This will require some technological innovation. Developments in offshore petroleum technology will bring valuable technological transfer and incentives to minerals technology.

Prior to 1974, the incentives for technological advance in mineral exploration of the seabed had not been very large. The possibility of shortages and the recent increases in price of minerals are encouraging technological innovation such as underwater bulldozers and crawler-mounted underwater suction dredges.

Just as on land, more and better maps of the seabed sediment provinces and topography will be an incentive to exploration, so will subsea geochemical surveys. However, there is little promise that offshore seabed mineral surveying techniques of the future will be as powerful as those of earth satellites on land.

A useful development in alluvial (detrital) mineral exploration would be faster and more reliable sampling techniques. A promising innovation may be the development of in situ mineral identification and assay by neutron-activation apparatus towed near the seabed. But significant departures from present technologies, whether in geophysics or sampling methods, are difficult to envisage for the next 10 to 15 years. The art of finding mineral deposits will remain risky.

The vast, already indentified, resources such as sand and gravel on the shallow seabed and phosporite nodules in deeper water, will certainly become more attractive economic targets if more reliable and less expensive mining methods are developed.

The development of ship motion compensation devices may allow dredging in higher energy wave conditions. Both ship motion and depth limitation (about 90 feet or 30 meters) for pumps operated from a surface vessel can be avoided by putting the excavation and pumping mechanisms on the seabed (Donkers and Groot, 1974). One can visualize a submerged gravel mining station on the sea floor successively loading ships or barges which would tie up to a buoy at the mining site. The underwater crawler-mounted, cutterhead suction dredge, housing a dredge pump and operator controls in a pressure chamber, was operated in Japan and the United States to recover sand short distances from shore.

The phosphorite nodules found in deeper water (300 feet or 100 meters) contain enough P_2O_5 to make them an economic target (NAS, 1975) if methods are available to collect them from the seabed and deliver them to surface transportation at low cost. Techniques being developed for manganese nodule mining experiments in deeper water may help bring phosphorite in production.

Concrete gravity production platforms in the North Sea will make artificial islands for mining in deep water possible (Figure 4-30). Once a satisfactory connection has been made with the seabed, it is possible to visualize reaching coal seams which are inaccessible from the shore (Austin, 1967). The problem of long underground haulage distances to mine entrances onshore may be resolved by automation and remote control of mining techniques (NUC, 1975) and by underground transportation of coal by pipeline. One can foresee virtually unmanned undersea coal operations by the year 2000 (Mining Journal, 1976).

Solution mining has a normal extension in bacterial leaching. The role of such microorganisms as thiobacillus on the oxidation of metallic sulphides has been shown to accelerate the rates of oxidation 1000 times over sterile conditions. The combination of solution mining techniques with new methods of underground rock fracturing by nuclear devices offers potentially dramatic new directions for the mining industry.

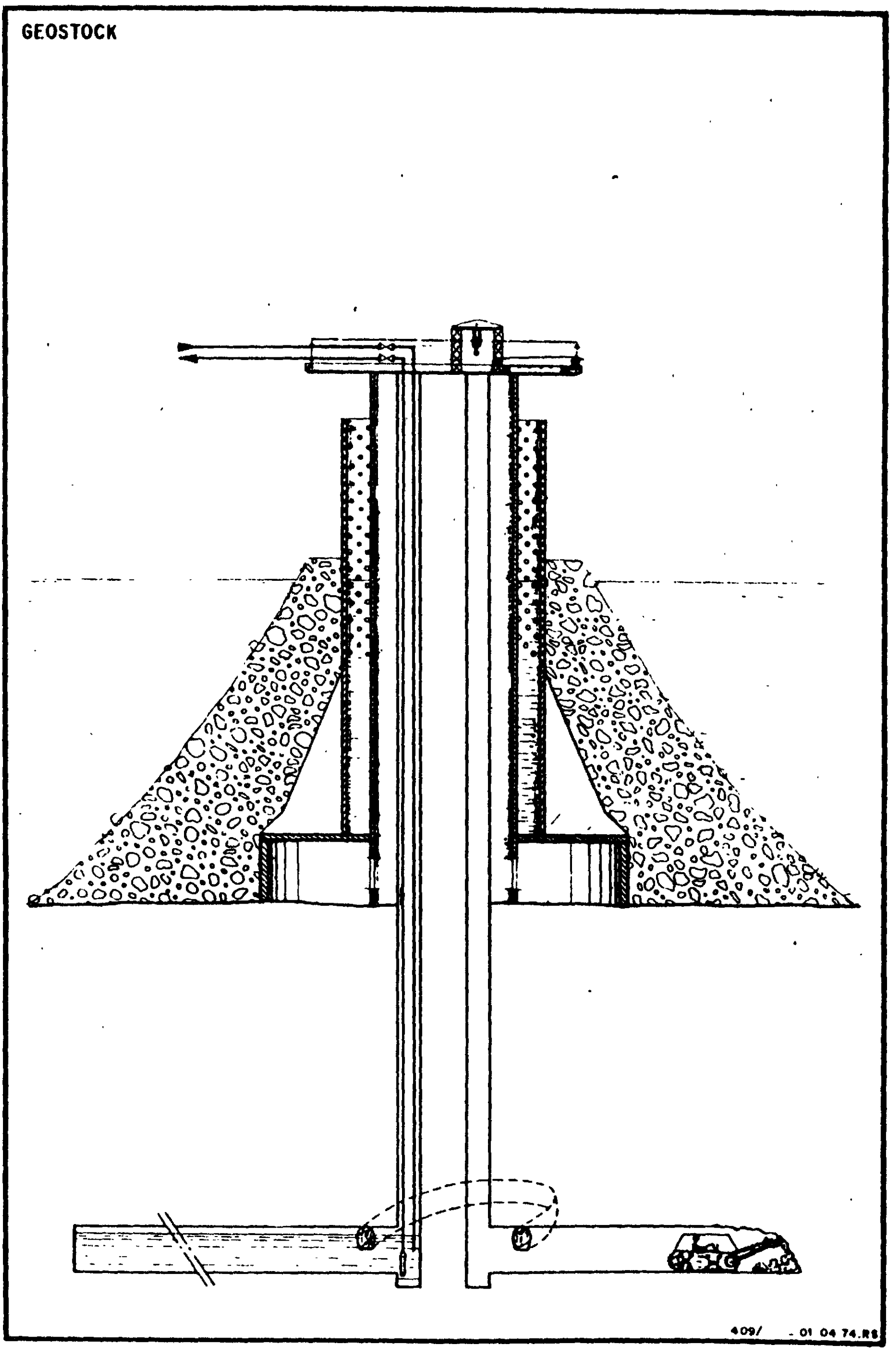

Figure 4-30. Artificial island for mining (from Revue de l'AFPT, No. 226, April 1974).

Many experiments with controlled nuclear devices have been suggested to fracture large quantities of rock underground at costs much lower than with chemical explosives. During the last five years in the United States, the projects RULLISON and RIO BLANCO of the U. S. Energy Research and Development Administration (formly the U. S. Atomic Energy Commission) have proved that simulation of hitherto unexploitable natural gas reservoirs in the Colorado area is possible by exploding underground nuclear devices. In May 1973, the first phase of project RIO BLANCO detonated a 30-kiloton device resulting in the experimental production of some 140 x 10^6 cubic feet (4 x 10^6 cubic meters) of natural gas by February 1974. Underground retorting of oil shales or fracturing of rock containing disseminated copper could be done on a large scale and inexpensively by nuclear explosion. A combination of underground explosion and solution mining would present the additional advantage that unsightly excavations and waste rock and tailings disposal would be eliminated.

The environmental implications of these new techniques are being closely scrutinized, and it is unlikely that many routine commercial operations will take place before 10 or 20 years.

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Attention is also drawn to the following list of journals concerned with offshore petroleum production and exploration.

1. General Petroleum

   Australasia Oil and Gas
   Drilling - DGW
   Industrie du Petrole
   Oilweek

General Petroleum (continued)

Petrole Informations
Petroleum Abstracts
Petroleum Economist
Petroleum International
Petroleum Times
Pipeline and Gas Journal
Pipeline Industry
Review of Sino-Soviet Oil
World Petroleum

2. Offshore Petroleum

North Sea Newsletters
North Sea Letters
Northern Offshore
Noroil
Ocean Engineering (Supplement de Petroleum Engineer)
Ocean Management
Ocean Oil Weekly Report
Offshore
Offshore Engineer
Offshore Service
Oilman

3. Marine Technology

ASTEO - Notes de syntheses
Aventure Sous-marine
Bulletin du CNEXO
Deep Sea Research
Holland Shipbuilding
IMS Newsletters
Journal de la Marine Marchande

Marine Technology (continued)

Journal of Hydronautics
Journal of Marine Research
Journal of Ship Research
Journal Water Pollution Control Federation
Journal of Waterways and Harbors Division
Oceanexpo (Bordeaux)
Oceanology International (Brighton)
Offshore North Sea (Stavanger)
Prevention and Control of Oil Spill Pollution
Marine Geology
Marine Pollution Bulletin
Marine Geophysical Research
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Oceanic Abstracts
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Revue hydrographique Internationale
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Sea Technology
Tanker and Bulk Carrier
Underwater Information Bulletin

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Underwater Journal

Water Research

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4.4.2 Organizations

AAPG	American Association of Petroleum Geologists
AIME	American Institute of Mining Engineers
API	American Petroleum Institute
FPI	French Petroleum Institute
IP	Institute of Petroleum (UK)
MTS	Marine Technology Society (U.S.)
	North-East Coast Institution of Engineers and Shipbuilders (UK)
OECD	Organization for Economic Cooperation and Development
SUT	Society of Underwater Technology (UK)
	Department of Energy (UK)
	Department of Commerce (U.S.)
NAS	National Academy of Science
NRC	National Research Council
	National Oceanic and Atmospheric Administration (NOAA) Environmental Research Laboratories
OTA	Office of Technology Assessment

CHAPTER 5

THE OFFSHORE ENVIRONMENT AND MINERAL PRODUCTION TECHNOLOGY

CONTENTS

CHAPTER 5

THE OFFSHORE ENVIRONMENT AND MINERAL PRODUCTION TECHNOLOGY

This chapter deals with the possible interaction between the offshore environment and the technology for oil and mineral production. Its purpose is to describe the kinds of interactions, the risks of their occurrences, and the techniques for preventing or controlling their undesirable effects.

The term interaction is used here as in Bellamy (1973) instead of the word impact, or accident, since the intent is to examine both the reciprocal effects of technology on the environment (environmental impact), and of the environment on technology (storm damage, corrosion, etc.). Comments are also made on the direct effects of both technology and environment on life and men today (safety). The indirect long-term effects on men tomorrow (coastal pollution) are also considered. The above is summarized in Table 5-1.

Table 5-1. Interactions between offshore technology and the environment.

Against Technology Against Environment	Direct Interactions	Indirect Interactions
Temporary or Short Term	Storm damage to equipment Massive oil spill	Economic loss of production and costs of cleanup Ecological disturbance; loss of amenity
Permanent or Long Term	Wear, fatigue, corrosion Regional pollution	Degradation of social structures; increased social costs Change in regional character; ecological change

Theoretically, undesirable interactions between technology and the environment have two fundamental causes - design deficiency or operator error. Other undesirable interactions resulting from deliberate environmental and social insults, such as the dumping of foreign toxic substances at sea or the discharge of oil tank ballast, are not discussed in this report. These abuses have been dealt with extensively in many other studies.

5.1 INTERACTION OF OFFSHORE MINERAL PRODUCTION TECHNOLOGY WITH THE OFFSHORE ENVIRONMENT

Before discussing the risks of accidents and of marine environmental damage associated with petroleum and gas technology, and dredging and mining, it is useful to review the methods of risk evaluation. Also, two questions must be raised: What is an acceptable risk of environmental damage or of personnel accident? and, At what cost can this be achieved?

5.1.1 Risk Evaluation

Risk is defined as the likelihood of the occurrence of an event or the chance of a negative outcome to a given situation. It is a familiar concept in technical and environmental literature. Safety factors in engineering design provide reserve strength against the risk that unknown forces will destroy a part or a whole system. In most instances, for simple parts, the safety factor is a compromise between the cost of the part itself and the chance that the device will perform adequately during a specified period of time. Its reliability or life is a measure of this performance.

As parts and components are grouped together into complex systems, the overall system safety and reliability become more difficult and more costly to evaluate (Howey and Gaarder, 1975). Preliminary testing and design redundancy (the duplication of parts) become important to establish system reliability. Testing and quality control have achieved nearly total reliability for such aerospace feats as Apollo, where cost has not been a constraint. More reliability usually entails higher costs. In offshore technologies, where costs are important, less than total reliability is considered acceptable at the present time (USEPA, 1973). Full reliability could only be achieved if all individual component safety factors were measured quantitatively during the design process and full systems tested prior to installation and operation.

The quantitative evaluation of risk can be in the form of a judgmental probability statement (e.g., there is a 90% chance that...) or by formal statistical manipulation of test data which will yield an explicit risk function of the chance of failure in time. Another approach to evaluating risks, widely practiced by insurance companies, uses actuarial records of casualty. For prototypes, the absence of actuarial records requires a prolonged testing under all types of anticipated conditions. The casualty record of supertankers is an example of the problems arising from the absence of prolonged testing of this sort. Aircraft technology, on the other hand, benefits from extensive and highly sophisticated tests.

The following main aspects of risk evaluation are relevant to offshore technology:

1. Relatively few explicit statements of risk of mishap for whole systems (such as platforms) appear to be available in the published record (Appendix B) (Schuëller, 1975). For new systems, risks are evaluated by relying on the assumption that enough similarity exists between the new and the old to allow a valid extrapolation. This may be supplemented by model or full-scale tests whenever possible. This kind of risk evaluation, supported by the judgment of expert consultants, is typically made by insurance underwriters. Its main drawback is that is cannot anticipate the chance of maximum possible events, unless the actuarial records cover a precedent. An example of this was the disaster of the SS Titantic. By comparison with offshore technology, the evaluation of risk is more similar to judging the risk of flood or earthquake for a building on land. The evaluation of the highest wave which may engulf an offshore platform is only a best judgment, based on available data. It does not guarantee that this

wave will not be exceeded during the first year of operation. Thus, a dilemma arises for the platform designer – whether to select the highest wave in 50 years or in 100 years, keeping in mind that this wave has not been measured and that for each extra foot of wave height extra steel or concrete costing some $5, 000, 000 of additional capital investment will be required.

2. Where human operators are involved, risk is difficult to evaluate and to control (the extensive training of aircraft pilots is an example). The reliability of human judgment and experience are only established by testing and by repeated practice under realistic conditions (Wyszynski, 1975).

3. Scenarios attempt to describe future sequences of events interconnected by risk factors. They are relevant to damage estimates,and powerful methodologies for making such estimates have been developed by the military and are being adapted to industrial situations.

4. Technology assessments are appraisals of the existing risks in a whole industry (for example, offshore oil production) and the evaluation of their social and economic consequences (OTA, 1975; Kash et al., 1973). Technological forecasts attempt to describe the future fate of whole technologies. Both of these methodologies, while potentially valuable for policy analysis and planning purposes, are still under development.

5. For single parts or subsystems, quantitative evaluations of life and reliability are readily available, e.g., the life of a valve is expressed by the number of cycles of opening and closing which it is expected to withstand before failure.

5.1.2 Risks in Petroleum and Gas Technology

The risks of petroleum and gas technology are examined under the following sections:

A. Oil spill statistics

B. Risks of massive oil spills
   1. Blowouts
   2. Pipeline ruptures
   3. Tanker operations
   4. Production operations

C. Long-term chronic pollution
   1. Repeated small oil spills and discharges of other materials
   2. Other direct and indirect disturbances of the marine environment

D. Risks to equipment

A. Oil Spill Statistics

Oil spills have been classified in three arbitrary categories[1] (NAE, June 1974, p. 15):

small spill (gallons)	medium spill (gallons)	large or massive spill (gallons)
0-100 (0-2.4 barrels)	100-10,000 (2.4-238 barrels)	over 10,000 (over 238 barrels)

Despite the public and private concern and the extensive literature, reliable oil spill statistics are not widely available in the published record.

The estimated amounts and causes of oil pollution in 1969-1970 are shown in Table 5-2.

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[1] U. S. classification is in U. S. gallons; UK classification proposes: small, less than 500 tons; large, greater than 500 tons (3500 barrels).

Table 5-2. Estimated annual direct and indirect oil pollution of the world's waters, 1969-1970 (from Kash et al., 1973, Table 18, p. 276).

Source	Volume (thousands of barrels)	% of total direct pollution
Marine Operations		
Tanker discharges, terminal operations, etc.	9, 710	46. 1
Tank barges	490	
All other vessels	5, 950	
Nonmarine Operations		
Refineries, etc.	17, 400	49. 9
Offshore Oil and Gas Operations		
Normal operations and blowouts, accidents	1, 400	4. 0
Total Direct Pollution	34, 950	100. 0

From Table 5-2, it can be concluded that offshore oil and gas operations, contributing approximately 4% of annual oil spills to the world's waters, are a relatively insignificant source of worldwide pollution compared to other causes. Since 1970, many efforts have been made to curtail pollution. However, much new technology has also been introduced. Thus, the proportions may have changed more recently.

In offshore areas in the United States, by contrast, depending on the years, offshore facilities have contributed about 7. 5% to 25% of the offshore oil spills until 1973 (USGS, 1974, p. 111-27). The high variance is due to occasional massive spills. The USGS records reflect a total of 159 spill incidents relating to oil and gas operations in the federal OCS between June 1956 and June 1973. The categories of these 159 incidents were:

- 105 were associated with fire and/or explosion.
- 44 resulted in the spillage of 50 barrels or more of oil.
- 43 were the result of, or resulted in, blowouts.
- 24 caused 123 personnel injuries and the loss of 29 lives.
- 13 involved a pipeline leak or break.
- 9 were caused by storms or hurricanes.
- 3 were the result of a ship colliding with an offshore structure.
- 1 resulted in a documented loss of marine and bird life.

The causes of oil spills associated with these incidents were as follows: fire and explosions resulted in 3 spills (83,600 barrels); hurricanes and storms resulted in 3 spills (11,869 barrels); ship collisions resulted in 1 spill (2,550 barrels); and producing/workover/abandonment operations resulted in 16 spills (12,208 barrels) (USGS, 1974, Table 111-1, p. 111-9).

The U.S. National Academy of Engineering (NAE, 1974) reported to the USGS concerning the safety of OCS petroleum operations from 1971 to 1974 that 38 spills resulted from drilling systems, 542 from production systems and 173 from gathering/distribution systems (NAE, 1974, p. 14).

The recorded frequency of oil spills has been greater than is consistent with prediction according to traditional methods (Paulson, 1975).

B. Risks of Massive Oil Spills

Massive oil spills can result from: blowouts, pipeline ruptures, tanker collisions and production operations.

1. Blowouts

Blowouts are violent, unexpected eruptions of gas[1] in wells. They can take place during both exploration and production. An uncontrolled

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[1] And/or associated hydrocarbon fluids and water.

blowout may result in the loss of the well, explosions, fire and catastrophic damage to installations. If oil is involved, massive oil spillage may result.

Blowouts are most frequent during exploration drilling when unknown formations are encountered. The well-casing program and control of mud are critical (Section 4.2.1B) (Crockford, 1975). Blowouts may be due to uncontrollable conditions or to operator error. All downhole operations, from formation testing to workover operations, present some risk of blowout. As drilling technology stands at present, the weight of the drilling mud column is the principal agent which keeps down the formation pressure. There are no direct downhole detectors of this pressure, and the operator in charge (the driller) can only judge potential danger from the level and gas content of the drilling mud.

A critical aspect of the blowout risk is the operation and control of mud in the system itself. Mud control instrumentation measures the presence and kind of gas in the mud column, and the flow rate of the mud or the level of mud in the tanks. However, in both cases the event recorded on the drilling platform (e.g., the presence of methane gas) takes place at the drilling bit in the bottom of the hole a considerable time before. (For a 1000-meter hole, for example, the mud circulates from the bit to the surface in about 30 minutes).[1]

Thus, despite instrumentation, drilling personnel have relatively little time to take remedial action against blowouts. This action includes a variety of alternatives which must be decided rapidly by the operators. These alternatives range from modifying the mud density to actuating the blowout preventers (BOPs) to seal the hole. There is also the ultimate measure of cutting the pipe by closing of BOPs and abandoning the hole.

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[1] This lagtime of information increases with greater depth of hole.

For past and present offshore exploration drilling practices, Kash et al. (1973) estimate that one blowout will occur in 450 wildcat wells. Thus, the risk level is at a probability of the order of 0.03% (independent of regional conditions). For production wells, recorded blowouts have occurred on an average of 1 in 3000 worldwide. These numbers originate from the record of 18,000 wells drilled offshore in the United States (Kash et al., 1973; Devanney et al., 1974).

There is some controversy over the actual amount of oil spilled in the blowouts which have occurred in the last few years and have been documented (Table 5-3).

Table 5-3. Blowouts, 1969 and 1970 (from Kash et al., 1973; Brockis in Cole ed., 1975, p. 53).

Year	Location	Estimated total oil spilled: barrels		
		Low	Intermediate	High
1969	Santa Barbara	18,500 (USGS)	77,400 (MIT)	780,000 (Foster)
1969	MP gathering net and storage Louisiana		12,200 (MIT)	
1970	Bay Marchand, Gulf of Mexico	53,000 (USGS)		130,000 (EPA)
1970	Shell ST26 B, Louisiana		52,400 (MIT)	
1970	Chevron MP 41 C Louisiana		30,950 (MIT)	

Most of the data are for the Gulf of Mexico and California. There are insufficient statistics available on blowouts which have occurred under other regional conditions or in waters other than the United States to make more meaningful estimates of the overall risk at this stage. It is rumored, however, that massive blowouts may have occurred in other parts of the world which may not have been documented (Appendix B).

It is clear that the actual amount of oil spilled is difficult to estimate accurately. The loss of well control, whether accidental or through human error, is not discussed extensively in Kash et al. (1973). The time to apply remedial measures and to regain control of a well blowing out can take several months.

The present technology of blowout prevention covers both the exploration and production phases. For exploration, drillers and drilling crews are trained, mud operations monitored and blowout preventers used. During production including workover, operating personnel receive further safety training and redundant safety devices are provided (Cole, 1975). Since 1970 in the United States, attention has been devoted to the development of reliable fail-safe oil flow shut-off devices. These safety valves are installed in the Christmas tree (surface safety valve) and downhole (downhole safety valve or storm choke). These valves are activated in response to abnormal flow pressure conditions detected by sensors (USEPA, 1973; Cole, 1975).[1]

At all stages of operations, the petroleum industry has strong incentives to avoid blowouts which mean costly downtime and costly remedial operations. During production, a blowout is even more damaging due to the loss of valuable oil. Despite this incentive and despite the apparently good record of blowout-free experience in the North Sea to date (no blowouts out of some 550 exploration wells and 250 production wells, Section 4.2.3), there appears to be a lack of explicit risk assessment and damage scenarios in the North Sea.

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[1] Kash et al. (1973) have pointed out that passive downhole valves are vulnerable to sand erosion. In the United States, the USGS requirements for safety valve installations are more easily complied with for new wells than for older wells previously in production.

Brockis (1975) describes a capability to deal with a blowout causing a 15, 000 barrels daily spill of oil (2, 000 metric tons) for 7 to 8-1/2 days (100, 000 to 128, 000 barrels or 14, 000 to 17, 500 metric tons). For the future, this capability may be low. For example, assuming a multiple blowout catastrophe on a single multiwell production platform (such as described in Section 4. 2. 2B), it is clear that quantities vastly more than 100, 000 barrels could be spilled in just a few days. What is the risk of such an occurrence? Probably very small, even when combined with storm conditions.[1]

In conclusion, it seems that a quantitative risk analysis and damage scenario for possible oil spillage resulting from blowouts of single exploration wells and multiple well platforms in the North Sea would be a useful final step to confirm the credibility of the prevention and remedial measures envisaged. This will be especially useful as the number of production units grows in the future.

2. Pipeline Ruptures

Kash et al. (1973) report on major accidents in the U. S. OCS water between 1970 and 1971. The largest accident, in 1967, was caused by an anchor rupturing a pipeline and resulted in a spill which was estimated at 160, 000 barrels (22, 000 metric tons). Of the 159 U. S. federal OCS accidents documented in the USGS (1974, pp. 111-96) between 1959 and 1973, 13 involved pipeline leaks of which 3 were attributed to anchors. Pipeline leaks resulted in 10 spills with a total loss of 12, 208 barrels of oil (1, 700 metric tons) (USGS, 1974, Table 111-1, pp. 111-97). The NAE (1974) reports only 1 major spill (more than 238 barrels) from a pipeline in the period 1971 to 1974 (Table 5-4).

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[1] The industry and public sector parties concerned must have more detailed estimates of blowout damage to arrive at the $ 16, 000, 000 level of compensation provided for in the OPOL and the Civil Liability for Oil Pollution Damage Convention (Chapter 6).

Table 5-4. Major spill events for offshore gathering/distribution systems by subsystem and spill category, 1971-1974 (from NAE, 1974, Table 4-7, p. 17).

Subsystem	Number of major spills	Total number of spills	%
Pipeline	1	44	78.5
Storage	0	2	3.6
Pump station	0	5	8.9
Safety	0	1	1.8
Gathering	0	2	3.6
Not identified	0	2	3.6
Total	1	56	100.0

Explicit estimates of the risk of pipeline leaks are not made in the technology assessment by Kash et al. (1973). In appraising the existing record, allowances must be made for:

1. The existence of many pipelines laid according to older standards in the Gulf of Mexico. Pipeline routes originally were not surveyed. Corrosion and metal fatigue were not anticipated. Standards for burying the pipe were not enforced. By contrast, in the North Sea the pipeline laying practices follow more rigorous standards, including coating with concrete, corrosion prevention and precise location and burial below the seabed.

2. The incidence of leaks in older pipelines must be greater than in more recent ones.

There is some confusion in the actual physics of oil escaping from a ruptured pipeline (Peters, 1974). Opinions range from almost no oil escaping to the loss of all the oil contained between the valves (depending on the attitude of the pipeline and the nature of the breach). Again, a damage scenario would appear valuable in appraising the overall risks.

3. Tanker Operations

In this section, the risks of massive spills attributable to tanker operations include: spills due to loading, resulting from operational errors; spills due to tanker groundings and collisions, resulting from faulty navigation or maneuvering; and spills due to structural failure or explosions at sea.

Spills resulting from operational errors due to loading at SPMs are not well documented as a separate category. For the North Sea, Taylor (1975) describes the transportation of 37 x 10^6 barrels (5 x 10^6 metric tons) from Ekofisk since the start of production in 1971. Two tankers, each approximately 40, 000 dead weight tons, experienced an average of 20 to 30% cumulative downtime between 1971 and 1974 with maxima in excess of 90% during the winter months. Associated with these operations were 21 spills of oil, most of which resulted from the rupture of hoses during adverse weather conditions. Spill sizes are not documented, except for one of 180 barrels which occurred on Dec. 8, 1974. (Spills due to unloading at the inshore dockside are not included in this discussion since they come within the scope of indirect effects of oil pollution.) Thus, the risks of spill in loading operations with SPMs[1] in high energy environments such as the North Sea are not explicit. It would seem reasonable to assume they are high.

Navigation incidents include collision with other ships, rammings (ship to object casualty) and groundings. Spills resulting from groundings and collisions of tankers in the years 1969 and 1970 have been extensively analyzed by Keith and Porricelli (1973). Smith (1973) has studied tanker incidents between 1968 and 1972. These studies show that 81% of the total incidents were attributable to tankers of 50, 000 dead weight tons or less — these tankers being the most numerous in the tanker world fleet. In the study period of a total of 3. 1 x 10^6 barrels (430, 000 tons) of oil spills, some 2. 6 x 10^6 barrels (360, 000 tons) were attributable to tankers

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[1] Present designs.

of 50, 000 dead weight tons or less. By categories, groundings accounted for 62, 000 tons, collisions for 25, 000 tons and rammings for 5, 000 tons. The remainder was due to nonnavigation incidents.

Assuming that there will be a production of 5. 0 x 10^6 barrels per day (250 x 10^6 metric tons per year)[1] in the North Sea from 50 to 80 installations by 1985 and that a moderate proportion of the production will be handled by tankers of 50, 000 dead weight tons, it would seem reasonable to assume that the risks of massive spillage could be relatively high for the North Sea in the future.

Mostert (1975) vividly describes the technology and problems of very large tankers (200, 000 dead weight tons). Although less numerous and making less frequent voyages, these tankers present obvious risks of larger spills per incident. Mostert also gives well-documented accounts of the dangers to navigation in areas of high traffic density. One is worth quoting:

> "On January 11, 1971, a 12, 000-ton Peruvian freighter, Paracas, entered the English Channel and, instead of using the northbound lane off the French coast as she was supposed to do, took the shorter and more convenient downbound lane along the English coast. She struck the Panamanian tanker Texaco Caribbean and the resulting explosion shattered windows five miles away in Folkestone. Nine men went down with the ship. The British coastal authorities marked the sunken Texaco Caribbean with three vertical green lights as a wreck warning. The following day a German freighter, the Brandenberg, outbound for North America, hit the wreck and sank with the loss of more than half her 31-man crew. The British added a lightship and five light buoys to the green lights on the site, but on February 28 a Greek freighter, Niki, struck the two ships and herself went down, taking her entire crew of 22. A second lightship and nine buoys were added to the collection of wrecks, but on March 16, an unidentified supertanker ignored a barrage of rockets and flashing lamps from the guard ships, ran through one row of buoys and, to everyone's

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[1] See Section 4. 2. 3B, Table 4-9.

> surprise, got away with it and vanished. Within a two-month period, 16 ships were reported by British coastal authorities for having ignored elaborate arrangements of lights and signals and entering the area of the wrecks, which have since been demolished." (pp. 82-83).

One can only conclude that unless navigation technology is vastly improved and marine maneuvering regulations are strictly enforced, the risks of spills of large tonnages of oil by any tanker-transportation from the North Sea fields will become higher in the future. Inasmuch as oil production from deep waters such as the Mediterranean is presently being contemplated, involving the loading of tankers from SPMs or floating spars, there should be serious concern about the methods of transportation to shore in such regions.

In making damage scenarios of ship collisions and rammings, an evaluation should also be made of the risks of ship collision with platforms (also military submarines ramming undersea storage tanks).

Spills due to structural failure or explosion of very large tankers have been recorded in a number of instances (Mostert, 1975). Their precise cause is unknown. It is assumed that failure has occurred due to metal fatigue. Explosions are not fully explained.

4. Production Operations

In the three-year period from 1971 to 1974, from the total of 935 oil spill events reported in the U. S. OCS, only 8 could be classified as major spills (over 238 barrels). As Table 5-5 below shows, 4 out of the 8 major spills occurred during the gathering stage.

Table 5-5. Major spill events for offshore production systems by subsystem and spill category, 1971-1974 (from NAE, 1974, Table 4-5, p. 16).

Subsystem	Number of major spills	Total number of spills	%
Well	0	14	1.5
Wellhead	0	44	4.7
Gathering	4	169	18.1
Separation	0	211	22.5
Treater	0	142	15.2
Local storage	0	185	19.8
Custody transfer	2	17	1.8
Safety	1	39	4.2
Water disposal	1	10	1.1
Not identified	0	104	11.1
Total	8	935	100.0

C. Long-Term Chronic Pollution

Under this heading are considered the risks of repeated small oil spills and discharges of other materials, and other disturbances of the marine environment. In considering these risks, the time span is of the order of 5 to 30 years (exploration and/or production). The physical scale ranges from a single drilling site (1 square kilometer) to a field or block (10 to 100 square kilometers) to a whole region (100,000 square kilometers).

Repeated Small Spills

Formation testing during exploration may result in accidental small to medium spills (20 barrels) of oil, water and mud filtrates. Normally, precautions are taken by operators to have dispersant spraying equipment on standby. Other discharges during exploration drilling include rock cuttings (1000 tons per 11,000-foot well), drilling mud, cement, and treated effluents.

Crockford et al. (1975) have given detailed descriptions of the practices and circumstances in which discharges are either routine or accidental. Rock cuttings are frequently oil contaminated even after treatment. Accidental loss of materials can also occur during transfer from supply vessels to rig.

During development and production, oil spills resulting from a variety of possible undetected causes have been reviewed by Kash et al. (1973), who estimate a total spill rate of 25 to 35 barrels spilled per million barrels produced in U. S. OCS operations. By categories, the principal causes are flow line leakage, pipe ruptures, valve failures, and discharges due to human error. By operating system categories, the causes of minor spills over a three-year period are given in Table 5-6.

Table 5-6. Minor spill events for offshore production systems by subsystem and spill category, 1971-1974 (from NAE, 1974, Table 4-5, p. 16).

Subsystem	Number of minor spills	Number of moderate spills	Total number of spills	%
Well	4	8	14	1.5
Wellhead	12	28	44	4.7
Gathering	64	90	169	18.1
Separation	100	100	211	22.5
Treater	63	67	142	15.2
Local storage	99	74	185	19.8
Custody transfer	7	8	17	1.8
Safety	13	21	39	4.2
Water disposal	4	4	10	1.1
Not identified	53	30	104	11.1
Total	419	430	935	100.0

Production operations normally release treated well brines which generally contain a low residual amount of oil. In the U.S. OCS, the specified level of oil content of the discharged water is 50 ppm or less. If this standard is enforced by monitoring, the oil released from treated brine discharges would amount to 365 barrels per million tons of water.

The total number of small and medium spills associated with gathering and distribution operations (Table 5-7) exclusive of tankers is less than that due to production systems.

Table 5-7. Minor spill events for offshore gathering/distribution systems by subsystem and spill category, 1971-1974 (from NAE, 1974, Table 4-7, p. 17).

Subsystem	Number of minor spills	Number of moderate spills	Total number of spills	%
Pipeline	19	21	44	78.5
Storage	0	2	2	3.6
Pump station	2	3	5	8.9
Safety	0	0	1	1.8
Gathering	1	1	2	3.6
Not identified	0	0	2	3.6
Total	22	27	56	100.0

Offshore storage tanks, with an oil-water interface, may be a source of oil dispersion to the marine environment. Other effluents during production are treated waste water (sewage) and rainfall washoff from the platform decks and equipment. Normally, various containment devices exist for coping with the latter.

Therefore, the spillage of small amounts of oil associated with routine exploration and production operations appears to be a virtual certainty. The question remaining is then — In what quantities does this constitute actual pollution, separately and in association with pollutants released by other agencies? For the North Sea, there are little or no data at present on the minor discharges of oil anticipated for production installations over the long term.

Other Disturbances of the Marine Environment

Other direct and indirect long-term disturbances of the environment include a wide range of effects resulting from corrosion, corrosion prevention (cathodic protection, paints and coatings), and the resulting chemical and biological interactions.

Physical disturbances may result from noise and mechanical vibrations transmitted acoustically to the water. Accidental disturbances of the environment may be the result of the release of debris, trash and other foreign objects washed overboard during storms. Disturbances of the seabed are possible from pipeline burial, anchoring, blasting, pile driving, and underwater welding. Finally, the possibility of seabed subsidence due to gradual collapse of the rock formations above the depleted oil reservoir is a risk unless pressures are carefully maintained during the life of a field.

The direct and indirect disturbances of the environment which have been outlined are the unavoidable effects of colonization of the seabed and open sea. Whether their impact is negative or harmless can only be judged in the light of present and future uses of these areas.

D. Risks to Equipment and Personnel

The purpose here is to comment on the gross or overall risks to equipment and personnel due to environmental forces, in contrast to individual personnel safety risks which are discussed in Section 5.2. Kash et al. do not specifically analyze the role of personnel in offshore operations. They record that human error is one of the two main causes of offshore accidents (p. 133) and recommend improvements. The major risks which can be visualized are:

Storms	Between 1955 and 1974, there were 95 rig mishaps worldwide. Of these, 46 occurred in bad weather conditions (Thobe, 1974). In the period 1966 to 1974, over 50% of these storm losses were in the North Sea and were estimated to have cost $60 million (Goldman, 1975).
Foundation Collapse	The most dramatic was the Sea Gem incident. Gravity structures can tip over if the foundations are eroded or if the seabed becomes unstable (the soil mechanics of this are not yet well known).
Seismic Disturbances	These are possible in the Mediterranean and the North Atlantic but are not likely to occur in the North Sea.
Collisions	With ships (these are covered in Section 5. 2. 1B), icebergs or other structures which may be adrift.
Sabotage and Acts of War	Platforms are easy and vulnerable targets.

5. 1. 3 Risks in Dredging and Mining Technology

This section describes the current and future risks and hazards associated with: mineral exploration, dredging, and hardrock and solution mining.

The present worldwide activity in minerals exploitation is small in relation to petroleum. The current importance of this technology is less than its prospects in the next 30 years. The scale of operations covers individual mineral deposits (a few square kilometers maximum) and regional areas (eastern UK sand and gravel).

A. Mineral Exploration

The mineral exploration techniques described in Section 4.3.2 are all essentially passive and do not entail the risk of direct major exposure of the environment to pollutants. No foreign substances are introduced or released in the process of exploration, sampling or geophysical surveying. Minor indirect effects of exploration include: acoustic disturbances (geophysics and drilling), accidental release of fuel and lubricants, minor amounts of turbidity, and general problems associated with human colonization of the seabed.

In general, the risks of mineral exploration are similar to those associated with the operation of small fishing vessels.

B. Dredging

As a method of excavation of the seabed, dredging involves: disturbances of the sea floor for a depth of several feet over areas up to several square kilometers, and agitation and suspension of fine sedimentary material (clay and silt) previously resting on or below the seabed and resulting in water turbidity up to several tens of square kilometers.

Dredging does not release or introduce foreign substances into the marine environment except for objects accidentally lost overboard. Thus, the major risk of environmental damage from dredging is in the long-term effects of seabed excavation and turbidity. There is little agreement in the literature and not enough data to allow positive conclusions. The possible long-term effects include: removal or burial of habitats and spawning grounds (Herbich, 1975; Bouma, 1975); biological impact due to turbidity and possible resuspension of pollutants (Wakeman and Calvin, 1975); coastal erosion and seabed movements (erosion and scour) in other areas to adjust and compensate for the removal of material in a given area (Hess, 1971); and possible indirect effects on navigation and fisheries of changes in sea floor topography.

The possible effects outlined above would differ with the regional regime of the area dredged. In high energy open sea environments, the seabed is likely to be filled back and rapidly become a suitable habitat. In estuaries (near-shore conditions) the environmental effects may be more severe and long-lasting. In coastal areas dredging may also risk disturbing freshwater aquifers.

Venice is an example of these long-term disturbances. Dredging the tanker canal of San Nicolo in the Venice lagoon has had an unfavorable impact on the hydrological balance of the lagoon. Uneven depths cause greater current velocities resulting in accelerated movements of sediment and possible further disturbances to the already fragile ecology of the area. There is violent environmental opposition to further deepening of the canal by dredging to an even depth of 12 meters and to excavation of 5.5×10^6 cubic meters of lagoon floor to increase the harbor capacity. Frassetto (1974) has summarized the oceanographic investigations in support of these views. It must be made clear that these are secondary impacts of dredging and that any other kind of excavation would give rise to similar objections.

Other possible direct adverse impacts of dredging at sea may include the disturbance of marine pipelines or cables and the same general hazards to navigation as for other vessels. One unusual hazard to suction dredges in the North Sea has been the occasional presence of old military devices (mines, etc.) which have exploded in the dredge pump.

Dredgers are susceptible to all the risks of storms and waves experienced by ordinary vessels with the additional aspect that, after starting to dredge on site, a dredge-master will be reluctant to run before the weather with partly filled hoppers. This operational compromise may increase risks of damage to the vessel (Wiggins, 1975). In addition, given the state of navigational practices, dredgers are exposed to frequent risks of collision. The operating conditions experienced by a London-based, 1200-ton dredger are reported in Hess (1971, pp. 64-65):

> "A dredger which produced 153, 000 tons of sand and gravel during the period from January to August 1970 lost 120 hours due to bad weather and 28 days for repairs due to two collosions."

Offshore dredging in the future need not have adverse effects. If during the next 10 to 25 years, a major portion of the UK consumption of sand and gravel were to come from offshore areas, it is likely that there would be fewer larger dredgers instead of many small ones, thus lessening the risks of collision. The main problem would be the larger seabed area affected to the detriment of the fishing or other resource potential at the same location. Sound information about the fauna and flora, on the need for the mineral resource, and on natural replenishment rates and a rational seabed management scheme should allow decisions to be made in the same manner as in good agricultural practice. This approach would strike a balance between the use and the replenishment of the resource involved.

C. Hardrock and Solution Mining

Hardrock mining from shore for coal, potash or tin, and mining from artificial islands (Japan) present few direct environmental impacts. In principle, the disposal of waste rock (tailings) may be effected by backfilling the mined-out areas. In the past, tailings and wastes have been dumped along the seashore, resulting in a change in the composition of sedimentary material. In the eastern UK, fine coal from a coastal mine dump was gradually carried by longshore currents and mixed with the beach sand for miles along the seashore, thereby spoiling the recreational uses of the beaches (Sibthorp, 1975).

Subsidence of the sea floor due to mining may be a possible long-term effect which could present a safety risk to personnel but not a significant stress on the environment. There is no doubt that submarine mining has had its share of disasters and dangers in the past. Inundation by seawater occurred in the Cape Breton (Nova Scotia) coal fields, in the Levant tin mine in England, in a Japanese coal mine, and in Alaskan gold mines. The thickness of overburden required for safety, the size of pillars and other support, and adequate bulkheads to prevent flooding are all aspects of risk involved in hardrock mining from the shore. However, on balance, submarine hardrock mining does not seem more dangerous than conventional land mining. Solution mining for sulphur (described in Section 4.3) requires the circulation of great quantities of heated water which may become contaminated with toxic ions. This would need to be treated before release to the offshore environment. Continuous monitoring of effluents, to ensure a satisfactory minimum level of impurities, may not be reliably achieved.[1] The removal of hard minerals by solution mining may result in seabed subsidence. The hazards to offshore sulphur mining installations in the Gulf of Mexico are principally storms, vessel collisions and fires, and are therefore not significantly different from those of offshore platforms.

Other possible future technologies contemplated for mining below the seabed (Section 4.2) would require a separate detailed analysis which at present belongs largely in the realm of speculation. For example, the EEC onshore areas do not appear well endowed with base metal or copper. Assuming that in the course of petroleum exploration drilling, high grade sedimentary copper formations of the Kupferschiffer type were found in the Permian basins in the North Sea, there would probably be a serious effort made to exploit this resource (either by submarine hardrock mining or by solution mining techniques). This would result in extensive waste material and waste water which would need to be disposed from artificial island sites. As in petroleum technology, the risk level acceptable is directly related to capital and operating costs of the proposed operations.

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[1] Uranium solution mining is reported to have a negligible effect on environmental effects such as surface disturbance and interference with natural ground water quality and distribution, etc. (Hunkin, 1975).

5. 2 PERSONNEL SAFETY

The risks of accidents to individuals, i. e., personnel safety, are in contrast with the dangers to groups of personnel resulting from damage to installations which are discussed under Sections 5. 1. 2D and 5. 1. 3. This section examines: the general human occupational risks associated with offshore mineral technology, and the aspects of safety in diving and submersible operations.

5. 2. 1 General Human Risks in Offshore Technology

Every technology embodies an economic value of human safety. This value may be implicitly related to the risk/reward profile of the occupational categories (Starr, 1972); the economic value of the end product; the occupational skill/training requirements; the labor intensity of the operation; and the working environment. All these factors enter into the evaluation of the risks to personnel.

The mining and petroleum extractive industries are a mixture of highly capital-intensive projects, requiring labor-intensive highly skilled operations such as rigging during construction and less-skilled operations such as drill-pipe handling on a rig floor. Personnel safety in the production of mineral resources offshore in Western Europe was addressed at the International Conference on Safety and Environmental Protection (SPC), sponsored by the UK in March 1973. This conference concluded that: safety begins with good design practices, which themselves depend on a good understanding of the needs of human operators and on good environmental data; and that there is a need to harmonize the attitude of the various nations involved toward safety in offshore mineral production.

Several working parties of the SPC are currently investigating proposals concerning operational petroleum and mining safety (the latter in conjunction with the European Mines Safety and Health Commission in Luxembourg). However, the SPC did not have any comprehensive statistics available for comparison of the safety records of the various countries involved. Nor do such statistics appear to be available at present except in a limited way for the UK Offshore Petroleum Drilling and Production Installations (pipe laying is not included). These are presented in Table 5-8. A breakdown by occupation categories is shown in Table 5-9.

Table 5-8. Accident statistics (from UK Department of Energy, 1975).

Year	Mobile Drilling Activity (rig years)	Fixed Platform Drilling Activity (rig years)	Production Platforms	Estimated Number of Men Employed	No. of Fatal Accidents	No. of Serious Injuries
1965	2.6	—	—	260	14	9
1966	6.4	0.5	—	690	0	15
1967	8.8	2.4	—	1120	1	18
1968	6.0	5.3	1	1210	3	21
1969	7.7	4.5	4	1450	2	19
1970	5.3	3.3	9	1150	1	12
1971	5.2	3.7	11	1260	4	17
1972	8.8	3.8	16	1850	3	17
1973	13.3	3.2	19	2430	3	22
1974	24.5	2.8	23	4030	12	25
1975	—	—	—	—	10	50

NOTES

1. Figures for the years 1965-1973 differ slightly from those reported previously. They have been adjusted so that they correspond to those given for 1974 which are in accordance with SI No.1842 of 1973, the Offshore Installations (Inspectors and Casualties) Regulation 1973, which came into operation on 1 December 1973.

2. Casualties associated with work on and from pipe-laying barges are not included as such vessels are outside the scope of the Mineral Workings (Offshore Installations) Act. During 1974, two diving fatalities occurred during pipe-laying operations.

Table 5-8. NOTES (continued)

3. Exact figures for the number of persons employed are not available. The estimates given above are based on the average number employed on each of the different types of installations on the basis of an average of a 42-hour week worked. Seamen employed on attendant vessels are not included in the figures given above.
4. Thirteen of the 14 fatal accidents in 1965 resulted from the loss of the mobile drilling platform Sea Gem.

Table 5-9. Fatal and serious accidents, UK sector of the North Sea petroleum drilling and production installations (from UK Department of Energy, 1975).

	Fatal							Serious						
Years	65-69	70	71	72	73	74	75	65-69	70	71	72	73	74	75
Drilling falling, crushing, etc.	3		2	2		5	2	42	4	5	7	10	10	26
Production operations										2				2
Maintenance: mechanical, electrical, etc.								2	1		2	1	2	6
Lifting equipment: cranes, etc.	2	1			1	1	2	10	3	2	5	5	6	7
Welding	1		1							1				
Diving	1		1	1	1	3	3	5		1	1	1		
Boats	6				1	3	1			2		2		4
Construction							2	1		1				5
Human error: trips, cuts, slips, etc.	1							15	2	3	2	5	5	
Miscellaneous	13							7	2					
Total	27	1	4	3	3	12	10	82	12	17	17	24	23	50

Up to 1974, there is a decreasing trend in the number of fatalities per 1000 persons employed on the installations themselves, but there is a sharp increase in the number of serious accidents for 1975. The UK Department of Energy attributes most of them to human error resulting from the expansion in activities and to the shortage of experienced personnel and supervisors.

Therefore, although no quantitative probabilistic statement of risk is yet available, it can be concluded that the occupation risks are high. Three aspects of official intervention could contribute to lowering these risks: standardization of safety measures, personnel training and inspection of facilities.

A. Standardization

Standardization of safety measures is complicated by the varieties of rig design and production systems, by the nationalities of the rig contractors and operators, and by the regional character of the mineral resources. However, this kind of difficulty has been overcome for merchant marine seagoing personnel by the International Marine Consulting Organization (IMCO) which has succeeded in developing and enforcing minimum safety standards. This should also be possible with offshore operations.

B. Personnel Training

Personnel training appears to be a promising field to start the harmonization of safety rules. This does not feature in the mandate of the SPC Working Group III, which is considering the welfare and safety of personnel engaged in offshore operations. A comprehensive review should be undertaken of the present training schemes conducted under various national auspices. These schemes include the blowout prevention training school of the IFP, the UK training course for offshore personnel, and the API guidelines for personnel going on offshore platforms (Quattlebaum, 1975). A major attempt should also be made to draw out comment from the management personnel of various companies on the safety training which they themselves receive. Drawing from the experience with seagoing personnel and aircraft pilots, a multinational certification scheme for all personnel categories (ranging from professional engineers to drillers and roughnecks) could be contemplated.

C. Inspection

Inspection of installations is already practiced by the UK and Norway, and also by the U. S. It was pointed out at the SPC that safety inspection, whether by national or by supranational authority, tends to shift the burden of responsibility away from the operators. The concept of more intensive inspection does not seem as promising as more voluntary measures based on regulations backed by penalties.

5. 2. 2 Diving and Submersibles

Despite many improvements made in technology, diving remains a hazardous profession. The 27 diving fatalities in the North Sea to date are evidence of this. For the UK sector alone in 1974, there were 3 diving fatalities out of about 270 divers employed (a rate of 11 per 1000), exclusive of pipe-laying operations.

There is no official record of nonfatal diving injuries and of other occupational hazards resulting from new developments in diving. For example, during decompression, divers with tooth cavities have been experiencing tooth explosions which are caused by expansion of undissolved gas in the cavity.

Divers are well paid for the voluntary risks they take. Yet are these economic rewards justifiable instead of taking another technological approach? In 1975, the UK Diving Regulations came into effect and may be followed by similar regulations from other North Sea countries. The licensing of divers according to international rules may be a measure worth investigating to reduce diving fatalities.

Diving as part of offshore technology deserves a special investigation. The use of divers in certain operations is now unavoidable, but their involvement in future technology should be questioned. The approach to the design of undersea wellhead systems offers the promise of being able to replace divers by operators in pressurized capsules or by remote control operations. Despite recent diving depth records, the development of manned submersibles appears promising as a substitute for diving operations in deeper water.

Submersibles of many categories, both manned and unmanned, are coming into use as workboats. As yet, the operation of manned submersibles does not have a very extensive safety record (Dawson, 1974), and is creating a new category of insurance problems requiring special risk evaluation (Dawson, 1975). The U. S. Marine Technology Society has formulated guidelines for the safety and operation of manned submersibles which can usefully assist the development of similar rules in Western European waters.

5.3 ENVIRONMENTAL PROTECTION TECHNOLOGY

This section describes the technical methods of protection of the environment from damage by offshore mineral production. These methods comprise: prevention, monitoring, and control and containment. Oil is discussed first, then minerals.

5.3.1 Oil Pollution

All aspects of environmental protection from oil pollution have been addressed at several conferences:

1973 and 1975 USEPA/API/USGS Conferences on Prevention and Control of Oil Pollution (CCOP)

1974 U. S. Department of Commerce Symposium on Oil Pollution Monitoring (SOPM) in association with IOC/UNESCO/WMO

1975 UK Geological Institute/Institute of Petroleum/Conference on Geology and Environmental Protection of the North Sea (CEPN)

1975 North Sea Conference (NSC)

1973 International Marine and Shipping Conference (IMSC)

1973 Conference on Safety and Pollution Safeguards in the Development of North-West European Mineral Resources (SPC)

Annual U. S. Offshore Technology Conference (OTC) in Houston

The findings of these conferences are reported in a host of specialized publications. An extensive periodical literature is also available.

The general conclusions which can be drawn from the mass of information on environmental protection from oil pollution are:

1. Prevention of oil spills is ideally the best method of protection, but is not fully achievable under present circumstances.

2. The fate of oil at sea and on marine fauna[1] is still poorly understood and difficult to study. There is an urgent need for better and more extensive monitoring of the oil content of seawater.

3. After oil has been spilled, control and containment devices and methods are very diverse in both kind and effectiveness. Their applicability is severely restricted by wind and wave conditions and by visibility. Their secondary effects on the marine fauna (as in the case of dispersants) are not fully understood.

Some of the points in support of these conclusions are summarized below.

A. Prevention

Ideally, the prevention of oil spills includes all the planning and design steps which would reduce the risks of oil spills to an absolute minimum, regardless of cost. This would entail comprehensive procedures to ensure reliability of engineering systems (Howey, 1975), redundancy of safety features, and containment of operating systems in double enclosures.

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[1] Except diving birds, which are the first obvious casualties of any oil spill.

Prevention on this basis could not be achieved without considerable changes in the existing technology at vast cost.[1] However, it appears desirable to keep absolute prevention as the norm against which future technology, especially the prevention of chronic pollution, is judged.

Despite recent criticism, the preparation of detailed environmental impact statements (Beyaert, 1975; USGS, 1974) is a planning measure toward prevention. An environmental impact statement ideally should be a comprehensive study of all the possible causes of pollution resulting from a project. The study should include measurements and descriptions of environmental conditions (baseline studies) as well as assessments of all the technical phases and functions of the proposed project (USGS, 1974).

Spill prediction studies (Devanney et al., 1974) are useful techniques to assess the possible regional impact of spills. Prevention appears to be the most promising area for further research in all aspects of future oil drilling and production technology. This should include investigation of existing operator functions (such as drilling) to reduce the human error factors in the technology.

B. Oil at Sea and Monitoring

The fate of oil in the marine environment is controversial. A variety of biochemical and physical processes affect oil on the sea surface (Beyaert, 1975). They include spreading, bacterial decomposition, evaporation, sinking, emulsification, dissolution and oxidation. These processes are less than fully understood and are highly variable with the energy of the marine area involved (oil tends to spread and sink faster in a high energy region; low-energy high-insolation areas provide high evaporation).[2]

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[1] Partial prevention has already been achieved by the mandatory installation of drip pans and floor sumps on U. S. installations to contain routine spills of lubricants, etc.

[2] Jeffrey (1973) reports on the experimental release of 900 barrels (120 metric tons) of oil in the North Atlantic. The oil disappeared after four days due to natural causes.

The fate of oil raises two basic questions: Exactly how harmful is it to the marine environment? and,Over what span of time are its effects rendered harmless? (Willard, 1974). Studies of the possible long-term effects of oil are controversial. Chan (1975) reported on the high recovery rates of marine fauna after an oil spill in California. Templeton et al. (1975) in studies in Lake Maracaibo found low concentrations of oil in the lake water and no detectable accumulations in selected organisms.

The detection and analysis of oil are part of the larger problem of monitoring (measuring regularly) the actual content of oil and its derivatives in the world oceans. Simonov (1974) describes the problems of monitoring at the global scale and comments on the need to standardize the methods of data collection and analysis. The Integrated Global Ocean Station System (IGOSS) for monitoring is described by White (1974). The United Nations instituted a global pollution monitoring program EARTHWATCH in 1973. The program involves international study groups concerned with aspects of pollution: IGOSS, Group of Experts on Scientific Aspects of Marine Pollution (GESAMP) and Marine Resources Monitoring and Prediction Program (MARMAP).

C. Control and Containment

The purpose of control and containment methods is to destroy the oil or to prevent its propagation after a spill has occurred. Beynon (1973) gives a comprehensive description of the methods and their applicability. The latter varies with the location (open sea, near-shore), kind of oil, the wind, wave and current conditions, and the size of the spill. The alternative techniques are:

> Deployment of barriers (booms) around the spill. Most are considered ineffective in moderate wave and current conditions. Improvements are reported.[1]

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[1] Glaeser (1973) describes a boom capable of open sea operation in 20-foot waves, 2-knot currents and 60-knot winds. The boom has a pick-up capability of 5000 to 10, 000 barrels (680 to 1370 metric tons) per day.

Skimming, absorbing and pumping methods to physically remove oil from the sea surface. Again, severely limited by daylight visibility, wind, waves and current conditions.

Burning. Ineffective because oil is difficult to ignite and may be dangerous.

Sinking (spraying with sand). Economically unattractive. Oil which has sunk may float back up.

Dispersing (by spraying chemicals) was found to be harmful to marine life because of high toxicity of dispersants. Now low-toxicity dispersants are available, but spraying methods are restricted by wave and wind conditions and by daylight.

In the North Sea, a large oil spill during a gale or storm from a blowout would be uncontrollable by any of the above methods. (This has been confirmed for the Atlantic coast of France by the spill which occurred there recently between January and March 1976 from the freighter Olympic Bravery.

5.3.2 Minerals

In contrast to oil, the environmental risks associated with mineral production have not given rise to a special containment or prevention technology. Nor does the present scale of offshore mineral production appear to warrant it.

The environmental effects of dredging offshore are not fully controllable by means other than changing the dredging pattern or preventing the dredge action altogether. Devices to prevent the discharge of fine silt by hopper dredges could be developed, but the merit of this would be disputable until the negative effects, if any, of fine silt turbidity could be demonstrated. Consequently, a detailed study of a dredging site to evaluate the impact of any proposed dredging action prior to operation appears to be the most valuable technological safeguard to the environment.

If solution mining for sulphur, potash or other similar minerals becomes an important offshore activity, special containment measures may be required to isolate the offshore installations. At the moment, precautions for treatment and monitoring of the effluents are all that appear necessary.

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5.4.2 Organizations

In addition to those organizations listed in Section 3.4.2, the following also are concerned with environmental aspects of offshore mineral production.

AAPG	American Association of Petroleum Geologists
API	American Petroleum Institute (U. S.)
CNR	Consiglio Nazionale delle Richerche (Italy)
CEQ	Council on Environmental Quality (U. S.)
DOE	Department of the Environment (UK)
	Geological Institute (UK)
IOC	International Oceanographic Commission (Paris)
IFP	Institute of Petroleum (France)
IMCO	Intergovernmental Consultative Organization (UK)
IP	Institute of Petroleum (UK)
MTS	Marine Technology Society (U. S.)
NAS	National Academy of Science (U. S.)
SUT	Society of Underwater Technology (UK)
UN	United Nations
USEPA	U. S. Environmental Protection Agency
USGS	U. S. Geological Survey

CHAPTER 6

OFFSHORE ENVIRONMENTAL PROTECTION AND MINERAL PRODUCTION REGIMES

CONTENTS

CHAPTER 6

OFFSHORE ENVIRONMENTAL PROTECTION AND MINERAL PRODUCTION REGIMES

This chapter describes the institutional framework in which offshore mineral production takes place, the nature of mineral production regimes, and existing laws and regulations for environmental protection.

The purpose is not to make an exhaustive analysis of this large and complicated subject but to evaluate the adaptability of the existing regimes to present conditions and future technological change. The main conclusions (see also Section 7. 5) are:

1. The existing institutional, legal and regulatory regimes provide considerable protection under existing conditions by recognizing liability to third parties (adjacent countries).
2. Effective regulatory measures should rely as extensively as possible on incentives to operators instead of attempts at more stringent enforcement.
3. Requiring environmental impact statements for proposed offshore projects to be exchanged by countries with adjacent offshore areas should be a meaningful way to anticipate possible future environmental problems.

6. 1 INSTITUTIONAL FRAMEWORK

The term institutional is used here to encompass the formal and informal relationships between the public and private sectors. It includes the various spheres of jurisdiction and the customary practices and postures of the various parties who influence future offshore mineral production.

6.1.1 Public Sector

The public sector comprises all the national and international bodies concerned with the protection of the environment on the one hand, and those desirous to find and supply the mineral resources (primarily oil) needed by the public on the other hand. National states, as owners, exercise the sovereign right to exploit the mineral resources within their boundaries. In practice, in Western Europe, exploitation takes place after ownership of the resource is transfered by leases, licenses, or other similar instruments to exploiting agencies of the public sector (national petroleum companies) or to entities of the private sector.

The stewardship of mineral resources by the states usually includes the following functions: to collect revenue from the production of the resources (taxes, royalties); to adjust interference with other resource interests (e.g., fishing); to safeguard health and safety; and to protect the environment. The regulation of the rate of production is not normally the direct purview of the public sector.

Resource management and planning functions are shared in various degrees between the public and private sectors. The public sector performs these functions by laws, regulations, licenses, guidelines and official inspection actions. An example may be drawn from the U. S. Geological Survey (USGS). Under the basic U. S. federal law governing offshore activities, the Outer Continental Shelf Lands Act of 1953, the U. S. Department of the Interior has regulatory powers over the leasing for exploration and development of mineral deposits offshore, and over the drilling and production operations (USGS, 1975; U. S. Department of the Interior, 1971; Adams et al., 1975). These powers are exercised respectively by the U. S. Bureau of Land Management and by the Conservation Division of the U. S. Geological Survey. In practice, the latter has issued regional OCS orders which are enforced by a technical inspectorate. The USGS inspectors are qualified petroleum engineering technicians who fly helicopter surveillance missions offshore and physically verify that offshore drilling and production installations comply with the OCS orders.

In the case of mining, the public sector involvement follows parallel lines to those for oil and hydrocarbons but at a proportionately reduced scale. In the UK, for example, offshore dredging for sand and gravel and other minerals is controlled by the Crown Estate Commissioner, while the Marine Division of the Department of Trade regulates the safety and navigation of vessels.

6. 1. 2 Private Sector

The private sector consists of the mining and petroleum companies and their contractors, who generally refer to themselves as the oil industry or the offshore industry, and their stockholders. The traditional role of the industry is to take the risk of finding and exploiting mineral resources under license from the states with the ultimate objective of making profits for the stockholder, or of securing resources in the case of national companies.

A. The Oil Industry

The oil industry has been the subject of many perceptive analyses (Sampson, 1975), which have underscored several aspects of its role. The first is a dual pattern of competition and of association between the oil companies. Associations or joint ventures are formed to share risks and for concerted political objectives. Competition prevails for the private ownership of resources and the means of producing them. This partly fosters secrecy and limits the exchange of technical information — for example, in the interpretation of geological or cost-saving data.

Another aspect of the oil industry is its reliance on contractors for many specialized operating functions (drilling, pipeline laying, well services, etc.). Contractors themselves employ subcontractors. All are grouped under the heading of service companies.

Typically, an oil company, acting on its own behalf or designated by a group of companies in a joint venture, is referred to as an operator. In general, one operator is designated to exercise management responsibility for a particular situation. A company that owns an exploration drilling rig will receive a contract to drill a well to the specification and under the supervision of an operator, whose representatives are on the rig.

Some petroleum companies are operators (owners of rigs) but most offshore equipment, especially for exploration drilling, is owned by contractors. Production equipment is generally owned by companies and operated by oil company personnel. Production structures designed by oil companies are constructed and assembled by specialized external organizations under contract in shipyards, steel works, and machine shops, etc. Production equipment such as valves, tubing, pipe, etc., is designed and built to the requirements of oil companies by a host of specialized manufacturers who can be loosely described also as service companies.

One important feature of many contracts is the award to the lowest bidder. Contracts are awarded to specialized firms for geophysical services, wave and weather forecasting, drilling mud services, pipe inspection, supply boat services, platform erection, pipeline construction and many others.

Research and development (R&D) for new techniques takes a dual pattern of private company initiative during early proprietary investigations (OECD, 1975), which may be followed later by joint-venture large-scale tests as, for example, in the case of subsea completion equipment or new platform concepts. The results are then interpreted individually and may be used for competitive advantages. Thus, although patent sales and cross licensing are widespread throughout the industry and ensure a partial dissemination of new technology, there remains a basic dichotomy between competitive motivation of the individual firms and industry-wide approaches to certain problems. A case in point is environmental pollution which, by affecting the public image of the industry, has given rise to multicompany responses and joint research undertakings in pollution control, yet receives very different treatment by individual companies in specific situations.

Another characteristic feature of the petroleum industry is the vertical integration of major companies which combine the functions of finding, exploiting, transporting and refining the oil and then marketing and distributing the end products. The majors, as they are called, stand in contrast to the independents. The independents are relatively smaller, though still large by other standards, firms engaged in more specialized aspects of the oil business. In the offshore industry, some independents may be pipeline or drilling companies which also have "a piece of the action."

Many of the traditional industry patterns have originated in the United States before gaining widespread acceptance in other parts of the world. A comprehensive analysis of the private and public sector roles in the United States offshore technology may be found in Kash et al. (1973).

In the private sector, the recruitment and training of personnel for offshore work follows highly channeled individual company lines for all categories, including technicians, engineers and management. There are multicompany joint training programs for technicians and engineers alike but only in certain special aspects such as blowout prevention or drilling.

At the engineering and management levels,there are widespread opportunities for exchanges of views between personnel of different companies at the numerous meetings of technical societies and industrial conventions. Experience and performance are currently the most important criteria for personnel assignment. But the offshore industry does not yet have standards comparable to those of other professions — for example, aircraft pilots and ship's officers and crews. This can be partly explained by the fact that it is still relatively young and has experienced an extraordinarily rapid growth during the last ten years.

B. The Mining Industry

By comparison, the mining industry occupies a very small position in offshore activities. Sand and gravel exploitation in the UK is the purview of several relatively small commercial firms. Most offshore mining elsewhere in the world is conducted by large vertically integrated private companies. Reliance on experience gained by on-the-job-training is a key factor for their personnel. In offshore sand and gravel dredging in the UK, the private sector patterns follow those of the offshore oil industry, especially with respect to competition, but at a much reduced scale.

6.1.3 Self-Regulatory Mechanisms

There exists within the institutional framework of the oil industry a number of mechanisms which appear to regulate the technology and to provide some measure of environmental protection. These will be referred to as self-regulatory for the purpose of this section, which is to learn whether these mechanisms can be utilized or encouraged for more effective environmental protection in the future.

A. Public Images

By means of publicity, the oil industry depicts itself as a dedicated provider of scarce energy to an energy-hungry society. Advertising, particularly in the numerous trade and technical publications, describes the offshore as a "new frontier," where the industry has to fight against the hostile environment in order to accomplish its mission (Figure 6-1).

In the United States, the industry has always been very sensitive to criticism which could affect its image of dedication. Consequently, its response was to take remedial action and to implement measures for environmental protection. In energy-hungry Europe, public opinion has less impact on the oil industry, especially when part of the latter consists of national companies. However, no groups are eager to encourage negative public images. Well-founded and properly documented public concern and criticism

IN THE TIME IT TAKES TO LOOK FOR NEW OIL, DRILL FOR IT, BRING IN THE WELL, AND TURN IT FINALLY INTO GASOLINE...

...THEIR BABY WILL BE STARTING FIRST GRADE.

The simple truth is – it can take about five to eight years to discover new oil offshore and turn it into gasoline. To get an idea of the time and work involved, let's look at a rough timetable.

1st year: Exploring for new oil fields. This, of course, is the first step. And then - before we can start drilling – we have to lease the acreage. All told, it can easily take a year or more.

2nd year: Start exploratory drilling for oil. Unfortunately the facts in the oil business are that most exploratory drilling does not recover commercial quantities of oil or gas. The odds are something like 50 to 1 against striking oil in amounts large enough to be commercially worthwhile.

3rd year: Developing the field. One well isn't enough for the field to be fully productive. Additional wells have to be drilled. And that doesn't happen overnight or without great expense.

4th year: Transporting the crude oil. Once the well does come in, you *may* have to build a pipeline to transport the crude oil.

5th year: Refining the oil. Finally, we're ready for the last step – turning the oil into petroleum products. New refineries *may* have to be built. Or present ones expanded or modernized. It all takes time *and money*.

As you see, it takes a lot of time and planning and capital investment often running into hundreds of millions of dollars - to find oil and turn it into petroleum products. The best way to supply you with the petroleum you need is through a free enterprise system that will enable us to generate the necessary capital.

TEXACO

We're working to keep your trust.

On December 6, join Texaco in a gala afternoon of opera. At 2 p.m., ET, on radio, Texaco begins its 36th season of live broadcasts from the Metropolitan Opera House in New York. At 5 p.m., ET, on CBS-TV, "Danny Kaye's Look-In at the Metropolitan Opera."

Figure 6-1. An example of advertising by the oil industry.

have had remedial or self-regulatory effects both with companies and with governments. Voluntary schemes such as the Offshore Pollution Liability Agreement (OPOL) or the Committee of the UK Offshore Operators Association (UKOOA) are examples of the initiative being taken by the industry (Band, 1975). The 1973 Western Europe Offshore Safety and Protection of the Environment Conference (SPC) is an example of initiative by the public sector.

The OPOL was signed in 1974 by 13 major oil companies(1) (Amoco, British Petroleum, Burmah, Compagnie Francaise des Petroles, Continental, Exxon, Gulf, Hamilton, Mobil, Petrofina, Phillips, Shell and Texaco). It is an example of the kind of measure in which the industry is prepared to voluntarily engage to protect its public image. The following are relevant excerpts from the OPOL agreement:

> "The parties to this contract are operators of or intend to be operators of offshore facilities used in connection with exploration for or production of oil."
>
> "Each of the parties has resolved to provide an orderly means for compensating and reimbursing any person who sustains pollution damage and any state which incurs costs for taking remedial measures as a result of a discharge of oil from any offshore facility so used and located within the jurisdiction of a state denominated hereunder."
>
> "Operator means a person which by agreement with other persons has been authorized to manage, conduct, and control the operation of an offshore facility, subject to the terms and conditions of said agreement, or which manages, conducts and controls the operation of an offshore facility in which only it has an interest."
>
> "License means a license, concession, permit or other authorization issued by a designated state to install or operate an offshore facility."

1) 1975 - 16 (shortly there will be a 17th member, the British National Cie)
L 25 000 000

> "Offshore facility means an installation of any kind, fixed or mobile, located within the jurisdiction of a designated state, (a) which is used for the purpose of exploring for, producing, treating, storing, or transporting oil and gas from the seabed or its subsoil, excluding any tank vessel not being used for storage of oil or gas commencing at the loading manifold thereof, and (b) which is located seaward of the low-water line along the coast as marked on large-scale charts officially recognized by the coastal state, excluding any portion thereof extending shoreward of said low-water line."
>
> "If a discharge of oil occurs from a designated offshore facility, and if, as a result, any state or states take remedial measures and/or any person sustains pollution damage, then the party hereto who was the operator of said designated offshore facility at the time of the discharge of oil shall reimburse the cost of said remedial measures and pay compensation for said pollution damage up to an overall maximum of $16,000,000 per incident."

B. Professional Attitudes

The personnel within an industry can apply opinion pressure for stronger safety and environmental standards on the part of their organization. By contrast with the U.S., the EEC countries do not yet seem to put much formal emphasis on professional attitudes. In the U.S., the personnel of the oil and mining industries pride themselves on receiving professional recognition and in their identity as a group. Professionals are normally the senior, more experienced personnel and are usually university graduates. In individual states of the federation, professional qualifications consisting of appropriate theoretical knowledge, combined with practical experience, are defined and tested before deliverance of a professional engineers license accrediting its holder to practice in a particular state.[1] Reciprocity may be extended between states having similar qualification standards. Professional licenses in the oil industry are usually for petroleum, mechanical and civil engineers.

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[1] States keep up-to-date registers of licenses.

Licenses may be required by law for individuals practicing their professional technical skills in either private industry or government functions. Some professions, such as naval architecture, effectively conduct their own informal licensing by having a strong professional society which encourages high standards of professional conduct in its members.

Professional societies or groups of professional engineers independently review and establish practices and standards within their industry. This gives rise to codes of practice and the establishment of standards recognized by all other members of the profession, generally to the benefit of the technology involved. Thus, the encouragement of strong professional attitudes and the licensing of technical expertise can be a mechanism for enhancement of safety and environmental protection.

C. Independent Consultants

Ideally, the role of independent technical consultants should be similar to that of chartered public accountants acting as independent auditors. This is certainly the case with certification societies (CS) for the construction of offshore structures. Certification societies provide independent opinions on such aspects as a structure's ability to withstand its design criteria. They issue certificates on the quality of materials and practices used for its construction (Taylor, 1975).

Some of the certification societies currently active in offshore installations are: American Bureau of Shipping, Det. Norske Veritas (DNV), Lloyd's Register of Shipping, Germanischer Lloyd and Bureau Veritas.

In 1974, the Offshore Installations (Construction and Survey) Regulations were passed by the UK Government to be administered by five CSs.[1] The CS may grant a certificate of fitness for new designs and is permitted to charge fees for the work involved. The fees are in two parts, a fixed price for design appraisal and approval, and a time rate charge related to the particular site(s) for fabrication, assembly and installation. The CS

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[1] They are referred to in the regulations as certifying authorities.

then submits particulars to the UK Department of Energy. The regulations are rather less concerned with environmental damage than with safety, particularly the strength and stability of installations[1] (Taylor, 1975).

D. Associations

Individual oil companies frequently form private associations for the purpose of communication with government authorities and with the public. These associations, while clearly promoting the cause of the industry at large, have a valuable effect on normalizing the activities of certain companies and in disseminating information.

Some of these associations are:

UKOOA	UK Offshore Operators Association In October 1974, the UKOOA was formed by 22 operators to provide a forum for the discussion of common technical and administrative matters relating to exploration and production in UK waters. The UKOOA is party to OPOL to establish collective responsibility in the event of a pollution incident. The UKOOA is participating in the sponsorship of the forthcoming Submarine Pipeline Bill (Band, 1975) and in environmental measurement programs (Section 3.3.1).
IP	Institute of Petroleum (UK) Located in London, the IP aims to promote and coordinate the scientific study of petroleum and its products. Specialized committees report on standardization, and the prevention of sea, atmospheric and fresh water pollution,

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[1] Environmental data must be supplied with each certificate application and includes parameters such as 50-year wave height, air and sea temperatures, etc.

	and on health and hygiene aspects of production. The IP publishes codes of practice, measurement tables, standards for petroleum and its products, and disseminates general information (IP, 1974).
IFP	French Institute of Petroleum Serves the French petroleum industry and exchanges information with other institutes. A noteworthy aspect of the IFP is that it was one of the first in Europe to set up a drilling and blowout prevention school. Management and technical staff attend the school and learn procedures for preventing blowouts using simulators.
API	American Petroleum Institute (U. S.) This organization presents the views of the industry to the government, and disseminates information within the industry. It recommends codes of practice and standards. The API is strongly involved in environmental activities and together with the Environmental Protection Agency of the USGS has sponsored conferences on all aspects of oil pollution.
NSOCSC	North Sea Operators Clean Seas Committee Formed in 1971 and comprising seven national participating organizations (UK, Denmark, France, the Netherlands, Norway, Sweden, and West Germany), the NSOCSC aims to develop contingency plans and provide assistance to any company suffering a major oil spill (Cole, 1975).

6.2 MINERAL PRODUCTION AND ENVIRONMENTAL PROTECTION REGIMES

This section provides a brief review of the legal and regulatory measures which presently govern offshore mineral production and environmental protection. Attention is drawn to the word presently which implies that these measures are neither complete nor final. As matters now stand, there are three reasons for this:

1. New legal regimes are in process of being enunciated at the Law of the Sea (LOS) Conference which will affect both international and national forms of jurisdiction over offshore resources and environmental protection.
2. New national laws and regulations are proposed, or are being passed, governing mining operations on the continental shelves (UK pipelines; Greenland offshore; Norway, fixed offshore oil installations).
3. Adaptability to change in technology and operating conditions is a necessary feature of regulations which must be modified periodically.

In view of the number of agencies and organizations involved and of the mass of material on the subject, the coverage provided here is necessarily highly abbreviated.

There is no existing international framework for environmental laws affecting offshore mineral exploitation. The primary focus of international agreements in this area, up to the present time, has been on prevention and reduction of marine pollution from vessels. Only two conventions – the 1958 Continental Shelf Convention and the 1972 Convention on Dumping of Wastes – can be construed to cover pollution from offshore structures and installations, or the adverse effects of offshore mineral exploitation. Of the two, the 1972 Convention of the Dumping of Wastes explicitly exempts from its provisions pollution arising from exploitation of the seabed.

Although treaties stand at the apex of the hierarchy of legal authority with national legislation and implementing regulations in descending order below them, in actual fact, national legislation and regulatory activity have the greatest direct impact on offshore mineral exploitation. It is national law, and administrative action under the authority of national law, with which exploiters of minerals are primarily concerned.

In the United States, treaties and international agreements require specific implementing legislation. This is not always the case in some civil law countries where the legislative step may be omitted and a single decree, with regulations issued thereunder, may embody full national implementation of an agreement. In order to display the full range of international and national law on the subject, the treaties and legislation outlined here are presented in their order within the total legal framework.

The present situation can perhaps be expressed by the 21st principle of the Stockholm Conference (1972 UN Conference on the Human Environment) which states:

> "States have, in accordance with the charter of the UN and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other states or of areas beyond the limits of national jurisdiction."

6.2.1 Jurisdiction

Offshore mineral production comes under two jurisdictions — international and national. These jurisdictions overlap with respect to the extraction of mineral resources at the present outer limits of the continental shelf. Within the continental shelf, resources remain under national sovereignty, but the effects of mineral exploitation such as pollution or the passage of drilling vessels once again fall under both national and international jurisdictions. The present situation distinguishes between national and international waters (high seas) with definitions shown in Figure 6-2. A detailed

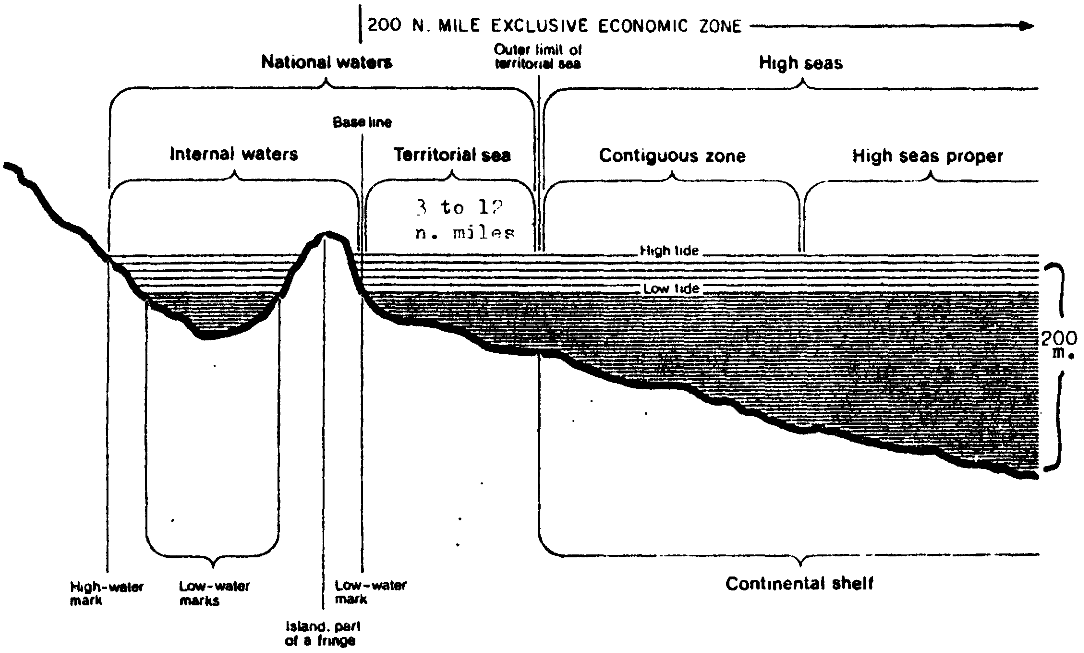

Figure 6-2. Jurisdictional zones (from Sibthorp, 1975, p. 89).

outline of the situation in the North Sea may be found in Sibthorp (1975, pp. 85-157) and in White et al. (1973).

The following jurisdictions are recognized by Sibthorp:

1. Flag jurisdiction. The state whose flag a vessel is entitled to fly has sovereign jurisdiction over it.[1] In the the case of drilling platforms, this jurisdiction changes once the platform is erected in other national waters.

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[1] The jurisdiction of any state to pass laws and to enforce them is, in theory, limited by international law which derives its authority from international treaties and conventions.

2. Zonal jurisdiction. The situation defined in Figure 6-2 is complicated by the current proposal before the LOS that states should be able to claim rights over the living mineral resources of the seabed for a distance of 200 nautical miles from the baseline, i.e., the exclusive economic zone.

3. Regulatory powers. Under international jurisdiction, these encompass fisheries, navigation, pollution, military uses and artificial islands (which do not have territorial seas of their own and fall under the jurisdiction of coastal states).

6.2.2 International Treaties and Conventions

A number of international treaties deal exclusively with pollution of the ocean by ships and are irrelevant to the operation of offshore drilling structures or installations except in so far as the use of vessels is required.[1] In addition to these treaties, there are two voluntary agreements that have been signed by many of the major oil tanker owners concerning the liability for oil spills. In 1969, the Tanker Owners Voluntary Agreement Concerning Liability for Oil Pollution (TOVALOP) began enforcement. In the same year, the Contract Regarding an Interim Supplement to Tanker Liability for Oil Pollution (CRISTAL) also began enforcement.

The history of international and regional treaties specifically applicable to offshore mining and drilling begins with the 1958 Convention on the Continental Shelf - the Geneva Convention (Pearson, 1975). This was signed by the U.S., UK, Denmark, Finland, France, the Netherlands, Norway and Sweden. It allows the coastal state to exercise sovereign rights over the

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[1] 1954 Convention for the Prevention of Pollution of the Sea by Oil
1969 Convention Relating to Intervention on the High Seas in Cases of Pollution Casualties
1969 Convention on Civil Liability for Oil Pollution Damage
1971 Convention for the Establishment of an International Fund for Compensation for Oil Pollution Damage
1973 Convention for the Prevention of Pollution by Ships, the IMCO Convention.
The U.S. and most North Sea countries have ratified these treaties but only the 1954 convention is in force at the present time.

continental shelf for the purpose of exploring it and exploitating its natural resources. These exploration and exploitation rights should not interfere with navigation, fishing or the conservation of living resources of the sea, nor result in any interference with fundamental scientific research. The coastal state, subject to the provisions above, can construct and operate installations necessary to explore and exploit the continental shelf. Safety zones can be established around the installations for a distance of 500 meters, and the coastal state is obliged to undertake the protection of living resources from harmful agents within these zones.

In 1972, the Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Matter (London) was more specifically concerned with pollution. This convention, signed by the U.S., UK, Denmark, Finland, France, the Netherlands, Norway and Sweden, is not in force.[1] Parties at the convention pledge to promote the effective control of all sources of pollution by regulating the dumping of waste and other matter except in the case of an emergency. The dumping of oil and oil products is strictly forbidden, but the deliberate dumping of other matter (including most metallic compounds) is allowed if a special permit is obtained from the coastal state and the dumping is conducted more than 150 miles from shore in water not less than 2000 meters deep.

The Third United Nations Conference on the Law of the Sea in 1975 (LOS) in its single negotiating text prepared for 1976 (Ref. UN, 1975) recognizes the pressing need to standardize laws and regulations concerning mineral exploitation. It accepts that a state has sovereign rights over its exclusive economic zone for the purpose of exploring, exploiting, conserving and managing the natural resources, whether renewable or nonrenewable of the seabed and subsoil and the superjacent waters (Anderson,

---

[1] Comprehensive summary of this convention may be found in Pearson, 1975, Chapter 3, which deals particularly with the economic dimension.

1975). A state has:

> "Exclusive rights and jurisdiction with regard to the establishment and use of artificial islands, installations and structures." (Section 3, Part 3, Article 45b)

> "Jurisdiction with regard to the preservation of the marine environment, including pollution control abatement." (Section 3, Part 3, Article 45d)

The limit of the economic zone is also defined in Article 46, Section 3, Limits of the Territorial Sea, as:

> "The exclusive economic zone shall not extend beyond 200 nautical miles from the baseline from which the breadth of the territorial sea is measured."

The conference advocates global and regional cooperation to investigate and control the risks of pollution:

> "States shall cooperate on a global basis and as appropriate on a regional basis, directly or through competent international organizations global or regional, to formulate and elaborate international rules, standards and recommended practices and procedures consistent with this convention, for the prevention of marine pollution, taking into account characteristic regional features." (Chapter II, Article 6)

> ". . . . shall endeavor to participate actively in regional and international programs to acquire knowledge for the assessment of the nature and extent of pollution and the pathways and risks of, exposures to and the remedies for pollution." (Chapter II, Article 9)

And in terms of standards:

> "States shall endeavor to harmonize their national policies at the appropriate regional level." (Chapter IV, Article 16, 2)

Another convention, the 1975 Convention on Civil Liability for Oil Pollution Damage Resulting from Exploration and Exploitation of Seabed Mineral Resources (London), proposes that adequate compensation should be available to those who suffer from the consequences of pollution, and provides for the adoption of uniform rules and procedures to determine questions of liability. This convention has not yet been ratified. France, Germany, the Netherlands, the UK and Eire attended the Convention which was sponsored by the UK Department of Energy. The Civil Liability Convention defines an installation as:

> "Installation means any well or other facility, whether fixed or mobile, which is used for the purpose of exploring for, producing, treating, storing or transmitting from the seabed for its subsoil." Also included in this definition are wells "exploring for or producing crude oil... gas or natural gas liquids... any mineral resources other than crude oil, gas or natural gas liquids... any facility which is normally used for storing crude oil which is located seaward of the low-water line along the coast as marked on large-scale charts officially recognized by the controlling state." (1975)

The operator of any installation will be liable for all damage except in special circumstances such as damage resulting from an act of war, or where damage has occurred more than five years after the date on which a well was abandoned (Article 3.4). The operator shall constitute a fund which would be the total sum of his liability as determined by the court or competent authority...

> "The fund shall be distributed among the claimants in proportion to the amounts of their established claims." (Article 6.4)

Finally, to cover his liability under the convention, the operator shall be required to have and maintain insurance or other financial security to the amount and on terms which the controlling state specifies (Article 8.1).

Some of the recommendations of the LOS conference of 1975 with regard to civil liability follow those made at the Conference of Safety and Pollution Safeguards in the Development of North West European Offshore Mineral Resources held in London in March 1973. This conference took the form of exploratory discussions and established working parties to investigate further the main issues discussed. Concern was expressed for the need of definition of territorial boundaries and matters of jurisdiction. In the event of accidents, it was generally felt that the choice of jurisdiction should be the plaintiff's — either the contracting state where the damage was caused or the contracting state licensing the operations. A compulsory insurance scheme (as proposed at the 1975 LOS Conference) was felt to be the best way to compensate for pollution damage.

6.2.3 Bilateral and Multinational Treaties Between North Sea Countries

The recommendations outlined in the international treaties arise from ideas advanced at the regional level, and it is not surprising to note repetition of the main points concerning pollution hazards, civil liability and territorial jurisdiction. In addition to these general considerations, the North Sea countries have been interested in establishing a cooperative approach to observe and monitor any pollution damage. For example, the 1969 Agreement for Cooperation in Dealing with Pollution of the North Sea by Oil, the Hamburg Agreement (signed by Belgium, Denmark, France, Germany, the Netherlands, Norway, Sweden and the UK),divided the North Sea into a number of zones for which the contracting parties have responsibility to observe the presence of an oil slick and to report it without delay when it is likely to constitute a serious threat to the coast or related interests of any other contracting party.

Further agreements in 1971 and 1973 echoed the need for regional rather than national views on the subject of pollution of the sea by oil and compliance with regulations. In 1971, the revision of the 1967 Agreement Between Denmark, Finland, Norway and Sweden Concerning Cooperation to Ensure Compliance with the Regulations for Preventing Pollution of the Sea by Oil recognized each state had a duty to the others to inform them if oil on the sea was drifting to their coast and that states should assist each other in the investigation of offenses.[1] The 1973 Conference on the Safety

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[1] The Convention on the Protection of the Environment Between Denmark, Finland, Norway and Sweden (1974) held in Stockholm had the same general outline as the 1967 agreement but was concerned with a smaller area. Special authorities were to be established to safeguard environmental interests.

and Pollution Safeguards in the Development of North West European Offshore Mineral Resources (previously discussed in Section 6.2.2) attended by Norway, the UK, the Netherlands, West Germany, France, Belgium, Sweden, and Eire advocates that plans and methods be devised for protecting the coasts in priority over protection of the high seas and that techniques to contain oil spills should be developed. Also recommended is a long-term plan to deal with pollution incidents.

There have been, in addition to these treaties advocating regional cooperation, other agreements dealing with more explicit problems. In 1973, the Agreement Between the UK and Norway Relating to the Transmission of Petroleum by Pipeline from the Ekofisk Field and Neighboring Areas to the UK establishes liability for pollution damage, including the costs of preventive and remedial action, under Norwegian law and jurisdiction. Other agreements regularize the territorial areas of North Sea countries. In 1968, for example, the Continental Shelf (Jurisdiction) Order subdivided the UK sector of the North Sea into Scottish and English areas; and the 1971 Copenhagen Agreement between West Germany, Denmark and the Netherlands allowed the extension of the West German sector to the mid-North Sea median line.

The Convention on the Prevention of Marine Pollution from Land-Based Sources (Paris) of October 1972, which covers the North Sea and the North Atlantic, includes pollution by persistent oil and hydrocarbons of petroleum origin on the blacklist and by nonpersistent oils and hydrocarbons of petroleum origin on the greylist. The sources of pollution covered by this convention include (Article 3) pollution "from man-made structures placed under the jurisdiction of a contracting party."

6.2.4 Legislation of Individual Countries

A. Present

National legislation affecting offshore mineral exploitation, like the international and regional treaties it shadows, can be divided into two areas of concern:

1. Laws which administer the exploration and exploitation of minerals through the establishment of leasing requirements and operational procedures.
2. Laws recognizing the environmental hazards of offshore activity and regulating discharges of oil and waste.

Both types of legislation generally follow a basic pattern by delimiting national sovereignty over the continental shelf and extending civil jurisdiction over the territorial sea. Procedures to obtain a concession or license to operate are followed by basic operating regulations (Ely, 1974; OECD, 1973). Environmental laws separately establish liability, penalties and compensations for violating pollution standards.

B. North Sea

All North Sea countries abide by the strictures of the 1958 Continental Shelf Convention and the Dumping of Wastes Convention, though Belgium did not sign either treaty and West Germany did not sign the Continental Shelf Convention. Each nation exercises sovereign rights over the continental shelf for exploration and exploitation purposes and each has exclusive control over the granting of concessions. Each provides that no offshore installation may hinder shipping, fishing, conservation of biological resources or scientific research. Safety zones of 500 meters are established around all installations, and both the zones and installations are governed by national law.

In the following compilation, the laws of some individual North Sea countries, Italy and the U. S. are shown. Laws dealing with mineral exploitation will appear first, followed by legislation on pollution. Most of the statutes are phrased in general terms. The UK and Norway, the two North Sea countries most involved in seabed exploitation, have passed more detailed legislation (UN Legislative Services a and b; Sibthorp, 1975).[1]

Legislation of Individual North Sea Countries

<u>United Kingdom</u>

1. Continental Shelf Act 1964
2. Mineral Workings (Offshore Installations) Act 1971
3. Prevention of Oil Pollution Act 1971

The UK is currently preparing important legislation relating to petroleum and submarine pipelines which is outlined in 6. 2. 5A. Three further regulations are to be added to the comprehensive 1971 Mineral Workings (Offshore Installations) Act (6. 2. 5A).

<u>Belgium</u>

1. Law of 13 June 1969 concerning the Belgian Continental Shelf
2. Legislation for Prospecting for and Producing Crude Oil (General)

<u>Denmark</u>

1. Act of 9 June 1971 concerning the Continental Shelf
2. Act of 8 May 1950 Concerning Prospecting for and Exploitation of Raw Materials in the Subsoil of Denmark
3. Order of 7 November 1963 Concerning an Exclusive Concession for Prospecting and Exploitation of Hydrocarbons and the Like
4. Act of 12 May 1965 Concerning Mineral Raw Materials in Greenland
5. Act of 7 June 1972 on Measures Against Pollution of the Sea by Substances Other than Oil

<u>Finland</u>

1. Law Concerning the Continental Shelf (5 March 1965)
2. Law Concerning the Prevention of Pollution of the Sea (5 March 1965)

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[1] A useful summary of mining and petroleum laws for Europe may be found in Ely (1974).

France

1. Loi du 30 Decembre 1968 Relative A L'Exploration Du Plateau Continental
2. Decret du 6 Mai 1971 Portant Application de la Loi 30 Decembre 1968
3. Decret du 6 Mai 1971 Relatif Aux Authorisations De Prospections
4. Loi du 26 Decembre 1964 Reprimant La Pollution Des Eaux de la Mer Par Les Hydrocarbones
5. 1975 Law regarding offshore petroleum installations

Germany

1. Declaration of 20 January 1964
2. Act of 24 July 1964 on Provisional Determination of Rights Relating to the Continental Shelf

Netherlands

1. Law of 23 September 1965 Containing Regulations Governing the Exploration for and the Production of Minerals Under the North Sea
2. Pollution of National Waters (5 November 1970)

Norway

1. Royal Decree of 31 May 1963 Relating to the Sovereignty of Norway over the Seabed
2. Act of 21 June 1963 Relating to Exploration and Exploitation of Submarine Natural Resources
3. Royal Decree of 9 April 1965 Relating to Exploitation of Petroleum Deposits
4. Regulations Relating to the Safe Practice in Exploration for and Exploitation of Petroleum Resources
5. Royal Decree of 31 January 1969 Establishing Rules Relating to Scientific Research for Natural Resources on the Continental Shelf
6. Royal Decree of 31 January 1969 Establishing Rules Concerning Exploration for Certain Submarine Natural Resources Other than Petroleum

Sweden

1. Act of 3 June 1966 Concerning the Continental Shelf

C. Italy

Offshore mineral operations in Italy are governed by Title 1 of Act No. 613 of July 21, 1967, as amended by Decree No. 1336 of December 30, 1969. Under this law, the state has the sole right to explore and exploit the natural resources of the continental shelf. It authorizes the Ministry of Industry and Trade to grant eligible applicants prospecting permits, exploration permits and production concessions.

D. United States

In the U. S., there are over 50 federal laws that impinge upon the leasing, construction and use of offshore structures. The primary piece of federal legislation in this area is the Deepwater Ports Act of 1974. Legislation dealing with the licensing and safe operation of offshore structures is listed first, followed by legislation which puts restrictions on activities that may harm the environment.

Licensing and safe operation of offshore structures:

1974	Deepwater Ports Act (USC 1503) Establishes license requirements for ownership, construction, and operation of fixed and floating man-made structures, other than vessels.
1953	Outer Continental Shelf Lands Act (43 USC 1331 et seq.) Establishes that jurisdiction over submerged lands and their mineral deposits beyond the state boundaries is retained by the federal government (Subsection N concerning state jurisdiction and mining laws).
1972	Ports and Waterways Safety Act. Title 1 (33 USC 1221-27) Gives the secretary of the department in which the Coast Guard is operating (Department of Transportation) authority to prescribe minimum safety equipment requirements for offshore structures and ensure protection against fire, explosions, natural disasters and other serious accidents.

Environmental aspects of offshore mining:

1970	National Environmental Protection Act (42 USC 4321 et seq.)
	All federal agencies must file an environmental impact statement before taking any action that will significantly affect the environment. This statement must include an assessment of adverse environmental effects of the proposed action, alternatives to the proposed action, a statement of the relationship between the proposed short-term use of the environment and the long-term effects on the environment, and a statement of any irreversible commitment of national resources resulting from the proposed action.
1972	Coastal Zone Management Act (16 USC 1456 et seq.)
	Federal licenses and permits may not be granted for any activity affecting a state's coastal zone unless the applicant provides a certification from the state that the activity complies with the states's coastal management program as approved by the Secretary of the Interior. Since no state has yet implemented its final management program, this provision is not yet in force.
1972	Marine Protection, Research and Sanctuaries Act. Title 111 (16 USC 1431 et seq.)
	The Secretary of the Interior is given authority to designate as marine sanctuaries coastal waters which he determines should be preserved or restored for conservation, recreational, ecological or esthetic purposes.
1972	Federal Water Pollution Control Act (33 USC 1251-1376)
	The Environmental Protection Agency (EPA) will, with other federal agencies, prepare comprehensive plans for preventing or reducing pollution. Violations of the water quality standards developed by the EPA may result in criminal and civil penalties. Applicants for a federal permit to conduct any activity which might result in a discharge into U. S. navigable waters must provide certification from a water pollution control agency that applicable water quality standards will not be violated.

Discharge of oil or other hazardous substances designated by the EPA is prohibited. Owners and operators of fixed offshore facilities are subject to a $10,000 fine or imprisonment for up to one year for failure to notify the government of an oil discharge.

1972 Marine Protection, Research and Sanctuaries Act. Title I Ocean Dumping Act (33 USC 1401)

Implements the convention on dumping of wastes by establishing a permit system by which the EPA regulates the dumping of all waste materials.

Miscellaneous Laws:

Clean Air Act (42 USC 1857 et seq.)

EPA is authorized to set up air pollution standards which, if violated, can result in a suit by the Attorney General and an injunction restraining activity.

Fish and Wildlife Coordination Act (16 USC 661-66c)

Whenever waters are impounded, deepened or otherwise controlled or modified for any purpose by a department of the U.S., adequate provision shall be made for the conservation, maintenance and management of wildlife resources.

Occupational Safety and Health Act (29 USC 655)

Establishes the safety and health standards which employers must meet. Any violation or failure to implement the regulations could lead to civil and criminal penalties.

State Mining Laws:

1953 Submerged Lands Act (43 USC 1301 et seq.)

Extends civil and criminal jurisdiction of all coastal states 3 miles seaward. (Texas and the Gulf Coast of Florida granted 9-mile jurisdiction.) Offshore mining conducted in this zone must comply with the coastal state's mining legislation.

Despite primary state jurisdiction as outlined in the Submerged Lands Act above, mining and oil structures may only be constructed with the consent of the U. S. Army Corps of Engineers (River and Harbors Act, Subsection C). Further inroads on state prerogatives are made by the Deepwater Ports Act, National Environmental Protection Act, Coastal Zone Management Act, and the Federal Water Pollution Control Act.

E. Greenland

No separate legislation exists concerning the offshore mineral resources of Greenland. The basic legislation contained in the 1965 Act on Mineral Resources in Greenland, as amended in 1969, concerns the granting of offshore licenses and concessions. It is anticipated that an Advisory Committee will publish a model act concerning future offshore concessions for the exploration and exploitation of petroleum (Ministry of Greenland, 1974).

6.2.5 Regulations and Guidelines

The purpose of this section is to comment on regulations and guidelines laid down by the various governments for offshore environmental protection. The possibility of harmonizing these regulations between countries with adjacent offshore mineral production interests was taken up in the 1973 Conference on Safety and Pollution Standards in the Development of North-Western European Offshore Mineral Resources (SPC).

The SPC established three working groups (with work still in progress today) to investigate the national requirements of participating countries:

Group I — environmental matters and the effect of offshore operations.

This group looked at measurements and procedures for collecting environmental data, presentation and evaluation of data, and environmental criteria used in the design of offshore installations.

Group II — requirements for the construction and use of offshore facilities.

The group looked at monitoring design and construction, underwater technology, movement of installations, hazards from ships, equipment installation and design strength, seaworthiness and stability.

Group III — existing and proposed national requirements relating to safety, health and welfare of personnel.

This group considered safety inspections and accidents and the exchange of information, standard definitions and reporting forms for accident, health and welfare (accommodation, working hours, training, medical provisions),drilling procedure, use of dangerous materials, safety of divers, and helicopter operations (UK Department of Trade and Industry, 1973).

A. United Kingdom

The Mineral Workings (Offshore Installations) Act 1971 (1971 and 1974), following close on the inquiry into the loss of the rig Sea Gem, led to seven sets of regulations (and three further sets in draft) outlined below:

1. The registration of all offshore installations with, and notification of, their locations to the Department of Energy.
2. Notification to the department of persons appointed as installation managers responsible for safety, and their qualifications.
3. The keeping of an official log book (similar to a ship's log), and the procedures for registering deaths.
4. The functions and powers of the inspectors of the department's petroleum directorate to enforce the provisions of the regulations,and the reporting of accidents.
5. The certification of offshore installations as suitable and safe structures for the operations in which they are used.
6. Public inquiries into serious accidents.
7. The safety of diving operations from or in connection with offshore installations (except pipelines).

Three further regulations proposed will cover:

8. Employer's Liability Compulsory Insurance.
9. Day-to-day safety, health and welfare matters, safety of equipment and working procedures.
10. Emergency equipment and emergency procedures.

The regulations governing the safety of diving operations (No. 7 above) were passed in 1974, Offshore Installations (Diving Operations) Regulations (UK, 1974), and went into force at the begining of 1975. Already 60 government approved doctors, all of whom have completed the Royal Navy course in diving medicine, are available to divers. A close watch is kept on diving contractors by the Senior Diving Inspector of the Department of Energy.

A Certifying Authority (CA),[1] appointed by the Secretary of State, issues certificates for offshore installations. These attest the suitability and safety of the installation, and are valid up to five years (less stringent annual surveys keep the certificate valid). Regulations were also drafted for older installations such as those in the southern North Sea. These are issued with restricted Certificates of Fitness. Enforcement of the licenses is undertaken by the Department of Energy Petroleum Engineering Directorate (Molyneux, 1975).

The 1971 Act appears to be as comprehensive a code for offshore safety so far instituted by any government in the EEC. Even so, it is far from complete since there is no mention, for example, of pipelines. New legislation is planned to cover offshore pipelines. The Petroleum and Submarine Pipeline Bill (Smith, 1975) will provide:

1. Powers to control offshore pipelines in much the same way as the government controls land pipelines. The government will promote safe and rational development of pipeline systems with due regard given to the safety of personnel.

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[1] For the CAs appointed by the Secretary of State, see Section 6.1.3.

2. Power to increase the government's control over the exploration, development and production of petroleum including the power to control depletion rates.

3. The setting up of the British National Oil Corporation (BNOC), whose main tasks will be to hold the nation's participating interest in licenses, working in partnership with private sector companies.

A comparison with respect to Norwegian guidelines on the construction of offshore installations is made in Appendix C. It appears that the Norwegian standards with respect to waves are more stringent (100-year wave versus 50-year wave) than those of the UK.

B. Norway

Norway has statutory rules only for mobile drilling platforms. Fairly detailed regulations concerning all aspects of exploration drilling (structural requirements, operational safety requirements, life saving applicance standards) are laid down in a single volume published in May 1975. Norway has no statutory regulations for the production phase and no certificates of fitness: instead, specific approvals of individual fixed platforms are given, usually based on recommendations by Det. Norske Veritas (Molyneux, 1975).

The Royal Commission, set up in Norway to work out the draft regulations, did not see the need to change the existing supervision by the Petroleum Directorate at all stages of offshore installations from their design to their construction and operation. Similarly, it regarded the production and landing of petroleum as an operation so complex as to deem it unrealistic to formulate a set of regulations to cover all situations. Instead, the responsibility is placed upon the operators to conduct their work in a safe manner and to not unreasonably interfere with others.

An interesting point raised by the Royal Commission is that in 1975 (Women's Year) the future employment of female personnel was foreseen. It was suggested that installations still under construction should have separate quarters which would be suitable for female personnel (Vogt, 1975).

C. The Netherlands

The Mining Regulations for the Continental Shelf were introduced in 1967 and adjusted in 1968 and 1971 to provide guarantees for safe procedures under the severe operating conditions of the North Sea while safeguarding a vulnerable environment. It was intended that the regulations be sufficiently flexible to accommodate new techniques.

Under the regulations, each exploration unit requires a valid certificate of fitness and drilling equipment must be approved by the Inspector General of Mines (IGM). But the regulations provide no detailed requirements for the design of production structures. Before a fixed platform can be put in position, final approval is required from the IGM. This will include approval of process systems, aspects of safety, living quarters, deck layouts, etc.

The intention to lay an offshore pipeline has to be sent in writing to several authorities,[1] who each approve an aspect of its design, construction or installation.[2] There are no regulations given for diving operations, but a permit is needed from the IGM for the use of diving equipment.

In 1975, although very little oil comes from Dutch waters, oil and gas transfer facilities for loading ships and barges were still not covered by the Mining Regulations (Van Boven, 1975).

D. The United States

The basic law governing petroleum operations offshore in the United States is the 1953 Outer Continental Shelf (OCS) Lands Act. Regulations under that act governing the drilling and production operations are administered by the Conservation Division of the Geological Survey, which also supervises federal, Indian and certain naval petroleum reserve lands.

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[1] The Ministry of Economic Affairs; IGM; the Head of the Hydrographic Department of the Ministry of Defence; the Director General of Pilot Services, Buoyage, Beacons and Lighting; and the Postmaster General.

[2] Approval of installation is given by the IGM, and the Minister of Economic Affairs, after consultation with other ministries, sees that it is buried to an adequate depth.

An oil installation is inspected once a year to see if production equipment complies with federal requirements. Personnel safety is also a prime concern of the inspectors. Operating regulations are applicable to all OCS areas but may be supplemented by OCS orders to deal specifically with problems unique to a certain area. There are 12 such orders for the Gulf of Mexico and 10 for the Pacific area. Typically, these orders cover:

1. Marking of wells, platforms and fixed structures.
2. Drilling procedures, including blowout prevention equipment and drilling mud programs.
3. Plugging and abandonment of wells.
4. Determination of well producibility.
5. Installation of subsurface safety devices.
6. Procedure for completion of oil and gas wells.
7. Pollution and waste disposal covering the various aspects of pollution control and reporting procedures.
8. Approval procedures for installation and operation of platforms, fixed and mobile structures, and artificial islands, covering design and nondesign features, procedure for application for installation and requirement for certification of structural plans.
9. Approval procedures for pipelines, covering requirements for approval of general design and installation, the installation of safety and pollution control devices, and procedures for inspection and maintenance.
10. Sulphur drilling procedures off Louisiana and Texas.
11. Oil and gas production rates, prevention of waste, and protection of correlative rights.
12. Public inspection of records. Outlines the reports received by the area offices which are available for inspection (USGS, 1975; U. S. Department of Interior, 1971; Adams et al., 1975).

6.3 SOURCES OF INFORMATION

The information sources are divided into two sections as in other chapters: first, the references which have been cited in the text together with other references of interest are given, and second, the organizations concerned with environmental protection offshore.

6.3.1 References

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UN. Legislative Series. National Legislation and Treaties Relating to the Territorial Sea, the Contiguous Zone, the Continental Shelf, the High Seas, and to Fishing and Conservation of the Living Resources of the Sea. (ST/LEG/SER. B/15).

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In addition, the edition of the Marine Journal, July 1974, is a special Law of the Sea issue with several useful articles including: "The oil industry goes to sea" by M.S. McKnight and "Law of the Sea at the end of a decade - a prediction" by L.M. Alexander.

6.3.2 Organizations

API	American Petroleum Institute
BNOC	British National Oil Corporation, UK Department of Trade (to be established)
	Committee Concerning Licenses and Concessions Under the Act on Mineral Resources in Greenland (Ministry for Greenland)
	Crown Estate Commissioners (UK)

	Department of Energy (UK)
	Department of Trade and Industry (UK)
IFP	French Institute of Petroleum
IP	Institute of Petroleum
NSOCSC	North Sea Operators Clean Seas Committee (London)
OECD	Organization for Economic Cooperation and Development
UKOOA	United Kingdom Offshore Operators Association (London)
UN	United Nations
USGS	United States Department of the Interior, Geological Survey
	United States Department of the Interior, Bureau of Mines
USEPA	United States Environmental Protection Agency

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

CONTENTS

7.1 RISKS OF SPILLS FROM OFFSHORE OIL TECHNOLOGY IN THE EEC AND THE NORTH SEA

7.2 SAFETY AND OTHER ASPECTS OF OFFSHORE OIL TECHNOLOGY

7.3 PREVENTION OF ENVIRONMENTAL DAMAGE

7.4 ENVIRONMENTAL ASPECTS OF OFFSHORE MINING

7.5 LEGAL AND INSTITUTIONAL REGIMES

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

This chapter contains independent views of the writer derived from the published information described previously. These views are intended to be constructive,not obstructive. They are presented in order of priority from particular to general.

7.1 RISKS OF SPILLS FROM OFFSHORE OIL TECHNOLOGY IN THE EEC AND THE NORTH SEA

Offshore oil production installations have historically contributed a small fraction of total estimated pollution of the world's oceans by oil.[1] In the EEC areas of the North Sea and the North Atlantic, where storm conditions are severe and where there is yet little operating experience, oil pollution from installations can be expected to be somewhat higher.

The direct risk of massive oil spills from oil production operations is relatively small,[2] but the extent of possible spills could be very large. (A major blowout, a pipeline breach or a collision with an offshore storage tank could be of the order of 1, 000, 000 barrels [140, 000 metric tons]). Major spills would usually be associated with other damage to facilities.

The risk of accidental release of small quantities of oil from existing U.S. production installations is high.[3] It is likely to be higher in the North Sea oil production areas due to the more difficult operating conditions. In

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[1] The other causes are tankers and effluents from onshore.
[2] Between 1 in 450 and 1 in 3000 in regions such as the Gulf of Mexico.
[3] Twenty-five to 35 barrels per million barrels produced on average.

the North Sea, there has been no major spill reported yet in the drilling of about 800 wells and the production of 5,000,000 barrels of oil. This is an outstanding record. There are no data on minor spills.

In the North Sea and North Atlantic, loading from SBMs and transportation of oil to shore by tankers presents a much higher risk of oil spill than transportation to shore by pipeline. This is due primarily to the navigation conditions.

In the U.S. and UK offshore areas, most spills are attributable to human error or to design deficiencies. The design criteria imposed by government regulations or selected by private industry have a direct relationship to the capital cost and to the level of risk of oil pollution of offshore installations. The question – What is an acceptable risk? — is critical.

In the EEC offshore areas (and in the North Sea in general), there are no published estimates of:

1. The risks of oil spills due to present and future installations, taking into account the regional conditions involved.[1]
2. Damage scenarios describing the possible causes, locations and extent of possible spills.
3. Predictions of spill trajectories and drift rates.

Recommendation A

1. The feasibility of making detailed risk assessments of individual systems and operating complexes (platforms) should be investigated by the EEC, in collaboration with organizations such as the International Institute for Systems Analysis and individual offshore operators.

2. A standardized methodology should be developed to assist in preparing risk evaluations and damage scenarios (including spill trajectories) for: exploration situations and production

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[1] Risk estimates available, or in preparation, rely on U.S. data.

operations. The assistance of international classification and certification societies should be enlisted in developing this methodology.

In existing offshore technology (systems now operating or under construction), risks cannot be appreciably reduced without costly design changes or major technological developments.

Sea conditions in the North Sea are prompting many improvements and some changes in platforms and vessels, but basic drilling technology and production operations remain the same. They are not likely to change radically in the future.

Drilling and production operations are subject to human operator errors. The risk of operator error is heightened by the shortage of experienced personnel due to the rapid growth of the industry. Unfamiliarity of the operators with the sea and storm conditions of the North Sea and North Atlantic regions is also an increased operating risk of oil spillage.

Recommendation B

The EEC Commission, in cooperation with Norway and other involved oil producing countries, should undertake a review of:

1. Offshore personnel occupational categories and functions.
2. Qualifications of offshore operating personnel and the training they have received.
3. Responsibilities of comparable personnel in other technologies such as civilian aircraft or merchant ship operators and the training they receive.
4. Feasibility and merits of multinational licensing schemes for various categories of operating personnel on offshore installations.
5. The advisability of sponsoring a multinational offshore technology institute for furthering the harmonious development of safety and environmental preservation practices and for implementing the licensing schemes in No. 4 above.

Future offshore oil technology comprises systems now being conceived, designed or tested for oil production in 5 to 15 years for regional environmental conditions in:

> Deeper water (3000 to 10,000 feet) (900 to 3000 meters) in the Mediterranean and North Atlantic slope areas.
>
> Rougher sea conditions associated with floating ice in the Northern North Sea (N of 62°) and the coasts of Greenland.

Concepts for future systems include floating platforms, subsea wellheads, and tanker transportation to shore from floating reservoirs. Pipelines are a problem in very deep water.

There are numerous opportunities for meaningful economic participation, for technological planning, and for research initiatives by the EEC in the development of such systems. An example is the existing participation of the EEC in the Groupement Europeen de Recherches Techniques sur les Hydrocarbures (GERTH) (Delacour, 1975).

Recommendation C

The division of the EEC concerned with environmental protection and human safety should initiate a dialogue with GERTH to learn:

1. The technological directions and problems associated with current research on deepwater production.
2. The merits of participation in GERTH by funding related investigations of future safety and environmental aspects of the new technologies.

7.2 SAFETY AND OTHER ASPECTS OF OFFSHORE OIL TECHNOLOGY

Storms are a major risk to oil installations and to the safety of personnel in offshore operations in the North Sea and the North Atlantic. Considerable resources have been devoted to improvements of storm warning and to forecasting procedures in general, but there remains a need for more observation stations at sea.

There are no damage scenarios published on the general risks of fires, explosions, capsizing, collisions and similar mishaps to offshore installations. The dangers to personnel and the attendant danger of oil spill are not explicitly discussed. The adequacy of safety equipment and of emergency procedures to combat disaster and/or to abandon platforms or installations are not widely discussed in the public record. The qualifications, experience and functions of safety engineers (both public sector and private company personnel) are not standardized between adjacent operating countries or on operating craft of diverse nationalities. While considerable efforts on the part of both private industry and government bodies appear to be devoted to safety and concern for the protection of the environment, there are few independent assessments of the adequacy of these measures made publicly available. There is still a prejudice against safety and environmental engineers whose activities are sometimes considered to interfere with the main objectives of the operation.

Recommendation D

> In the interest of its member countries, the EEC should undertake a detailed study of existing safety procedures and disaster response plans of offshore oil installation operators. This study should be conducted by an independent entity, with the participation of insurance underwriters to provide actuarial and historical data on past occurrences.

The secondary onshore impacts of offshore oil production (pipeline landfalls, refineries, etc.) are receiving considerable attention by governments and regional councils. The impacts on the open sea environment have received much less attention. The process of colonization of the seabed by man today is some what akin to the incursion by man in the 19th Century into the great plains of the U.S. and Australia. The aesthetics of offshore installations and their future role after the oil supply has been exhausted appear to be a negligible preoccupation compared with the urgency to extract oil.

7.3 PREVENTION OF ENVIRONMENTAL DAMAGE

There is a great contrast in offshore technology between views of the hostile environment and of the fragile environment. This arises from the lack of adequate information on the environment itself. In particular, for the EEC offshore regions, there is still insufficient information on:

Offshore regional characteristics.

Oceanographic conditions (winds, waves, currents) and climatic changes.

Sea-floor topography and properties.

Ecosystems.

Existing levels of pollutants (including hydrocarbons).

Hydrocarbon reserves and resources.

Recommendation E

The commission of the EEC should undertake the preparation of a regional environmental atlas, supported by regional data banks, to foster a more harmonious advance between economic development and environmental protection. The cooperation of adjacent countries should be enlisted for their benefit. Much of the existing data should be standardized, and new data should be collected in standard form. Consideration should be given to calling a conference of groups currently collecting or planning the acquisition of offshore environmental data, including:

The COST 43 Environmental Data Buoy Project

The UKOOA Oceanographic Committee

The Oil Industry International Exploration and Production Forum (E&P Forum).

The North Sea Oceanographic Study Group (NSOSG).

The fate of oil at sea under various climatic conditions is poorly known or understood. There are no synoptic systems for measuring the level of oil content in seawater on a regional scale (e.g., the North Sea). There are no standards for making measurements and for reporting and interpreting data. There is no published information available on present and planned procedures and programs for monitoring the level of hydrocarbons released to the offshore environment in the oil producing areas of the EEC.

Recommendation F

The Division of Prevention of Pollution and Nuisances of the EEC should support and participate in:

1. Existing research on the chemistry and physics of oil in seawater.
2. The development of standards and criteria for analysis and for monitoring methods.

It is clear that environmental protection and safety measures are more effective when they are anticipatory, instead of critical. In future offshore technology (systems now being conceived, designed or tested for installation in 5 to 15 years), there are opportunities for the reduction of the risks of oil spill and the enhancement of safety by following principles of containment and redundancy in design and of reliability by testing. These, and aspects of economic viability of future offshore technology, belong to the realm of long-term planning and of technology assessment.

Under present UK requirements, an independent design review of proposed installations is provided by specialized consultants in collaboration with certification societies. This function, while satisfactory for the present situation, does not fully anticipate future needs, i.e., consultants in this capacity do not originate new designs. There appears to be a meaningful role for an independent advocate at the design concept and research stage. This should be part of the merits of an overall technology assessment and environmental impact concern about new technology.

Recommendation G

The EEC should consider the merits of developing, within the planning activities of its commission, a technology assessment group. The function of this group would be to assess future technology and to support long-term planning by (in the case of petroleum):

1. Supporting policy option analyses with technical recommendations.
2. Participating in technological research to enhance safety and environmental protection considerations.
3. Assisting national public and private sector interests by developing evaluations of environmental risk in standardized form, i.e., environmental impact statements (see Recommendation A).

The cooperation of the U.S. Office of Technology Assessment should be enlisted as part of this study.

The existing techniques to combat the spread and propagation of oil after a spill has occurred are very unreliable at night or in stormy conditions. According to published information, spraying of low-toxicity dispersants from ships is currently the primary technique available in case of a major spill in the UK sector of the North Sea.[1] It is very doubtful that all the dispersant available for an emergency could be effectively sprayed under storm conditions. Consequently, a major spill in the open sea could remain unattended for a considerable period of time.

Recommendation H

A review should be undertaken of emergency preparedness and procedures against oil spills in the various nations of the North Sea. This should include consideration of the size and trajectories of possible spills (see Recommendation A).

7.4 ENVIRONMENTAL ASPECTS OF OFFSHORE MINING

The environmental effects of present offshore mining technology are small, or negligible, and unlikely to have international impacts.

Mineral resources under the waters of EEC countries may include extensive quantities of coal, potash, sand and gravel, sulphur, geothermal energy and possibly base metals. The future importance of these resources may lead to extensive offshore mineral projects patterned after petroleum technology (solution mining and artificial islands).

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[1] Dispersant capacity is for 15, 000 barrels of oil per day for 7 1/2 days or approximately 120, 000 barrels of oil by 12 spraying units.

Recommendation I

The Commission of the EEC should undertake an inventory of the mineral resources which may exist under the waters of member countries with a view to providing alternatives to land resources.

7.5 LEGAL AND INSTITUTIONAL REGIMES

At the national public sector level in all EEC member countries, the priority for obtaining reliable supplies of oil is very high. The need for oil is an incentive to foster reliable technology.

At the private sector level, the potential economic losses usually associated with major spills are a deterrent to risky or faulty practices.

Public opinion pressure against oil spills is not as great in EEC member countries as in the U. S. but is nonetheless a motivation toward safe environmental practices. There is little effort to provide the public with detailed factual information,and there appears to be little demand for it.

These common interests in avoiding oil spills and related types of accidents have given rise to a number of cooperative endeavors for the protection of the environment by governments and operators. These have taken the form of agreements and international conventions.

Various North Sea countries have accepted the legal principle that compensation for damage should be provided by defining liability across international jurisdictional boundaries.[1] This principle should be extended to the waters of the EEC countries in the Mediterranean and the Atlantic.

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[1] See OPOL — Oil Pollution Liability Agreement and the Convention on Civil Liability for Oil Pollution Damage Resulting from Exploration and Exploitation of Seabed Mineral Resources.

Regulations emanating from legislation are usually promulgated after an interim period during which a dialogue is encouraged with the operators to whom the regulations will apply. Regulations are not normally anticipatory and do not make direct provisions for experimental undertakings. In the North Sea, the main feature of regulations is to follow an individual case approach and to encourage multiple reviews of the soundness of proposed installations.

As matters stand at present in the North Sea, the UK and Norway have the most advanced regulations. Other North Sea countries have much less developed regulations. The UK regulations are much broader in scope and more numerous than Norwegian regulations, but the latter are more conservative (Appendix C).

Recommendation J

1. Future policies for regulation and enforcement should rely, as extensively as possible, on incentives to the operators to maintain high levels of environmental protection and high standards of safety in their own interest.

2. Consideration should be given to an international agreement between EEC members and adjacent countries on requiring the exchange of environmental impact statements of proposed offshore oil programs as a means of further reciprocal protection.

3. Policies for future regulation and enforcement of environmental protection should be guided by the principle that technical criticism for environmental protection would most meaningfully result from participation in offshore research (sharing the risk) (Recommendation C). It is recommended that a study should be made of the possible methods for participation by the EEC in environmental protection associated with offshore technology research.

Larger technical and financial resources will be required for future oil exploration and production in deeper water or more stormy environments, where the public and private sector common interests will be even more closely associated than in present technology.

Recommendation K

It is recommended that an investigation should be made of the future public and private sector roles in insuring oil supplies to the EEC. This investigation should determine whether the economic risks taken by the private sector in exploration and production for hydrocarbons are a deterrent to their taking maximal safety and environmental protection measures.

APPENDICES

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A. TERMS OF REFERENCE

B. BRIEF HISTORIES OF OFFSHORE OIL TECHNOLOGY ACCIDENTS

C. COMPARISON OF UK AND NORWEGIAN GUIDELINES AND RULES FOR OFFSHORE PLATFORMS

APPENDIX A
TERMS OF REFERENCE
Annex Technique

A. 1 Titre de l'Etude

Aspects écologiques liés à la production de combustibles et de minéraux sur la plateforme continentale en particulier dans la Communauté Européenne.

A. 2 Introduction

Le milieu marin constitue une importante source d'approvisionnement en combustibles et dans une moindre mesure en substances minérales pour la C. E. E. et l'exploitation de ces matières premières va connaître une expansion notable dans ces prochaines annés. Dès lors il convient d'analyser l'impact de la production off-shore sur l'environnement marin et d'en déterminer ses conséquences possibles, ce d'autant plus que la conférence de Caracas sur la Loi de la mer a proposé d'étendre les eaux territoriales pour l'exploitation des ressources marines et des fonds marins à plus de 200 miles c'est-à-dire bien au delà de la plateforme continentale.

A. 3 But de l'Etude

- Evaluer les conséquences possibles de la production off-shore des matières premières minérales et combustibles sur l'environnement marin et sur l'homme compte tenu de l'évolution technologique.
- Analyser d'une manière critique les méthodes de contrôles et de prévention de la pollution off-shore et des risques encourus par la production de combustibles et de substances minerales.

- Comparison des aspects législatifs et institutionnels dans le monde et dans les différents pays membres en matière d'exploitation des substances minérales et des combustibles en milieu marin et de protection de l'environment.
- Présentation de recommandations susceptibles d'être adoptées à l'échelle communautaire pour la protection de l'environnement marin lors de l'exploration, de l'exploitation et du transport de substances minérales et de combustibles produits off-shore.

A. 4 Contenu de l'Etude

L'étude comprendrait plusieurs volets:

Dans un premier volet, l'étude fournirait un inventaire detaille des ressources minérales et des combustibles off-shore dans la C. E. E., de leurs perspectives ainsi que de leur importance future sur le plan de l'approvisionnement communautaire. Ce premier volet donnerait également une description de l'environnement off-shore du point de vue physique et écologique.

Le second volet aborderait les principales techniques utilisées pour la prospection, le développement, l'exploitation et le transport des matières premières minérales et des combustibles produits off-shore en particulier dans la C. E. E. ainsi que les aspects économiques, humains et sociaux liés à la production off-shore. It mettrait également en évidence les inconvénients de ces techniques du point de vue risques humains et environnement marin et les améliorations escomptées.

Le troisième volet analyserait:

- Les conséquences possibles de la production minérale et de combustibles off-shore sur l'environnement marin en particulier dans la C. E. E. en prenant en compte l'évolution technologique probable (pollution – effets directs et indirects).

- Les méthodes de contrôle et de prévention de la pollution off-shore et des risques encourus par la production de combustibles et de substances minérales et mettrait en évidence les lacunes existantes.

Le troisième volet aborderait également les problèmes d'environnement et les risque encourus par l'exploitation en grande profondeur des richesses minerales.

Le quatrième volet rassemblerait et comparerait la législation et les réglementations existantes en matière d'expolitation de substances minérales et de combustibles en milieu marin et aussi de protection de l'environnement et s'attacherait particulièrement aux mesures prises ou en projet dans les différents Etats membres.

En conclusions, sur la base des données acquises, ce contrat devrait fournir des recommandations susceptibles d'être adoptées au niveau communautaire pour la protection de l'environnement marin lors de l'exploration, de l'expolitation et due transport de substances minerales et de combustibles off-shore.

APPENDIX B

BRIEF HISTORIES OF OFFSHORE OIL TECHNOLOGY ACCIDENTS

This appendix is provided to illustrate some of the offshore catastrophes of recent years. The reader is warned that such a list can easily lead to a distorted image of the technology, unless one keeps in mind that similar lists can be assembled for aircraft, automobiles, trains, etc.

Table B-1. Rig mishaps, 1954-1974 (from Thobe, Offshore, June 5, 1974, pp. 24-28).

Year, rig name	Type	Owner	Mishap	Cost of Damage (millions of dollars)
1955				
S-44	Submersible	Chevron	Damaged by blowout and fire in Gulf of Mexico. Repaired and put back into service. Later retired.	1.8
Rig. No. 101	Submersible	American Tidelands	Capsized while moving off location in Gulf of Mexico. Put back into service. Later retired.	1.6
Rig No. 52	Jackup	Offshore Co.	Mishap occurred while jacking up. Salvaged.	0.3
1956				
Rig 22	Submersible	Sedco	Capsized at Gulf of Mexico shipyard. Salvaged.	1.4
1957				
Qatar Rig No. 1	Jackup	Royal Dutch/ Shell	Broken up by sudden storm while preparing to move into Persian Gulf. Not salvaged.	1.7
Mr. Gus I	Jackup	Glassrock Drilling Co.	Capsized while preparing to move in Gulf of Mexico. Lower hull salvaged.	2.5
Deepwater No. 2	Jackup	Deepwater Drilling Co.	Collapsed while drilling in Gulf of Mexico. Not salvaged.	1.6
Ed Malloy	Submersible	John W. Mecom	Drill barge destroyed by Hurricane Audrey. Drydock salvaged but not returned to service.	2.1
1958				
Translake No. 3	Jackup	Underwater Gas Developers	Capsized while being towed to first location in Lake Erie. Not salvaged.	2.0
Rig No. 55	Jackup	Offshore Co.	Storm damage during tow. Salvaged.	0.7
1959				
Rig No. 10	Jackup	Trans-Gulf	Capsized while preparing to move in Gulf of Mexico. Not salvaged.	3.2
C. E. Thornton	Jackup	Reading & Bates	Damaged by blowout in Persian Gulf. Extensive fire damage. Repaired and returned to service.	1.0
1960				
Nola 2	Drill barge	Zapata Off-Shore	Beached during storm in Bay of Campeche while moving to new location. Not salvaged.	1.3
1961				
No. 55*	Jackup	Offshore Co.	Beached in British Honduras during Hurricane Hattie while being towed from Trinidad to U.S. Repaired and returned to service.	1.7
Delta	Submersible	Offshore Co. (formerly Louisiana Delta)	Damage in hurricane in Gulf of Mexico. Repaired and returned to service.	1.5
Mr. Louie	Jackup	Reading & Bates	Damaged in Gulf of Mexico storm while under tow. Salvaged.	0.5
1962				
SM-1	Drill barge	Global Marine	Sunk by storm while on location off Santa Barbara, Calif. Not salvaged.	3.0
1964				
C. P. Baker	Drill barge	Reading & Bates	Turned end-over-end during blowout and fire in Gulf of Mexico, 22 casualties. Not salvaged.	2.3
Rig No. 1	Semi-submersible	Blue Water Drilling Co. (now Santa Fe)	Capsized and sank during Hurricane Hilda in Gulf of Mexico. Not salvaged.	7.5
1965				
Penrod 52	Jackup	Penrod Drilling Co.	Capsized while moving on location, broke up during Hurricane Betsy in Gulf of Mexico. Not salvaged.	2.5

Table B-1. Rig mishaps, 1954-1974 (continued).

Year, rig name	Type	Owner	Mishap	Cost of Damage (millions of dollars)
Marlin No. 3	Jackup	Marlin Drilling Co.	Partially submerged while moving to location in Gulf of Mexico. Repaired and returned to service.	1.7
Santa Fe Explorer (formerly Orient Explorer)	Jackup	Santa Fe (formerly Royal Dutch/Shell)	Damaged in Mediterranean Sea while under tow from Borneo to England. Repaired and returned to service.	1.5
Triton	Jackup	Royal Dutch/Shell	Damage caused by blowout and fire in Nigeria. Not salvaged.	1.5
Bruyard (Sedco 135 B)	Semi-submersible	Royal Dutch/Shell	Broke up in South China Sea while under tow, 13 casualties. Not salvaged.	7.5
Paguro	Jackup	Saipem S.p.A.	Destroyed by blowout and fire in Adriatic Sea, 3 casualties. Not salvaged.	6.0
Maverick I	Jackup	Zapata Off-Shore	Destroyed by Hurricane Betsy in the Gulf of Mexico. Not salvaged.	5.7
1966				
Sea Gem	Jackup	Compagnie General D'Equipments	Collapsed in North Sea while preparing to move, 13 casualties. Not salvaged.	5.6
Roger Butin (formerly Neptune III)	Jackup	CEP	Capsized after moving on location off Cameroon, Africa. Water and hull damage. Not salvaged.	7.0
Mercury (formerly Nola I)	Converted YF barge	Golden Lane Drilling	Capsized and sank during storm off Tuxpan, Mexico. Not salvaged.	1.5
Rig No. 52*	Jackup	Offshore Co.	Leg damage. Salvaged.	0.2
1968				
Julie Ann	Jackup	Dixilyn Corp.	Sank while under tow during storm in Gulf of Mexico. Not salvaged.	4.0
Dresser II (converted to Dresser VII)	Jackup	Dresser Offshore	Capsized on location. Salvaged and returned to service. Refurbished rig valued at $1.5 million.	2.0
Little Bob	Jackup	Coral Drilling Co. (now Fluor Drilling)	Blowout and fire in Gulf of Mexico. Derrick collapsed and rig badly burned. 7 casualties. Not salvaged.	2.0
Ocean Prince	Semi-submersible	ODECO	Destroyed on location by North Sea storm while operating as submersible. Hull broken up. Not salvaged.	7.0
Ocean Traveler	Semi-submersible	ODECO	Minor structural damage during storm in Norwegian North Sea. Sprung leak in one of its two main supporting pontoons. Repaired.	Insignificant
Ocean Viking	Semi-submersible	ODECO	Minor structural damage during Norwegian North Sea storm. Repaired.	Insignificant
Nola III	Drill barge	Zapata Off-Shore	Fire damage in engine room, several engines replaced. Incident occurred off Sumatra. Repaired.	Unknown
Chaparral	Jackup	Zapata Off-Shore	Lost three legs during Gulf of Mexico storm while under tow to Italy. Repaired and returned to service.	2.0
Unknown	Inland drilling barge	Service Contracting	Sank while under tow in Gulf of Mexico. Not salvaged.	1.5
1969				
Wodeco II	Drill barge	Fluor Drilling Services	Ice damage to hull, mast blew off during storm in Hudson Straits while rig under tow. Repaired.	0.4

Table B-1. Rig mishaps, 1954-1974 (continued).

Year, rig name	Type	Owner	Mishap	Cost of Damage (millions of dollars)
Wodeco III	Drill barge	Fluor Drilling Services	Blowout, Red Sea. No damage to rig, but underwater equipment lost.	0.5
St. Louis	Submersible	ODECO	Water damage in engine room from Hurricane Camille. Repaired.	Insignificant
OV-2	Tender	Offshore Co.	Capsized and partially sank during storm in Lake Maracaibo. Not salvaged. Deliberately sunk by owner.	1.5
Estrellita	Jackup (tender assisted)	Offshore Co.	Capsized while under tow in Gulf of Mexico. Declared total loss by insurance company. Salvaged by owner and returned to service.	2.5 (paid by insurance company) 1.9 (for salvaging & refurbishing)
Constellation	**Jackup**	**Offshore Co.**	**Sank during North Sea storm while in tow. Not salvaged.**	**5.8**
North Star	**Jackup**	**Offshore Co.**	**Sustained leg damage while in tow during North Sea storm. Repaired.**	**Unknown**
John C. Marthens	**Jackup**	**Offshore Co. Constructors**	**Suffered leg damage during storm in Gulf of Alaska. Repaired.**	**Less than 100,000**
George M. Reading	**Tender**	**Reading & Bates**	**Grounded during Hurricane Camille. No reported damage.**	**None**
Rimtide	**Submersible**	**Rimrock Tidelands (now ODECO)**	**Blowout in Gulf of Mexico. Salvaged.**	**Less than 100,000**
Mariner I	**Catamaran, semi-submersible**	**Santa Fe**	**Structural damage to hull during rough weather off Argentina. Repaired.**	**0.2**
Sedco 135G	**Semi-submersible**	**SEDCO, Inc.**	**Severe fire damage from blowout in Timor Sea off Australia. Repaired and returned to service.**	**3.5**
Mercury	**Jackup**	**Offshore Co.**	**Damaged in Lisbon harbor. Salvaged.**	**0.1**
Scorpion	**Jackup**	**Zapata Off-Shore**	**Sank in storm off Canary Islands while in tow. Not salvaged.**	**2.3**
Unknown	**4 tenders**	**Chevron Oil**	**Damaged in Hurricane Camille. All repaired and returned to service.**	**Less than 100,000**
Rig 20	**Inland barge**	**Rowan Drilling**	**Destroyed in Hurricane Camille.**	**800,000**
Rig 14	**Inland barge**	**Rowan Drilling**	**Minor damage sustained during Hurricane Camille.**	**Insignificant**
1970				
Rig 15	**Inland barge**	**Field Drilling**	**Destroyed in Hurricane Celia.**	**500,000-1 million**
Wodeco V	**Barge-shape**	**Fluor Drilling Services**	**Drill collars fell from derrick and pierced main deck and bottom of hull. All electrical gear in DC generator room, including generators and switch controls, had to be overhauled. Engines were overhauled and hull was patched.**	**0.7**
Unknown	**Inland barge**	**Kelly Drilling Co.**	**Blowout occurred with fire damage. Not salvaged.**	**0.5 to 1**

Table B-1. Rig mishaps, 1954-1974 (continued).

Year, rig name	Type	Owner	Mishap	Cost of Damage (millions of dollars)
Kenting I	Jackup	Kenting Ltd.	Storm in mid-Atlantic while in tow—structural damage (1/70). Repaired. Sabotaged off Ivory Coast—hull damage (3/70). Repaired.	Total damage for mishaps 0.5 million
Rig 59	Jackup	Offshore Co.	Leg damage (1/70). Repaired. Out of work approximately 12 days. Toppled over while operating off Nigeria (5/70). Towed out to sea and sunk by owner. Not salvaged.	Damage less than 0.2 million (4.0 million) (total loss)
Discoverer III	Ship-shape, self-propelled	Offshore Co.	Blowout damage (no fire). Repaired.	0.6
Rig 60 & Tender OV-1	Jackup (tender assisted)	Offshore Co.	Slight fire damage from diesel fuel line. Repaired.	Insignificant
Discoverer II	Ship-shape, self-propelled	Offshore Co.	Blowout off Malaysia. Deck hatches left open—minimal water damage. Repaired.	Insignificant
Sonda I (formerly Drillship)	Ship-shape	Reading & Bates	Gash in hull when collided with French freighter in Gulf of Lyons—damage slight. Repaired.	0.15
J. W. Nickle	Jackup (tender assisted)	Reading & Bates	Storm damage in Arabian Gulf. Jackup declared total loss. Tender salvaged.	2.5
E. W. Thornton	Catamaran	Reading & Bates	Blowout off Malaysia. No reported damage.	None
Stormdrill III	Jackup	Storm Drilling Co.	Severe fire damage from blowout off Texas, 1 casualty. Repaired and returned to service.	3.5
Transworld 61	Semi-submersible	Transworld Drilling	High wind and rough water damage to legs while moving onto location off South Africa. Repaired.	0.8
Glomar North Sea	Drillship	Global Marine	Severe storm in North Sea moved rig off drill site and damaged drilling equipment. Repaired.	Unknown
Mercury*	Jackup	Offshore Co.	Heavy weather damage. Salvaged.	0.3
Westdrill I	Jackup	Westburne Int'l.	Damaged in storm while in tow off Ivory Coast. Salvaged.	0.5
1971				
Big John	Drill barge	Atwood Oceanics	Blowout off Brunei. Severe fire damage to drilling equipment. Water became aerated and vessel sank until main deck was 3 ft - 4 ft under water, 9 casualties. Repaired and returned to service.	4.3
Endeavor	Jackup	Zapata Off-Shore	Lost top part of leg while under tow in rough seas off West Africa. Repaired.	1.7
Ocean Driller	Semi-submersible	ODECO	Gas blowout off Louisiana. Rig eased off location and abandoned. No fire or damage. BOP stack slammed closed but didn't stop gas from escaping and bubbling water 20 ft into air.	None
Wodeco II*	Barge	Fluor	Blowout and fire off Peru, 7 casualties. Not salvaged.	4.5
Panintoil II	Jackup	AMOCO-Iran (IPAC)	Damaged by storm on location in Persian Gulf. Salvaged.	2.8

Table B-1. Rig mishaps, 1954-1974 (continued).

Year, rig name	Type	Owner	Mishap	Cost of Damage (millions of dollars
1972				
Alta Mar II	Tender	Perforaciones Alta Mar	Sank during storm in Lake Maracaibo. Salvaged.	Less than 1.0 million
M. G. Hulme	Jackup	Reading & Bates	Blowout (no fire), cratering. Rig capsized in Java Sea. Not salvaged.	7.5
Rig 60	Jackup	Transworld Drilling	Blowout in Gulf of Martaban off Burma. Lost at sea. Not salvaged.	10.0
J. Storm II	Jackup	Marine Drilling Co.	Blowout in Gulf of Mexico. Not salvaged.	8.0
Intrepid	Jackup	Zapata Off-Shore	Leg failure in Eugene Island area of Gulf of Mexico. Salvaged.	3.5
Ocean Tide	Jackup	ODECO	Sustained high wind damage in U.K. sector of North Sea. Salvaged.	Unknown
Mr. Arthur	Submersible	Fluor Drilling Services	Major damage in Gulf of Mexico (South Pass, Block 26). Salvaged.	Unknown
1973				
Neptune 6	Tender	Forex-Neptune	Struck platform during storm in Persian Gulf and sank. Total loss.	1.0
Mariner I*	Semi-submersible	Santa Fe	Blowout off Trinidad, 1 casualty. Repaired and returned to service.	Unknown
Topper III	Jackup	Zapata Off-Shore	Damaged in Gulf of Mexico. Under repairs in Vicksburg, Miss.	Unknown
C. E. Thornton*	Jackup	Reading & Bates	Damaged while under tow from Persian Gulf to Red Sea. Total loss.	5.0
Rowan Anchorage	Jackup	Rowan Drilling Co.	Leg collopsed while jacking up in the Macassar Strait off E. Kalimantan. Salvaged.	3.0
1974				
Transocean III	Semi-submersible	Transocean Drilling	Capsized and sank in U.K. sector of North Sea during Storm. Crew evacuated. Not salvaged.	20.0
Transworld 61*	Semi-submersible	Transworld Drilling	Started cracking up in Danish North Sea during storm. Under repairs.	Unknown
Dresser VII*	Jackup	Dresser Offshore	Capsized while under tow in Gulf of Mexico, 1 casualty. Not known whether rig will be salvaged—it is lying on its side in 30 ft of water. Mishap under investigation.	Unknown

Table B-2. Recent offshore mishaps, 1974-1976.

October 1974, Scotland — Platform Sunk

Production platform DPI sank while under tow between Scotland and Norway. Two of the platform legs were broken. The platform sank in 350 feet of water 2 miles from its original site after 16 floatation tanks failed and ripped apart.

December 22, 1974, Gulf of Mexico off Louisiana — Damaged Wellhead

Workmen knocked off wellhead when repairing valve section damaged by hurricane. No casualties, but oil spill of more than 500 barrels was reported from a flow of 700 barrels of water and oil daily. Oil spill later reported as only 60 barrels when well was killed on January 6.

January 5, 1975, Galveston Bay — Blowout

Flow from a burning and leaking oil and gas well which started on June 19, 1974 (nearly 200 days) was finally killed. Wellhead was rebuilt and blowout preventers installed. Blowout did not lead to casualties, and observers reported that a minor oil spill was quickly dispersed (Oil and Gas Journal, Jan. 13, 1975).

January 24, 1975, Shetland — Crane Accident

Crane toppled from drilling platform Sedco 135G into 540 feet of water. Crane was off-loading a supply vessel when torn from its mountings. The crane driver was killed, and there was slight structural damage to the rig.

February 20, 1975, Loch Kishorn Scotland — Storm Damage

Drilling barge having new leg fitted at pier at Kyle of Lochalsh was damaged in severe storm. No casualties, but 120-foot steel column was sheared from the barge and lost.

March 21, 1975, North Sea — Barge Adrift

The barge Intermac 504, loaded with a 3300-ton steel platform jacket, broke free from the two tugs towing her and drifted close to the Leman gas field in Force 9 winds.

Table B-2. Recent offshore mishaps, 1974-1976 (continued).

March 19, 1975, Gulf of Mexico — Blowout

An exploration well in High Island Block A471 blewout through the conductor pipe in the early stage of drilling. Efforts to control the blowout were unsuccessful. The blowout resulted in a crater in the ocean floor which undermined the legs of the jackup drilling barge Topper III, causing it to capsize.

April 4, 1975, North Sea — Wellhead Damaged

Riser base equipment on a well in the Argyll field was damaged, probably by an anchor cable.

April 8, 1975, Isle of Skye, North Sea — Storm Damage

Drilling platform Bedford X broke from moorings in 100 mph gale and went onto the rocks. Platform seriously damaged but no casualties.

April 8, 1975, North Sea — Vessel Sank

The wooden motor oil-survey vessel Compass Rose 3 was lost in a storm when bound for the Beryl oil field. A search of the coast failed to locate the vessel, but the body of one crew member was recovered.

April 15, 1975, Trinidad — Storm Damage

Barge MM 151 sank in heavy seas while under tow. No casualties.

Aprill 22, 1975, Gulf of Mexico — Blowout

A natural gas blowout occurred at a well site in High Island Block 96. The semisubmersible platform Mariner II was drilling below 1, 250 feet in 50 feet of water when a shallow pocket of natural gas was struck. The crew began pumping mud into the hole to kill the well, but the gas broke out around the casing shoe and began bubbling to the surface. It continued to come up through the water in about a 200-yard diameter area. The platform lost the blowout preventer stack but was not damaged.

Table B-2. Recent offshore mishaps, 1974-1976 (continued).

June 1, 1975, Grand Isle Gulf of Mexico — Capsize

Drilling rig PMI No. 11 capsized and sank in 50 feet of water while under tow by tug. Rig raised by two derricks. Five men were trapped in the rig when it sank, and another man was killed.

June 11, 1975, Gulf of Mexico — Blowout

A development well being drilled from Amoco's Platform B in South Marsh Island Block 50, 52 miles offshore Louisiana, blew-out and caught fire. This second well to be drilled from the platform encountered high pressure natural gas during operations to change drilling mud. Gas began escaping from the blowout preventer stack. The well blew a mixture of gas, water and condensate. On June 13, the platform structure collapsed and a fire started. The 13-man crew was evacuated from the platform Seadrill No. 8 which was destroyed. Flow was killed after 40 days. A condensate sheen about 5 by 8 miles formed around the area and was recovered by skimmers (Oil and Gas Journal, June 23, 1975).

June 19, 1975, Dubai — Blowout

Production in the Fateh and southwest Fateh oil fields of Dubai was cut back when a wildcat well began blowing salt water and poisonous hydrogen sulphide gas. Gas was said to be escaping at a rate of 3.5 million cubic feet a day. Two rigs were involved when the blowout occurred. On July 27, government officials and Conoco's management maintained a local news blackout on the effects of the blowout. Temporary closure of the producing wells had cut output by 280,000 barrels per day (Reuter News Service).

On August 22, the self-elevating platform W. D. Kent began drilling a relief well about 3000 feet from the wildcat well, but operations were hampered by high winds. On September 14, a second attempt was made to kill the gas blowout. Drilling barge Wodeco 3 and drilling platform Rowan-Texas were brought in to drill directional wells. On February 23, 1976, Wodeco 3 broke loose from its moorings in high winds and collided with the platform W. D. Kent which sank in 170 feet of water. One man was killed and five injured. On February 27, 1976, the fire went out by itself after burning out of control since July. The cost of the fire, including damage and lost production, was estimated at between $60 million and $100 million.

Table B-2. Recent offshore mishaps, 1974-1976 (continued).

August 15, 1975, Galveston Bay — Collision

Motor tanker Globik Sun, carrying 350,000 barrels of crude, struck an oil platform. In the explosion, 7000 barrels of oil escaped from the tanker and resulted in a two-mile-long slick which caught fire. The tanker also caught fire. The tanker suffered extensive damage and was towed to Galveston. The platform caught fire, but burned itself out before major damage was done. Three men were reported killed. Chevron Oil Co. later filed a $5,000,000 damage suit against Exxon and Globik Tankers Ltd., claiming "the platform was damaged through unseaworthiness of Globik Sun and the negligence of those in charge of her."

November 1, 1975, North Sea — Explosion

Ekofisk Platform A was abandoned following an explosion. The explosion was later found to have been caused by a fracture resulting from corrosion to the 10-inch test pipe. Concrete casing on the outside of the pipe was reported to have been torn off some time before the explosion. A rescue capsule being lowered from the platform after the explosion crashed, killing three men and injuring three others. The reason for the crash is unknown (New York Herald Tribune, February 5, 1976).

Fire damaged the living quarters of the crew on the platform, and the explosion left the helicopter pad dented. At the time of the explosion, nine wells closed automatically. On November 5, the Norwegian State Oil Directorate ordered production work in all but three wells in the Ekofisk field to stop when corrosion had been found in test pipes.

December 8, 1975, North Sea — Storm Damage

A 480-foot steel tanker mooring buoy with a draft of 115 meters broke away from Beryl field in bad weather. Production was delayed several months while the buoy was recovered and relocated.

January 9, 1976, Bombay — Helicopter Crash

A helicopter crashed at the motor drilling platform Haakon Magnus, killing four men. It reportedly crash landed and caught fire on the helipad of the rig after its tail rotor struck part of the rig superstructure.

Table B-2. Recent offshore mishaps, 1974-1976 (continued).

March 1, 1976, North Sea — Storm Damage

The 19,000-ton platform North Sea Driller broke loose while being towed in heavy seas. Platform overturned and later ran aground 50 miles north of Bergen. Six men were killed and 17 slightly injured. The last North Sea rig which collapsed, Transocean III, sank on January 1, 1974, 100 miles northeast of the Orkney Islands.

March 2, 1976, North Sea — Fire

The Norwegian semisubmersible drilling platform Deep Sea Saga sustained a small blowout on the Valhall structure in the southern part of the Norwegian sector. The blowout resulted in a fire which was quickly extinguished. None of the crew was injured.

April 16, 1976, Gulf of Mexico — Capsize

A drilling rig leased by Marathon Oil capsized and sank while under tow 40 miles offshore. Naval divers later found 12 men dead in a fiberglass survival capsule. The capsule had flooded and overturned in heavy seas and was found in 120 feet of water. Twenty-two men survived the incident and of these 17 were saved by a similar capsule which later sank after being buffeted by 15-foot waves (New York Herald Tribune, April 17, 1975).

APPENDIX C

COMPARISON OF UK AND NORWEGIAN GUIDELINES AND RULES FOR OFFSHORE PLATFORMS

Reference is made to the UK Department of Energy (DOE, 1974) publication, Guidance on the Design and Construction of Offshore Installations, and to the Norwegian Det. Norske Veritas publications, Rules for the Design, Construction and Inspection of Fixed Offshore Structures 1974, (DNV, 1974), and Rules for the Construction and Classification of Mobile Offshore Units, 1975 (DNV, 1975). The guidance and the rules of these publications are intended as standards and do not have the legal force of regulations. However, they are technically more specific than regulations.

In making a comparison between these works, it must be remembered that the purpose of the guidelines is to provide safety of the offshore structures themselves. Thus, the guidelines are limited to reducing the hazards resulting from the use of certain materials, or from the configuration of the structures themselves. The guidelines do not intend to reduce the hazards resulting from operating procedures (including drilling, erection, transit, emplacement) or from drilling equipment placed on the structure.

In brief, the guidelines are primarily intended to prevent the recurrence of an event such as the Sea Gem disaster.

A comparison can best be made by considering:

1. Scope and Organization of Work
2. Environmental Aspects
3. Special Aspects

1. Scope and Organization of Work

DOE, 1974	DNV, 1974	DNV, 1975
Offshore Installations (79 pages)	Fixed Offshore Structures (79 pages)	Mobile Offshore Units (98 pages)
Contains eight main sections and one appendix as follows:	Contains seven main sections and four technical appendices as follows:	Contains eight main chapters and three technical appendices as follows:
Sec. 1. Explanatory Notes pp. 1-2 Sec. 2. Environmental Considerations, pp. 3-22 Sec. 3. Foundations, pp. 23-25 Sec. 4. Primary Structures, pp. 26-35 Sec. 5. Secondary Structures, pp. 48-52 Sec. 6. Materials, pp. 53-56 Sec. 7. Construction, pp. 57-59 Sec. 8. Equipment, pp. 60-71 App. Certification Procedures, pp. 72-79	Sec. 1. General Regulations, pp. 1-3 Sec. 2. Environmental Conditions, pp. 4-6 Sec. 3. Loads, pp. 7-9 Sec. 4. Steel Structures, pp. 10-22 Sec. 5. Concrete Structures, pp. 23-33 Sec. 6. Foundations, pp. 34-38 Sec. 7. Certification Surveys, pp. 39-40 App. 1. Environmental Conditions and Loads, pp. 41-44 App. 2. Steel Structure Analysis, pp. 45-75 App. 3. Testing Steel, pp. 76-77 App. 4. Foundations, pp. 78-79	Ch. 1. General Regulations, pp. 1-6 Ch. 2. Design Principles, pp. 7-26 Ch. 3. Special Design, pp. 27-32 Ch. 4. Stability and Integrity, pp. 33-38 Ch. 5. Machinery, pp. 39-43 Ch. 6. Electrical Installations, pp. 44-48 Ch. 7. Fire Protection, pp. 49-55 Ch. 8. Class Notation, pp. 56-64 App. 1. Environmental Conditions and Loads, pp. 65-70 App. 2. Stress Analysis, pp. 71-96 App. 3. Testing Steel, pp. 97
Applies to drilling vessels both mobile and fixed and production platforms. More general and discursive. Covers living accommodation standards.	Formulation of specific standards with formulas and specific applications.	More detailed and specific than both DOE, 1974 and DNV, 1974.

2. Environmental Aspects

Wind Speeds	Wind Speeds	Wind Speeds
Wind force corresponding to one-minute mean speed and three-second gust speed once in 50 years. Points out lack of suitable wind records.	Wind force corresponding to one-minute mean speed and three-second gust. Highest speed in period of N years when data available or suggested maximum of 50 meters per second sustained for North Sea.	Same as DNV, 1974.
Waves	**Waves**	**Waves**
Maximum wave height in 50 years.	Spectral and statistical treatment. 100-year wave height.	Spectral and statistical treatment. 100-year wave height or 30 meters (90 feet). Same as in DNV, 1974.
Currents	**Currents**	**Currents**
Nonspecific.	Specific variations of current velocity with depth. Maximum open sea current as 0.01 of wind velocity.	Same as DNV, 1974.