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EFFECT OF COASTAL PROCESSES ON THE DISTRIBUTION AND PERSISTENCE OF OIL SPILLED BY THE AMOCO-CADIZ
- PRELIMINARY CONCLUSIONS -

par

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R E S U M E

La partie de la Bretagne nord polluée par les hydrocarbures de l'AMOCO-CADIZ a un rivage très découpé qui est caractérisé par une dynamique côtière importante ayant favorisé une dispersion rapide des hydrocarbures. Entre le 19 mars et le 2 avril d'une part et du 20 au 28 avril 1978 d'autre part, il a été réalisé par air et le long du littoral l'étude de la zone touchée pour examiner la distribution et la longévité des hydrocarbures sur la côte. La pollution a d'abord été contrôlée par la géomorphologie régionale (promontoires rocheux, tombolos, baies crénelées, etc...) et ensuite par les vents. Nos résultats indiquent qu'environ 62.000 tonnes d'hydrocarbures avaient touché 123 km de rivage et de rochers au large lors de la première étude. Durant la deuxième partie (du 20 au 28 avril) les hydrocarbures avaient atteint 375 km de côte et îlots rocheux , ceci étant du à un changement dans la direction des vents ; par contre la quantité d'huile était de 9.200 tonnes, soit une réduction de 85% par rapport à la première estimation. Cette étude confirme un index de vulnérabilité développé antérieurement qui classe les côtes suivant une échelle de 1 à 10 en ce qui concerne la longévité potentielle des hydrocarbures après une pollution.

A B S T R A C T

The section of North Brittany contaminated by the "AMOCO-CADIZ" oil spill (17 March 1978) is a low-lying ria coastline dominated by dynamic processes favorable for the rapid dispersion of the oil. Aerial and ground surveys were made of the impacted area on 19 March - 2 April and 20 - 28 April 1978, to detail the distribution and persistence of oil along the shoreline. Oil deposition on the shoreline was primarily controlled by local geomorphology (e.g. rocky headlands, tombolos, crenulate bays, etc..) and wind-driven currents. Our results indicate that approximately 62.000 tons of oil was spread along 123 km of coastline and offshore rocks at the time of our first study. During the second study period, oil was distributed along 375 km of shoreline and offshore rocks due to a shift in wind direction. However, the calculated quantity of oil was reduced by 85% to 9,200 tons. This study supports a previously developed oil spill vulnerability index which classifies shorelines on a scale of 1-10 as to the potential longevity of oil after an oil spill.

M O T S - C L E S : Pollution Hydrocarbures, Géomorphologie côtière, Processus côtiers

K E Y W O R D S : Oil spill, coastal geomorphology, Coastal processes.

INTRODUCTION

This paper presents a summary of our results concerning the influence of beach processes and sedimentation on the dispersal, grounding, burial and long-term fate of the Amoco Cadiz oil. These observations should provide valuable insights for coastal zone managers concerned with contingency planning for oil spills. This is true especially with regard to understanding the vulnerability of different coastal environments to oil spill impacts, as well as to planning for the availability of equipment and manpower needed for shore protection and clean-up in the event of a major spill.

Study of the spill site was carried out during two field sessions, one starting three days after the spill (19 March - 2 April) and the other beginning a month after (20 - 28 April). Field work consisted of a series of overflights and intensive ground inspection and surveys of the entire affected area. In total, 19 permanent beach survey stations and 147 beach observation stations were set up during the two study periods (Fig. 1). Extensive photography was carried out with approximately 4200 photographs being taken. A more detailed report of our activities is currently being prepared for publication by the National Oceanic and Atmospheric Administration, Environmental Research Laboratories, Boulder, Colorado.

GEOLOGICAL SETTING

The geology of the Brittany peninsula is dominated by a suite of ancient igneous and metamorphic rocks that have been subject to a complex deformational history. The principal rock types along the oil spill site are granites, migmatites[3], and metamorphic rocks. In as much as the last major tectonism took place 200 million years B.P., the area is tectonically stable at the present time. However, the resistant nature of the rocks to erosion and adjustments

[3] A composite rock, made up of igneous and metamorphic materials mixed together as a result of intensive igneous and metamorphic action.

of land-sea levels over the past few thousand years have created a rugged coastline composed of numerous inshore islands and erosional cliffs separated by minor pocket beaches and ria[4] systems. Everywhere, the primary shoreline trends are controlled by bedrock geology, with local trends being controlled by weathering and erosion along structural elements, such as faults and joints.

COASTAL PROCESSES

This section is a brief discussion of those physical processes related directly to beach dynamics and oil grounding. Our field observations indicate that the spill site is one of intense dynamic coastal processes. These conditions of high wave and tidal energy are generally conducive to rapid natural dispersion of the oil in exposed environments. However, the intricate topography of the shoreline allows for the sheltering of some environments from the waves and currents.

Winds and Waves

Wind patterns played a major role in the dispersal of the Amoco Cadiz oil along the shoreline. The wind pattern during the weeks following the spill was as follows:

a. 17 March: to the south at 15-35 Km/hr.

b. 18-28 March: westerly at over 20 km/hr.

c. 29 March - 2 April: northeasterly at 10-20 km/hr.

d. 2-10 April: southwesterly at 10-40 km/hr.

Wind blew consistently from the west between 18 March and 2 April, the time during which all the oil was lost from the tanker. Winds commonly blew over 20 km/hr throughout this period. This consistent, strong westerly wind accounts for the uniform west-to-east dispersal of oil immediately after the

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[4] Drowned river valley.

grounding. The wind changed on 2 April and blew consistently from the northeast until 10 April. Presumably, it was these and later northeast winds, aided by tidal currents, that dispersed the oil to the west and south during early April. Wind measurements that we made in the field between 22 and 26 April showed variable results, but easterly winds predominated.

Large waves were observed at high tide throughout the first field study period (19 March to 3 April). Estimates of significant wave heights were consistently on the order of 1-1.5 m, with heights of 2 m being common during the first few days of the spill. On the other hand, waves observed during the second field visit in late April were quite small, rarely exceeding 15 cm (at low tide). Unfortunately, no precise wave measurements (i.e., wave gauge recordings) were made during the spill to our knowledge.

Tides and Currents

The tidal range of the oil-affected area varies from 6 m at Brest to 9 m at Sillon de Talbert. The mean tidal range at Morlaix, which is centrally located in the spill site, is on the order of 7-8 m. These large tides generate strong tidal current throughout the spill site. We measured (with floats) tidal currents of 1.4 m/sec in the channel north of Roscoff. From the air, streaming lineations of mousse and other floating debris around stationary objects (e.g., rocks and buoys) gave evidence of the strong tidal currents. An exceptional spring tide, caused by a combination of spring tides and wind set-up associated with an intense low pressure system, occurred on the weekend of 25-26 March. This high tide greatly enhanced the pollution potential of the spill, in that areas not normally reached by the sea were exposed to the oil.

COASTAL MORPHOLOGY

The portion of the Brittany coast impacted by the *Amoco Cadiz* oil is an irregular, low-lying ria[5] coastline, which is composed mainly of small drowned river valleys and protruding rocky headlands. The Brittany coast is one of the most widely recognized ria coasts in the world, as a result of the writings of de Martonne (1903; 1906) and Guilcher (1948; 1958). Guilcher's (1958) text on coastal morphology is liberally endowed with references to and illustrations of the Brittany coast. A more recent publication by Chasse (1972) describes the morphology and sediments of selected segments of the spill site in great detail.

Depositional beaches are rare on the Brittany coast. Where present, they consist of sheltered pocket beaches, crenulate bays[6], and tombolos[7]. In some embayments, broad tidal flats (mostly fine-sand) are exposed at low tide. Salt marshes are small compared to most coastlines with tidal ranges of this magnitude. Occasional dune areas are located near the mouths of the small streams.

The dominant aspect of the area is one of shoreline erosion, with bedrock composition and structure controlling shoreline orientations. Rock scarps flank the seaward portions of all the islands and headlands. Beach sediments are generally thin and overlie eroded marsh clays and other eroded material. From Portsall east, all morphological indicators (spit orientation, crenulate bays, etc.) show a dominant longshore transport direction

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5 "Rias may be defined as river systems partly or wholly flooded by the sea. The degree of drowning depends on the magnitude of the movement of base-level and on the altitude of the source of the rivers. The subaerial origin of rias is demonstrated by the occasional existence of incised meanders as on the Aulne at Landevennec in the Rade de Brest." (Guilcher, 1958, p. 153).

6 A crenulate bay is an asymmetrical semicircular bay carved by refracting waves that has a shape resembling a fish hook. Sediment is normally transported up the shank of the hook away from the barb.

7 A tombolo is a sand or gravel spit which connects an offshore island to the mainland or to another island. "In the Molene archipelago in Finistere, certain islets are connected twice a day (at low tide) to the larger islands and are called in Breton 'ledenez' ('extension of the island')." (Guilcher, 1958, p. 90).

from west to east, which agrees with the direction of transport of the oil during the first two weeks after the spill. The shoreline in the region of Brest and Baie de Douarnenez, however, is more complex, showing no general trend of sediment transport direction.

COASTAL SEDIMENTS

Beach and intertidal sediments of the spill site show a wide range of size, sorting, and composition. Gravels are present along retreating headlands, along arcuate beaches, and as a high-tide rim around intertidal sand flats. Sands occur as coarse-sand beaches within exposed pockets, and as flat, fine-sand beaches in sheltered areas and in front of coastal dunes. Muddy sediments are rare, except in a few sheltered *rias* and marshes, presumably because of the high wave and current conditions that prevail. Grain size data from the 19 stations studied in detail are presented in Table 1.

METHODS OF STUDY

The study of a major oil spill requires techniques, amenable to rapid implementation, that provide for maximum information gained with the least amount of field time expended. Large geographic areas have to be classified and sampled rapidly. In order to achieve this goal, we applied a modified version of the *zonal method* to the *Amoco Cadiz* oil spill site. The *zonal method*, which was developed by Hayes and associates (first described by Hayes *et al.*, 1973), has been applied in several areas of the world, including the southeast coast of Alaska (Hayes *et al.*, 1976) and during studies of the *Metula*, *Urquiola*, and *Jakob Maersk* oil spills (Gundlach and Hayes, in press). A modified form of the *zonal method* has been used to determine the vulnerability of coastal environments to oil spills in several parts of Alaska under the sponsorship of NOAA's OCSEAP program.

The <u>zonal method</u> consists of extensive use of aerial surveys verified by a series of ground stations. During the study, six flights were taken for purposes of visual inspection of oil distribution along the shoreline, observation of oil transport and dispersal processes, and for interpreting shoreline morphology and sedimentation patterns.

For verification of the oil distribution seen from the air, a total of 166 beach stations were visited during the two survey periods. Stations of two types were established, F stations and AMC stations (see location of stations on Figs. 1A and 1B). At the 147 F stations, the site was visually inspected, photographs taken, and observations were recorded on tape. Work at the 19 AMC stations included the following:

a. Measurement of a topographic profile of the beach (at low tide). The profile is measured by the horizon-leveling technique of Emery (1961). As the profile is measured, notations are made concerning all relevant changes of the beach, including the nature and occurrence of the oil. Permanent stakes were established to mark the location of the profile. Six of the profiles were resurveyed twice during the first visit and one was resurveyed three times. All of these stations will be revisited to repeat the surveys during each succeeding visit to the site.

b. Three equally-spaced sediment samples were collected. These were taken for the purpose of characterizing the beach with respect to its oil-sediment interactions (e.g., oil penetration and burial). These samples have been analyzed for textural characteristics (mean grain size, sorting, etc.) in the laboratory (see Table 1). A total of 53 sediment samples were collected on the first trip.

c. Trenches were dug to determine the distribution of buried oil. Each trench was sketched and photographed in detail.

TABLE 1. Grain size data for all AMC stations. All values are calculated according to Folk (1968). Stations locations are presented in Figure 1A and 1B.

Sample	Graphic Mean	Size Class[1]	Skewness	Standard Deviation[2]
AMC-1A	0.691	CS	0.101	1.594 (PS)
AMC-1B	0.952	CS	0.197	1.413 (PS)
AMC-1C	1.954	MS	-0.134	1.350 (PS)
AMC-2A	-4.0	P		(PS)
AMC-2B	1.492	MS	-0.093	1.119 (PS)
AMC-2C		no sample		
AMC-3A	-7.0	C		(PS)
AMC-3B	2.415	FS	-0.571	1.243 (PS)
AMC-3C	0.123	CS	-0.042	1.316 (PS)
AMC-4A	0.503	CS	-0.263	1.024 (PS)
AMC-4B	0.847	CS	-0.003	0.561 (MWS)
AMC-4C	2.082	FS	-0.383	0.978 (MS)
AMC-5A	1.047	MS	-0.001	0.759 (MS)
AMC-5B	2.415	FS	-0.207	0.593 (MWS)
AMC-5C	2.026	FS	-0.134	0.757 (MS)
AMC-6A	0.306	CS	-0.129	1.601 (PS)
AMC-6B	1.007	MS	-0.813	2.670 (VPS)
AMC-6C	2.597	FS	-0.678	1.275 (PS)
AMC-7A	1.887	MS	-0.291	0.733 (MS)
AMC-7B	1.538	MS	-0.393	1.339 (PS)
AMC-7C	2.495	FS	-0.161	0.901 (MS)
AMC-8A		no sample		
AMC-8B	2.536	FS	-0.545	1.103 (PS)
AMC-8C	2.158	FS	-0.235	0.728 (MS)
AMC-9A	1.959	MS	0.010	0.434 (WS)
AMC-9B	2.112	FS	-0.049	0.459 (WS)
AMC-9C	2.197	FS	-0.011	0.486 (WS)
AMC-10A	2.955	FS	-0.095	0.358 (WS)
AMC-10B	3.005	VFS	-0.093	0.389 (WS)
AMC-10C	3.017	VFS	-0.123	0.419 (WS)

TABLE 1. Grain size data (cont.)

Sample	Graphic Mean	Size Class[1]	Skewness	Standard Deviation[2]
AMC-11A	1.947	MS	-0.116	0.536 (MWS)
AMC-11B	2.124	FS	-0.059	0.639 (MWS)
AMC-11C	1.798	MS	-0.117	0.690 (MWS)
AMC-12A	0.533	CS	0.168	0.531 (MWS)
AMC-12B	0.106	CS	0.201	1.993 (PS)
AMC-12C	1.306	MS	-0.125	0.689 (MWS)
AMC-13A	1.824	MS	0.116	0.640 (MWS)
AMC-13B	2.400	FS	-0.409	0.948 (MS)
AMC-13C	2.348	FS	-0.367	1.016 (PS)
AMC-14	1.468	MS	-0.245	1.210 (PS)
AMC-15A	3.136	VFS	-0.057	0.461 (WS
AMC-15B	0.926	CS	-0.633	2.819 (VPS)
AMC-15C	3.277	VFS	-0.052	0.363 (WS)
AMC-16A	-4.693	P	0.149	0.330 (VWS)
AMC-17A	-0.174	VCS	-0.238	2.236 (VPS)
AMC-17B	1.461	CS	-0.266	0.713 (MS)
AMC-17C	-0.577	VCS	-0.498	2.000 (VPS)
AMC-18A	4.613	CS	-0.295	1.863 (VPS)
AMC-18B	2.100	FS	-0.134	0.934 (MS)
AMC-18C		no sample		
AMC-19A	3.220	VFS	-0.217	0.393 (WS)
AMC-19B	3.319	VFS	-0.124	0.353 (WS)
AMC-19C	3.310	VFS	-0.141	0.336 (VWS)

[1] Size Class

C = cobbles
P = pebbles
VCS = very coarse-sand
CS = coarse-sand
MS = medium-sand
FS = fine-sand
VFS = very fine-sand

[2] Sorting

VWS = very well sorted
MWS = moderately well sorted
WS = well sorted
MS = moderately sorted
PS = poorly sorted

d. A sketch was drawn in order to show the general coastal geomorphology and the surficial oil distribution.

e. A number of photographs were taken of all aspects of the beach.

The Institute de Geographie Nationale (IGN), the Centre National pour l'Exploration des Oceans (C.N.E.X.O.), and the Institute Francais du Petrole (IFP) carried out a series of flights to study the distribution of oil on the water and along the coast. A total of 9 surveys have been completed, during which vertical aerial photographs were taken (2000 infrared black and white, 1800 black and white, and 400 color). These photographs, which are extremely useful, are still under study.

PRELIMINARY CONCLUSIONS

When our second site visit ended on 28 April, significant quantities of oil remained in the water and on the shoreline of the Amoco Cadiz oil spill site. It may take several years, or at least several months, for the remaining oil to be fully degraded. Therefore, any conclusions drawn at this early date will have to be considered preliminary. However, the complexity of the coastal system, plus the unusually large quantity of oil, provided a hitherto unequaled opportunity to learn about the behavior of spilled oil in the coastal zone.

Oil Dispersal Processes

The spill of the Amoco Cadiz provided a classic field experiment for the demonstration of the effects of dynamic coastal processes and coastal morphology on oil deposition along the coast. Strong, almost unidirectional winds from the west rapidly forced the oil eastward during the period from 18-28 March. The rugged and indented topography of the coast then played a major role in determining where the oil would be deposited. The shorelines facing westward were hardest hit, whereas those facing eastward, particularly those with the larger embayments, were mostly unaffected. This process is depicted diagramatically in Figure 2.

During early April, the dispersal pattern of the oil changed. Major oil accumulations were broken up and dispersed. Due to the wind shift at the beginning of April, the oil was spread far into many of the large embayments, thereby oiling previously clean areas. However, instead of single large oil masses, only thin bands of small mousse balls or oiled algae were deposited along the swash lines.

Effects of Wave Action

During our earlier studies of the Metula and Urquiola oil spills, we observed that the degree to which an area is exposed to wave action greatly influences the longevity, or persistence, of oil within that area. Similar observations were made at the Amoco Cadiz site. Rocks, heavily oiled south of Portsall, were clean a short time later due to high wave energy at that locale. Many of the exposed environments along each northward-jutting peninsula were generally free of oil within a month. Conversely, as wave energy decreases, oil persistence increases. Very little change in oil coverage was noted inside the harbor at Portsall, at Castel Meur (F-60), and at Primel-Tregastel (F-94). The marsh environment at Ile Grande illustrates an area with very low exposure to waves and, consequently, one with the longest potential duration of effects.

Beaches versus Sheltered Rocky Areas

In general, the sand beaches responded to natural cleansing much faster than sheltered rocky areas. Beaches undergo natural erosion and depositional cycles in which large amounts of sediment are continuously reworked by waves. This action removes much of the oil within a relatively short period of time. In contrast, sheltered rocky areas and coarse-cobble beaches undergo change only during great storms. Also, oil seeping between rocks or into crevasses will be removed from direct wave. Thus, under similar conditions of wave exposure, a sand beach is much more likely to be cleaned by natural processes than a rocky area.

Localized Geomorphic Controls of Oil Deposition

Within the areas receiving the oil, specific morphological features influenced the oil distribution pattern. Included among these features are: (1) crenulate bays, (2) tombolos, (3) low-tide terrace, ridge- and runnel-systems, (4) scour pits around boulders, and (5) regional bedding and joint patterns in the bedrock.

The catchment of oil by crenulate bays is illustrated in Figure 3. Where they occur on west-facing shorelines, as at stations F-39, -62, -68, and AMC-9 and -17, crenulate bays tend to trap oil at the head of the bay (northeast end), where the shoreline has its maximum curvature. The tail or southwest portion was usually free of oil during the first days of the spill (when the winds were westerly).

Another morphological feature, the tombolo, also had a marked influence on the initial deposition of oil. As illustrated at stations AMC-5 and F-20, oil became trapped behind rocks or a small island due to the convergence of wave fronts around the offshore rocks. This process is illustrated in Figure 4.

Other small-scale features that tended to cause localized oil deposition included scour pits around boulders and jointing and bedding patterns in bedrock, both of which were observed at station AMC-13. An oil pond 5 cm deep was observed in a runnel on the low-tide terrace at station AMC-12.

Oil Response to Beach Cycles

Beaches undergo a cycle of erosion and deposition in response to changing wave conditions. By making repeated measurements of our permanent beach profiles, we were able to observe the effect of the beach cycle on erosion and retention of the oil. The recovery of the beaches (by berm formation) after the initial period of high wave energy (during the early days of the spill) commonly caused deep burial of oil layers in the beach face (see Fig. 5). Therefore, a basic understanding of the beach cycle provides a good foundation for interpreting the behavior of oil on beaches.

The Vulnerability Index

Based on studies of other spills, we have developed a system of classifying coastal environments with respect to oil spill impacts called the vulnerability index (Hayes, Brown and Michel, 1976; Gundlach and Hayes, in press). The index is based mostly on predicted longevity of oil within each environment, but it has some biological criteria. Data derived from the study of this spill supports some of our initial conclusions and allows for further refinement of others.

Table 2 presents a summary of the oil spill vulnerability index with particular reference to the _Amoco Cadiz_ oil spill. The order listed (1-10) is toward increasing vulnerability to oil spill damage. The higher the index value, the greater the long-term damage.

Oil Response to Tide-Level Changes

One of the questions raised by our previous oil spill studies (mainly the _Metula_ and _Urquiola_ spills) is whether or not the oil lifts off the bottom with every flood tide (or does it become sediment-logged and remain on the bottom?). At Portsall (AMC-1) and Les Dunes-East (AMC-5), we monitored oil reaction during a flooding tide. At AMC-5, we also watched oil reaction during the ebb cycle. During the initial oiling, the first week after the grounding, oil definitely lifted off with the incoming tide and was redeposited on the ebb. However, during the second study period of late April, a large patch of sediment-bound oil was found on the tidal flat at Portsall. Some oil had mixed with the sediment and sunk (see Fig. 6).

TABLE 2. The Oil Spill Vulnerability Index with particular reference to the Amoco Cadiz oil spill. Higher index values indicate greater long-term damage by the spill. (For further information, consult Hayes, Brown, and Michel (1976) or Gundlach and Hayes, in press).

Vulnerability Index	Shoreline Type; Example	Comments
1	Exposed rocky headlands; Douarnenez to Pte. du Raz and Primel-Tregastel to Locquirec	Wave reflection kept most of the oil offshore; no clean-up was needed.
2	Eroding wave-cut platforms; south of Portsall and F-1 to F-82	Exposed to high wave energy; initial oiling was removed within 10 days.
3	Fine-grained sand beaches; stations south of Roscoff (AMC-9 and -10) and east of Portsall (AMC-5)	All only lightly oil-covered after one month, mainly by new oil swashes.
4	Coarse-grained sand beaches; AMC stations 4 (near Portsall) and 12 (St. Cava) and F-38	Oil coverage and burial after one month remains at moderate levels.
5	Exposed, compacted tidal flats; La Greve de St. Michel	No oil remained on the sand flat but did cause the enormous mortality of urchins and bivalves.
6	Mixed sand and gravel beaches; no really good example of this beach type	The index value is due to rapid oil burial and penetration; all areas had compacted subsurface which inhibited both actions.
7	Gravel beaches; stations F-80, -95, and -129, also AMC-16	Oil penetrated deeply (30 cm) into the sediment; clean-up by use of tractors to push gravel into surf zone seemed effective and not damaging to the beach.
8	Sheltered rocky coasts; common throughout the study area.	Thick pools of oil accumulated in these areas of reduced wave action; clean-up by hand and high pressure hoses removed some of the oil (this process is valid in non-biologically active areas.
9	Sheltered tidal flats; behind Ile Grande and at Castel Meur	Tidal flats were heavily oiled; clean-up activities removed major oil accumulations but left remaining oil deeply churned into the sediment; biological recovery has yet to be determined.
10	Salt marshes; Ile Grande marsh	Extremely heavily oiled with up to 15 cm of pooled oil on the marsh surface; clean-up activities removed the thick oil accumulations but also trampled much of the area; biological recovery has yet to be determined.

Therefore, as has been hypothesized by others, a possibly significant percentage of the oil spilled by the Amoco Cadiz may have actually sunk to the bottom.

Oil Contamination of Interstitial Ground Water

After visiting a number of oiled areas, it became obvious to us that the problem of oil contamination of the ground water within the beach may be a cause of death to organisms living within the sediment. In many sites, even though the surface of the beach or tidal flat appeared completely clean, the interstitial ground water was severely oiled. Localities such as Portsall (AMC-1), Roscoff (AMC-6), and St. Michel-en-Greve (F-55) provide typical examples.

Oil may enter the ground water directly from the ocean water itself or through solution along the upper part of the beach. Contaminated ground water has an obvious sheen and often has visible droplets of mousse. If the concentration of oil in the ground water reaches lethal proportions, then death of infauna (cockles, heart urchins, razor clams and worms) may result, even though the surface of the area is not visibly oiled.

A question that remains to be answered concerns the longevity of this type of oil contamination. Is the ground water periodically flushed clean, or will it remain contaminated for months or even years?

Quantity of Oil Along the Shoreline

In a basic attempt to determine the total amount of oil along the coastline during each study period, the total amount of oiled coastline was multiplied by the quantity of oil per km of coastline and offshore rocks as determined from the individual study sites (Table 3). For this calculation, the marsh at Ile Grande was excluded because it represents a single environment that had extremely heavy oil accumulations. General weaknesses of the overall method are:

1. Our study areas were generally limited to beaches, thus extrapola-

Table 3. Oil quantity per length of beach for 17 AMC-stations during study period one (19 March - 2 April) and study period two (20 - 28 April).

AMC-STATION	LENGTH OF BEACH (KM)	OIL CONTENT (metric tons)		
		SESSION ONE	SESSION TWO	
			Light Coverage	Heavy Coverage
1	0.50	50.2		7.3
2	0.25	1.8		2.4
3	0.25	44.6		5.5
4	0.20	284.1		2.5
5	1.25	1146.9	2.5	
6	0.20	51.8	1.0	
7	0.20	102.5	1.7	
8	0.20	9.6	0.4	
9	2.00	1039.4	10.6	
10	1.25	46.3	6.0	
11	0.45	175.2		1.0
12	0.40	357.7		6.3
13	0.55	248.3	0.6	
15	0.30	83.3		3.9
16	0.40	81.2		66.3
17	0.30	136.4	1.6	
18*	4.00	7400.0		2760.0
SUB TOTAL	8.7	3859.1	24.4/5.9 km	95.2/2.75 km
TOTAL (metric tons/km)		443.6	4.1	34.6

*Not included in this calculation because the Ile Grande Marsh represents an anomalously large concentration of oil within one particular environment.

tions to rocky areas may not be valid.

2. We may be counting the same oil twice. For example, most of the oil within our Roscoff stations was removed by erosion on the night of 24 March. This could be the same oil that we encountered in the Ile Grande area on 29 March.

Our results are summarized in Tables 4 and 5. The total amount of oil along the coastline (72 km oiled) and offshore rocks (51 km) was 62,000 metric tons. During the second study period, the estimated quantity of oil was reduced to 9,200 metric tons, a difference of 85%. However, it was now distributed along 375 km of coast and 55 km of offshore rocks.

These estimates vary slightly from calculations (64,000 and 11,000 metric tons, respectively) done originally for NOAA (Gundlach and Hayes, Chapter 4, in press). For this report, we had access to detailed vertical aerial photographs, while before we did not. However, differences between the two methods are quite small.

In conclusion, approximately one-third of the oil spilled from the *Amoco Cadiz* (estimated at 62,000 metric tons) went aground on at least 72 km of shoreline and 51 km of offshore rocks during the first two weeks of the spill. During the following three weeks, the quantity of oil along the shoreline was reduce by 85% (to approximately 9,200 metric tons). This reduction was due to natural dispersion and to clean-up activities by man. On the other hand, the amount of shoreline visibly contaminated by the oil increased to 375 km of shoreline and 55 km of offshore rocks by late April. This increase was due to the breakdown and dispersion of the large oil masses by wave and currents and to a major shift in wind direction (from westerlies to easterlies.

Table 4. Extent of oil coverage during study periods one and two. Oil is only described as heavy during study one (19 March - 2 April). During study two (20-28 April), it is described as light or moderate to heavy.

Section of Coast	Study Period 1		Study Period 2			Total km of Coastline
	km coastline oiled	km offshore rocks oiled	km lightly oiled	km heavily oiled	km heavily oiled offshore rocks	(excl. offshore)
I	0	0	52	39	4	280
II	11	4	5	8	4	24
III	16	9	15	8	9	43
IV	4	9	30	0	9	38
V	4	3	43	0	3	43
VI	8	3	10	4	3	27
VII	4	4	24	9	4	76
VIII	9	4	10	20	4	35
IX	5	3	4	4	3	16
X	2	4	12	6	4	35
XI	9	8	8	9	8	36
Subtotal	72	51	213	107	55	653
Total km oiled		123			375	

Table 5. Summary of data concerning shoreline coverage by oil and estimated total quantities for study sessions one and two.

	Session one (19 Mar - 2 Apr)	Session two (20 - 28 Apr)
km shoreline heavily oiled	72	107
km offshore rocks heavily oiled	51	55
km shoreline lightly oiled	–	213
total km oiled	123	375
quantity of oil (metric tons)		
subtotal (excluding Ile Grande)	54,600	6,440
total at Ile Grande	7,400	2,760
total	62,000	9,200

Total reduction between sessions = 85%

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FIGURE CAPTIONS

(D'Ozouville, Gundlach and Hayes)

1. A. Location of observation stations within western portion of the spill-affected area. Oil distribution for study periods one (19 March - 2 April) and two (20 - 28 April) are indicated.

   B. Observation stations within eastern portion of the spill-affected area. Oil distribution is indicated.

2. A. Oil pushed by strong westerly winds during the first two weeks was mainly deposited along westerly-facing headland areas. Interior embayments generally remained free of oil.

   B. A wind shift during the beginning of April spread a light layer of oil deep into the embayments. Previously deposited oil along the exposed headlands was greatly reduced in quantity.

3. Entrapment of oil by crenulate bays. Generally, the southerly section of each bay remained free of oil.

4. Illustration of the tombolo effect causing localized oil deposition behind offshore rocks.

5. Comparaison of beach profiles for site AMC-4 on (A) 23 March and 31 March, and (B) 31 March and 22 April. The erosion along the upper beachface was caused by storm waves, the applied clean-up operation, or a combination of both. The deposition of new sand on the beach by 22 April caused deep (25 cm) oil burial.

6. Observation of oil response at Portsall. During the first week after the grounding, most of the oil repeatedly lifted off the surface of the sand flat with each incoming tide. During our second survey of late April, we found mousse, mixed with the sediment, remaining on the sand flat and beachface even as the tide flooded. Only a light oil sheen was visible on the surface of the water at this time.

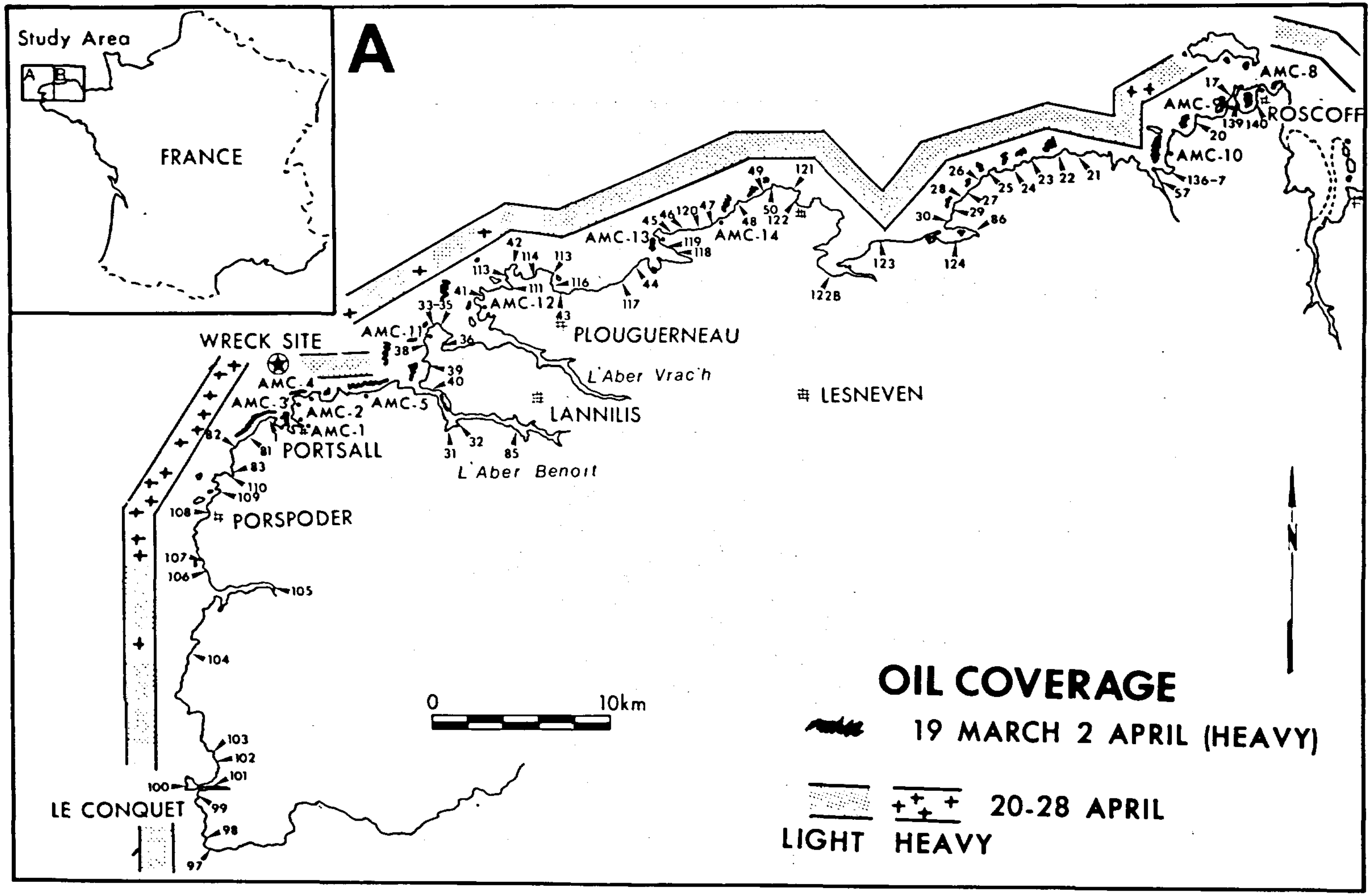
Study Area
A
B
FRANCE
A
WRECK SITE
AMC-4
AMC-3
AMC-2
AMC-1
AMC-5
AMC-11
AMC-12
AMC-13
AMC-14
AMC-8
AMC-9
AMC-10
PORTSALL
PORSPODER
LE CONQUET
PLOUGUERNEAU
L'Aber Vrac'h
LANNILIS
L'Aber Benoit
LESNEVEN
ROSCOFF
N
0
10km
OIL COVERAGE
19 MARCH 2 APRIL (HEAVY)
20-28 APRIL
LIGHT
HEAVY

FIGURE 1A.

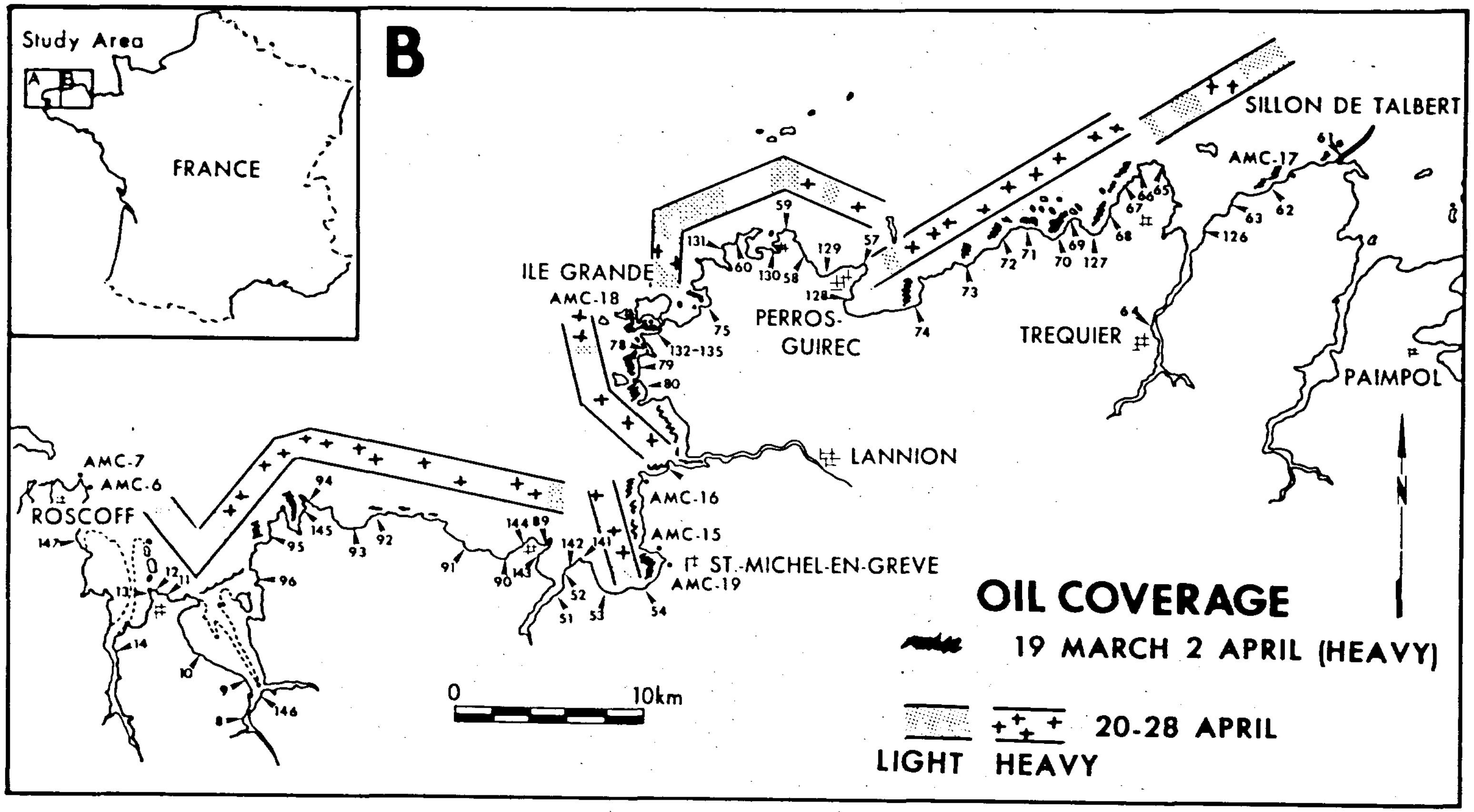
Study Area
A
B
FRANCE
B
SILLON DE TALBERT
AMC-17
ILE GRANDE
AMC-18
PERROS-
GUIREC
TREQUIER
PAIMPOL
LANNION
AMC-7
AMC-6
ROSCOFF
AMC-16
AMC-15
ST.-MICHEL-EN-GREVE
AMC-19
132-135
0
10km
OIL COVERAGE
19 MARCH 2 APRIL (HEAVY)
20-28 APRIL
LIGHT
HEAVY
N

FIGURE 1B.

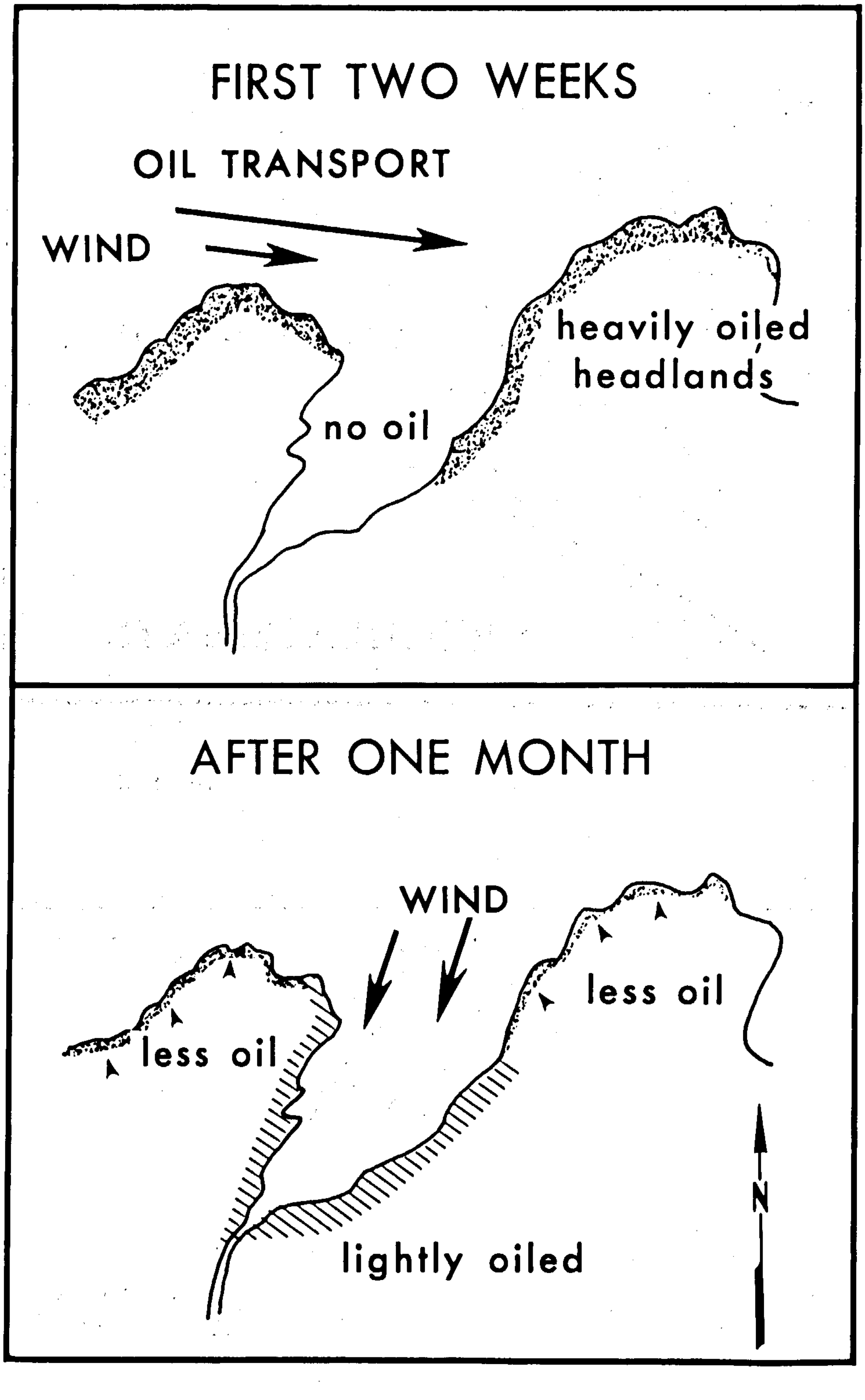
FIRST TWO WEEKS
OIL TRANSPORT
WIND
heavily oiled
headlands
no oil
AFTER ONE MONTH
WIND
less oil
less oil
lightly oiled
N

FIGURE 2.

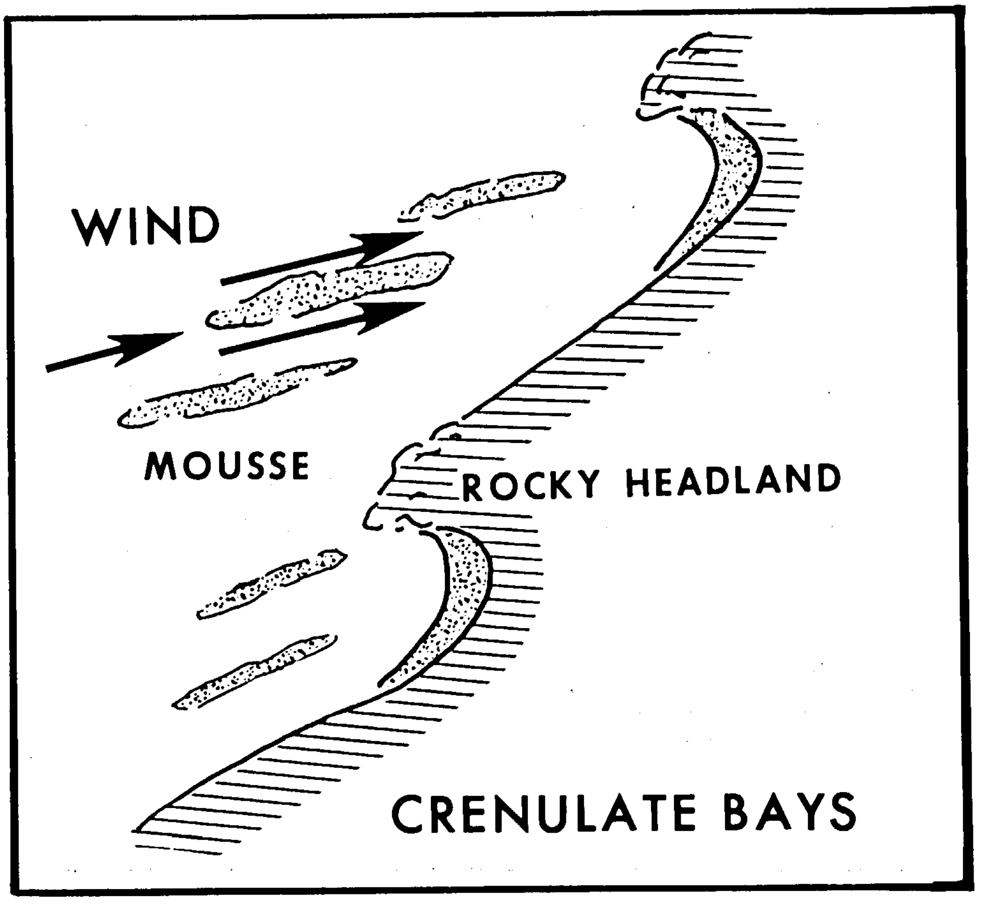

FIGURE 3.

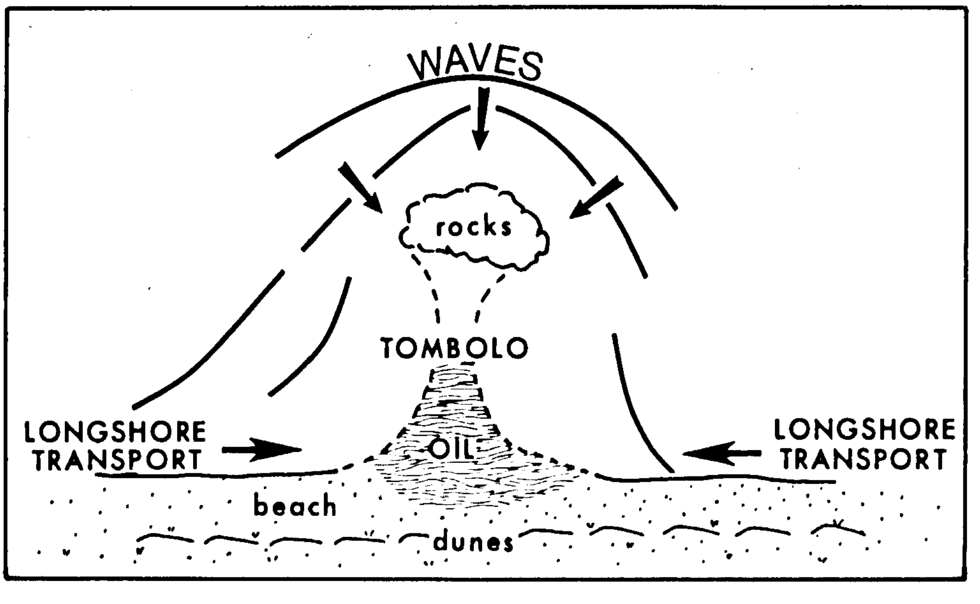

FIGURE 4.

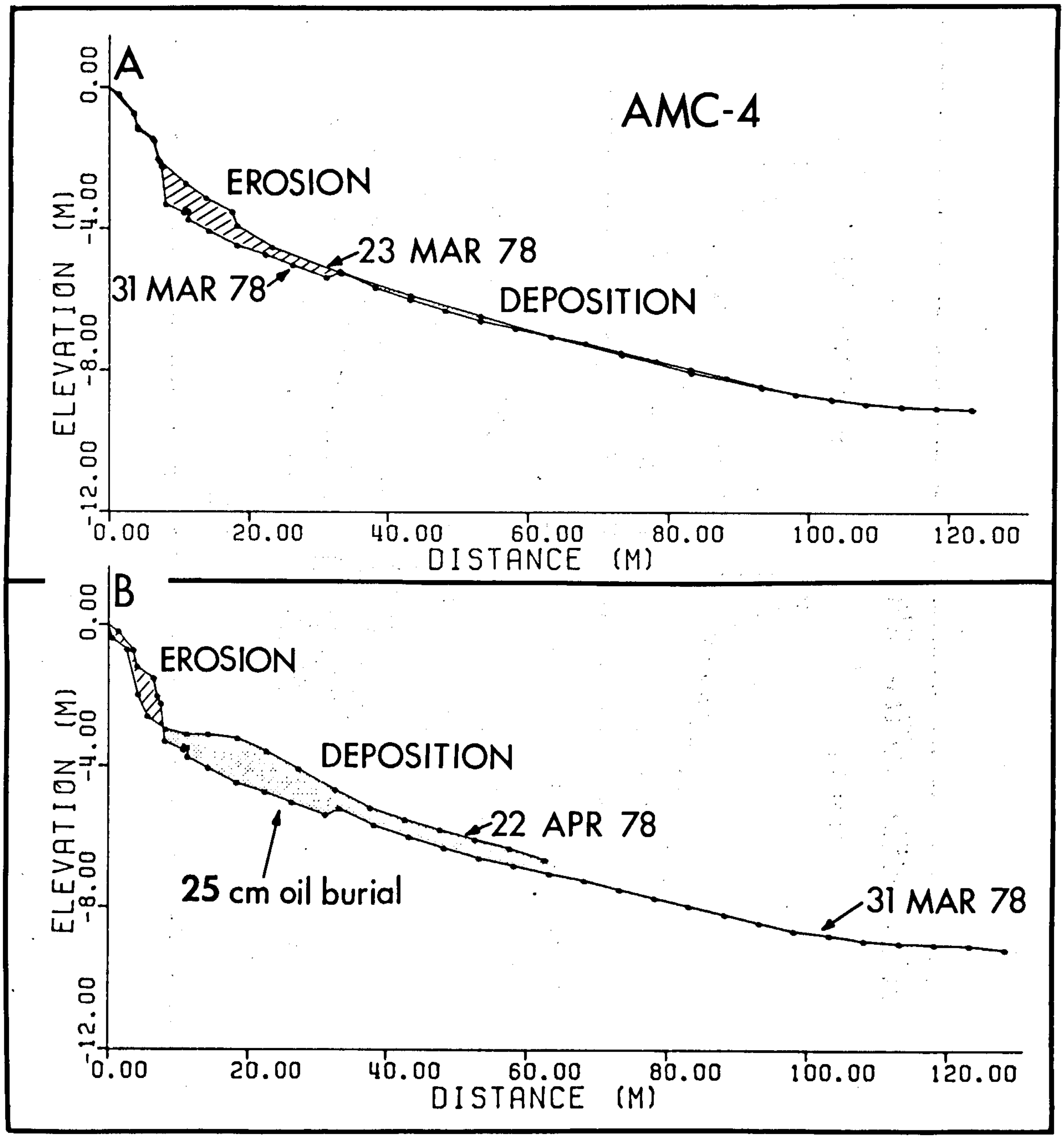
A
AMC-4
EROSION
23 MAR 78
31 MAR 78
DEPOSITION
ELEVATION (M)
0.00
-4.00
-8.00
-12.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
DISTANCE (M)
B
EROSION
DEPOSITION
22 APR 78
25 cm oil burial
31 MAR 78

FIGURE 5.

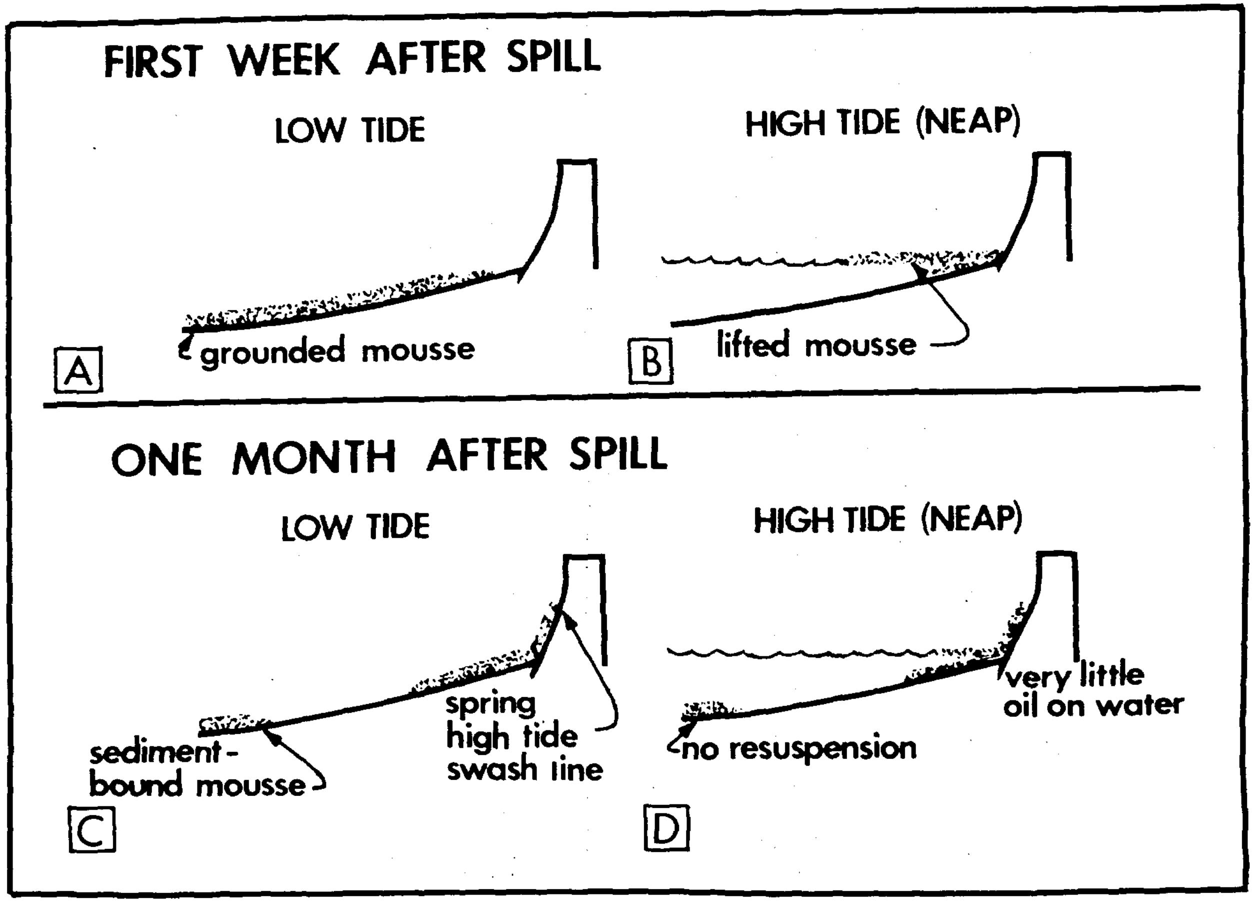
FIRST WEEK AFTER SPILL
LOW TIDE
HIGH TIDE (NEAP)
grounded mousse
lifted mousse
A
B
ONE MONTH AFTER SPILL
LOW TIDE
HIGH TIDE (NEAP)
sediment-bound mousse
spring high tide swash line
no resuspension
very little oil on water
C
D

FIGURE 6.