NOAA/EPA Special Report

The AMOCO CADIZ Oil Spill

A Preliminary Scientific Report

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4. INVESTIGATIONS OF BEACH PROCESSES

Erich R. Gundlach* and Miles O. Hayes*

4.1 Synopsis

According to our best estimate, 64,000 tons of the Amoco Cadiz oil came ashore along 72 km of the shoreline of Brittany during the first few weeks of the spill. A prevailing westerly wind pushed the oil against west-facing headlands and into shoreline embayments as it moved east. A wind reversal in early April moved the oil in the opposite direction, contaminating previously untouched areas and transporting the oil as far southwest as Pointe du Raz (southwest of Brest). At the end of April, the total volume of oil onshore was reduced to 10,000 tons, but, by that time, 320 km of shoreline had been contaminated.

Coastal processes and geomorphology played a major role in the dispersal and accumulation of the oil once it came onshore. For example, oil accumulated at the heads of crenulate bays and on tombolos (sand spits formed in the lee of offshore islands). Local sinks, such as scour pits around boulders, bar troughs (runnels), marsh pools, and joints and crevasses in rocks, tended to trap oil. The grounded mousse was either eroded away, or buried (up to 70 cm) under new sediment deposits, in response to the vagaries of the beach cycle. The details of oil erosion and burial were determined by resurveying 19 permanent beach profiles which were established during the first few days of the spill.

Classification of the coastal environments of the Amoco Cadiz oil spill site according to our oil spill vulnerability index (scale of 1-10 on basis of potential oil spill damage) revealed a good correlation with earlier findings at the Metula and Urquiola oil spill sites. Exposed rocky coasts and wave-cut platforms (index nos. 1 and 2) were cleaned of extremely heavy doses of oil within a few days. Fine-grained sand beaches (no. 3) proved to be easily cleaned, whereas coarse-grained sand beaches (no. 4) showed considerable oil burial in areas where berms were developed. Exposed tidal flats (no. 5) underwent extensive biological damage and experienced potential long-term pollution of the interstitial ground water. (No. 6 was not represented.) Gravel beaches (no. 7) were deeply penetrated by the oil, creating special cleaning problems. And

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finally, sheltered rocky coasts (no. 8), sheltered tidal flats (no. 9), and estuarine marsh systems (no. 10) once again proved to be the most vulnerable of all coastal environments to oil spill damage. These observations provide encouragement and incentive to continue to apply the vulnerability index to areas in the U.S. threatened by potential oil spills. The Brittany coastline is particularly analogous to the coastline of Maine and parts of southern Alaska.

During the first week after the grounding, oil on tidal flat and beach surfaces lifted off the bottom with each incoming tide. However, one month later, a large patch of oil mixed with sediment was found on the tidal flat surface at Portsall, and many beaches retained oil during the flooding tide. In these cases, oil became sediment-bound and remained on the bottom. The physical mixing of oil with sediment to form a denser-than-water mixture provides a possible mechanism for causing oil from the Amoco Cadiz to sink to the bottom.

Although the surfaces of the beaches and tidal flats at many places were free of oil, the interstitial ground water was contaminated. This may have been the cause of the extensive biological kills at certain areas. Unfortunately, the use of large pits and trenches as collection sites for the oil may increase the amount of ground water contamination.

The use of bulldozers to plow heavily oiled gravel into the surf zone for cleansing by wave action is a sound practice, from a geological point of view because no sediment is removed from the beach. Removal of sediment from certain areas increased the rate of beach erosion. The unrestricted use of heavy machinery on the beach and low-tide terrace generally turned oil deeper into the sediments. Where possible, traffic should be limited to specified access routes.

4.2 Introduction

The objectives of the work discussed in this chapter are to describe 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 in the United States 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.

In order to achieve these objectives, a program of field studies was begun on Sunday, March 19, 1978, three days after the initial wreck of the tanker. In total, 15 days were spent in the field during the first visit. The first field crew consisted of Miles O. Hayes, Erich R. Gundlach, and R. Craig Shipp of the U. of South Carolina (under contract to the Research Planning Institute, Inc. (RPI) of Columbia, South Carolina, U.S.A.). Also, Laurent D'Ozouville of the Centre Oceanologique de Bretagne (COB) participated in several days of field activities. The site was revisited between April 20 and April 28, 1978, by Gundlach and Kenneth Finkelstein of RPI. Dr. D'Ozouville again participated in each day of the field work.

In the field, our work consisted of overflights and intensive ground inspection and surveys of the entire affected area. For purposes of description, the study area is divided into 11 sections. Descriptions of 19 permanent beach survey stations and 147 beach observation stations (Fig. 4-1) are given under the discussion of each of the 11 sections (below). Extensive photography was carried out, with approximately 3,000 photographs being taken on the first trip and approximately 1,200 on the second. Thirty-five representative color photographs that illustrate the beach processes are given in Plates 4-1 through 4-33 (Appendix B).

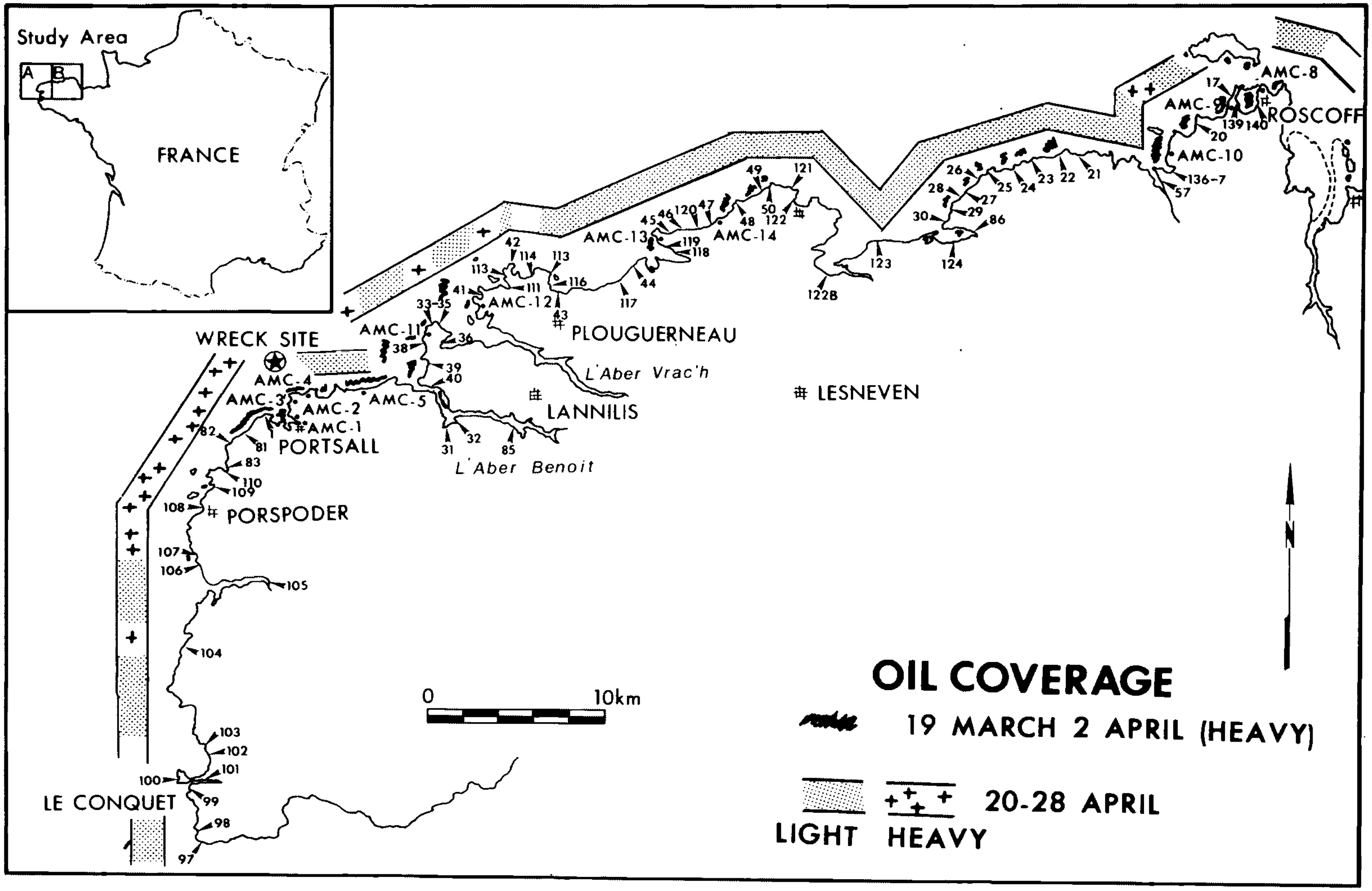

Figure 4-1A. Locations of observation stations within western portion of the spill-affected area. Oil distribution for study periods one (March 19 to April 2) and two (April 20 to 28) are indicated.

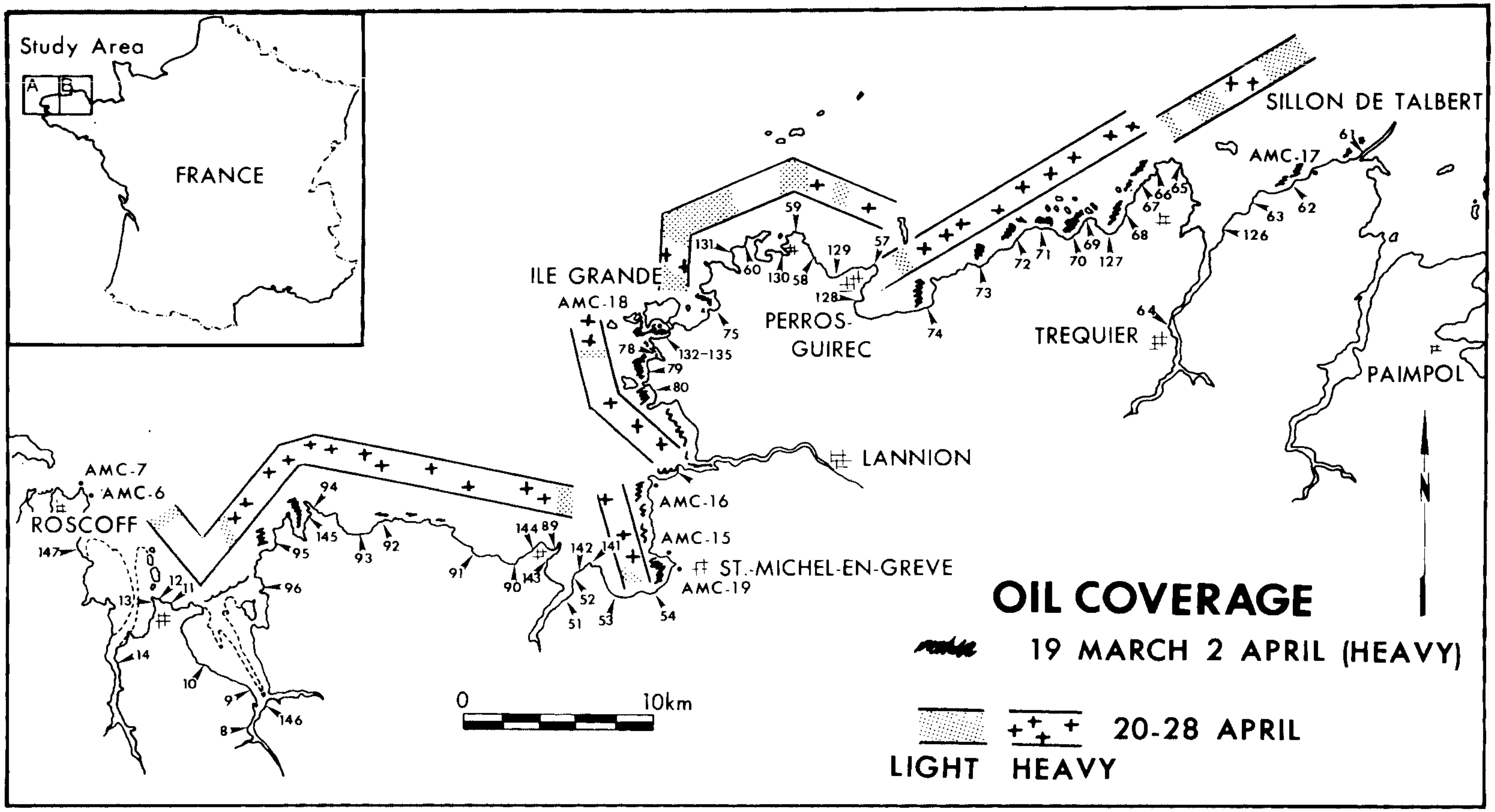

Figure 4-1B. Observation stations within eastern portion of the spill-affected area. Oil distribution is indicated.

4.3 Acknowledgments

The primary purpose of our work on the *Amoco Cadiz* spill was to provide assistance to the NOAA Spilled Oil Research team (SOR) in the areas of coastal processes and oil-sediment interaction. All of our work was performed under Contract No. 03-78-B01-50 with the Environmental Research Laboratories (ERL) of NOAA. We wish to acknowledge the help and support of a number of SOR team personnel, including Wilmot Hess, Jerry Galt, David Kennedy, Bud Cross, and Peter Grose. We also gained from helpful discussions with Roy Hann of Texas A & M University. Living facilities, a stimulating scientific environment, and miscellaneous logistical support were provided by CNEXO, Centre Oceanologique de Bretagne. Our field work was greatly facilitated at all times by the helpful and enthusiastic cooperation and support we received from Laurent D'Ozouville of COB. We anticipate that we will continue to work together and that several joint publications related to the scientific aspects of the spill will result.

4.4 Geological Setting

The entire area affected by the *Amoco Cadiz* oil spill lies within a geological province of France called the Massif Armoricain. This province is composed of a succession of zones of anticlinoria and synclinoria that trend WNW and ESE. The surficial rocks of the synclinoria are usually Paleozoic metamorphic and sedimentary rocks, whereas the surface rocks of anticlinoria contain the oldest rocks in the area, Precambrian granites and metamorphic rocks (Debelmas, 1974). Localized massifs of granite intruded during the Hercynian orogeny (approximately 300 million years before present (B.P.) occur throughout the area. Two major zones of strike-slip faulting separate the central area (Domain Centre Armoricain) as a result of relative westerly motion of the north shore region and easterly motion of the south shore region during the Hercynian (Fig. 4-2).

In short, 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[1], and metamorphic rocks. Inasmuch 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 of land-sea levels over the past few thousand years has created a rugged coastline composed of numerous inshore islands and erosional cliffs separated by minor pocket beaches and ria[2] systems. Everywhere, the primary shoreline trends are

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[1] A composite rock, composed of igneous and metamorphic materials mixed together as a result of intensive igneous and metamorphic action.

[2] Drowned river valley.

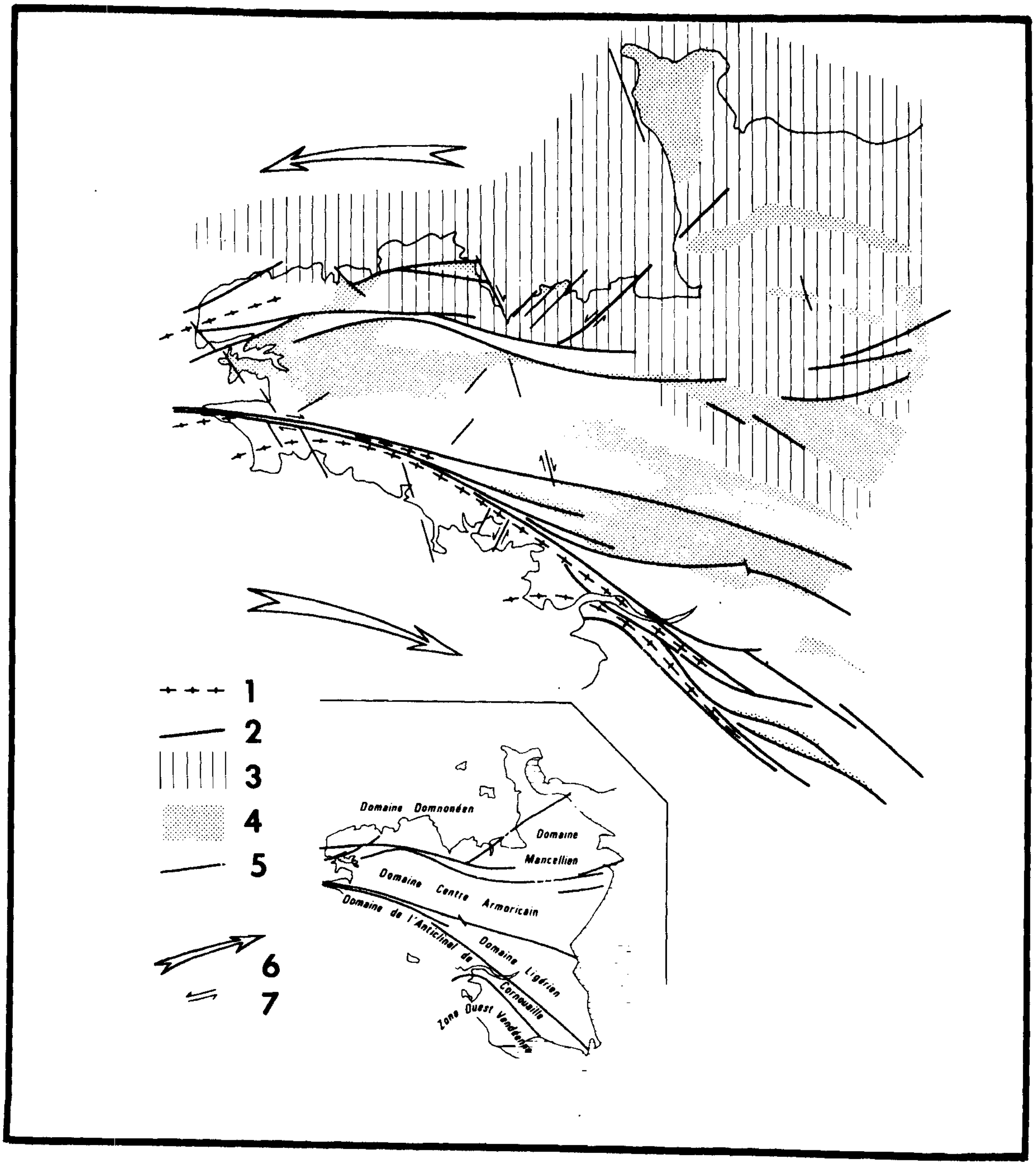

Figure 4-2. Tectonic development of the Massif Armoricain (from Debelmas, 1974); (1) zone of early activation, (2) major shear zones, (3) region of minor activation of Hercynian basement by pre-Cambrian granites, (4) Paleozoic cover sheets and regions of large synclines, (5) post-Stephanian fractures, (6) primary displacement, and (7) secondary displacement.

controlled by bedrock geology, with local trends being controlled by weathering and erosion along structural elements, such as faults, joints, and dikes. An example of this type of control along the coast near St. Malo is illustrated in Figure 4-3.

4.5 Coastal Processes

Information on physical processes of the spill site is discussed by Galt and Grose in Chapter 2. This section is a brief discussion of those physical processes related directly to the beach dynamics and oil grounding.

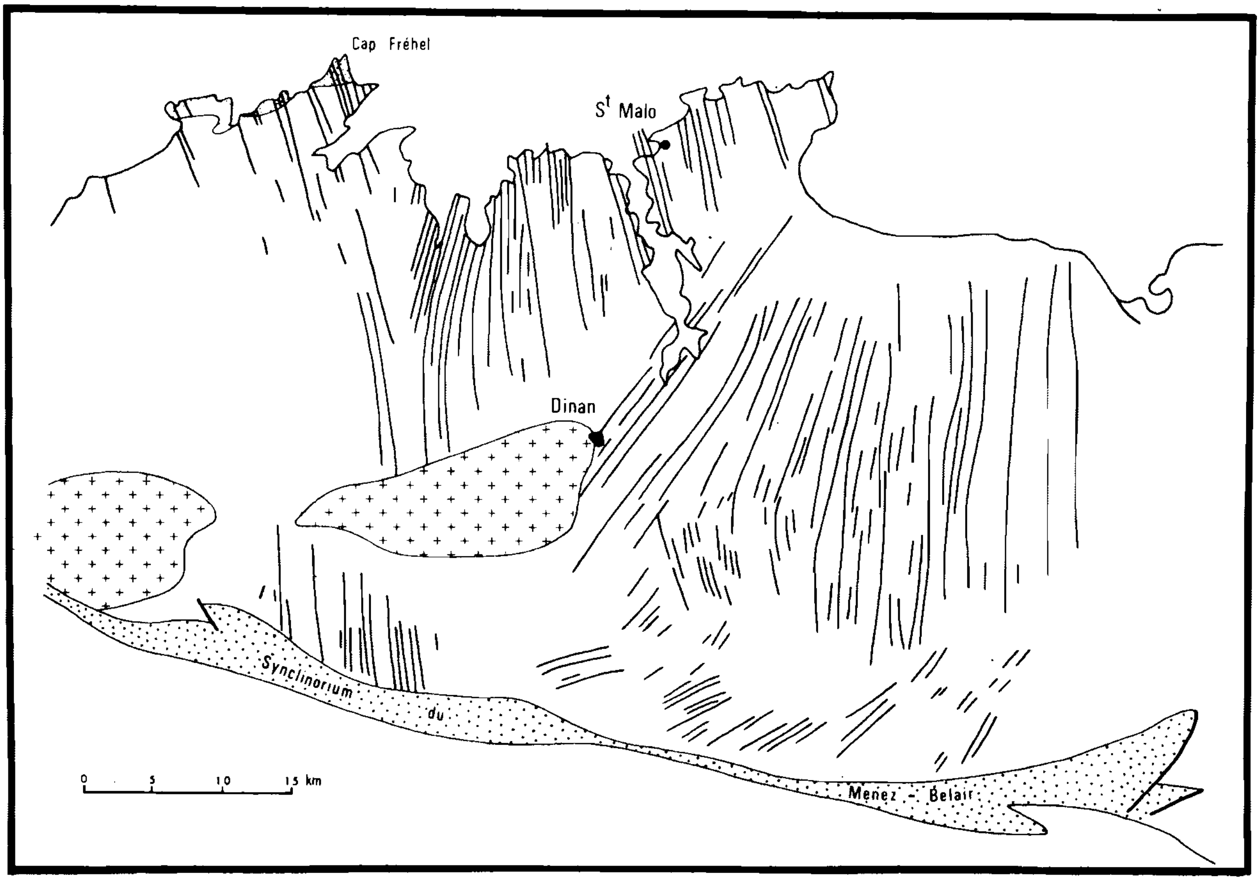

Figure 4-3. Orientation of vein field and jointing pattern of north-central Brittany (from Debelmas, 1974). Note control of structural elements on shoreline configuration.

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.

4.5.1 Winds and Waves

Wind patterns played a major role in the dispersal of the Amoco Cadiz oil along the shoreline. Data collected by the French Meteorological Agency (presented in Fig. 4-4) show that the wind blew consistently from the west between March 18 and April 2, 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 during late March. The wind changed on April 2 and blew consistently from the northeast until April 10, the date on which our records (from the French Meteorological Agency) end. 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 April 22 and 26 showed variable results, but easterly winds predominated.

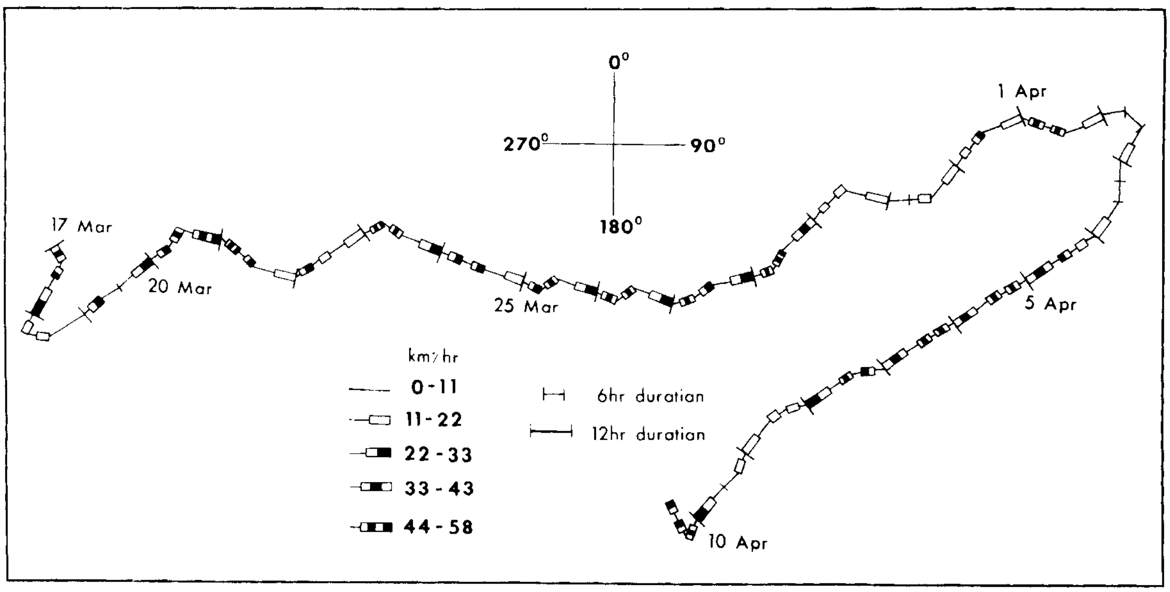

Figure 4-4. Wind pattern for March 17 to April 10, 1978, from the French meteorological station 1 km north of l'Aber Wrac'h. The wind shift on April 2 caused the oiling of previously clean coastal areas south of the wreck site.

Large waves were observed at high tide throughout the first field study period (March 19 to April 3). Estimates of significant wave heights were consistently on the order of 1 to 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.

4.5.2 Tides and Tidal Currents

The mean tidal range at Morlaix, which is centrally located in the spill site, is on the order of 6 to 7 m (Fig. 4-5). These large tides generated strong tidal currents throughout the spill site. The tidal current variability for the area is illustrated by the graphs in Figure 4-6. Our team 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 of 8.1 m, which was caused by a combination of spring tides and wind set-up associated with an intense low pressure system, occurred on the weekend of March 25-26 (Fig. 4-7). 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.

4.6 Coastal Morphology

The portion of the Brittany coast impacted by *Amoco Cadiz* oil is an irregular, low-lying ria[3] 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 Chassé (1972) describes the morphology and sediments of selected segments of the spill site in great detail.

[3] "*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 meander as on the Aulne at Landevennec in the Rade de Brest." (Guilcher, 1958, p. 153)

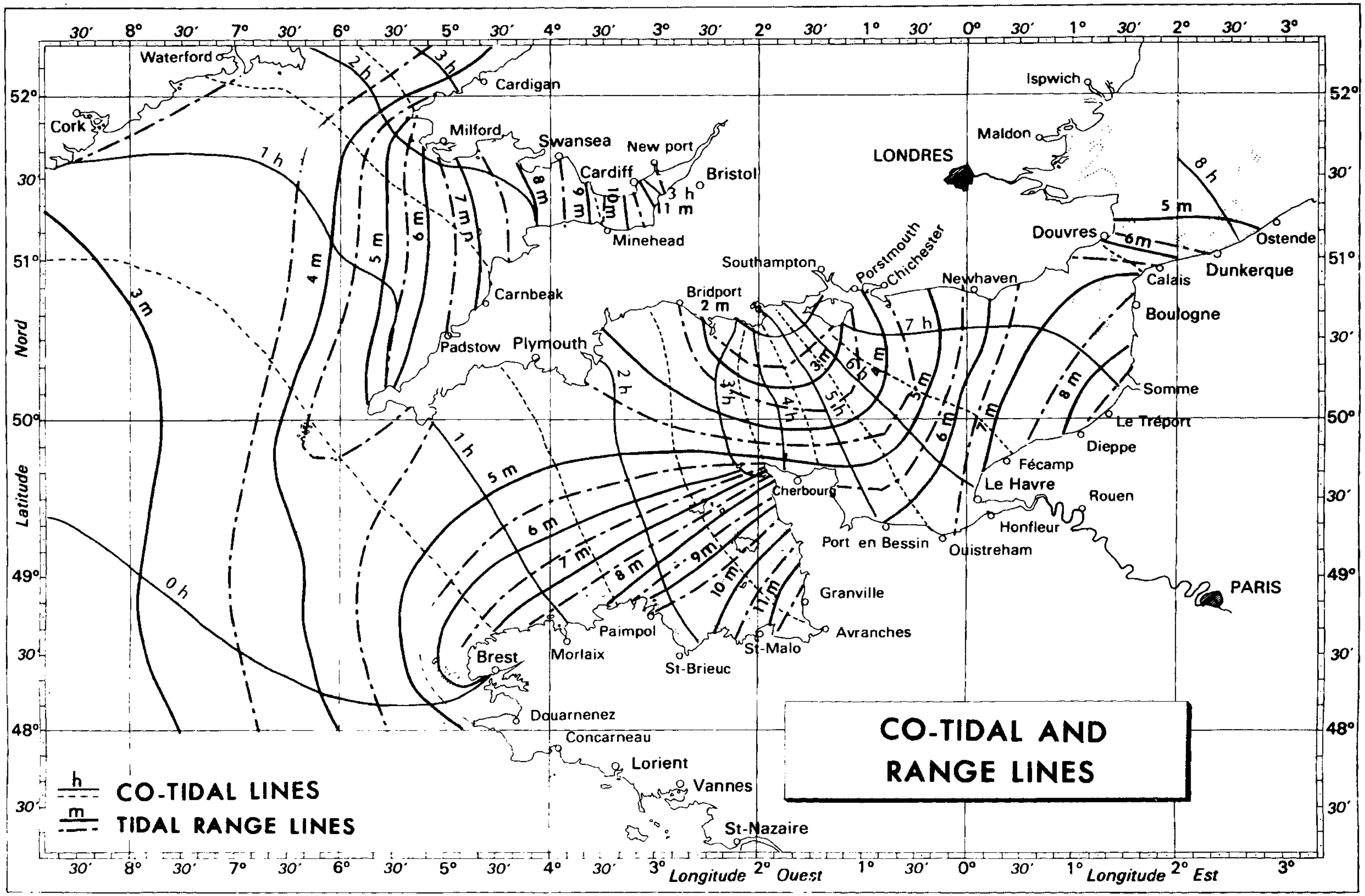

Figure 4.5. Tidal range lines for the English Channel (from French Hydrographic Service Pub. 551). Tidal range increases, going from 6 m at Brest to over 9 m at Paimpol.

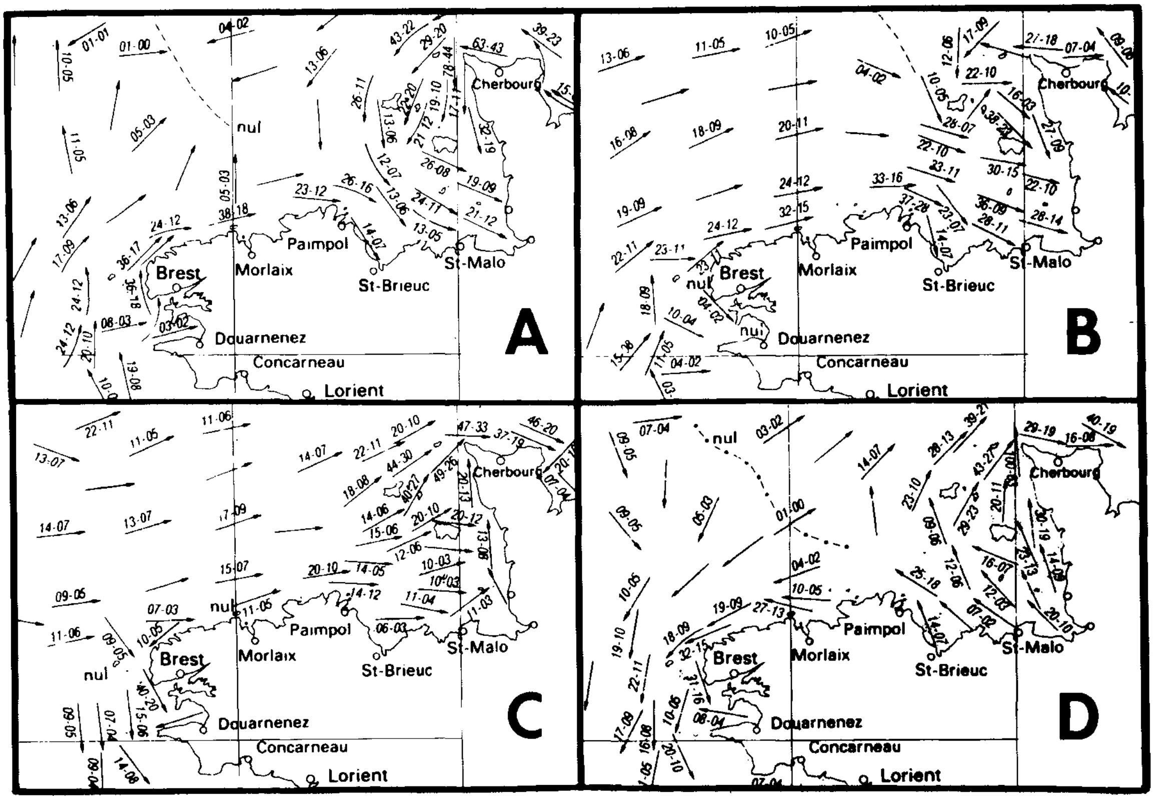

Figure 4-6. Currents (m/sec) for the English Channel north of Brittany (from French Hydrographic Service Pub. 551). (A) 6 hours before high tide at Cherbourg; (B) 4 hours before; (C) 2 hours before; and (D) during high tide at Cherbourg.

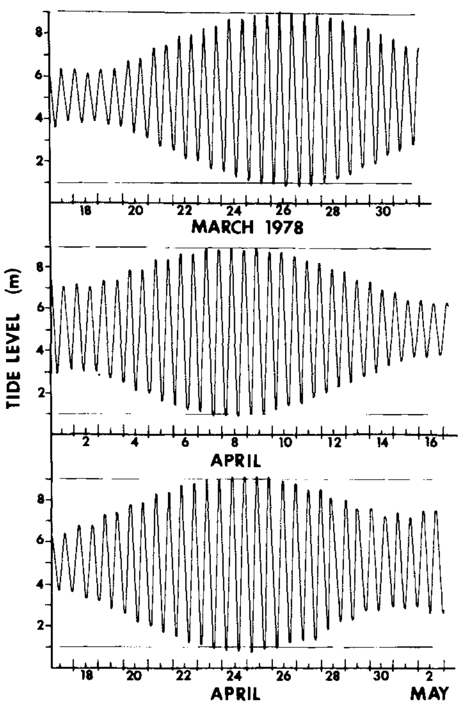

Figure 4-7. Tide curve for Morlaix from March 17 to May 2 (from French Hydrographic Service Pub. 785). Spring tides during March 25 to 28, coupled with an intense low-pressure storm, spread oil very high along the shoreline.

Depositional beaches are rare on the Brittany coast. Where present, they consist of sheltered pocket beaches, crenulate bays[4] (Plate 4-20), and tombolos[5] (Plate 4-21). In some embayments, broad tidal flats (mostly fine-sand) are exposed at low tide. Salt marshes are small compared with those of 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 sediment transport direction 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 the Baie de Douarnenez, however, is more complex, showing no general trend of sediment transport direction.

Taking the impacted area as a whole, some regional morphological trends are apparent:

(1) The shoreline in the large embayments of the Rade de Brest and Baie de Douarnenez are flanked by high cliffs with narrow intertidal zones. Coastline orientations are controlled by major structural elements, such as regional faults (e.g., the south shoreline of Baie de Douarnenez).

(2) Granite plutons which form massive headlands predominate along the northwest and northern shores. Minor structural elements such as minor faults and joints control local shoreline orientations. The western sides of those headlands, which usually have wide intertidal wave-cut platforms, have suffered more erosion than the eastern sides, which have steeper intertidal areas.

(3) Intertidal areas increase in width from west to east, as a result of the increasing tidal range (Fig. 4-5). The wider tidal flats to the east appear to contain a greater abundance of sediments than those to the west.

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[4] 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.

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

The closest analog to this coastline in the United States is the northern half of the coast of Maine, which bears many similarities. The most notable comparisons are the bedrock and coastal topography (massive granite plutonic headlands separated by drowned river valleys), as well as similar wave and tidal conditions.

4.7 Coastal Sediments

Beach and intertidal sediments of the spill site show a wide range of size, sorting, and composition. House-sized granite boulders occur at retreating headlands and along some arcuate beaches (see examples in Plates 4-16 and 4-22). Intermediate-sized, well-rounded cobbles (20 to 40 cm in diameter) make up some beaches exposed to high wave action (Plate 4-27). In more sheltered areas, gravel beach ridges similar to those of New England and Alaska have accumulated (Plate 4-14 and 4-15). In places, moderately sorted gravel accumulations occur as a high tide rim around intertidal sand flats (Plate 4-13). Thin gravel veneers overlie clay and peat substrates on some of the erosional beaches (Plate 4-33).

Sand also occurs under a variety of conditions. Steep, cuspate coarse-sand beaches occur in some of the more exposed pocket beach areas (e.g., Plate 4-12). Sheltered pocket beaches usually contain flat, fine-grained sand beaches (Plate 4-26). The finest sands are found in the coastal dunes that occur at several localities between Portsall and Roscoff (Plate 4-23).

A wide variety of sediment types may occur within a small geographic area because of the complexity of the nearshore and coastal morphology. For example, note the variation in grain size of the sediments in the vicinity of the tombolo illustrated in Plate 4-21.

After the spill, dead organisms became a part of the transported sediment. At St. Cava, dead cockles were transported along with quartz pebbles and accumulated in rows at the toe of the beachface (Plate 4-25). Swash lines of dead razor clams and heart urchins were accumulated along the beach at St. Michel-en-Grève on April 2 (Plate 4-7).

Muddy sediments are rare in the spill site, presumably because of the high wave and current energy conditions that prevail. Some of the rias (in Brittany, the ria is often called an aber, Guilcher, 1958, p. 154) contain muddy flats in their upper reaches, and the salt marshes usually contain muddy sediments.

Chassé (1972, p. 3) made the following comment about the sediment variability of the spill site (translated by Jacqueline Michel):

> "Brittany's shoreline offers a great diversity of headlands, bays, and rias. Present-day sediments are a complex mixture of sand of Tertiary age and aeolian silts, fluvia pebbles, and more

or less relict sand of Quaternary age (both Tyrrhenian and Flandrien). But all along this submerging coast of rias and incised marine gulfs (Morbihan, Bay of Douarnenez, Rade de Brest, Aber Wrac'h, Bay of Morlaix, etc.), only one sediment type is poorly represented, the aeolian quartz dune sands between 200 and 400 microns, which corresponds to the most mobile grain size."

Chassé presented detailed maps of the sediment distribution in several of the areas where oil accumulation was heaviest. These maps will provide a useful base for follow-up studies.

4.8 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.

4.8.1 The Zonal Method

The zonal method was developed by Hayes and associates (first described by Hayes et al., 1973) in order to determine the geomorphic variation of large sections of coast. It has been applied in several areas of the world, including the southeast coast of Alaska (Hayes et al., 1976b) and during studies of the Metula, Urquiola, and Jakob Maersk oil spills (Gundlach and Hayes, 1978). 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. In a study of Lower Cook Inlet (for the State of Alaska), a total of 1216 km of coast was classified within 21 days by a team of three persons (Hayes et al., 1976a). A similar approach was taken during our study of the Amoco Cadiz oil spill.

4.8.2 Flights

Extensive aerial photography and tape descriptions were carried out during the following flights over the Amoco Cadiz spill site:

(1) March 21--Wreck site to Roscoff.
(2) March 30--Mont St. Michel to Roscoff.
(3) April 3--Portsall to St. Michel-en-Grève.
(4) April 20--Pointe du Raz to Portsall.
(5) April 28--Pointe du Raz to Roscoff.

These 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.

4.8.3 Beach Stations

A total of 166 beach stations was visited (locations in Fig. 4-1). Stations of two types were established, F-stations (plain numbers) and AMC-stations (numbers preceded by AMC). A brief description of each station is presented under each section heading. At the 147 F-stations, the site was visually inspected, photographs were taken, and observations were recorded on tape. Work at the 19 AMC-stations included the following:

(a) A topographic profile of the beach (at low tide) was measured. 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.

(b) Three equally spaced sediment samples were collected. These were taken for the purpose of characterizing the beach with respect to its oil penetration and burial. These samples have been analyzed for textural characteristics (mean grain size, sorting, etc.) in the laboratory and they are discussed below; 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.

(d) A sketch was drawn to show the general coastal geomorphology and the surficial oil distribution. Several examples are given in discussions of the different shoreline sections.

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

4.8.4 Oil Distribution

Distribution Maps

The occurrence of oil along the shoreline was mapped both from the air and from the ground during both visits to the site. The oil distribution for the two time intervals is shown on Figures 1A and 1B.

Calculation of Tonnage

During study of each AMC-station, the thickness of mousse was measured at a maximum interval of 5 m along the profile line. The percent oil coverage of the surface was also noted. The assumed volume of mousse present is the measured thickness multiplied by the overall length of the beach as measured on 1:25,000 scale topographic maps. Where oil did not cover the entire area, appropriate reductions were made. Buried oil was noted and photographed. An estimate of the amount buried was made by calculating the volume of oiled sediment and assuming that 10% of this volume was mousse. The 10% value was derived from analyses by Anne Blount (of our group) on over 50 oiled sediment samples from the Metula site. All mousse was assumed to be 60% water. The specific gravity of the oil, used to calculate total metric tonnage, was assumed to be 0.85 gm/cc.

In order to derive the total amount of oil on the beaches in the spill area, an average oil content per km of shoreline was calculated from our 19 AMC-stations. The amount of similarly oiled coastline was then measured on 1:25,000 scale topographic maps and multiplied by this value. This was done for both study periods (March 19 to April 2 and April 20 to 28) to determine the net change.

4.8.5 Observations of Biological Impact

Because of the emergency situation surrounding the spill as well as the opportunity to contribute to a basic understanding of oil spill impacts, a special effort was made by our group to observe the biological effects of the spill, although this was not our primary objective. Notes were taken on tape, and numerous photographs were taken wherever biological damage was observed. Some of our general observations are presented in our descriptions of the individual coastal sections for the record. For a complete discussion of the investigations of biological processes, refer to Chapter 5.

4.8.6 Chemical Samples

Samples of mousse and oiled ground water were collected at selected localities for chemical analyses (during both trips). These samples were passed on to the SOR team or to John L. Laseter of the University of New Orleans' Center for Bio-Organic studies for processing.

4.8.7 Observations of Cleanup Activities

Wherever cleanup was observed in progress, photographs were taken (see Plates 4-4, 4-5, 4-8, 4-9, 4-11, and 4-19) and conclusions were recorded on tape in order to note in detail the success or failure of each method. Cleanup was studied in depth by Roy Hann and his associates from Texas A & M University (see Chapter 6). Reference is made to the cleanup effort in this chapter where either (a) the cleanup technique affected the normal beach processes, or (b) an understanding of beach processes would aid in the cleanup exercise.

4.9 Field Observations of Oil Impact

For purposes of description, the impacted coastline is divided into 11 separate sections (located on Figures 4-8 and 4-9). The individual sections will be discussed in sequence from west to east. Observations made during both of the field visits are included.

4.9.1 Section I--Pte. du Raz to Penfoul

Section I is located to the south-southeast of the Amoco Cadiz wreck site (Fig. 4-10). The coastline generally consists of high-energy rocky headlands with small pocket beaches. Cliffs over 40 m in height are common toward the south. Although the tidal range is 5.5-6.0 m, little more of the coast is actually exposed during low tide than at high tide because of the steeply-dropping offshore bathymetry. This is in distinct contrast to the many wide tidal flat systems that lie to the north and northeast.

Oil impact, March 17-April 2

During the first two weeks after the grounding, little or no oil was transported to this area. Winds were blowing strongly from the west and southwest. A survey of station F-82 and stations further north on March 31 revealed only a few small tar blotches (of unknown origin) on the rocks. A sample was taken for chemical analysis.

Oil impact, April 20-28

A distinct change in oil distribution was observed during our second study period. During the aerial survey on April 20, heavy oil accumulations were observed as far south as Pointe du Raz, 126 km (77 miles) from the wreck site. Very heavy oil accumulations were observed at station F-104 (Fig. 4-10) and northward. A photograph of station F-82 that was taken on the following day is presented in Figure 4-11. Stations F-97 to F-103 were lightly to moderately oiled. Table 4-1 summarizes oil impact for this area. A photograph of a newly oiled area near Argenton (F-109) is presented in Figure 4-12. As observed during the aerial survey on April 20, moderate to heavy oil accumulations were found at (a) beaches near Camaret, (b) in small pocket coves along the cliffs from Douarnenez to Pointe du Raz, and (c) at the beach at Pointe du Raz. Lighter accumulations were observed at Ile de Sein, located offshore of Pointe du Raz. The last two areas mark the most southerly extension of major contamination from the Amoco Cadiz.

The heavy oiling of this section during April was a result of the offshore winds of March 28-31 followed by strong south/southwest winds during April 2-10. The wind at this time blew ashore much of the oil that was still at sea, therby causing the oiling of an additional 91 m of shoreline.

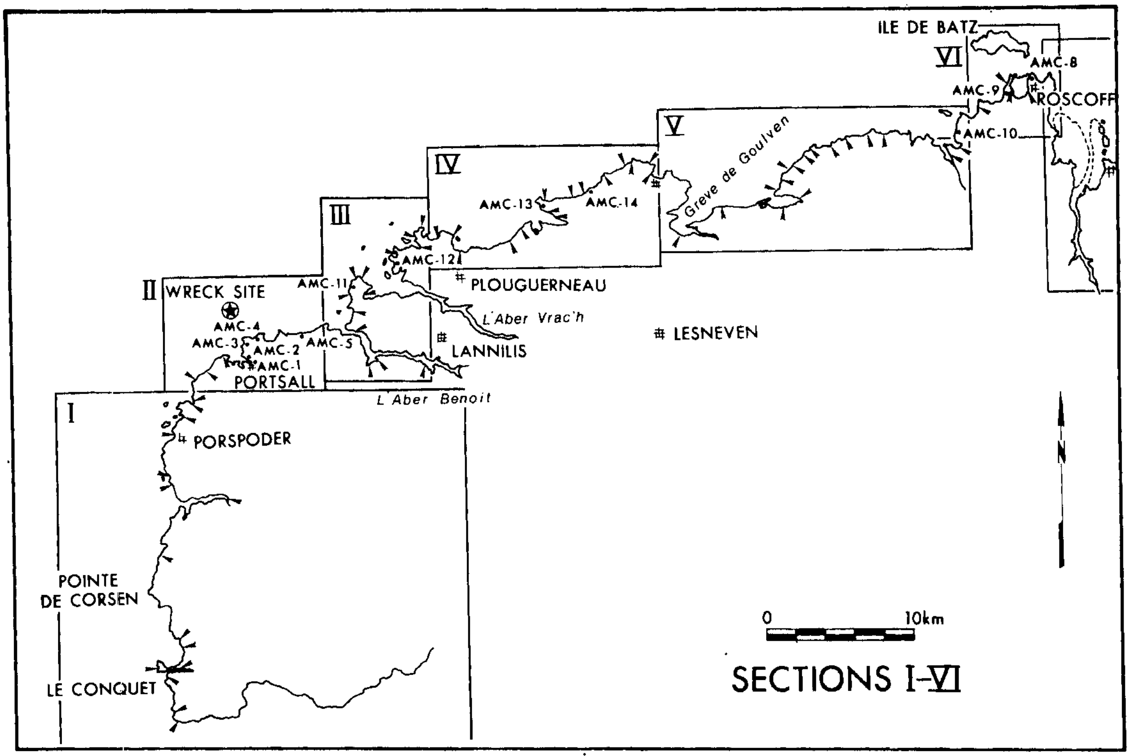

Figure 4-8. Locations of Sections I to VI of the spill study area.

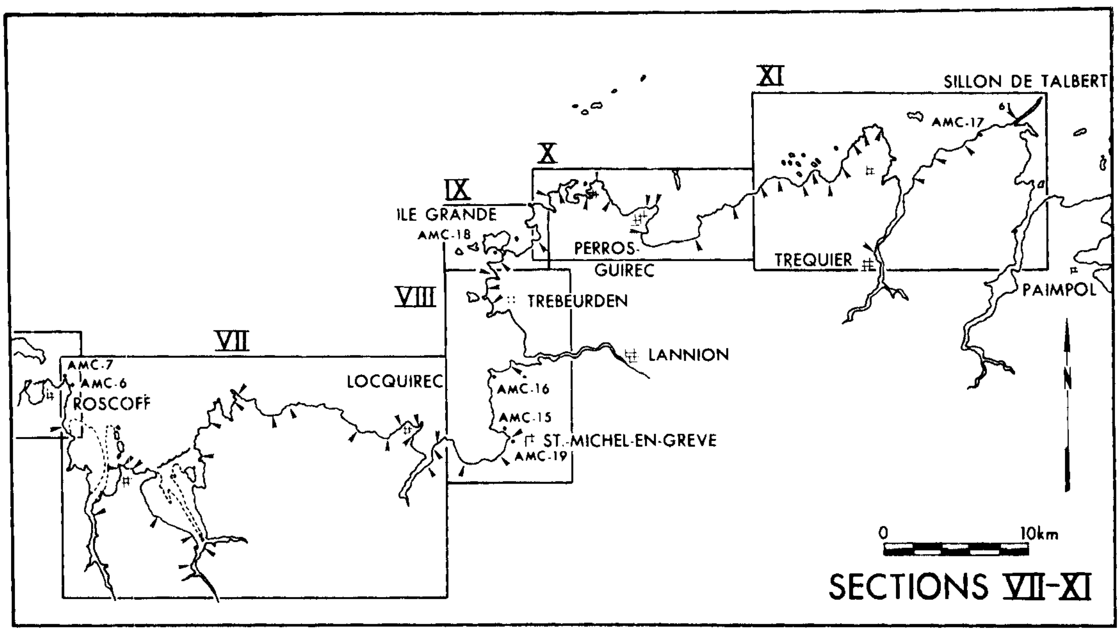

Figure 4-9. Locations of Sections VII to XI of the spill study area.

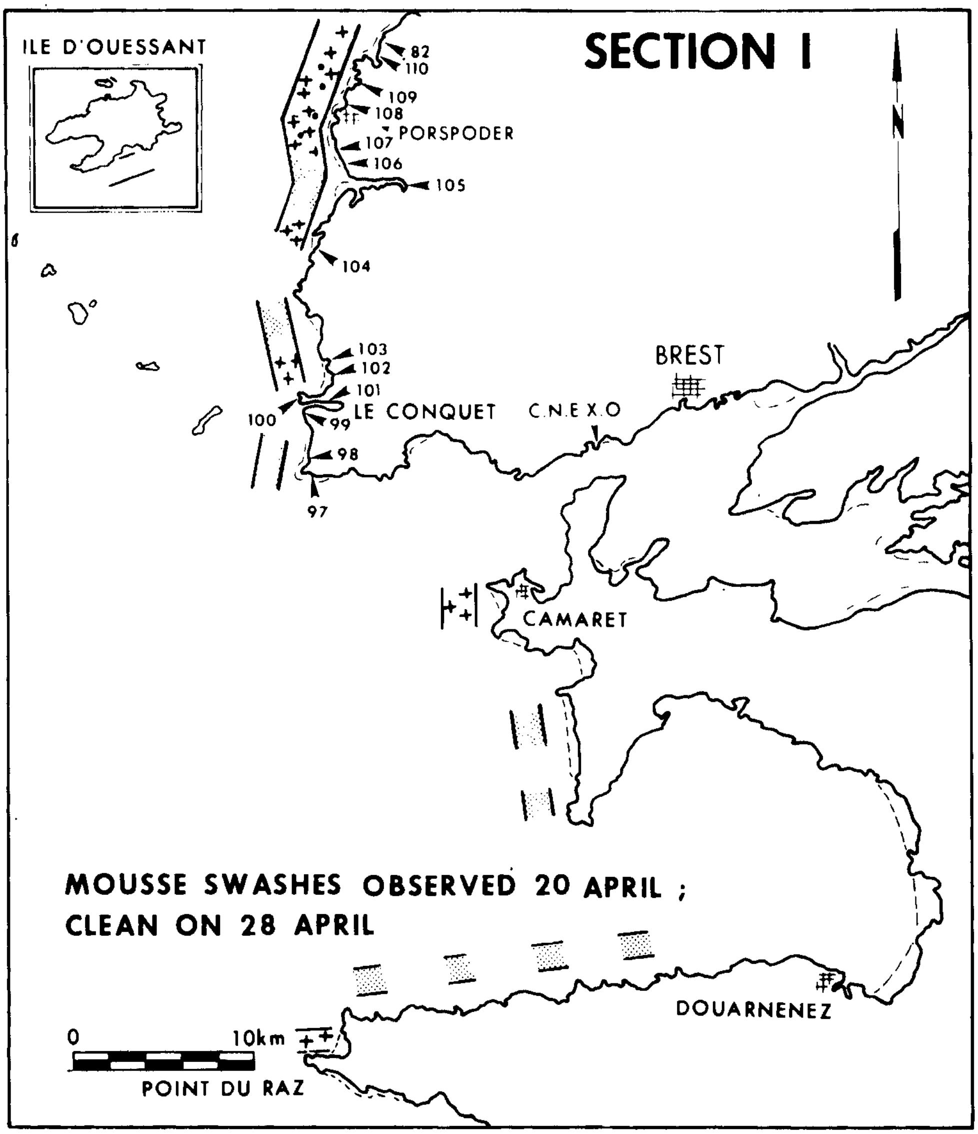

Figure 4-10. Locations of observation stations in Section I, Pointe du Raz to Penfoul. No oil was in this area during the first two weeks of the spill. The pattern between heavy lines indicates oil distribution as observed during second study period (April 20 to 28). Pluses indicate moderate to heavy oiling of upper intertidal rocks and/or beachface; circles indicate moderate oiling of lowtide terrace; dot pattern indicates light oiling on rocks or beachface. Mousse swashes and heavy oiling were observed south of F-97 during aerial survey of April 20. By second flight on April 28 the oil was no longer present.

Figure 4-11. Heavily oiled rocks at station F-82 on April 21. Three weeks before, the area was observed in detail and found to be clean except for some small tar blotches. Re-oiling occurred as a result of a wind shift during the early part of April.

Figure 4-12. Heavily oiled pocket cover near Argenton (F-109) on April 28. Mousse also covers the surface of the water.

Table 4-1. Field observations of oil distribution at stations of Section I, Pointe de St. Mathieu to Penfoul.

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
F-97	21 Apr	Pointe de St. Mathieu A rocky platform with a small cobble beach.	A few oil blotches along the swash line - mostly small; a few 5 cm tar or mousse balls; rocks spotted with small amount of mousse. Area seemed biologically productive - much algae and limpets.
F-98	21 Apr	Grève de Porsliogan A small cove/pocket, medium grained sandy beach surrounded by a rocky area.	Light oil at all swash lines. Algae productive. Many worm burrows. Some oil burial of 5 cm - very minor.
F-99	21 Apr	Le Conquet - Beach A small sandy pocket beach surrounded by a rocky area.	Very light oil swash lines with more oil along the upper swash line and on some of the rocky areas.
F-100	21 Apr	Pointe de Kermorvan A boulder beach.	Small amounts of mousse in water. Heavy oiling of boulder beach on the north side of the lighthouse.
F-101	21 Apr	Le Conquet-Harbor (East side) Large sand flat exposed at low tide.	Free of oil - boom at harbor entrance.
F-102	21 Apr	Plage de Blancs-Sablons Wide sandy (fine to medium-grained) beach. Rocks at both ends of beach.	Oil streaks over the entire intertidal portion of the beach. Heavy mousse on rocks in NE corner. Oil pools of mousse located on beach - some mousse in water.
F-103	21 Apr	Port Illian Small pocket beach protected by a jutting rocky headland. Fine-sand on beachface; some gravel on the lower portions.	Oil streaked swash lines. Small mousse patches left on the beach surface.
F-104	21 Apr	Rubian Coarse-sand beach with many cobbles especially on lower beach.	Heavily oiled rocks; moderately oiled coarse-sand beach. Oil pools 5 cm thick in some areas and a coating on the boulders at the base of the sand. Oil buried due to clean-up activity.
F-105	21 Apr	l'Aber Ildut - Estuary Narrow entrance with 2 booms present.	Oiled seaweed along the edge of the channel. Oil sheen on both sides of the booms.
F-106	21 Apr	Melon - South side Small rocky beach with little wave activity.	Entire intertidal zone heavily oiled. Very heavily oiled rocks and mousse in water.
F-107	21 Apr	Melon - North (harbor) A u-shaped harbor with an island offshore to protect it. Fine-sand beach.	Very heavily oiled beach. Rocks in northern pocket very heavily oiled. Active clean-up effort.
F-108	21 Apr	Porspoder Fine-grained pocket beach with rocky headlands on both sides.	Rocks heavily oiled; 10-15 cm thick oil on the beach. Mousse in water. Clean-up operation in effect.
F-109	21 Apr	Argenton Small cove, very well protected fine-grained beach.	Thin oil layer covers most of the beach. Heavy oil along edge of the pocket cove. Small amount of mousse in water.
F-110	21 Apr	Penfoul Small fine-grained estuary.	Heavy oiling on both sides of the estuary; slicks seen over entire area. Clean-up operation in effect.
F-82	31 Mar- 21 Apr-	Pointe de Landunvez High energy boulder beach on wave-cut granite platform.	-minor tar blotches (3-5 cm) on rocks. -heavily oiled rocks and boulders with some mousse in the water.

Table 4-2. Field observations of oil distribution at stations of Section II, St. Sampson to Les Dunes-East.

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
F-81	31 Mar	St. Sampson Boulder beach on wave-cut rock platform; high energy (1 m waves present).	No oil.
F-1	19 Mar-	Trémazan Boulder beach on wave-cut rock platform (close to wreck site).	-light mousse in water and along shore.
	20 Mar-		-very heavy oiling, oncoming waves 2 m in height.
	31 Mar-		-only very small scattered blotches of oil remain.
	21 Apr-		-heavily reoiled.
AMC-1 (F-2)	20 Mar (F)- 22 Mar-	Portsall Sheltered embayment, with seawalls, small coarse-grained beaches and fine-sand tidal flat.	-very heavily oiled beach and tidal flat; extensive skimming operation.
	31 Mar-		-still heavily oiled beach; minor oiling on tidal flat.
	21 Apr-		-still heavily oiled beach; some stationary oil on tidal flat; heavy oiling of rocks and seaweed along eastern shore; little oil on surface of water; extensive shoreline clean-up activity.
AMC-2	22 Mar 31 Mar 21 Apr	Portsall Angular, gravel beach; fine-sand tidal flat.	Heavily oiled beach; clean tidal flat.
AMC-3 (F-3)	20 Mar (F)- 22 Mar- 31 Mar-	Portsall-North Cobbles against a seawall along the upper beachface; coarse-sand on rest of beachface; fine-sand low-tide terrace with some algae covered rocks.	-heavily oiled beach, upper low-tide terrace and rocks.
	21 Apr-		-moderate coverage of beachface with thick (10 cm) mousse swashes; still heavily oiled rocks.
F-84	31 Mar-	Prat Leac'h-Kerras 0.5 km sand pocket beach with eroding sedimentary backshore.	-very heavily oiled beachface; extensive clean-up operation.
	21 Apr-		-clean beach but new erosion scarp formed along the backshore.
AMC-4 (F-4)	23 Mar-	Les Dunes-West Three pocket, sand beaches within a large sheltered cove. A fine-sand tidal flat is exposed at low tide; each beach has a clay base with eroding clay scarp along the backshore.	-very heavily oiled beachface and upper tidal flat along eastern shore. Very large amphipod kill. Center beach has moderate oiling; western beach clean.
	31 Mar-		-heavily oiled upper beachface.
	21 Apr-		-heavy oil swashes; front-end loaders removing oil and sand from beachface.
AMC-5 (F-5)	20 Mar (F)-	Les Dunes-East Large deposition area with a grass stabilized dune field. A flat profile fine-sand beach/low-tide terrace abuts an eroding dune scarp.	-moderate oil streaks on eastern side; fewer on western side.
	23 Mar-		-very heavy oil covering the entire beach on east side and on upper beach of west side.
	26 Mar-		-very heavy oil on east side of stream; large amount of oil buried on west side.
	31 Mar-		-clean east side; very heavy oil on west side.
	22 Apr-		-very light oil swashes; some oil burial on both sides of stream.

During our last aerial survey on April 28, no oil was observed at Camaret and Pointe du Raz. Nor was oil seen on the surface of the water. However, north of station F-97, the oil appeared the same as before. A large cleanup operation also remained active in the area.

Although we did not observe any oil on the beaches south of Pointe de St. Mathieu (F-97) from the air, it should be noted that in all likelihood a ground survey would find light swashes of small mousse balls on these beaches. These features were very common throughout the study area, and were even found on the beach next to the CNEXO lab at Brest.

Summary

Section I proved to be a surprise to us:

(1) It had become very heavily oiled more than three weeks after the spill, illustrating the ability of massive quantities of oil still to be transported several weeks after initial spillage.

(2) Thick mousse concentrations were observed on the water's surface along the cliffs between Douarnenez and Pointe du Raz, a full month after the beginning of the spill.

(3) Heavy oil accumulations extended southward to Pointe du Raz, a total of 126 km (77 miles) from the wreck site.

4.9.2 Section II--St. Sampson to Les Dunes-East

This section, shown on the maps of Figures 4-13 and 4-14, is located in the vicinity of the wreck site; it was the first area to be oiled (Table 4-2). South of station F-1 (Fig. 4-13), the shoreline consists of an eroding wave-cut platform in granite that has a shoreward scarp 3 to 15 m in height. The intertidal platform is covered with large boulders.

Portsall Harbor

Week of March 20. Stations AMC-1 and AMC-2 (Fig. 4-13) are both located in Portsall Harbor, a sheltered, relatively low-energy environment. Figure 4-15 is a detailed map of the Portsall area which shows the oil distribution at first impact and at one month later. During the first week after the wreck, a large oil mass was located in the harbor. The profile at station AMC-1, which crosses the embayment (Fig. 4-15), was measured at that time (see field sketch in Fig. 4-16). As the profile was surveyed, measurements of oil thickness and estimates of percentage of oil cover were made as often as warranted. A plot of these measurements along the surveyed topographic profile is presented in Figure 4-17. Sediment grain size data for the A, B, and C samples are presented in Table 4-3. All the sediments are poorly sorted, with

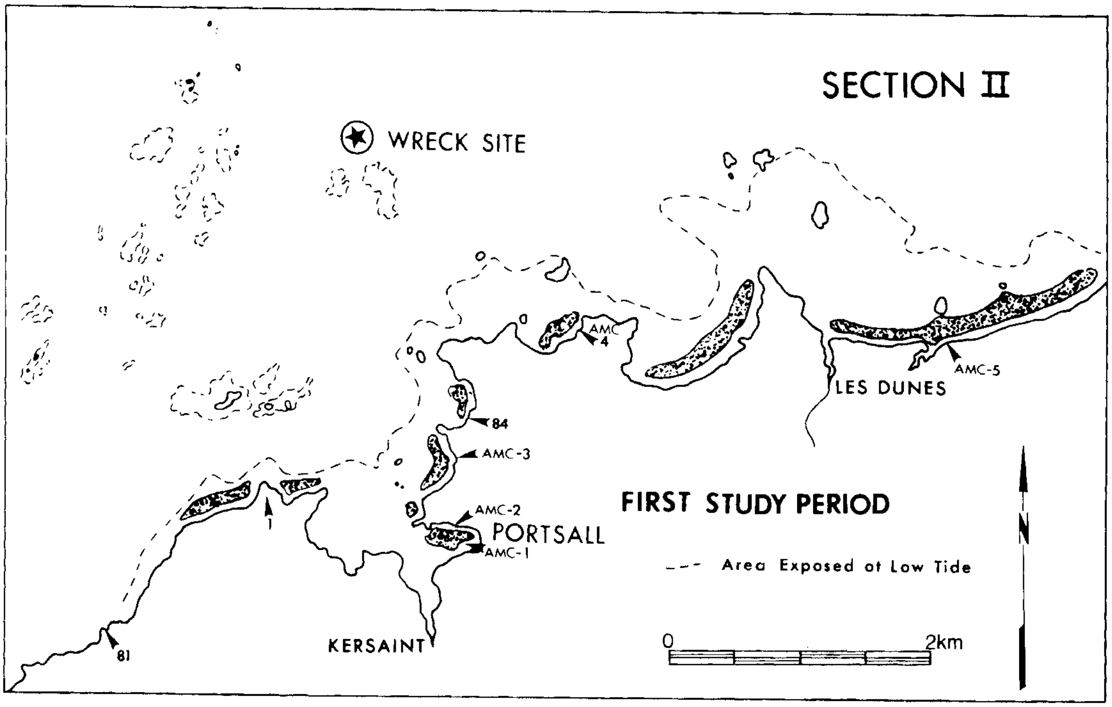

Figure 4-13. Locations of observation stations in Section II, the Portsall area, during the first study period (March 19 to April 2). Heavy oil accumulations are indicated by the dark-stippled pattern.

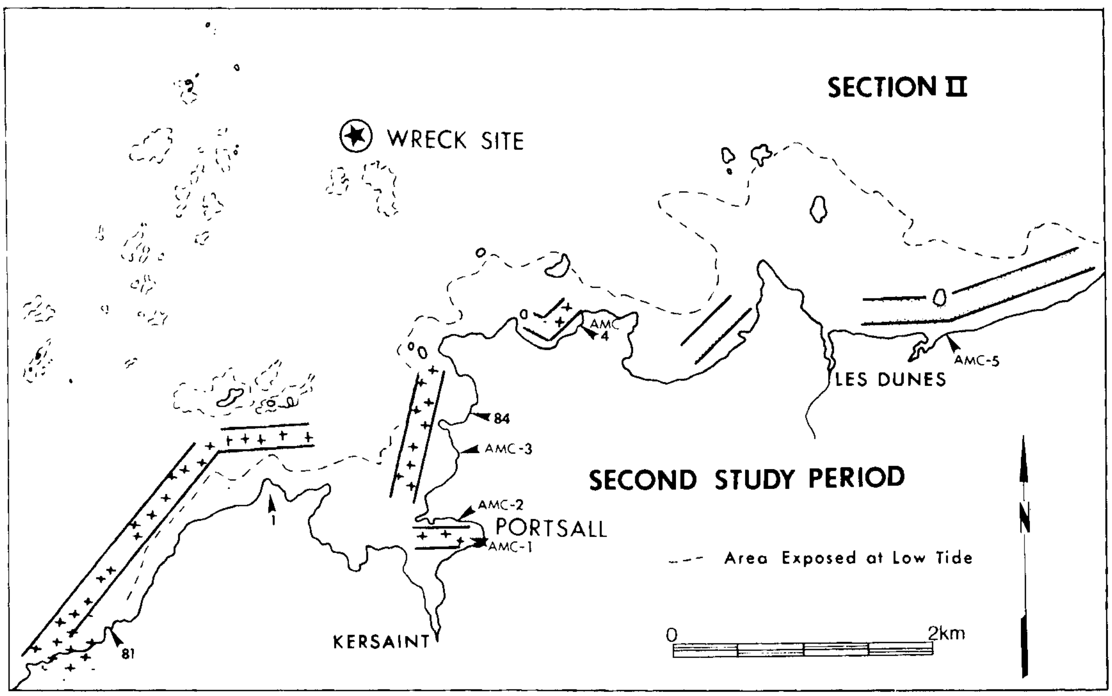

Figure 4-14. Oil distribution for Section II for second study session, April 20 to 28. Heavy and light oil coverage are indicated by the plus and light-dot patterns, respectively.

Table 4-3. Grain size data for AMC stations of Section II. All statistics are calculated according to Folk (1968).

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)

[1]Size Class

C = cobbles
P = pebbles
CS = coarse sand
MS = medium sand
FS = fine sand

[2]Sorting

MWS = moderately well sorted
MS = moderately sorted
PS = poorly sorted

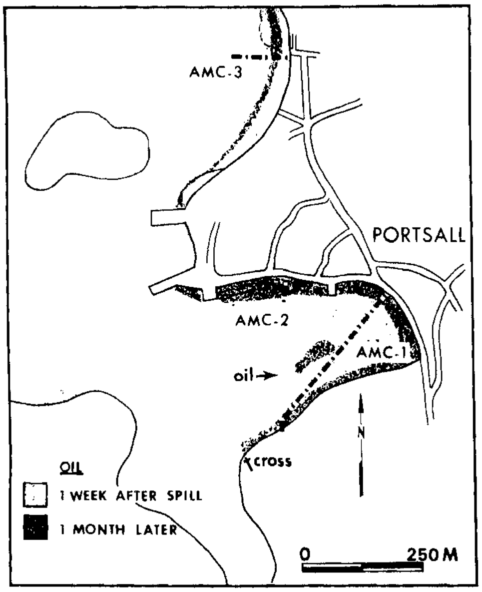

Figure 4-15. Detailed location map for the Portsall area. Oil distribution, as observed during our two study sessions, is indicated.

the coarsest sediment occurring near shore. Our calculations indicate that 50.2 metric tons of oil were present in the AMC-1 area during the first survey (after subtracting 60% for water content of the mousse)[6]. This relatively low value is attributed to the lack of very thick accumulations on the tidal flat surface.

Clean-up activities initially consisted of the deployment of several tank trucks with skimmers. Their ability to remove the floating oil was restricted to periods of high tide, since the harbor is dry at low tide (see Plate 4-9, 4-19, and 6-4).

During the survey of AMC-1, we counted several dozen polychaetes on the surface of the flat in a generally moribund condition. However, several live polychaetes and small shrimp were found in the sediment, even though the interstital water was seriously contaminated with oil. By walking around on the flat, we found five different species of dead fish (Plate 5-20). Each had oil-blackened gill structures.

[6] Inasmuch as the oil was usually distributed in distinct masses, these oil volume calculations are an attempt to include the whole mass in a given area. This particular calculation includes all the oil in the eastern and southeastern portion of Portsall Harbor (Fig. 4-15), as determined from ground surveys and aerial photography.

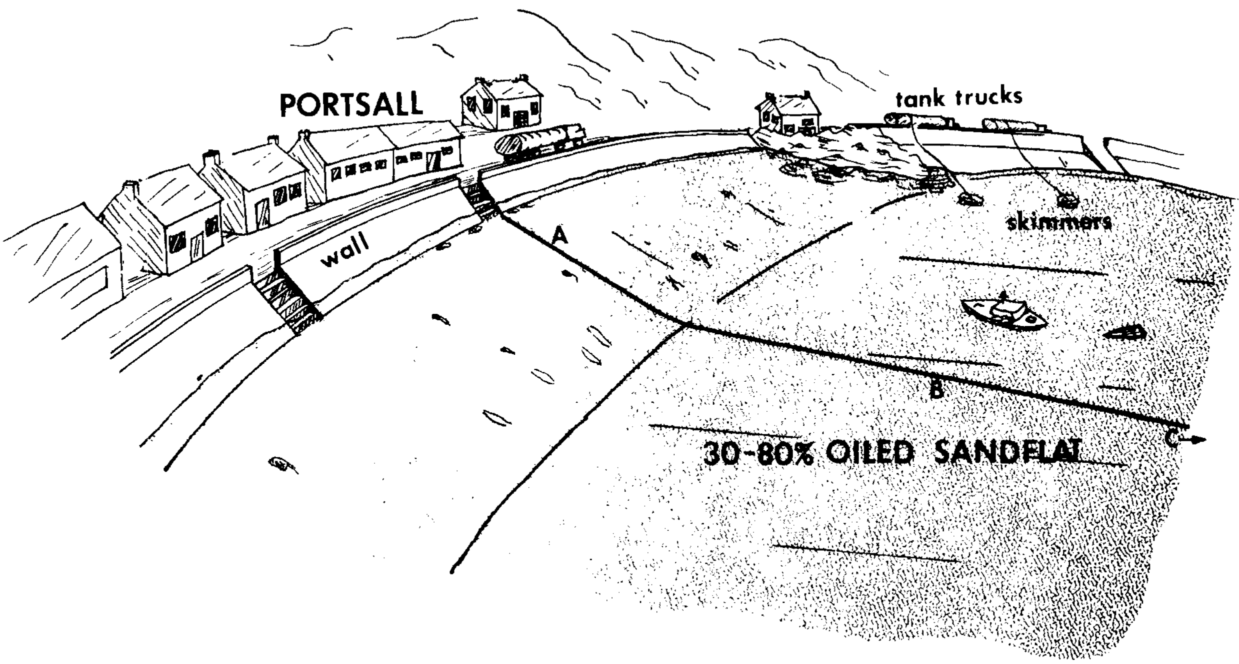

Figure 4-16. Sketch of station AMC-1 (Portsall) on March 22. Sediment sampling sites A, B, and C are indicated.

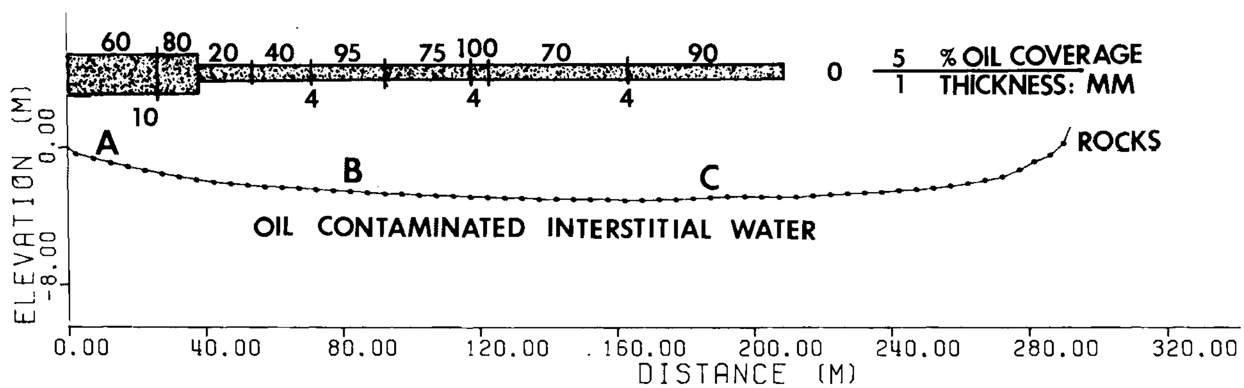

Figure 4-17. Topographic beach profile and oil coverage for station AMC-1 on March 22. The thickness of the shaded line is roughly proportional to the oil thickness. Letters A, B, and C indicate sediment sampling sites.

Table 4-4. Change in estimated oil tonnage at AMC stations in Section II. Oil increased at station AMC-2 because of oiling of the upper beach face and seawalls during spring tides.

Station Number	Date	Oil Present (metric tons)	Date	Oil Present (metric tons)	% Change
AMC-1	22 Mar	50.2	22 Apr	7.3	-85.46
AMC-2	22 Mar	1.8	22 Apr	2.4	+33.00
AMC-3	22 Mar	44.6	22 Apr	5.5	-87.70
AMC-4	23 Mar	284.1	31 Mar	36.9	-87.01
			22 Apr	2.5	-93.22
AMC-5	23 Mar	1146.9	22 Apr	2.5	-99.80

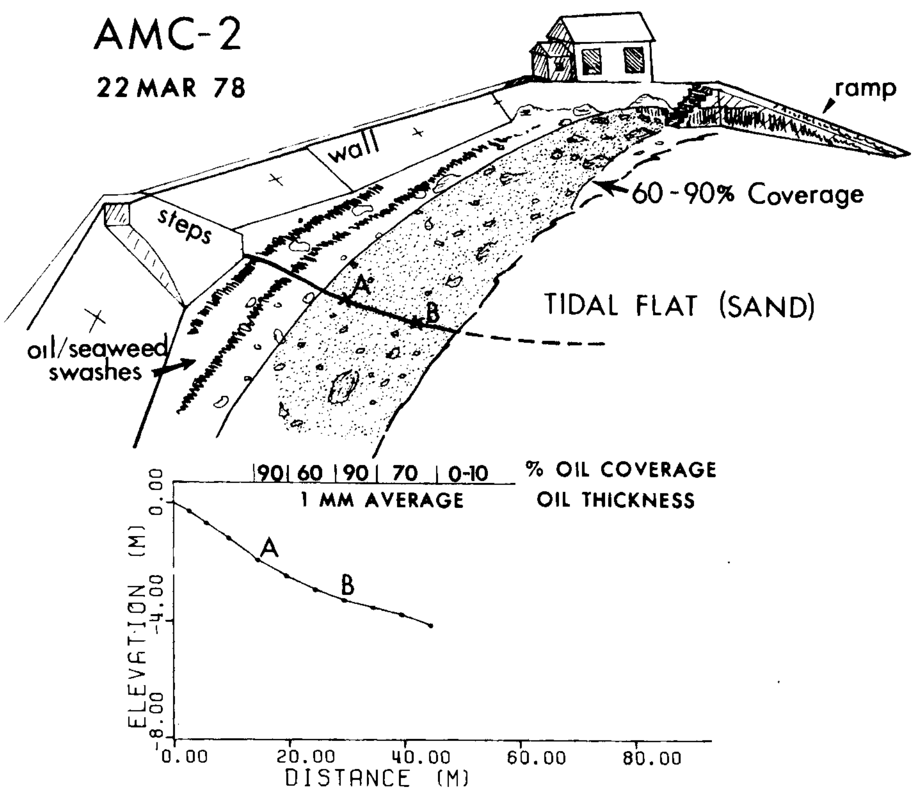

Figure 4-18. Sketch and topographic beach profile for station AMC-2 on March 22. A thin coating of oil was present on the beach at this time. After the spring tide conditions of March 25-28, the coating of oil extended 1.5 m up the seawall.

Station AMC-2 is located a short distance west of AMC-1 (Fig. 4-15). It was surveyed because it represented a coarse gravel environment with little wave activity. A sketch and profile of the area on March 22 is presented in Figure 4-18. Grain size data for the beachface area are presented in Table 4-3. During the March 22 survey, a thin coating of oil covered the lower beachface. The total volume present at that time was 1.8 tons.

Week of March 29. The beachface at AMC-1 was 100% covered by a thin layer of oil on March 29. Oil coverage of the intertidal flat area was reduced to 10%-15%. At station AMC-2, the beachface and lower portion of the seawall had become completely covered with oil. From observations, it became obvious that the majority of the oil was lifted off the tidal flat and transported shoreward to the beaches and seawalls as the tide rose. By March 29, the clean-up operation had changed from a skimming operation to cleaning the oiled walls with high-pressure hoses (Plate 6-14).

Week of April 20. Over a month after the grounding of the *Amoco Cadiz*, we resurveyed our stations at Portsall. The beachfaces of both stations (AMC-1 and AMC-2) were still covered with a 2 mm layer of oil. At AMC-2, an apparently new layer of mousse, brown in appearance, had been deposited at the last high tide swash line. The surface of the tidal flat had a few light oil sheens and a few large patches (approximately 30 m in diameter) of sediment-bound oil. The algal-covered rocks on the western side of the harbor were 80%-90% covered by brown mousse. Our calculations showed 7.3 metric tons present at AMC-1 (85% decrease) and 2.4 metric tons at AMC-2 (33% increase; see Table 4-4).

It appears that while most of the incoming oil was lifted off the tidal flat with each incoming tide (observed on March 22), a small percentage of it eventually became sediment-bound and stabilized on the bottom of the flat. These patches are not subject to resuspension and would be expected to degrade slowly by physical action. A diagram of this process is presented in Figure 4-19. The interstitial water of the tidal flat remained oil-contaminated.

Cleanup activity still continued on April 22. At least 30 men were raking up oil and seaweed, which was placed in buckets and carted away.

Summary. Because of the initially large quantity of oil within the Portsall area, much of the surface of the tidal flat was covered. As time progressed and the tidal range increased, much of this oil was lifted and transported shoreward. However, some oil did become sediment-bound and remained on the bottom. By April 22, the nearshore areas, especially the rocks with algae on the west side of the harbor, were still covered with oil. In addition, some oiled sediment patches remained in the center of the tidal flat. All interstitial water was still oil-contaminated.

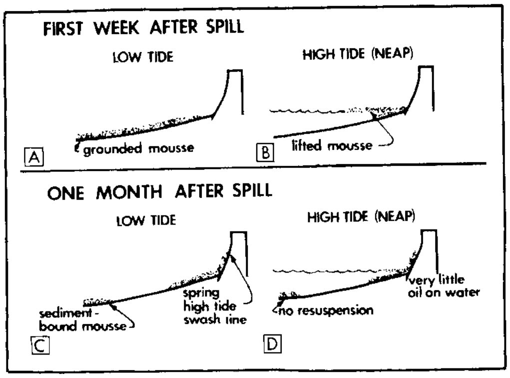

Figure 4-19. Observation of oil response at Portsall. During the first week after the spill, most of the oil lifted off the surface of the sand flat with every incoming tide. During our second survey mousse mixed with the sediment remained on the sand flat and beachface even as the tide flooded. Only a light oil sheen was visible on the surface of the water.

Station AMC-3

AMC-3 is located in a semi-sheltered area north of Portsall, somewhat closer to the wreck than stations AMC-1 and AMC-2 (Fig. 4-13). The station consists of a small beach composed of mixed sand and cobbles, which has a low-tide terrace with some algal-covered rocks. Grain size data are presented in Table 4-3. A sketch of the site during maximum coverage by oil (on March 31) is shown in Figure 4-20. There were approximately 44.6 metric tons of oil on this beach at that time. The leaching of ground water from the beach removed 10%-15% of the total surface cover. Also, in the area where the stream crossed the beach at low tide (Fig. 4-20), all oil was removed. This observation suggests that a similar technique (i.e., using flowing water to wash oil into collecting basins or troughs) could be used to clean similar beaches with a great deal of efficiency.

The major difference between our site surveys on March 22 and 31 at AMC-3 was the progressively higher oiling of the beach and seawall as a result of the spring tides of March 25 through 28. The amount of oil present did not significantly vary between the two visits. On March 31, there was an extensive cleanup operation taking place in which mousse and seaweed debris were raked, placed in buckets, and then dumped into a large metal container. A screen separated the newly added seaweed from a pool of oil below. Soldiers forced the oil through the screen by stomping.

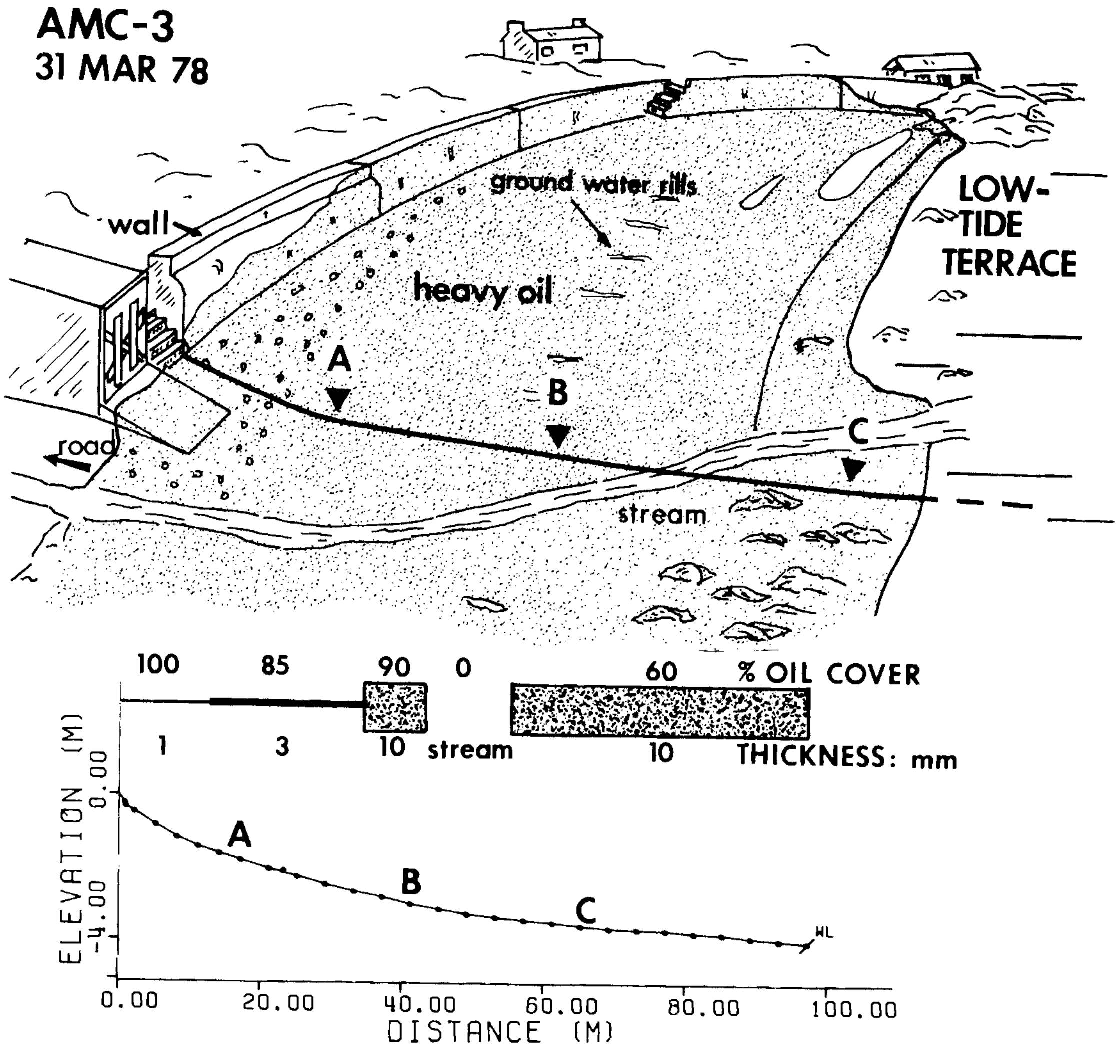

Figure 4-20. Topographic profile and oil coverage at station AMC-3 on March 31. High spring tides of March 25-28 were responsible for spreading oil up the wall behind the beach. Sediment sampling sites A, B, and C are indicated.

By April 21, most of the oil was gone from the area. An apparently new mousse swash line formed along the upper beachface. There were also some light oil streaks across the beach. The cobble area was still as heavily oiled as before. We calculated that 5.5 metric tons of oil were present on April 21, a reduction of 88% (Table 4-4).

In terms of biological damage, the most impressive observation was the presence of thousands of dead amphipods along the uppermost portion of the beach (by the steps). In contrast, new grass was found growing in the same area. On the low-tide terrace, new worm burrows were common. Oiled but empty cockle shells were also found, indicating the possible death by oiling of these organisms.

No burial of oil was observed on this particular beach, partly because of the occurrence of a hard peat-like layer from a relict marsh a short distance below the surface of most of the upper and middle beachface.

Station F-84

F-84 (Prat Leac'h-Kerros; Fig. 4-13) was an area that was also exposed to an extremely large quantity of oil. The entire intertidal zone was heavily oiled. An extensive cleanup program utilizing many trucks and tractors was carried out during the first few weeks after the spill. By April 21, the beach was 95% clean. However, some erosion of the scarp behind the beach had occurred, possibly as a result of removal of beach sediments during the cleanup operation.

Station AMC-4

This station lies within a northwesterly-facing cove which contains three arcuate beaches (Fig. 4-21A). Because of the strong prevailing westerly winds during the first weeks of the spill (a) the west side of the cove escaped oiling completely; (b) the central beach was oiled only on the eastern side; and (c) the remaining beach (AMC-4) was heavily inundated. The station at AMC-4 consists of a coarse-sand beachface grading into a fine-sand low-tide terrace. Dune sands overlying a clay base occur behind the beach. A sketch of the area on March 31 is presented in Figure 4-21B. The survey of March 23 is illustrated in Figure 4-22. Between March 23 and 31, the quantity of oil on the beach had decreased from 284 to 37 metric tons (see Table 4-4). During that same time interval, a total of 14.5 m^3 of sand was eroded from each meter of beach width (see Fig. 4-23). The cause of this extensive erosion was either the storm waves during the week of March 22 or the cleanup method applied, or possibly, a combination of the two. A small amount of recovery had already occurred when the profile was measured on March 31, in that some oil burial had taken place at the mid-beachface area and a small neap berm had formed.

The high spring tides of late March permitted the waves to wash oil high up onto the dune scarp (see sketch of March 31 in Fig. 4-21). Thousands of dead amphipods, identified by Jeff Hyland as Talitrus saltator (an upper intertidal species), littered the dune scarp (see Plate 4-24).

By April 21, deposition of 475 m^3 of sediment had occurred along the central portion of the beach (Fig. 4-23B). Oil was buried 20 to 25 cm by new sand. The beach appeared quite clean with only a light mousse swash along the last high tide swash line. Oil volume further

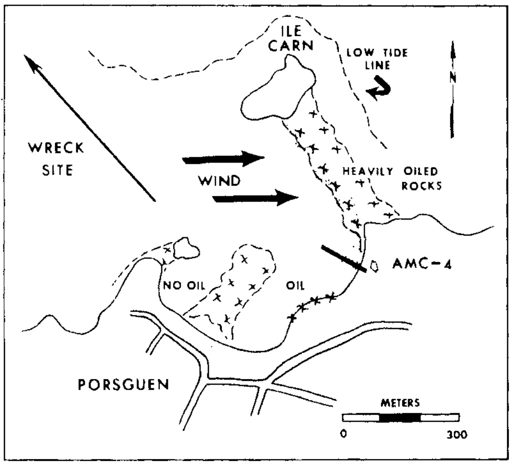

Figure 4-21A. Detailed location map and oil coverage for station AMC-4 during initial oiling.

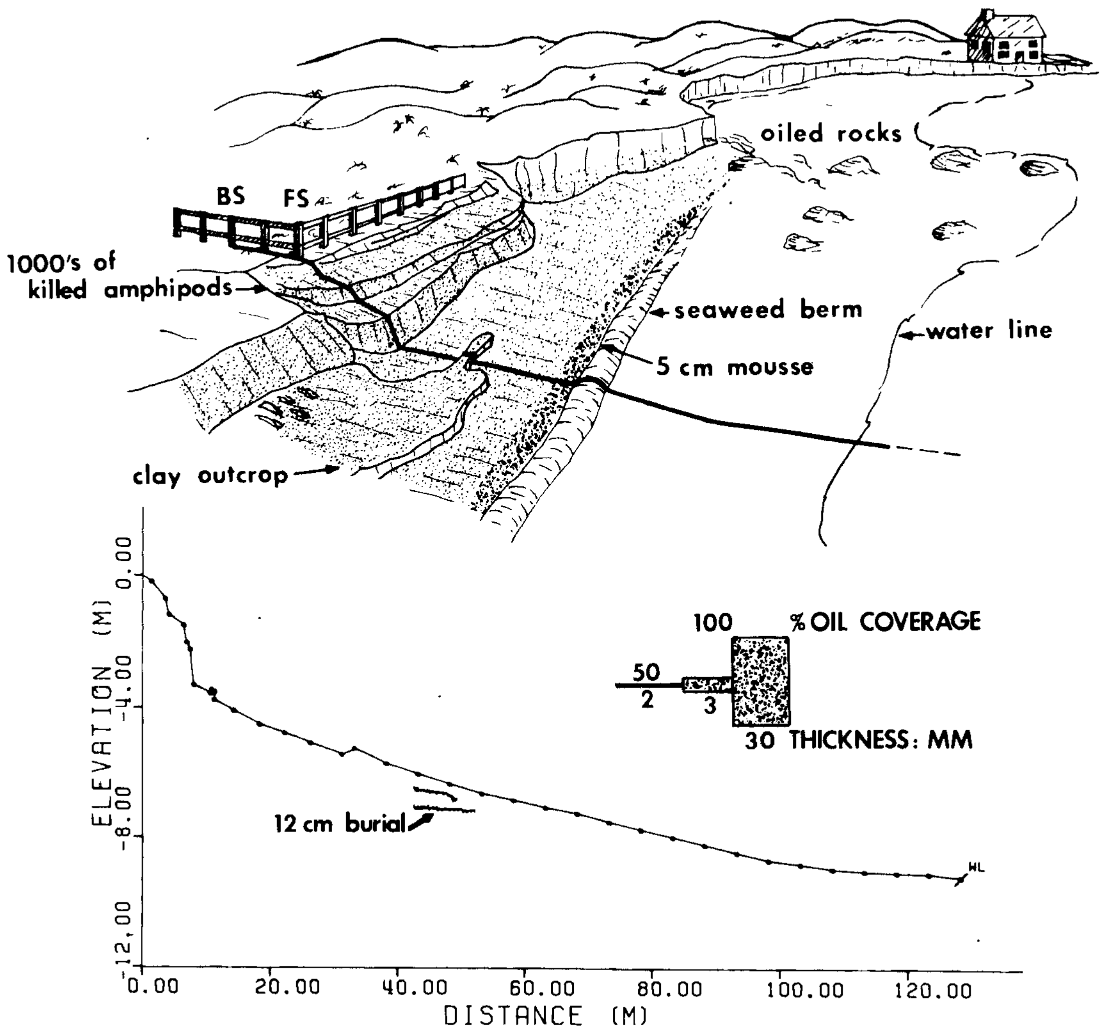

Figure 4-21B. Topographic profile and oil coverage at station AMC-4 on March 31. During the previous week, the shoreline had eroded significantly back, removing most of the oil from the lower beachface and exposing a relict red clay surface. Thousands of dead amphipods (Talitrus saltator) littered the dune scarp (Plate 4-27).

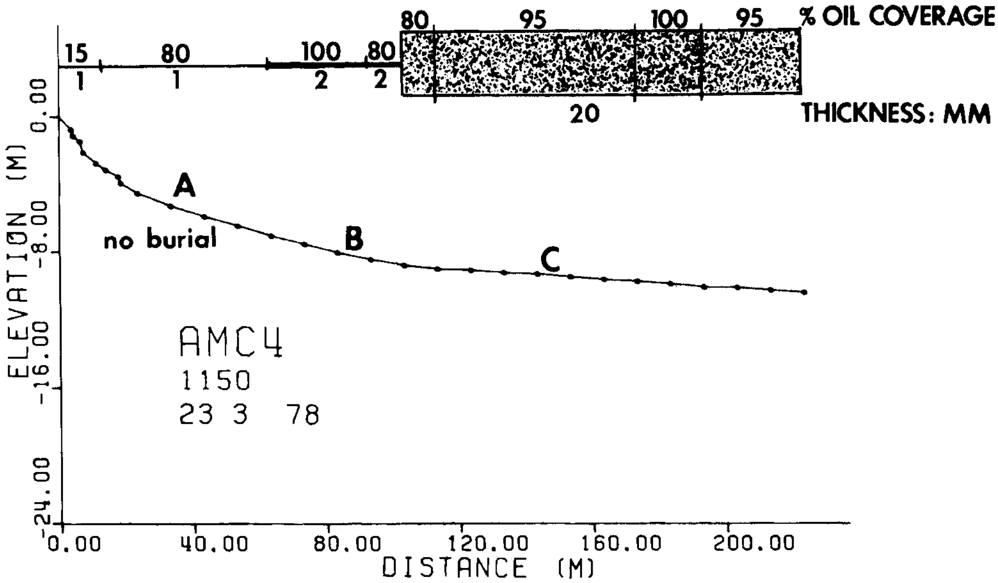

Figure 4-22. Beach profile and oil coverage at station AMC-4 on March 23. Oil coverage was more extensive on this date than during our second survey on March 31 (compare with Figure 4-21).

decreased to only 2.5 tons. There remained an ongoing cleanup operation in which oil on the beach was shoveled into buckets and then carted away by trucks and front-end loaders. Unfortunately, the use of heavy machinery on the beach may have succeeded in working oil deeper into the sediments.

Station AMC-5

The beach at AMC-5 (Fig. 4-13) consists of a wide fine- to medium-sand (Table 4-3) beach and low-tide terrace backed by an eroding dune scarp. The dunes, which are stabilized by short grasses, extend back from the beach over 1 km. Figure 4-24 shows a field sketch of the site on March 26.

We surveyed this station five times in order to monitor the short-term variability of the deposited oil. In addition, the beach was observed from mid-flood to mid-ebb tides on March 23, during which time all oil was lifted off the beach and transported further shoreward (because of the increasing water level). More importantly, most of the oil was transported into the channel behind the foredunes. As the tide receded, oil was again deposited on the beach. Oil was not transported alongshore because of the refraction of the incoming waves around the offshore mass of rocks. This system is diagramatically illustrated in Figure 4-25. We call this a tombolo effect. The role of the tombolo effect in causing localized oil deposition was observed in several other localities.

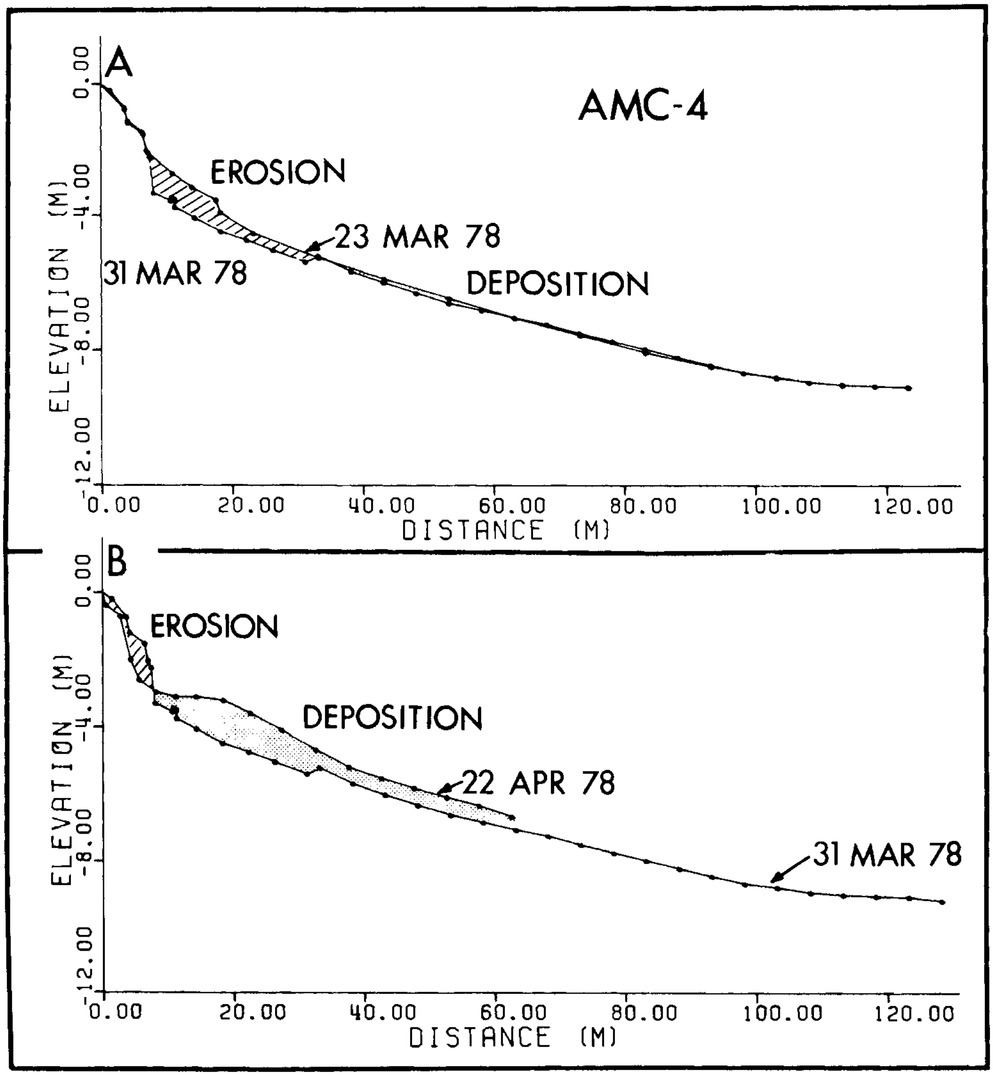

Figure 4-23. Comparison of beach profiles for site AMC-4 on (A) March 23 and March 31, and (B) March 31 and April 22. The erosion along the upper beachface was caused by storm waves, the applied cleanup operation, or a combination of both. The deposition of new sand on the beach by April 22 caused deep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

By March 31, a great quantity of oil was still present, but it had shifted across to the eastern side of the stream. All that remained on the western side were some very light oil swashes. In contrast, the eastern side contained oil layers 3 to 5 cm thick. A cleanup operation utilizing a front-end loader and dumptruck was underway (Plates 4-8 and 6-31). Oil and sand were being actively removed. During the spring tides of a few days earlier, the grassy areas along the stream channel behind the foredunes became heavily oiled. This area was being cleaned by bucket and shovel.

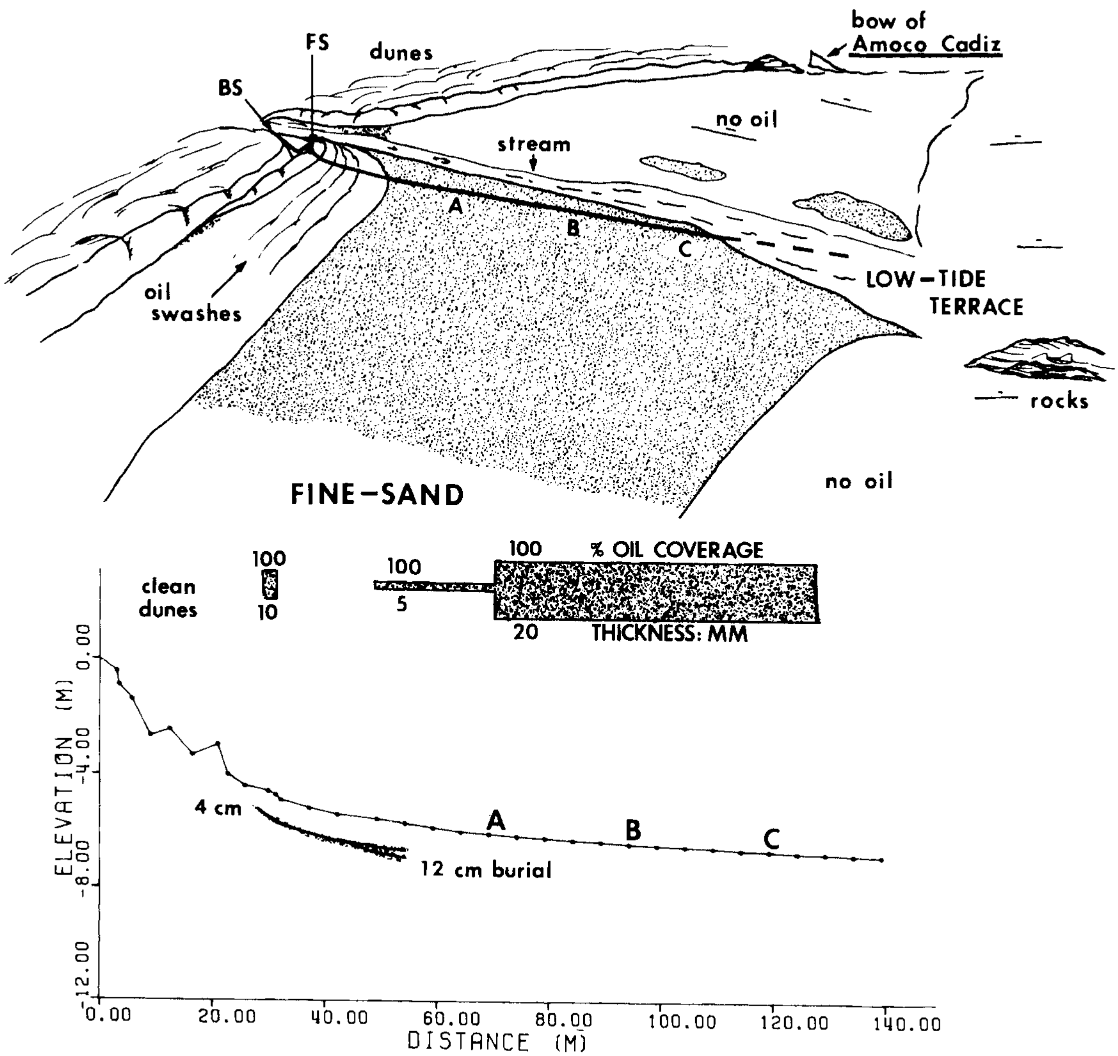

Figure 4-24. Topographic profile and oil coverage at station AMC-5 on March 26. Oil was trapped in this area because of the tombolo effect (see Fig. 4-25).

By April 22, the entire area appeared quite clean. Only light (probably recent) oil swashes remained. There was oil burial on both sides of the stream, but even this was relatively minor. We estimate that 2.5 tons of oil remained across the entire area. It appears that the use of the front-end loader was effective since the oil was thickly pooled in a single area. The removal of sand from this area will probably not prove to be a serious problem because the wide dune area behind the beach should provide adequate sand to replenish the beach.

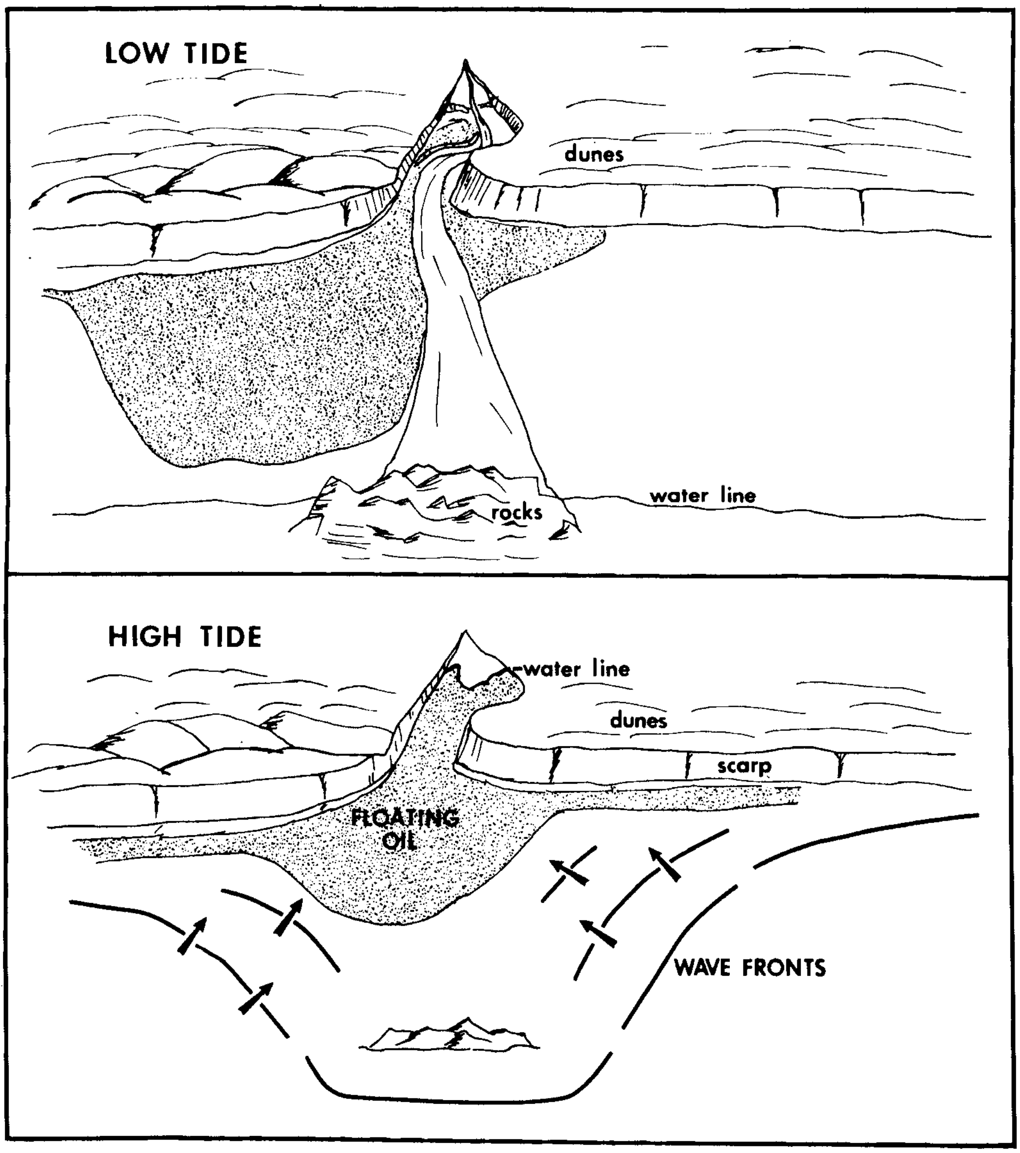

Figure 4-25. Illustration of local geomorphic control of oil deposition at station AMC-5. Oil became trapped because of the refraction of waves around the offshore rocks (a tombolo effect). During flood tide, all oil was lifted off the surface of the fine-sand beach and transported back into the marsh channel causing serious oiling. As the tide receded, oil was redeposited on the beachface. This cycle continued until the oil was removed by front-end loader (Plates 4-8 and 6-31).

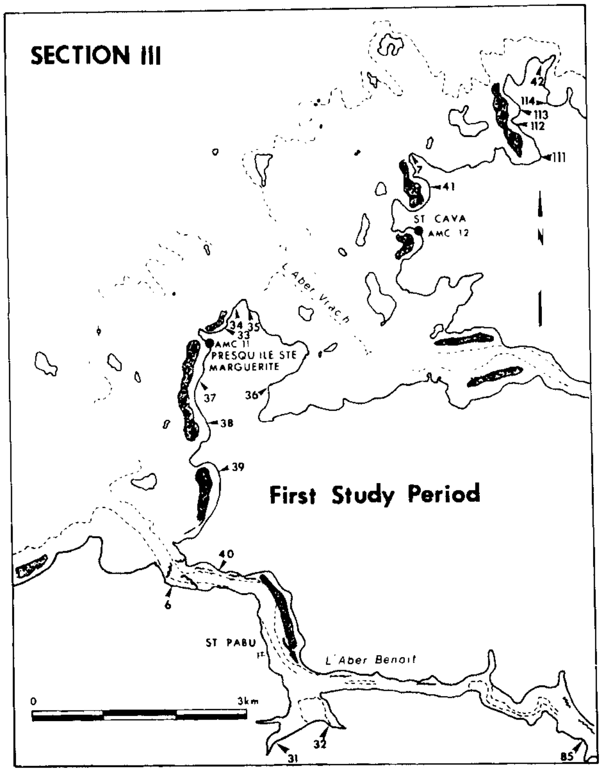

Figure 4-26. Detailed location map of Section III for stations between Les Dunes (East) and the Plouguerneau peninsula (F-6 to F-142). Initial oil concentrations are indicated by the dark-stippled pattern.

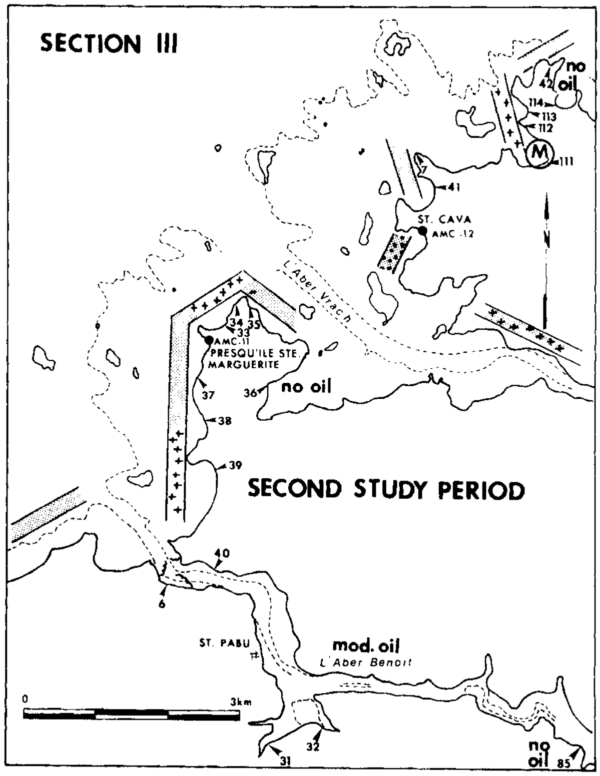

Figure 4-27. Oil distribution along Section III during our second study period, April 20-28. Heavy and light oil coverage are indicated by the plus and light-dot patterns, respectively. Oiled marshes are indicated by a circled M.

<u>Summary</u>

The stations surveyed in Section II illustrated a wide variety of morphological controls of oil deposition and oil-sediment interaction, including the following:

(1) The rocky environment south of Trémazan illustrated how rapidly oil can be removed under heavy wave action. Also, the re-oiling of these beaches three weeks later demonstrated the persistence of oil in the offshore waters during a massive oil spill.

(2) In the low-energy environment of the Portsall region, the upper levels of the beaches showed an increase of oiling through time. The behavior of oil on the tidal flats also changed through time, with the oil being lifted off the flats at high tide during the first few days, but later being partly sediment-bound to the bottom.

(3) Station AMC-4, which is located in a large, sheltered cove, illustrated how winds and coastal morphology can interact to cause heavy oiling on one side of the embayment, while opposite beaches remain clean.

(4) AMC-4 also illustrated a definite beach erosion phase during the early stages of oil inundation. The erosion period was followed by sand deposition, which caused deep burial of some of the oil.

(5) An illustration of the tombolo effect was provided by station AMC-5, where an oil mass became compartmentalized behind offshore rocks, thus escaping alongshore transport.

With respect to biological impacts, stations AMC-3 and AMC-4 had total kills of the indigenous amphipod populations. All stations contained heavily oiled algae. Dead fish and polychaetes were found on the tidal flat at Portsall.

4.9.3 Section III--Les Dunes East to Plouguerneau Peninsula

Section III includes two north-south trending bedrock headlands as well as two major rias, l'Aber Benoit and l'Aber Wrac'h (Figs. 4-26 and 4-27). Each ria was an important aquaculture area before the oil spill. The headlands have 1 to 2 km wide intertidal flats on the northwesterly-facing exposures. These flats were probably formed as a result of erosion by major storm waves approaching from the northwest. Oil impact was extremely heavy along most of the westerly-facing areas because of their position relative to the wreck site (for description of individual stations, see Table 4-5).

Table 4-5. Field observations of oil distribution at stations of Section III, Les Dunes-East to the Plouguerneau peninsula.

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
F-6	20 Mar	Ker-Vigorn Mouth of estuary.	Oil boom deployed - no oil at this time - to become heavily oiled starting 21 March.
F-31	26 Mar	Grand Moulin Western arm of l'Aber Benoit; tidal flat (mud) with rocks along shore.	Very light sheen.
F-32	26 Mar	Le Carpont Arm of l'Aber Benoit; tidal flat.	Heavily oiled.
F-85	31 Mar	Treglonou Large fine-grained tidal flats.	Heavily oiled along shoreline.
F-40	26 Mar	l'Aber Benoit Entrance to estuary.	Boom in place.
F-39	26 Mar	Prat Allan Arcuate cobble beach.	Heavily oiled with a large oil pool offshore.
F-38	26 Mar- 22 Apr-	Presqu'ile Ste. Margarite Coarse-sand pocket beach.	-heavily oiled. -oil burial 70 cm and 35 cm with light swashes on surfaces.
F-37	26 Mar	Presqu'ile Ste. Margarite Coarse-sand pocket beach.	Heavily oiled.
AMC-11	26 Mar-	les Dunes de Ste. Margarite Medium-sand pocket beach backed by eroding dune scarp.	-heavily oiled; extensive clean-up operation with manpower, front-end loaders, and backhoes.
	1 Apr-		-heavily oiled upper berm; front-end loader removing oiled sand.
	22 Apr-		-95% cleaned; some minor burial.
F-33	26 Mar	South of Penn Enez Sand pocket beach.	Heavily oiled.
F-34	26 Mar	Penn Enez Boulders in front of small scarp beach.	60 m - heavily oiled.
F-35	26 Mar	Penn Enez (East side) Small pocket beach.	Moderate oiling.
F-36	26 Mar	Poullac Harbor Wide exposed sand flat.	No oil.

Table 4-5 (continued)

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
AMC-12	27 Mar-	St. Cava Coarse-sand beach with a medium-sand, very broad, low-tide terrace lying between two rocky headlands.	-very heavy oiling of beach and upper tidal flat; large kill of cockles.
	1 Apr-		-still heavily oiled beach; manual clean-up operation.
	23 Apr-		-beachface is oil-stained, but without significant accumulations; oil mixed 17 cm into the low-tide terrace by the heavy trucks; interstitial water still contaminated.
F-41	20 Mar-	Kervenny Brag Sand tidal flat abutting a seawall and rocks located in a large pocket cove.	-very light swashes.
	27 Mar-		-very heavily oiled; extensive clean-up operation underway.
	23 Apr-		-95% clean, but the tidal flat has been churned up by heavy equipment.
F-7	20 Mar-	Lilia Rocks with algae along a channel at tow tide.	-oil streaks on the water; very light oil on shore.
	1 Apr-		-light oil sheen on water; very light oil on shore.
	23 Apr-		-definite mousse zone on algae and rocks.
F-111	23 Apr	Kerjegu Small embayment off of a large sand flat.	Marsh in upper portion of embayment - lightly oiled; otherwise clean.
F-112	23 Apr	Kelerdut Large tidal flat embayment protected by island and rocks offshore.	Clean tidal flat, but badly oiled shoreline; oiled gravel is piled up to be removed.
F-113	23 Apr	Porz Guen Rocky headland with small harbor/embayment.	All of the rocks heavily oiled, especially the northern corner of the harbor; beachface is lightly oiled; clean-up operation previously removed much of the oiled algae.
F-42	27 Mar	Porz Guen Angular boulder beach.	Lightly oiled.
F-114	23 Apr	Porz Guen Sandy pocket beach protected by rocky headlands on the north and west.	No oil.

Oil Impact, l'Aber Benoit and l'Aber Wrac'h

No oil was visible in l'Aber Benoit during our first visit on March 20. A number of booms had been laid in preparation for the oil. However, during our flight on the next day, oil could definitely be seen entering the estuary through the booms (Plate 4-30). Later, oil coverage became very heavy along the edge of the estuary and on some surfaces of the fine-grained tidal flats.

L'Aber Benoit has been selected for special study by CNEXO-COB. Dr. Laurent D'Ozouville had prepared a preliminary report on their work, and has given us permission to include his results in this report. His report follows (translated by Jacqueline Michel):

Impact of Pollution by the *Amoco Cadiz* in l'Aber Benoit

L'Aber Benoit can be divided into three geomorphological units:

Part A: from the entrance of l'Aber Benoit to Loc Majan (Fig. 4-28A), a zone characterized by well-developed sand or pebble beaches.

Part B: from Loc Majan to Treglonou (Fig. 4-28B), a narrower zone with midflats flanking a rocky shore.

Part C: from the port of Treglonou to the head of l'Aber Benoit (Fig. 4-28C); this zone is dominated by marsh grasses which become more prevalent toward the head of the bay.

Oil Distribution in l'Aber Benoit

(1.1) Geographical distribution

Several aerial surveys (fixed wing and helicopter) allowed us to map the oiled zones in l'Aber Benoit. It appears that:

-past the port of Treglonou toward the head of l'Aber, little pollution occurs.

-between the entrance of l'Aber Benoit and the port of Treglonou, the orientation of the shoreline with regard to the winds and currents explains the geographical distribution of the oil and helps us understand why certain areas are less polluted.

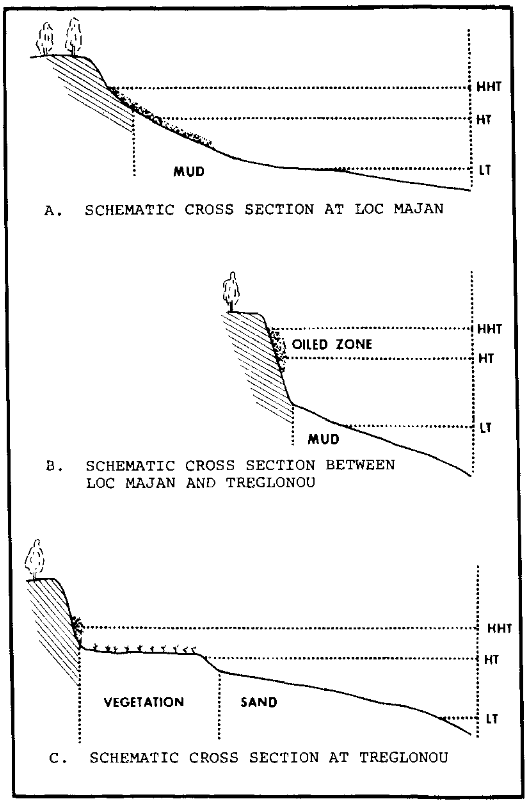

Figure 4-28. Oil distribution within l'Aber Benoit: (A) at Loc Majan, (B) Loc Majan to Treglonou, and (C) Treglonou to the head of the Aber (from preliminary report by D'Ozouville).

(1.2) Distribution with depth:

variable depending on the nature of the substrate.

-sand: penetration occurs but it is hard to say just how deep.

-mud: surficial, yet animal burrows permit some oil to penetrate.

-marsh grass: oil sits on the surface of the grasses which are covered only during high tides.

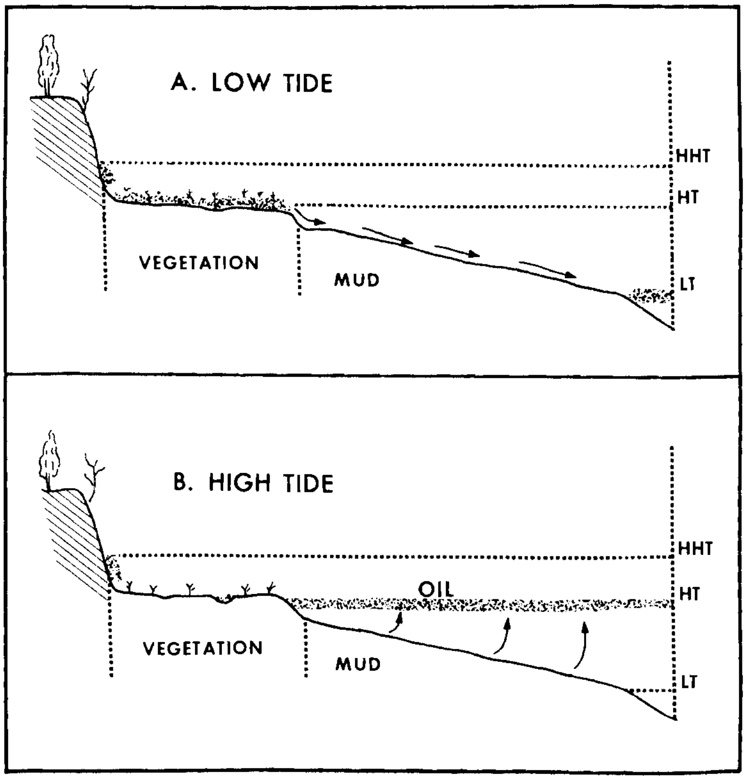

Figure 4-29. Oil reaction within l'Aber Benoit estuary during low and high tides. Much of the oil was resuspended off the flat as the tide flooded. (From a preliminary report by D'Ozouville.)

(1.3) Study of the pollution along transverse cross-sections (Fig. 4-29).

Oil which has accumulated in depressions in the rocks and grasses flows downhill on the surface of the mud during ebb tide. During flood tides, some oil is resuspended and slowly removed. It should be noted that a simple disturbance in the water causes the resuspension of bottom-held oil. It appears that the oil held in these depressions will have a long residence time in l'Aber Benoit.

Recommendation for Cleanup

Generally, it is necessary to prevent mechanical equipment on the polluted areas, and even more so on the marsh grasses.

(2.1) Upriver of the port of Treglonou--this area is covered by marsh grass and was not affected much by the oil. It is best not to attempt to clean this area except locally where the oil has accumulated in gaps in the marsh grass.

(2.2) Between Loc Majan and the port of Treglonou--this zone is primarily rocky, and is best cleaned by water spray and recovery of the oiled water.

(2.3) From Loc Majan to the mouth of l'Aber Benoit--cleanup consists of manual methods for the beaches and water spray for the rocks.

(2.4) Aerial observations showed that there were places of preferential oil accumulation (indicated on Figure 4-26). At these sites, with well-placed booms, oil could be accumulated rapidly and removed by pumps much more easily.

After these reflections, it seems to us indispensabe to continue the study of l'Aber Benoit. Through further study, we will gain a better understanding of the mechanisms of estuarine oil pollution and recovery. Also, the economics of the oyster fisheries make it essential to follow the de-contamination of the estuary in space and time.

Oil Impact on the Coast between F-36 and F-39

The area under discussion is the headland that separates l'Aber Benoit from l'Aber Wrac'h. Initially, oil accumulation was very heavy on the western side of the headland, while the eastern side (F-36) escaped oiling entirely (Fig. 4-26). As a result of the strong westerly winds, large oil pools formed at each indenture in the coastline. Station F-38 was particularly interesting in that it contained several thick layers of buried oil (Fig. 4-30), the deepest of which was 70 cm. This was the deepest burial observed during our study.

A detailed study was conducted at station AMC-11, a medium- to fine-sand pocket beach. A sketch of the area is provided in Figure 4-31. Sediment data are presented in Table 4-6. This area was selected because of its location with respect to the wreck site, the large amounts of oil present in the area, and because it had an ongoing cleanup operation.

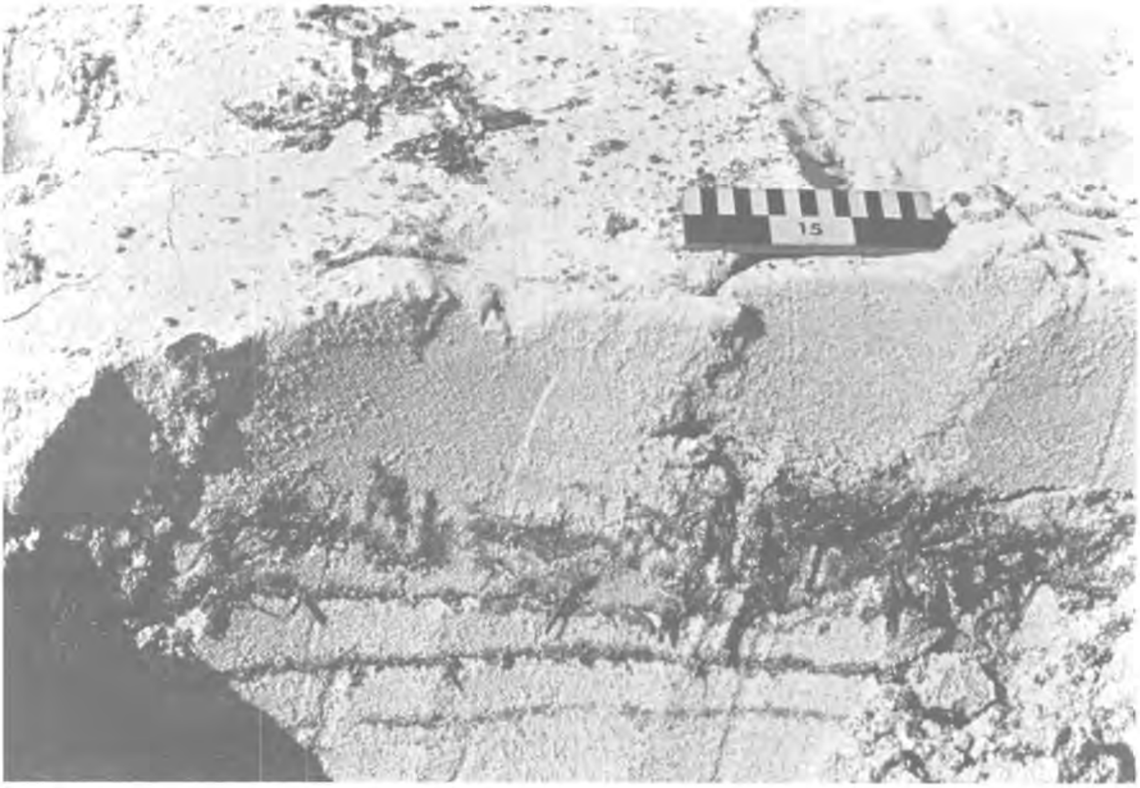

Figure 4-30. At station F-38 on April 22, we found buried oil, the deepest of which was 70 cm (not pictured). This was the deepest burial we observed at any site during the entire study. The sediment is composed of well sorted coarse-sand.

On March 26, oil covered the entire beachface and much of the fine-sand low-tide terrace (Fig. 4-31). We estimate that 175 tons of oil were present at that time (Table 4-6). In an attempt to remove the oil, a long trench was dug with a backhoe to collect the oil on the incoming and receding tides. The trench system was necessary to operate the suction hoses from tank trucks and honeywagons. Sand was taken from the base of the dune scarp to form a barrier to direct oil runoff into the trough.

Upon our return on April 1, some erosion had occurred at the upper beach face, possibly in response to the previous sand removal. As is shown in Figure 4-32, approximately 3 m of beach was lost. The upper 25 m of beach remained heavily oiled, up to 1.5 cm thick in some areas. A newly formed neap berm buried oil 5 cm below the surface. The lower part of the beach was clean, more likely due to wave and tidal current action than to mechanical cleanup. The trench that had been dug earlier was filled in. Unfortunately, the sand filling the trench was heavily mixed with oil. This oil could be the source of the noticeable ground water contamination in the area, and, hence, could have a long-term impact on the biological productivity of the area.

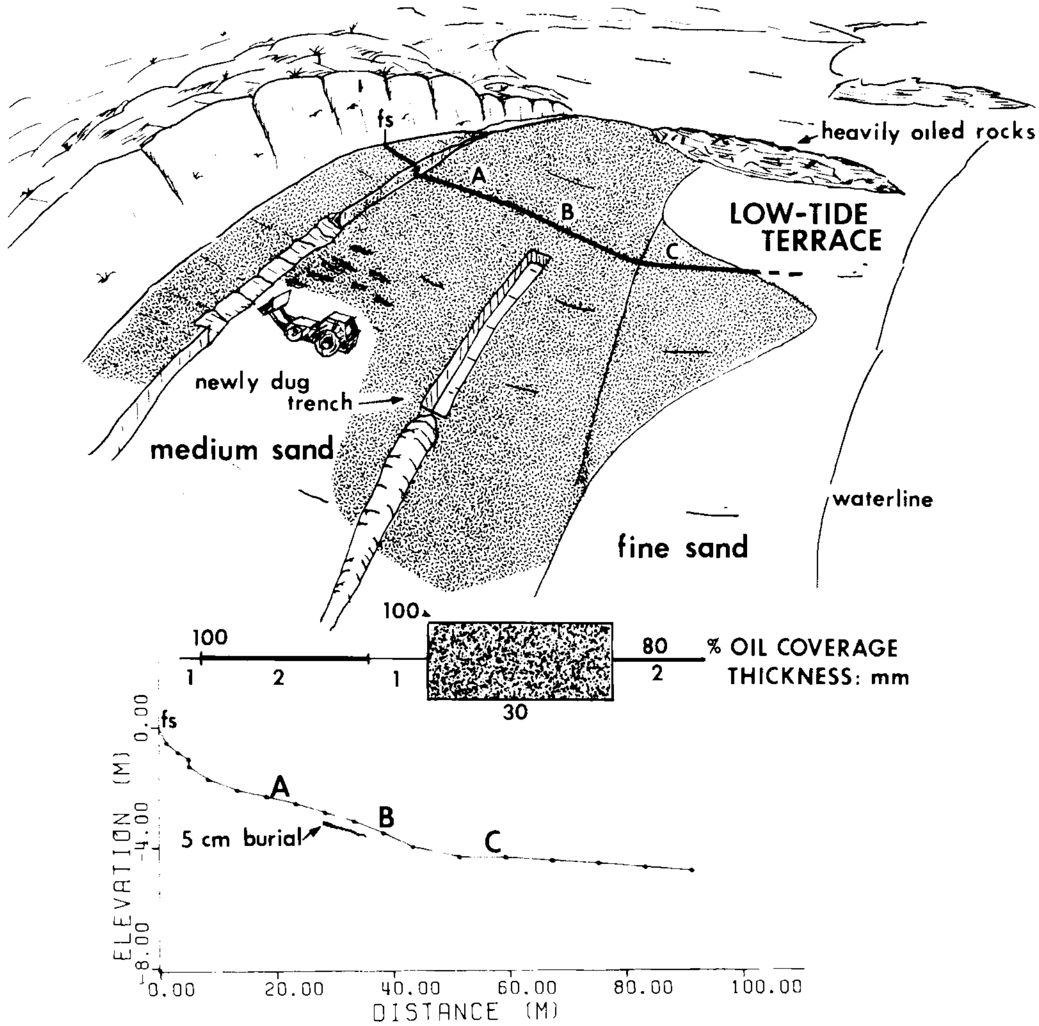

Figure 4-31. Topographic profile and oil coverage at station AMC-11 on March 26. Heaviest oil accumulations occurred on the lower portion of the beach.

When we returned to the site on April 22, we observed very little oil on the beachface. By our calculation, only one ton of oil remained on the whole beach (Table 4-6). Therefore, over 174 tons of oil was removed during the month following the spill. The upper beachface was extensively populated by amphipods, even in areas previously heavily oiled, indicating a rapid recovery by that organism. Cleanup activities had shifted from the beach to the still heavily oiled rocky areas on either side. Cleanup consisted of blasting the oiled cobbles with water under high pressure. The process was successful, though it mixed oil into the cleaner sediments on the beach, but was very time consuming. On the southern side, volunteers were scooping oil from between the boulders by hand.

Figure 4-32. About 3 m of beach erosion occurred at AMC-11 during the week after mechanical removal of sand from the base of the dune scarp. Deposition on the lower beachface caused oil to be buried 5 cm below the surface.

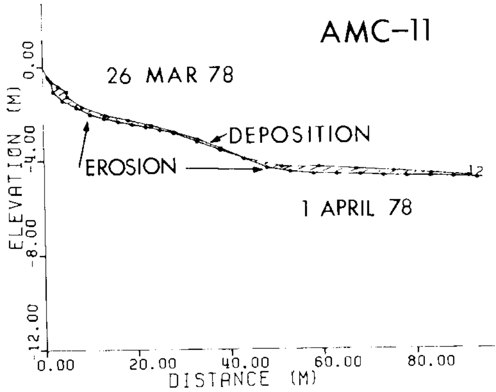

Table 4-6A. Grain size data for stations AMC-11 and AMC-12 in Section III.

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)

[1] Size Class

CS = coarse sand

MS = medium sand

FS = fine sand

[2] Sorting

MWS = moderately well sorted

PS = poorly sorted

Table 4-6B. Change in oil quantity at stations AMC-11 and AMC-12.

Station Number	Date	Oil Present (metric tons)	Date	Oil Present (metric tons)	% Change
AMC-11	26 Mar	175.2	22 Apr	1.0	-99.40
AMC-12	27 Mar	357.7	23 Apr	6.3	-98.30

Oil Impact on the Coast between AMC-12 and F-42

This west-facing shoreline (Fig. 4-26) was exposed to predominant wave and wind approach during the early days of the spill. The area between stations AMC-12 and F-7 was impacted by major concentrations of oil, whereas the more northerly stations received lesss.

Station AMC-12, which was studied in some detail, is a coarse-to medium-sand beach abutting an eroding, low-lying dune field (see Table 4-5 for sediment data). Rocky headlands flank both sides of the beach. A sketch and topographic profile are presented in Figure 4-33.

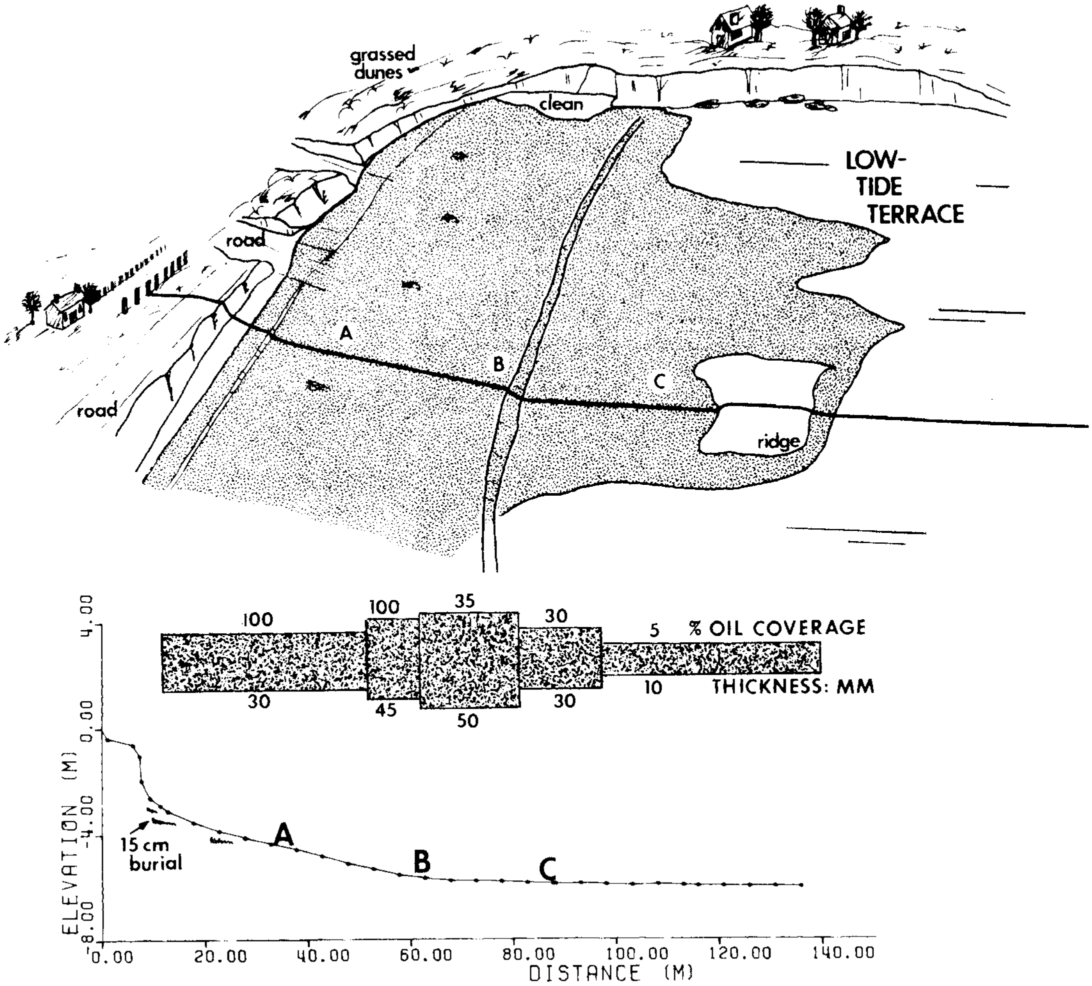

Figure 4-33. Topographic profile and oil coverage at station AMC-12 on March 27. The thickness of the oil coverage line is proportional to actual oil thickness. Heaviest accumulations occurred on the low-tide terrace in a low-relief runnel behind a ridge.

On the date of our first survey (March 27), the beachface at AMC-12 was entirely coated with oil, as was much of the low-tide terrace. Oil was ponded 4 cm thick in a runnel landward of a low-relief ridge on the low-tide terrace. Our estimates indicate that 358 metric tons of oil were present on the beach on March 27 (see Table 4-6)[7]. A large number of dead cockles (Cerastoderma) had accumulated along the step of the high-tide beachface (avg. of $6/m^2$; see Plate 4-25).

During our return visit on April 23, the beachface and low-tide terrace were cleared of massive quantities of oil; however, 70% of the beach sediments still appeared oil stained. Some slight burial (6 cm) was observed. The hard gravel and clay base that underlies the beach inhibited much oil penetration. On the low-tide terrace, oil was mixed 17 cm deep into the sand by the trucks used in the cleanup operation. Interstitial waters were contaminated to as far as 50 m seaward on the low-tide terrace. We estimate that 6.3 tons of oil remained on the beach on April 23.

When we first viewed station F-41 (Kervenny Brag) on March 20, it contained only light oil swashes. By March 27, it was extremely heavily oiled. An extensive cleanup operation which began before March 27 continued past our visit of April 1. By April 23, the sand flat was 95% cleared of oil. Only the seawalls retained oil. Unfortunately, the tidal flat was badly churned up by the cleanup machinery.

Some of the areas north of F-41 were moderately oiled (F-112 and F-113 in particular), but most areas only received light oil. These areas appear to have escaped major oil damage because of the sheltering effect of offshore islands.

Summary

Section III provided a number of interesting observations with regard to oil deposition:

(1) Oil booms across the mouth of l'Aber Benoit and l'Aber Wrac'h were ineffective in preventing pollution in those rias, which were badly damaged in places.

(2) The maximum depth of oil burial observed in the study (70 cm) occurred at the coarse-sand beach at F-38.

(3) There was noticeable erosion of the dune scarps at beaches where sand was removed by the cleanup operation.

[7] This is a revised value from our preliminary field report, in which we reported 538 tons on this beach.

(4) The trenching technique observed at AMC-11, while effective for cleanup, probably increases the pollution of the interstitial water of the beach.

(5) Oil deposition is closely controlled by local beach morphology, as was illustrated by oil accumulation in the runnel at AMC-12 (see Fig. 4-33).

(6) In general, most of the stations in this section located on the exposed headlands were remarkably clean one month after the spill, especially considering the large volumes of oil that came ashore during the first few days of the spill. The rapid natural cleaning of these areas is probably a function of the high degree of exposure of the headlands to northwest winds and waves. The general erosional nature of the area is evidenced by (a) the overall retreat of the shoreline (leaving behind a wide, wave-cut intertidal platform), and (b) the thin, non-depositional character of many of the beaches.

4.9.4 Section IV--Trouloc'h to Brignogan-Plage

The coastline of Section IV is oriented northeast-southwest (Fig. 4-34). Much of the coastline consists of depositional dune areas with granitic bedrock outcrops. An exception to this general shoreline orientation is the Neiz Vran peninsula (AMC-13), which is oriented roughly north-south. Table 4-7 gives brief descriptions of the study sites, and Table 4-8 presents sediment and oiling data.

Oil Impact

Little of the oil spilled by the *Amoco Cadiz* impacted this coastline. Oil impact during the first two weeks of the spill was generally restricted to those areas that are aligned in a north-south direction (e.g., stations F-44, AMC-13, F-48, and F-50; see Fig. 4-34).

One month after the spill, all major oil accumulations were dispersed. Only light oil swashes were visible at all stations. Sheltered rocky areas commonly were more heavily oiled than neighboring sand beaches.

Station AMC-13 (Fig. 4-34) was studied in detail. It consists of a small medium- to fine-sand crenulate beach oriented north-northeast/south-southwest. Rocky headlands are located on both sides of the beach. Because of its orientation with respect to the wreck site, a large quantity of oil estimated at 248 metric tons (Table 4-8B) accumulated during the first two weeks after the spill. During our first site visit on March 26 , most of the beachface and upper low-tide terrace was 100% oil covered. The topographic profile and oil coverage diagram are presented in Figure 4-35. Thick (30 cm) mixtures of mousse and algae accumulated at the upper portions of the beach and along the

Table 4-7. Field observations of oil distribution at stations of Section IV (Trouloc'h to Brignogan-Plage).

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
F-115	23 Apr	Penn ar Stréjou Small sandy pocket beach facing north; sandy dunes backing the beach; tidal flat in front of beach.	The beach contains some light oil swashes; rocky areas are moderately oiled; some of the algae is coated by a thick covering of mousse.
F' 116	23 Apr	Corejou Neck of a peninsula, connects an island offshore; embayments north and south.	No oil on north side of jetty; lightly oiled cobbles on south side.
F-43	27 Mar- 23 Apr-	Mogueran An embayment with a large tidal flat (1-1½ km) in front; rocky on both sides with much rock debris on beach.	-clean; no oil. -some new oil has come onshore; very light, a mousse froth that is on the upper portions of the beach and is mixed in with the algae.
F-117	23 Apr	la Secherie Large sandy beach with sand dunes backing it.	Lightly oiled along the swash lines as well as on some of the rocks.
F-44	27 Mar- 23 Apr-	Le Curnic Contains a jetty separating two sandy beaches; much rock debris on the beaches.	-rocks on the jetty are lightly to moderately oiled. -light oiling of rocks on both sides of jetty; beaches clean except for light oil swash lines.
F-118	23 Apr	Lerret Near the head of a large estuary/tidal flat.	Marsh in the upper intertidal zone is moderately oiled; light oil swashes on sand leading down from oiled seawall.
F-119	23 Apr	Tréssény Middle of a large estuary/tidal flat.	Lightly oiled rocks and seaweed swash line.
AMC-13	27 Mar- 23 Apr-	Roc'h Quelennec Medium- to fine-sand beach and tidal flat with rocky headlands on both sides; large boulders on beachface.	-very heavily oiled beachface; oil 30 cm thick, mixed with algae along upper swash zone. -surface 99% clean, but deep 38 cm burial along upper beachface; also has oil contaminated interstitial water.
F-45	27 Mar- 23 Apr-	Neiz Vran Mixed sand and rock debris beach with large tidal flat in front.	-no oil. -upper intertidal algae and seaweed lightly oiled.
F-46	27 Mar	Boutrouille Well-sorted granule beach	Very light oil swashes.
F-120	23 Apr	(near) Louc'h an Dreff Coarse-grained beach with a fine-sand low-tide terrace.	Clean except for a few minor oiled swash lines.
F-47	27 Mar	(near) Kerlouarn Steep, mixed-sand and granule beach.	Lightly oiled rocks.

Table 4-7 (continued)

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
AMC-14	27 Mar- 23 Apr-	Kerlouarn Sheltered, grassed, embayment used as a small harbor.	-5 m wide heavily oiled grasses. -a dirt road constructed over oiled swash.
F-48	27 Mar- 23 Apr-	Carrec zu Sandy beach with large dune system; relict marsh outcropping on beach - therefore, an erosional beach.	-light oil swashes. -clean sand with light oil swashes.
F-49	27 Mar	(near) Chapelle Pol Sandy beach with large dune system; some rocks and rock debris scattered along beach.	Heavily oiled rocks.
F-50	28 Mar- 23 Apr-	Lighthouse at Pointe de Beg Pol Rocky point sticking out with sandy beaches on both sides.	-heavy oiling on both rocks and beaches. -sand tinted brown, but now only lightly oiled; rocks also oiled lightly.
F-121	23 Apr	Kervernen Rocky beach with some sand underneath.	Sand is clean, but rocks are lightly to moderately covered with oil; some algae is clinging to rocks and surviving the oil coverage.
F-122a	23 Apr	Brignogan Plage Large harbor tidal flat.	Light oil swashes; light oil on algae; some of the rocks are dark from light oil staining.

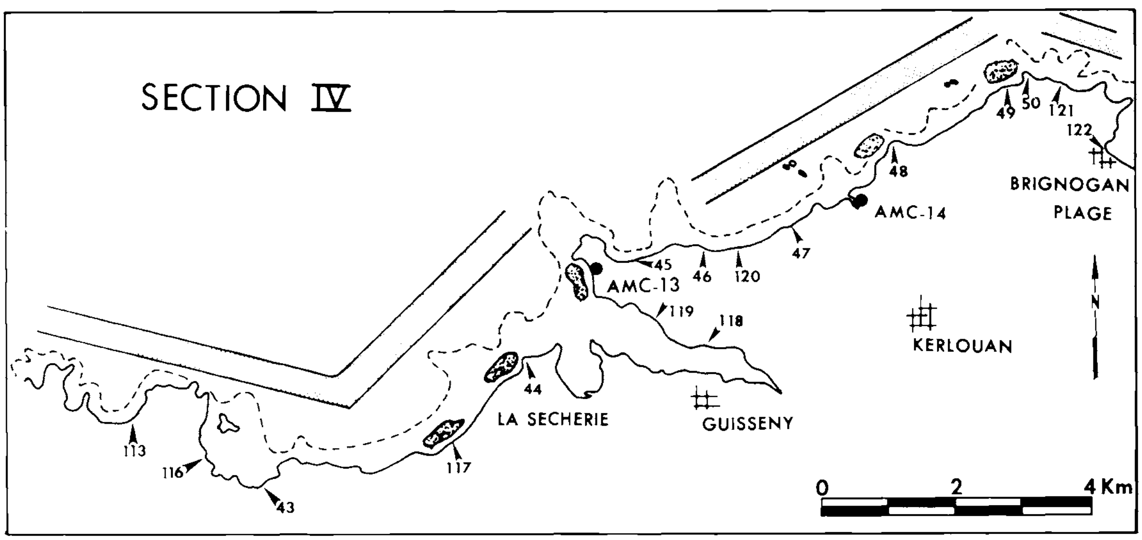

Figure 4-34. Locations of stations in Section IV, from Trouloc'h to Brignogan-Plage. Initial oil depositon was generally limited to those areas trending perpendicular (north/south) to overall oil transport. Initial oil depositon is indicated by the dark-stippled pattern. Oil coverage during our second study period (April 20-28) was light in all areas (indicated by the light-dot pattern).

Table 4-8A. Grain size data for AMC stations 13 and 14 located in Section IV of the survey area.

Sample	Graphic Mean	Size Class[1]	Skewness	Standard Deviation[2]
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)

[1]Size Class

MS = medium sand

FS = fine sand

[2]Sorting

MWS = moderately well sorted

MS = moderately sorted

PS = poorly sorted

Table 4-8B. Estimated quantity of oil present during first and second surveys. Unfortunately, station AMC-14 was destroyed by road building and had to be discontinued.

Station Number	Date	Oil Present (metric tons)	Date	Oil Present (metric tons)	% Change
AMC-13	27 Mar	248.3	23 Apr	0.6	99.97

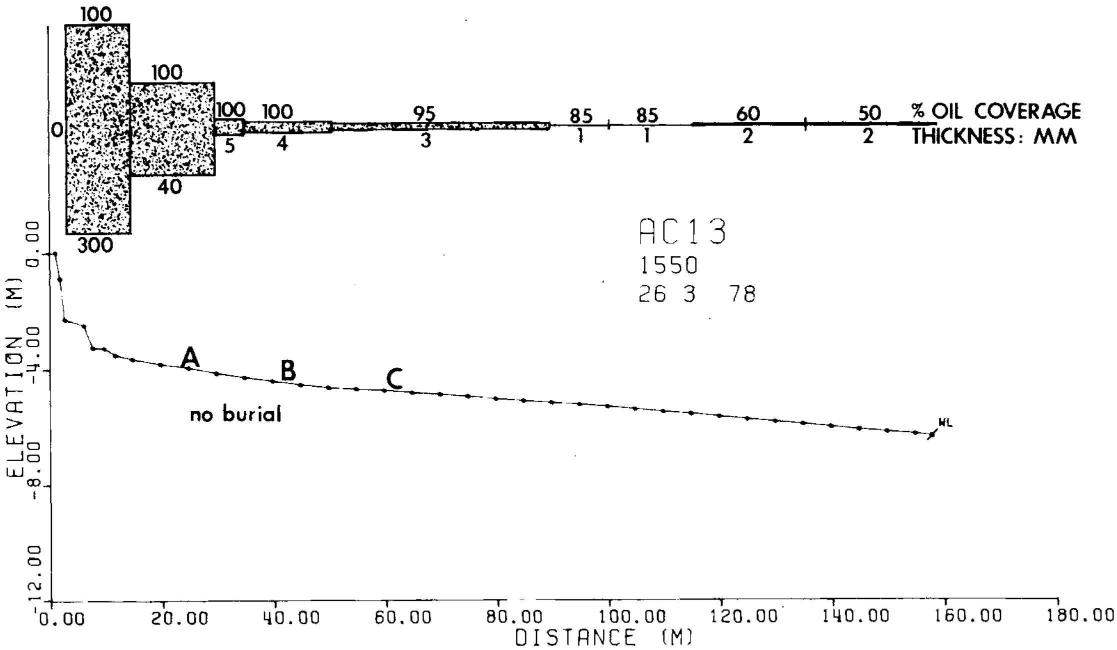

Figure 4-35. Topographic profile and oil coverage at station AMC-13 on March 26. Thick oil and algae were found along the upper beach face.

joint pattern of the rocks (see Plate 4-17). Around some of the large boulders on the beach, thick oil accumulations collected in the scour pits (see Plate 4-16).

On our return visit on April 23, the beach had recovered remarkably. The sand was clean with only recent, very light oil swashes. The rocks, previously dripping with oil, appeared only slightly blackened. According to a person living in the area, there was a cleanup operation during the first week in April. However, part of the visible recovery was due to the burial (38 cm maximum) of some of the oil by new sand. The comparison of our profiles (in Fig. 4-36) shows this deposition. The interstitial water of the low-tide terrace remained noticeably oil contaminated; however, castings of the worm Arenicola sp. were found in abundance. We have estimated that the oil remaining on the beach on April 23 was less than one metric ton. Altogether, an amazingly rapid recovery of the area is indicated, due to a combination of natural and man-engineered cleaning processes.

Station AMC-14 is located in a small embayment populated by marsh grasses. On March 27, a 5-m-wide, 3-cm-deep band of mousse froth had been deposited on the grass. However, by April 23, a dirt road had been constructed over the oil, thereby destroying its value as a study area.

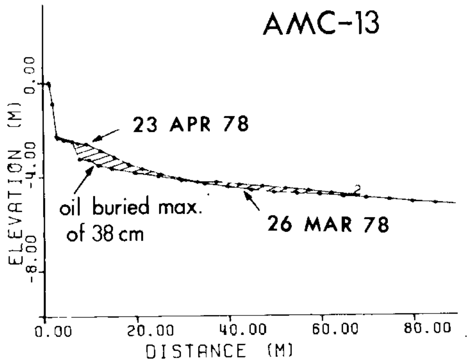

Figure 4-36. Comparison of topographic profiles on March 26 and April 23. Oil was buried to a maximum depth of 38 cm by the deposition of clean sand. Therefore, the beach appeared unoiled.

Summary

Section IV illustrates the following points:

(1) There was a lack of significant oil deposition along those stretches of coast oriented NE-SW, which were at an angle of 45° to the primary oil transport direction. All areas trending roughly north-south (perpendicular to oil transport) were heavily impacted (particularly station AMC-14).

(2) The burial of an oil layer by up to 38 cm of new sand at AMC-14 gave the beach a deceptively clean appearance on 23 April.

(3) Oil was observed to accumulate in pools in scour pits around boulders at station AMC-14.

4.9.5 Section V--Grève de Goulven to Plougoulm

Section V can be divided roughly into two sections, a depositional section to the west, and an eroding granitic bedrock massif to the east (Fig. 4-37). The depositional system is composed of an extensive dune area and very wide fine-sand tidal flat (Grève de Goulven). Beaches within the bedrock area are usually small and bounded by rocks. Most of the oil passed by this coast. However, there were significant accumulations during the first two weeks in those areas jutting north into the channel, and those that had coves or crenulate features facing west. A brief description of the individual study sites is presented in Table 4-9.

Table 4-9. Field observations of oil distribution at stations of Section V, Grève de Goulven to Plouscat.

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
F-122b	23 Apr	Gourven Large tidal flat/estuary with a fringing marsh.	Very lightly oiled marsh grass.
F-123	23 Apr	Plage de Ker Emma Wide sandy beach with dune system; large rocks offshore as well as on the lower portions of the beachface.	Some light oil and small tar balls aong the last high tide swash line. Fresh mousse (moderate-heavy concentration) coating on algae and rocks.
F-124	23 Apr	Anse de Kernic Large tidal flat with a harbor on one side; fringing marsh on shoreline.	Some darkened marsh grass from light oiling; a few mousse balls along the high tide swash line.
F-86	1 Apr- 23 Apr-	Plouescat Marsh at head of estuary.	-heavily oiled marsh -oiled marsh grass all ripped out; little marsh grass remains; still some patchy oil.
F-30	25 Mar- 23 Apr-	End of Spit at Porz Meur Beach with rocky area to the southwest.	-very light oil. -rocky area moderately oiled; a little mousse foam in the water; light oil swashes on the last high tide line.
F-29	25 Mar- 23 Apr-	Por au-Streat Breakwater harbor with seawall protecting it from direct wave attack.	-beach heavily oiled; lots of clean-up activity. -just a little oil on beach with some burial along the upper swash line. The rocks are all lightly oiled.
F-28	25 Mar	Frouden Rocky cobble beach with some sandy areas.	Oil pools; clean-up operation in effect.
F-27	25 Mar	(near) Au Gered Pocket beach.	Heavily oiled gravel beach and rocks.
F-26	25 Mar	Point at St. Eden Pocket sand beach with rocky headland on both sides.	Heavily oiled rip-rap seawall.
F-25	25 Mar- 23 Apr-	Pornejen High energy boulder beach.	-heavily oiled rocks; 200 m slick of mousse. -light oil coverage on rocks; much of the oil on rocks removed by high pressure hoses.
F-24	25 Mar	Poulfuen Pocket beach with rocks on sides.	Heavily oiled.
F-23	25 Mar- 23 Apr-	Kerfissien Small pocket beach with rocks on sides.	-moderately oiled especially in the eastern zone. -beachface was clean with half-buried, discontinuous mottled oil zone along the swash zone and a few buried tar balls at 50-60 cm.
F-22	25 Mar- 23 Apr-	Anameid High-energy beach with eroding dune scarp and rocky headlands on both sides of a small embayment.	-beach is heavily oiled; heavy mousse swash. -area entirely clean.
F-21	25 Mar	Tavenn Kerbrat Sandy beach with heavy rock debris.	Very light mousse in water.

Table 4-9 (continued)

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
F-57	28 Mar- 26 Apr-	Plage de Trestrignel Sandy shoreline with some rocks sticking thru a muddy sand flat at the center of the tidal channel.	-light sheen in water. -light oil swash lines along the upper part of the shore; oil burial 6-8 cm on the upper portion of the beachface; live amphipods found along the high tide swash.
F-87	1 Apr	Kerbrat Side of estuary.	Lightly oiled.
F-136	26 Apr	Kerbrat Fine- to medium-sand tidal flat	Very light oil swash along the high tide swash line; no oil burial; live amphipods on the beach.
F-137	26 Apr	Cantel Marsh area at the mouth of an estuary.	Marsh heavily oiled with 1 cm thick coverage of oil over marsh; no clean-up operation.
F-138	26 Apr	Traon Feunteun Upper portion of marsh where channel flows into the marsh.	Very lightly oiled; boom ineffectively positioned.

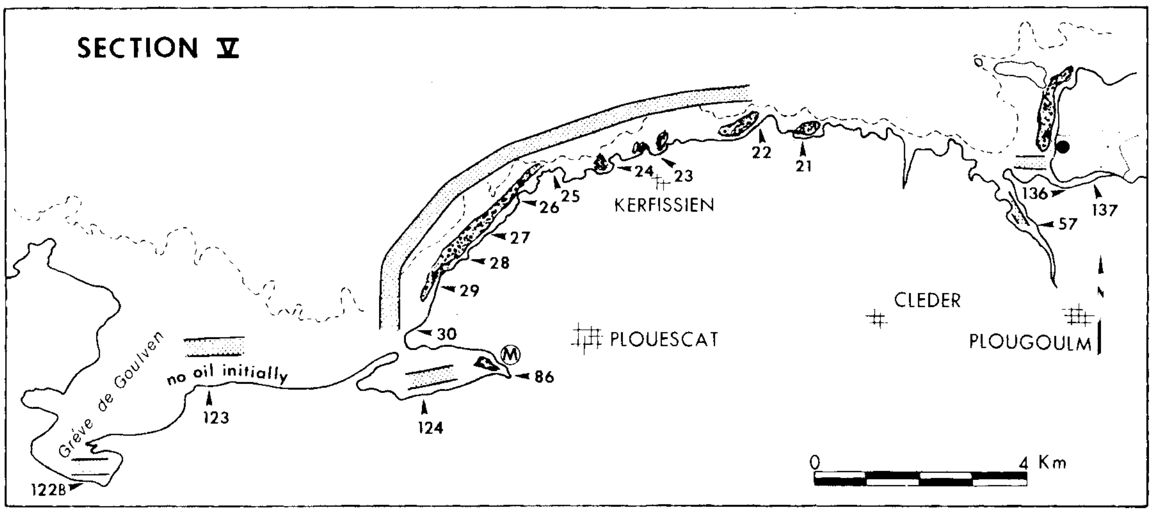

Figure 4-37. Station locations and oil distribution for Section V (Grève de Goulven to Plougoulm). Oil distribution for the first (March 19 to April 2) and second (April 20-28) study periods is indicated.

Oil Impact

The nature of oil deposition was distinctly different in the two morphological areas. Because the entire depositional system was sheltered by the Brignogan-Plage peninsula of Section IV, no oil reached the beaches during March. On our return visit during mid-April, light oil swashes were present on all beaches but no oil burial was found.

Beaches of the granitic massif were more exposed to the wind-transported oil; however, most of the oil simply passed by this area because of the general northeast/southwest orientation of the coast and the lack of large catchment areas. Significant amounts of oil accumulated only in those areas with crenulate shapes (crenulate beaches) or on those areas oriented more directly into the westerly winds (see Fig. 4-37). Commonly, the northern end of the beach would be heavily oiled, whereas the southern end would be clean.

During our site survey of late April, only a very light oil swash was visible at most locations. Cleanup occurred rapidly because of the exposure of most of the oiled areas to high wave energy. The exceptions were the sheltered marsh environments, such as the one at Cantel (F-170).

Summary

Importantly, Section V illustrates the change in form that the oil spill took after a period of one month. Originally, large oil masses were trapped at specific locations, depending on local shoreline configuration with respect to the wind. As the oil became worked into the water column, and the winds shifted, oil was spread over almost every inch of the shoreline in the form of light oil swash lines, which were usually composed of very small mousse balls.

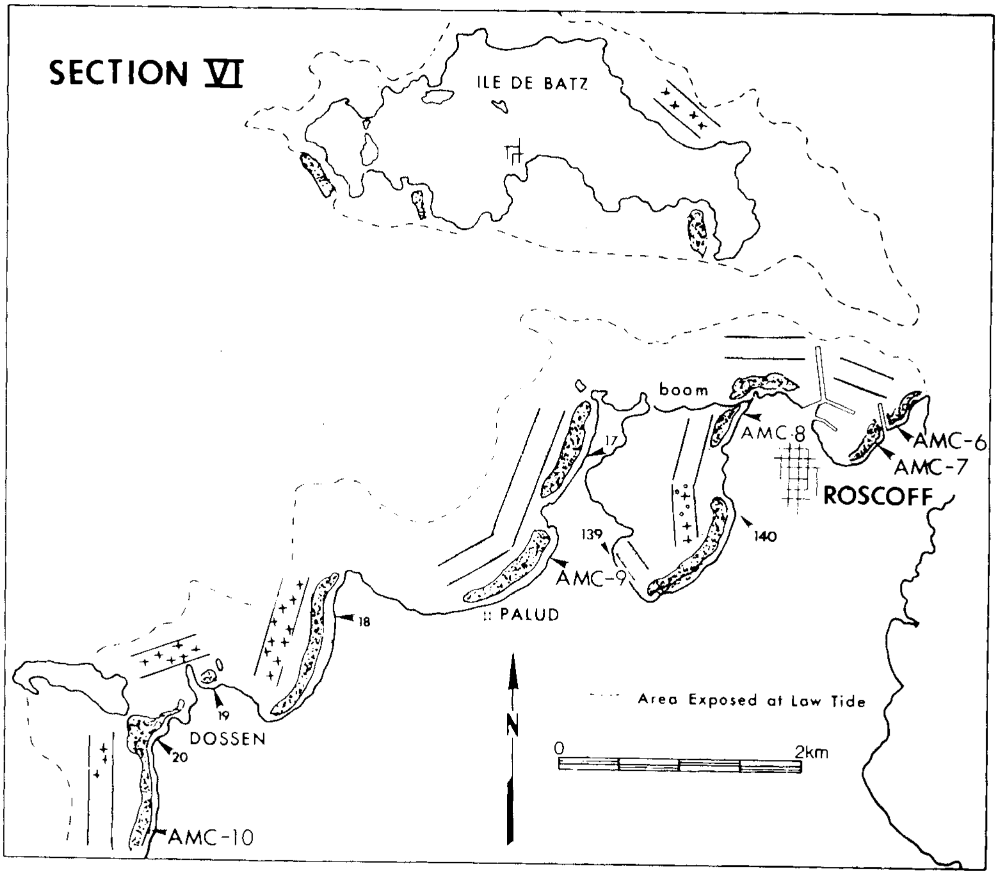

Figure 4-38. Station locations and oil distribution for Section VI (Forêt Dom. de Santec to Roscoff). Oil distribution for period one (March 19 to April 2) is indicated by the dark-stippled pattern. Heavy and light oil coverage during period two (April 20-28) are indicated by the plus and light-dot patterns, respectively.

4.9.6 Section VI--Forêt Dom. de Santec to Roscoff

Geomorphologically, this section can be divided into two distinct areas: (1) a large relict dune field with broad, flat fine-sand beaches (between stations AMC-10 and F-17; see Fig. 4-38); and (2) the highly embayed area around Roscoff. All the fine-sand beaches of the first area were heavily contaminated because of their north-south orientation and generally crenulate shape. Roscoff was one of the hardest hit areas in the whole spill site during the first week after the spill and, therefore, was studied more intensely than some of the other areas. Summaries of field observations in section VI are listed in Table 4-10.

Table 4-10. Field observations of oil distribution at stations of Section VI (Forêt Dom. de Santec to Roscoff).

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
AMC-10	24 Mar (F) 25 Mar (AMC)	Forêt Dom. de Santec	-contains a 20 m band of oil along the upper beachface; 12 cm burial.
	1 Apr-	Eroding dune scarp with wide fine-sand beach grading into a broad low-tide terrace.	-light oil swashes on beach surface; a discontinuous layer buried 8 cm.
	26 Apr-		-very light oil swashes on beach surface; discontinuous layer buried a maximum of 23 cm.
F-20	24 Mar 25 Mar	Dossen	-tombolo effect; heavy oiling of entire area behind island.
	1 Apr-	Wide fine-sand beach/low-tide terrace behind an island.	-surface of low-tide terrace clean; oiled rocks along shoreline; signs of a clean-up operation.
	26 Apr-		-rocks still moderately to heavily oiled; some burial 10-12 cm along upper beachface.
F-19	24 Mar-	Port au Vil	-very heavily oiled.
	26 Apr-	Small pocket sand beach	-clean beach surface and rip-rap, but 12 cm burial of 4 cm thick oil layer by spring berm deposition; signs of clean-up operation.
F-18	24 Mar-	Tevenn	-very heavily oiled.
	26 Apr-	Large sand beach oriented into direct wave attack; has a marsh deposit outcropping on the beachface.	-oil well mixed into the beachface by heavy machinery and trenches used in clean-up operation; men working to spray clean rocks to south.
AMC-9	24 Mar (F) 25 Mar	Cough ar Zac'h	-very heavily oiled beachface and upper low-tide terrace; 8 cm burial along upper beachface.
	1 Apr-	Broad medium- to fine-sand beach backed by eroding dune scarp; some rip-rap.	-heavy oiling restricted to 12 m along upper beachface; 8 cm burial.
	26 Apr-		-only light swashes along beachface; burial to 25 cm; clean-up by raking.
F-17	24 Mar-	Centre Helio-Marin	-very heavy oiling of the entire beachface.
	26 Apr-	Wide fine-sand beach backed by eroding dunes.	-no oil on beach surface or buried, but has oiled interstitial water; evidence of mechanical clean-up effort.
F-139	26 Apr	Ruguel Large sand flat with seawall.	Light oil swashes and lightly oiled rocks.
F-140	26 Apr	Lagadenou Small beach with seawall fronting a large sand flat.	Very heavily oiled during March; now has buried oil (3 layers) along beachface; tidal flat still oiled and has oil contaminated ground water.
AMC-8	24 Mar (F)-	Roscoff - West	-heavy oil coverage of beach, tidal flat and seawall; oil thrown over seawall and into park; oil boom in place across sand flat.
	25 Mar-	Small mixed-sand and gravel beach leading onto a very broad sand flat with some algae coated rocks; seawall and park back the beach.	-decreased amount of oil on the tidal flat; the rest was the same.
	1 Apr-		-very light oiling on the beach; oil buried under 20 cm of cobbles; park heavily oiled, but walkway clean.
	26 Apr-		-oil stained cobbles and wall, but beach appears clean; park is replanted.

Table 4-10 (continued)

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
AMC-7	24 Mar-	Roscoff - central harbor Small medium-sand beach between rocks on both sides; backed by a seawall.	-pooled oil 6 cm deep by seawall; rest of beach 70-90% oil covered.
	25 Mar-		-an approximate 70% reduction in oil coverage.
	1 Apr-		-some oil-bound sediment on low-tide terrace; oily sheen present; beachface clean; cleaning wall witn detergents.
	26 Apr-		-clean beachface; very minor amount of oil buried at 22 cm.
AMC-6	24 Mar-	Roscoff - East Small coarse-sand and gravel beach grading onto a fine-sand tidal flat; rocks are found on both sides; seawall abuts the shore.	-the entire beachface and low-tide terrace had 35-100% oil coverage.
	25 Mar (F)-		-total oil coverage decreased to approximately 20%.
	1 Apr-		-beachface very lightly oiled; seawall and rocks on tidal flat still oil blackened; oil contaminated interstitial water.
	26 Apr-		-still lightly oiled rocks and seawall; cobbles of beachface are oil stained; interstitial water still contaminated.

Oil Impact in Western and Central Areas

Station AMC-10. This station, which is located at Forêt Dom. de Santec, is a very broad fine-sand beach backed by an eroding dune scarp. The total length of beach is 1250 m. A sketch of the area on March 25 is presented in Figure 4-39. Sediment data are listed in Table 4-11. During our site visits on March 24 and 25, oil was deposited along the uppermost 20 m of beachface. Because of the compact nature of the fine-grained sediments, heaviest accumulations occurred along the upper swash zone. The quantity of oil present determined the total amount of surface area coverage. Some burial of oil was observed (see Fig. 4-39), illustrating that minor deposition had occurred since oil first came onshore. The quantity of oil present along this beach was estimated at 446 metric tons (Table 4-12).

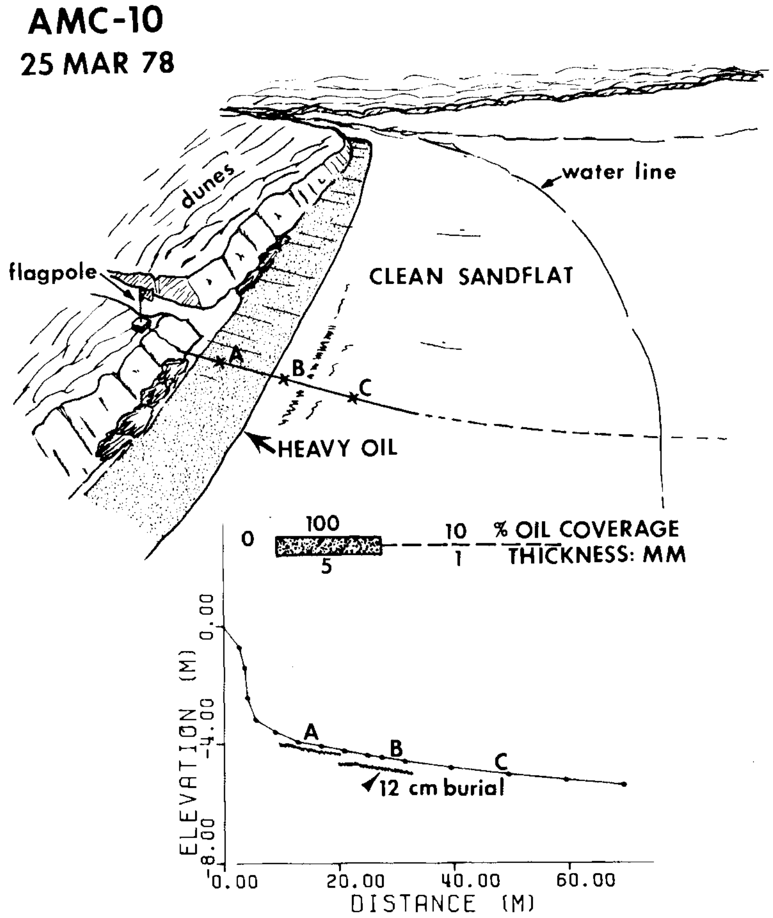

Figure 4-39. Sketch and topographic profile for station AMC-10 on March 25. All oil deposition was along the upper beach face. The total width of oil deposition on similar fine-sand beaches depends on the total quantity of oil within the area. Greater quantities will cover more of the beach face. Two distinct oil layers were buried, illustrating deposition of new sand since initial oil impact.

On our follow-up survey of April 26, only lightly oiled seaweed debris, and a series of light oil swashes remained on the beach surface. A 5-cm-thick oil/sediment layer was buried 10 to 15 cm below the surface by a newly formed berm. This recent deposition of clean sand gave the beach the appearance of being completely unoiled. We estimated that 6 tons of oil remained in the area, a net decrease of 87%. Approximately half of this oil was buried.

Table 4-11. Sediment data for AMC stations in Section VI. All values are calculated according to Folk (1968).

Sample	Graphic Mean	Size Class[1]	Skewness	Standard Deviation[2]
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)

[1]Size Class

CS = coarse sand
MS = medium sand
FS = fine sand
VFS = very fine sand

[2]Sorting

WS = well sorted
MS = moderately sorted
PS = poorly sorted
VPS = very poorly sorted

Table 4-12. Estimates of the quantity of oil present at AMC stations in Section VI during first and second field surveys.

Station Number	Date	Oil Present (metric tons)	Date	Oil Present (metric tons)	% Change
AMC-6	24 Mar	51.8	26 Apr	1.0	-98.10
AMC-7	24 Mar	102.5	26 Apr	1.7	-98.30
AMC-8	25 Mar	9.6	26 Apr	0.4	-96.50
AMC-9	25 Mar	1039.4	26 Apr	10.6	-99.00
AMC-10	25 Mar	46.3	26 Apr	6.0	-87.00

Coast between Stations F-20 and F-18. Station F-20 provided another example of the tombolo effect. Waves coming around both sides of the offshore island caused a large amount of oil to accumulate at Dossen. Follow-up surveys showed that the surface of the area was cleaned, but some oil still remained on the rocks as well as buried along the upper beach face. There were signs of cleanup at each station (F-18, 19 and 20); however, we saw none in operation.

Stations F-19 and F-18 proved to be very similar. Each initially had very large oil accumulations. During the mid-April survey, the surface of each area was generally clean, but some oil was buried. Station F-18 remained slightly more oiled than the other.

Station AMC-9. This station is a 2.0 km long, very broad medium-to-fine-sand beach. Sediment data are presented in Table 4-11. As at Station AMC-10, the beach area is backed by an extensive dune field. The waves are eroding the dunes at high tide forming a steep scarp. A sketch and topographic profile of the area are presented in Figure 4-40.

At the time of our survey on March 25, much of the beach face and low-tide terrace were covered with oil. Thickness of the oil varied from 6 m along the mid-beachface to 3 mm along the low-tide terrace. There was some oil burial along the upper beach face. An estimated total of 1039 metric tons of oil was on the beach on March 25.

By April 1, heavy oiling was restricted to the uppermost 12 m of beach. Oil thickness varied from 2 cm to 3 mm. Oil was found buried in a discontinuous layer 10 to 15 cm below the surface (Plate 4-26). Natural processes were responsible for the cleansing of the lower beach-face, since there had been no signs of beach cleanup effort.

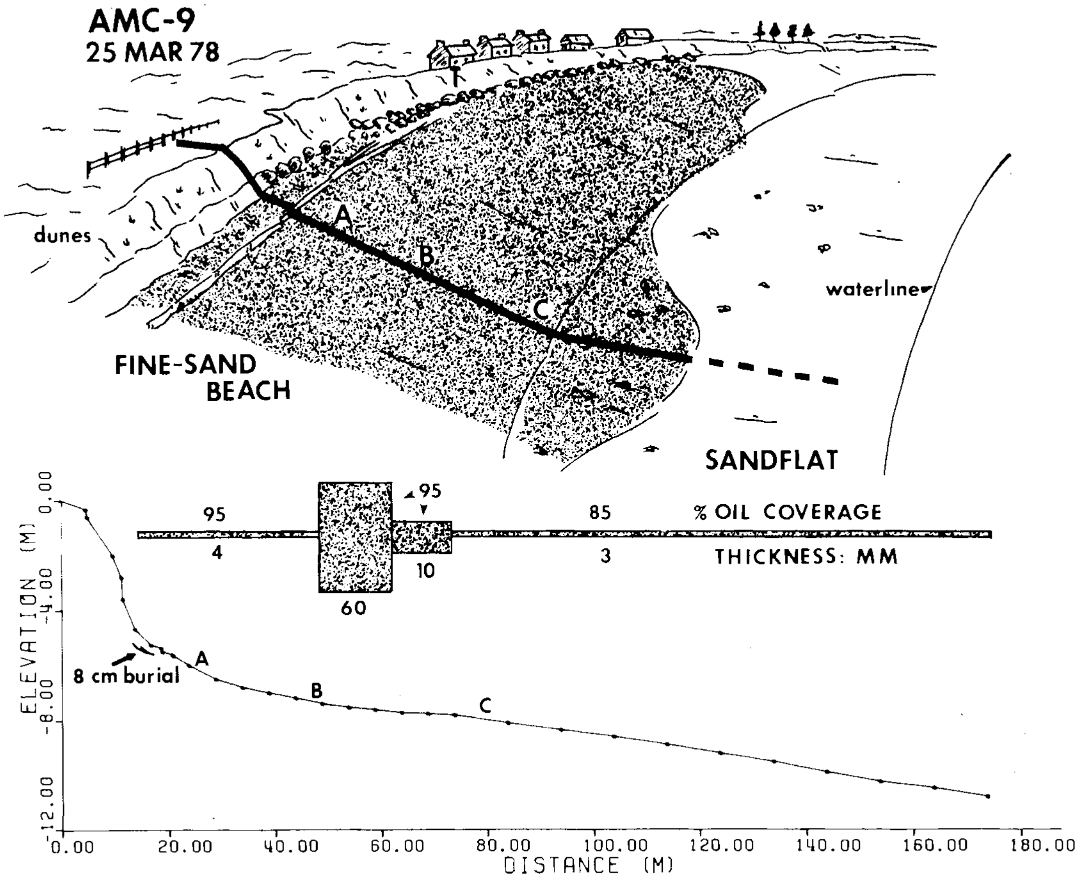

Figure 4-40. Topographic profile and oil coverage of Station AMC-9 on March 25. Oil covered most of the beach face and upper low-tide terrace. The profile is compressed, compared with the computer plot.

On April 25, only light oil swashes remained on the beachface. However, a good deal of oil was buried in two layers up to 25 cm deep. Comparison of beach profiles show that the formation of a neap berm caused the burial of the oil (Fig. 4-41). The rip-rap wall to the south continued to be heavily oiled. An estimated 11 metric tons of oil remained in the area. This comparatively large amount of oil is essentially due to the exceptional length of the beach over which the calculation was made.

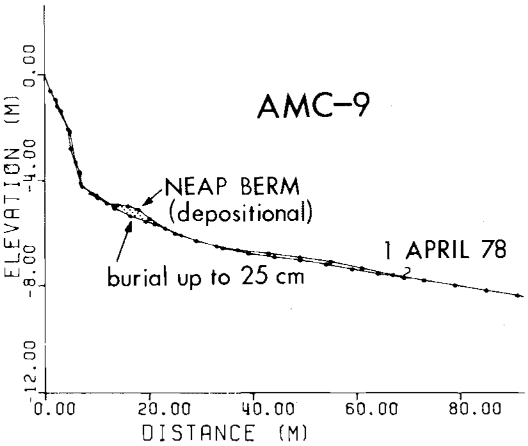

Figure 4-41. Although the beach at AMC-9 appeared clean on April 1, oil had been buried in two layers beneath the surface by formation of the neap berm.

The coast from F-17 to F-140. Station F-17 was very similar to the others of this coastline (e.g., AMC-10, F-18 and AMC-9). Backed by a small dune field, it contains a broad fine-sand beach and low-tide terrace. This area was initially very heavily oiled. Plate 4-10 shows this area on March 21. On April 26, little evidence could be found to indicate how extremely contaminated this area had been.

Station F-139 is located in a sheltered sand-flat embayment. Because of the prevailing westerlies during the first two weeks of the spill, no oil came into this area. During our second site inspection on April 26, minor oil swashes were found along the upper portions of the sandflat, and the rocks were lightly oiled.

Across the bay at site F-140, it was a different situation. This area was very heavily oiled during the first days of the spill. Skimmers and tank trucks worked to remove some of the floating oil. During site inspection on April 26, we found several layers of oil buried in the beach, and a surface film of oil on the sand flat. The interstitial water of the flat was noticeably contaminated.

Oil Impact in the Roscoff Area

Station AMC-8. This station is located on the west side of Roscoff. It consists of a steeply dipping mixed coarse-sand-and-gravel beach leading onto a sandy tidal flat. Grain size data are presented in Table 4-11. Behind the beach is a large seawall with a small park located at street level. We observed that the beach and most of the sand flat were oil covered during the flight of March 21 (see Plate 4-32). Our station is located along the seawall at the upper right of this photograph.

By March 25, much of the oil on the tidal flat was gone. However, the lower beach face remained oiled. An estimated 10 tons of oil remained (Table 4-12). Figure 4-42 and Plate 4-33 show the extent of the surface oiling. A hard, sandy gravel substrate prevented deep penetration of the oil. The walkway and park above the beach had received heavy oiling due to overwash by large, mousse-laden waves on March 24. Over 3 cm of oil was on the walkway at that time (Fig. 4-43).

By the first of April, little oil remained on the beach face. A minor amount was found buried by pebbles along the upper beach face. The walkway was cleared of oil, but the park was still blackened. By April 25, the park had been restored. Only the lightly stained cobbles and blackened sea wall (which was being cleaned with pressurized steam) remained as evidence of the spill. We estimated that less than 0.4 ton of oil remained in this particular area on April 25(Table 4-12).

Station AMC-7. This station is located within the jetties at Roscoff harbor (Fig. 4-44). The site is pictured in the background of Plate 5-17A. It is a small medium-sand beach bounded on both sides by large rocks. A fine-sand tidal flat is located seaward of the beach, while in back is a high seawall. Sediment data are presented in Table 4-11.

Our observations indicate that the heaviest accumulations of mousse arrived in Roscoff on March 20. On March 24, there was heavy oil coverage over most of the intertidal area at low tide (see our survey of that day, Fig. 4-45). Only where the ground water rills cropped out on the beachface did oil coverage reduce (to 70%). Some oil was also found buried. Returning the next day (two tidal cycles later), 60%-70% of the oil in the area had been removed. Comparing the two beach profiles presented in Figure 4-46, it can be seen that a large amount of material had been eroded from the beachface. In total, 23 m^3 of sediment per 1 m width of beach had been removed during the night. High wave activity brought about by a low pressure storm and near spring tides combined to create the new beach profile.

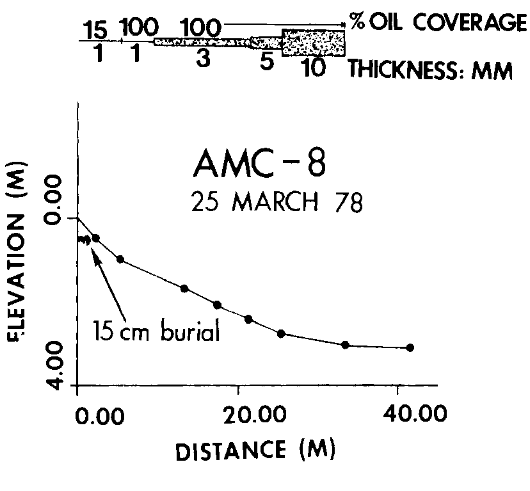

Figure 4-42. Topographic profile and oil coverage for station AMC-8 on March 25. The beach is composed of mixed sand and gravel leading onto a large sand flat.

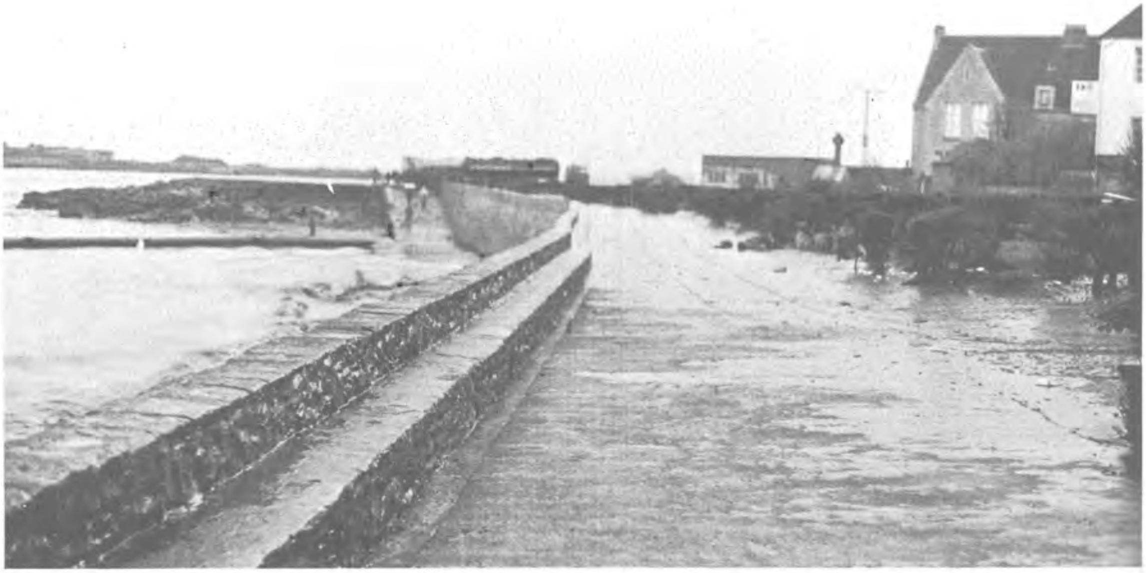

Figure 4-43. More than 3 cm of oil was thrown up onto the walkway at station AMC-8 in Roscoff on March 24. The small part to the right was also heavily oiled. Most of the oil was cleaned up before April 1. The park was restored a short time after.

Figure 4-44. Aerial photograph of the harbor at Roscoff on March 21. Station AMC-7 is the beach to the center-left of the photograph. Station AMC-6 is located at the far left.

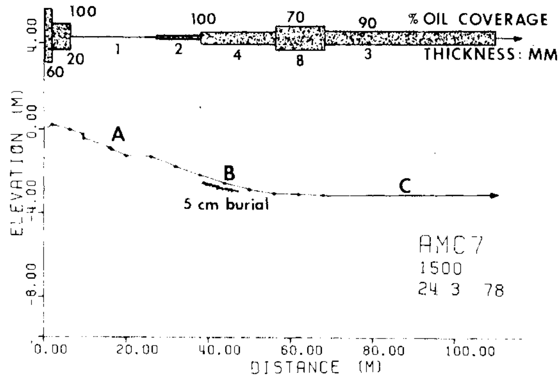

Figure 4-45. Topographic profile and oil coverage for station AMC-7 in Roscoff on March 24. A significant portion of the oil was removed by erosion of the beach during the following two tidal cycles (see Fig. 4-46).

On our return on April 1, we found that the entire beachface was clean. However, there was some burial of oil on the lower beachface (to depths of 3 cm). By comparing profiles (Fig. 4-46), it can be shown that new sand had been deposited between March 23 and April 3, thereby burying some of the oil. In total, nearly 30% of the original volume of sediment previously lost had been returned.

By April 26, only very light oil swashes were found on the beach. In addition, slightly oiled sediment was found 22 cm below the beach surface in one locality. The walls had been cleaned in some spots. The remaining oiled rocks and walls were being cleaned with high pressure water and detergents. This is the only place where we saw detergents applied to any oiled area. The total amount of oil present on April 26 was estimated at 1.7 tons (Table 4-12).

Another cleanup instrument, a vortex skimmer, was moored at this locality, but was seen being towed only once, and then it did not have the hoses connected for actual operation.

Station AMC-6. This station is located on the eastern side of Roscoff next to the lobster pens shown in Plate 5-17A. It consists of a small, 150 m gravelly sand beach that grades into a fine-sand low-tide terrace. Rocks are located on both sides of the beach. A seawall abuts the upper beach (see Fig. 4-47).

The oil pollution history of this area is very similar to that of AMC-7. During our overflight on March 21, the entire intertidal zone was covered with oil (Plate 5-17A). At the time of our survey on March 24, a considerable amount of oil remained on the beach face and low-tide terrace. Figure 4-47 shows oil coverage superimposed on the beach profile. We estimate that 52 metric tons of oil were present, excluding oil within the rocky areas. After a storm on the night of March 24, approximately 80% of the surface oil was removed. Once the oil drifted into the main channel, swift currents, aided by strong winds, carried it further to the east, towards Ile Grande.

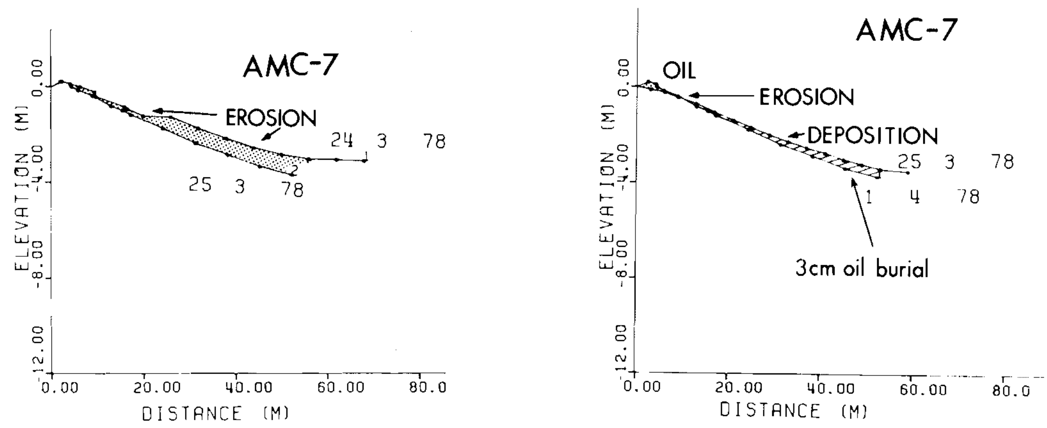

Figure 4-46. Extensive erosion occurred at station AMC-7 during the night of March 24. During this time, 60%-70% of the oil in the area was removed. The partial recovery of the beach on April 1, by the deposition of new sand on the beachface, caused a 3 cm burial of old oil.

A follow-up survey on April 1 showed a further diminution of the oil. On April 26, the beach still remained lightly oiled and the rocks and sea wall were still oil-blackened. The interstitial water was also contaminated. Approximately 1 metric ton of oil was still in this particular area on April 26. Limpets on the rocks seemed to be healthy, illustrated by their being able to hold firmly to the rocks when prodded.

Summary

(1) Exposed fine-sand beaches were cleaned rather rapidly (2-3 weeks) by natural processes. Only where oil was artificially worked deep into the beach sediments by cleanup machinery, did major contamination remain.

(2) Another example of the tombolo effect on oil accumulation was observed at station F-20 (Dossen).

(3) Tremendous quantities of oil were removed from the beaches of Roscoff overnight during a period of high wave intensity (March 24 and 25). Even though the large majority of oil was removed naturally, total recovery of the environment at Roscoff still seems somewhat distant. Oil that was naturally removed probably drifted eastward and contaminated other environments to the east.

(4) The use of sprayed detergents to clean the rocks at AMC-7 was the only use of chemicals we saw during our field studies.

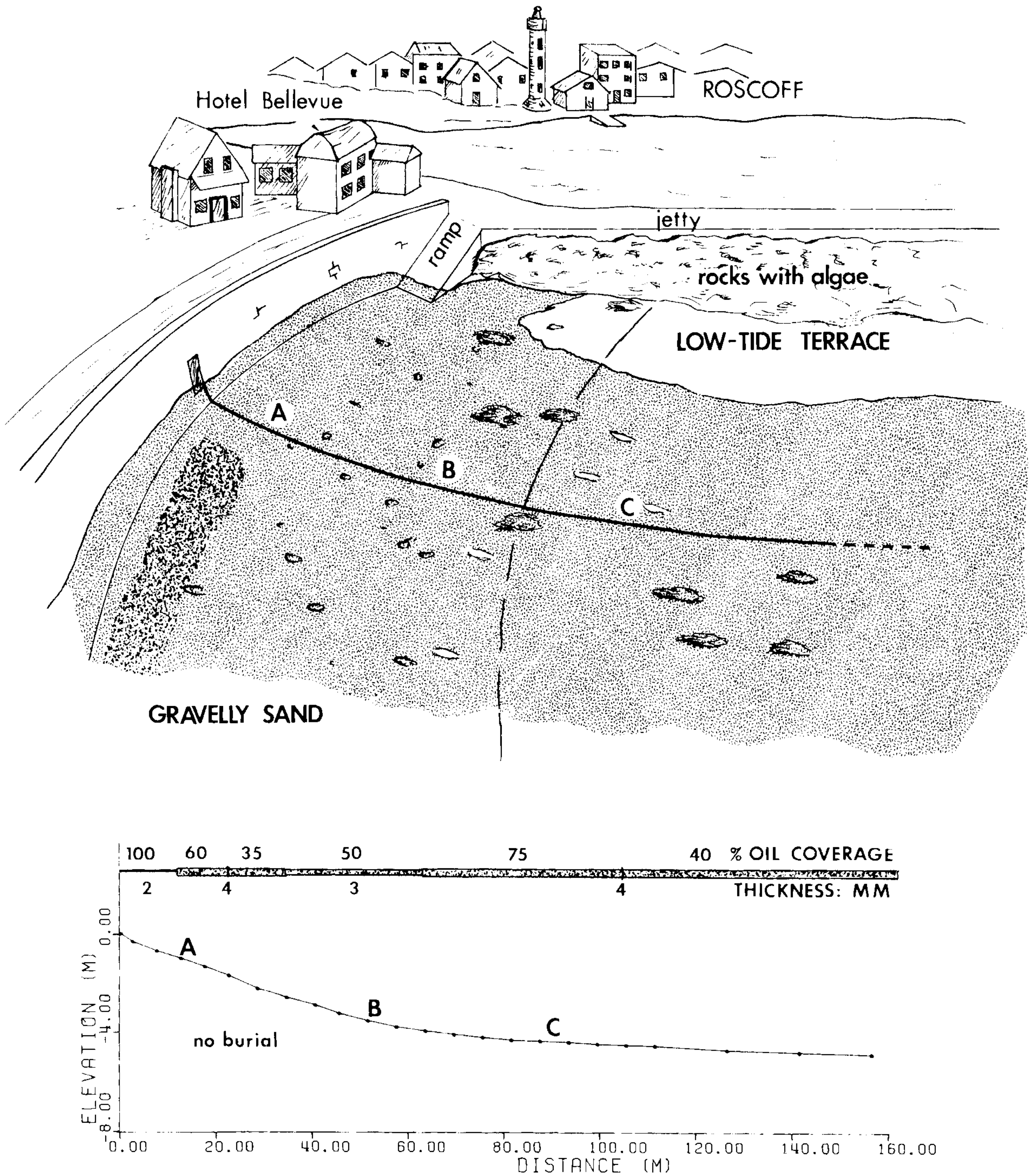

Figure 4-47. Sketch, topographic profile, and oil coverage for station AMC-6 in Roscoff on March 24. On the evening of March 24 approximately 80% of the accumulated oil was removed from the area by natural processes.

4.9.7 Section VII--Roscoff to Pte. de Plestin

A location map for Section VII is given in Figures 4-48 and 4-49. The coastline is oriented roughly east-west. Geomorphologically, the coastline is quite similar to Section IV, with a depositional, estuarine (ria) area to the west and a granite massif to the east. In this case, there are two large fine-grained tidal flat systems in the west separated by a bedrock headland, Locquirec peninsula. Another difference is that this bedrock area (between Locquirec and Primel-Trégastel) forms steep cliffs often over 20 m in height. The individual stations in the section are described in Table 4-13.

Oil Impact

The coast from F-147 to F-96. This entire section of coastline was sheltered from initial oiling by the Roscoff peninsula. No oil was found in this area during our first survey, which ended on April 2. There was a very long floating oil boom located across the eastern side of the estuary at this time (indicated in Fig. 4-48). The effectiveness of the boom could not be determined.

Since much of the large oil pools had shifted location with the changing wind direction of early April, we remonitored the area on April 27 in greater detail than before. During this survey, light oil swash lines were found at stations F-147, F-13, F-11, and F-96 (see Fig. 4-49). The rest of the area continued to be unoiled.

The coast from F-96 to F-89. This area was more exposed to the oil drifting over from Roscoff in the early days of the spill. Many areas became heavily oiled. Stations F-94 and F-95 were among the hardest hit. The latter consists of a large heavily oiled cobble beach. Because oil sank deep into the sediments, tractors and high pressure hoses were being used to clean the area. A tractor cut across the upper beachface creating a trough in front of the heavily oiled section (see Fig. 4-50). Water under high pressure was then applied to the oiled cobbles. The oily runoff drained into the trough and was later collected.

Station F-94 at Primel-Trégastel is a sheltered rocky environment which acted as a perfect sink for the oil. Even after an extensive cleanup of the area, it was still heavily oiled on April 27.

Along the cliffed rocky coast between F-92 and F-91, mousse stringers were still seen floating on the water surface on April 27, more than 5 weeks after the beginning of the spill. Wave reflection kept most of the oil a short distance offshore (Plate 4-28). However, some small cobble coves became heavily oiled. Oil is not expected to remain in this area because of the highwave energy conditions.

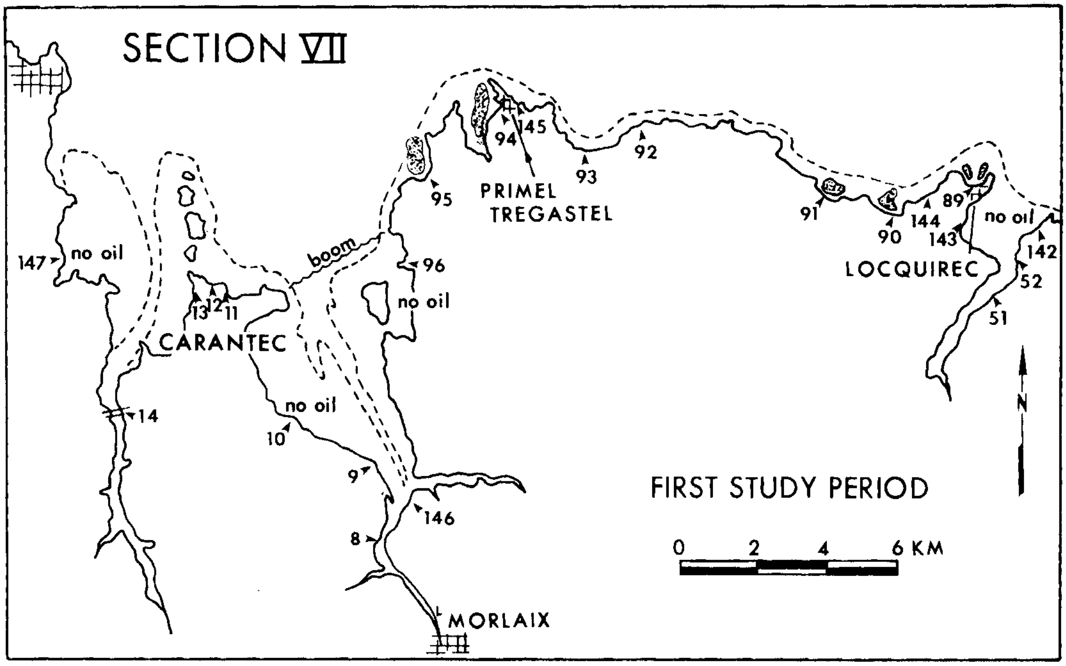

Figure 4-48. Location of stations in Section VII, Roscoff to Pointe de Plestin (F-142). Oil distribution during the first study session, March 19 to April 2, is indicated by the dark-stippled pattern.

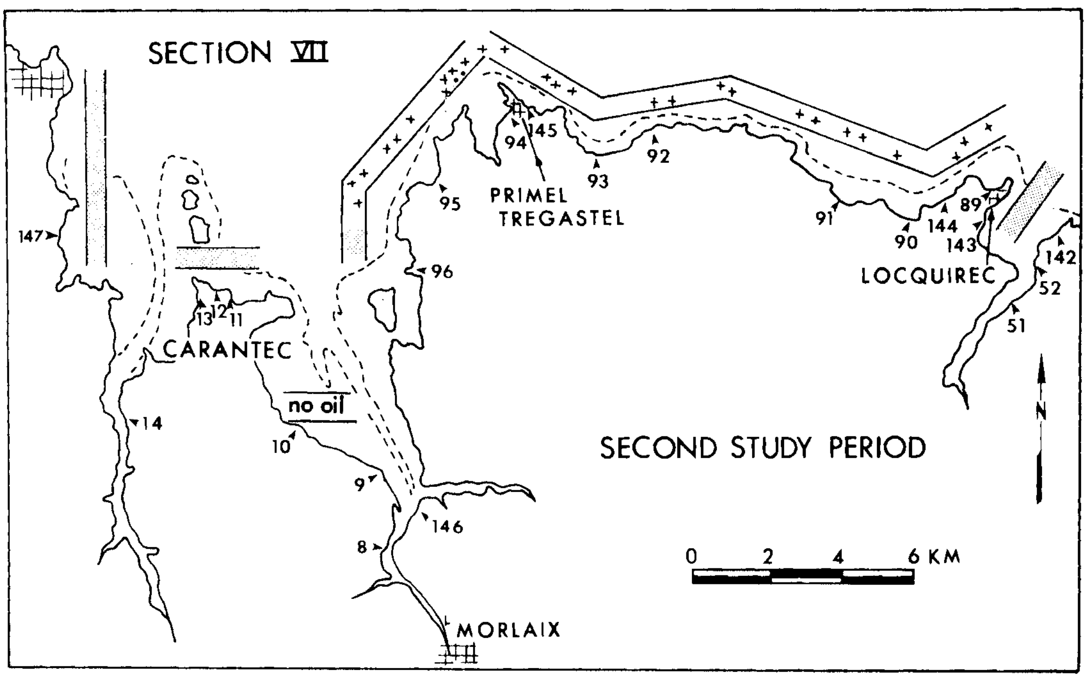

Figure 4-49. Oil distribution along the coastline of Section VII during the second study session, April 20-28. Heavy and light oil coverage are indicated by the plus and light-dot patterns, respectively.

Table 4-13. Field observations of oil distribution at stations of Section VII, Roscoff to Pte. de Plestin.

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
F-147	27 Apr	Port de Pem Poul A seawalled harbor; coarse-sand tidal flat.	Light oil swashes.
F-14	24 Mar- 27 Apr-	Pont de la Corde Tidal flat/estuary with small channel; station at bridge over river.	-no oil. -no oil.
F-13	24 Mar- 27 Apr-	Carantec - West A harbor with a sandy beach and large tidal flat.	-no oil. -light oil swashes.
F-12	24 Mar	Carantec - North Near the mouth of a large estuary and tidal flat.	No oil.
F-11	24 Mar- 27 Apr-	Carantec - East Granule beach.	-no oil. -very light oil on rocks; sand was removed to protect it from being oiled - it will be pushed back later; some light discontinuous burial.
F-10	24 Mar- 27 Apr-	(near) Ty Nod Gravel beach.	-no oil. -no oil.
F-9	24 Mar- 27 Apr-	East toward Dourduff Tidal flat/estuary.	-no oil. -no oil; possible light sheen in the water.
F-8	24 Mar	(near) Morlaix (2 km downriver) Small tidal flat with channel.	No oil
F-146	27 Apr	Dourduff en Mer Wide tidal flat area.	Clean except for an occasional mousse glob on the upper portion of the tidal flat (3 mousse globs/m^2); algae very productive.
F-96	2 Apr- 27 Apr-	Terrenez Small harbor with cobble beaches on both sides.	-no oil; boom deployed offshore. -light oiling of cobble beaches.
F-95	2 Apr- 27 Apr-	le Diben Cobble beach gently sloping onto a very rocky low-tide terrace.	-heavily oiled. -beach and rocks on low-tide terrace heavily oiled; extensive clean-up operation - tractors pushing oiled cobbles into lower swash zone to be cleaned by the waves; high pressure water also being used.
F-94	2 Apr- 27 Apr-	Primel Trégastel - West Sheltered harbor; cobble and boulder beach.	-very heavily oiled; extensive clean-up. -moderately to heavily oiled; rocks are extensively coated with oil.
F-145	27 Apr	Primel Trégastel - East Gravel beach with a large sand tidal flat fronting it; backed by a seawall; upper beach portion consists of cobbles and boulders.	Upper beach is moderately to heavily oiled.

Table 4-13 (continued)

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
F-93	2 Apr-	St. Jean de Doigt	-light oil on rocks.
	27 Apr-	Cobble and gravel beach.	-rocks and gravel all heavily oiled; oil has sunk into the gravel beach; signs of previous clean-up effort.
F-92	2 Apr-	West of St. Jean de Doigt	-no oil on shore; mousse streaks offshore.
	27 Apr-	Small rocky indentation of the coast.	-some mousse still in the water and now the rocks have a light coating of oil.
F-91	2 Apr-	Poul Rodou	-no oil.
	27 Apr-	Pocket beach surrounded by rocky headlands.	-moderate to heavy oil on the rocks along the shoreline; light oil swashes on the beachface.
F-90	2 Apr-	le Moulin de la Rive	-moderately oiled rocks; clean low-tide terrace.
	27 Apr-	Cobble and gravel beach.	-rocky area heavily oiled; low-tide terrace moderately oiled; active clean-up operation - a tractor is pushing oiled cobbles onto the lower beachface; also use of a high pressure hose.
F-144	27 Apr	les Sables Blancs Small sandy beach backed by dunes; algal covered rocks on low-tide terrace; rocky headlands on both sides.	Headlands moderately oiled; light oil swashes on beach; location of an oil storage pit.
F-89	2 Apr-	Locquirec	-moderately oiled rocky area.
	27 Apr-	Rocky and sandy beach with a similar low-tide terrace.	-rocks are moderately to heavily oiled; even the rocks on the low-tide terrace are oiled; a very small clean-up attempt is in effect - mainly steam cleaning.
F-143	27 Apr	Locquirec Port Small jetty protecting a little harbor.	Both sides of jetty clean and no oil in the water; boom in place at front of the port; this area is very biologically productive.
F-51	28 Mar-	Toul an Héry	-no oil.
	27 Apr-	Upper part of tidal flat in harbor.	-light coating of mousse globs along the shoreline; some very light oiling of the seaweed.
F-52	28 Mar-	(near) Kerdrehoret - West	-no oil.
	27 Apr-	Beach and tidal flat in harbor.	-very light oiling here - one small oil glob for each 2 square meters; otherwise, completely clean.
F-142	27 Apr	(near) Kerdrehoret - North Small fine-sand pocket beach.	Some oil droplets on the surface of the rocks; beach is entirely clean; no burial.

Figure 4-50. Oil clean-up at the cobble beach at station F-95 on April 27. A tractor created the runoff trench at the foot of the beach. High pressure water helped remove the deeply penetrated oil from the cobbles. The method is sound from a coastal geomorphic standpoint since beach sediment is not removed. Reworking by waves will re-establish the normal beach profile.

Closer to Locquirec, most of the rocks were still moderately oiled on April 27. At F-90, a tractor was pushing oiled gravel into the swash zone, and a small steam cleanup operation was in effect at F-89.

The coast between F-143 and F-142. This large embayment reacted similarly to those at the western side of Section VII. No oil was initially deposited along the shoreline, since the Locquirec peninsula acted as a barrier. However, during the survey on April 27, light swash lines of small mousse balls (less than 1.0 cm in diameter) were found throughout the area. These mousse balls apparently drifted in as a result of shift in wind direction.

Summary

Two points of interest are illustrated in Section VII:

(1) It is possible to use tractors and high pressure water to clean heavily oiled coarse gravel beaches without removing the gravel.

(2) Thick mousse stringers remained in the nearshore water more than 5 weeks after the beginning of the oil spill. Therefore, previously unoiled areas were still subject to potential pollution, depending upon the vagaries of the winds and currents.

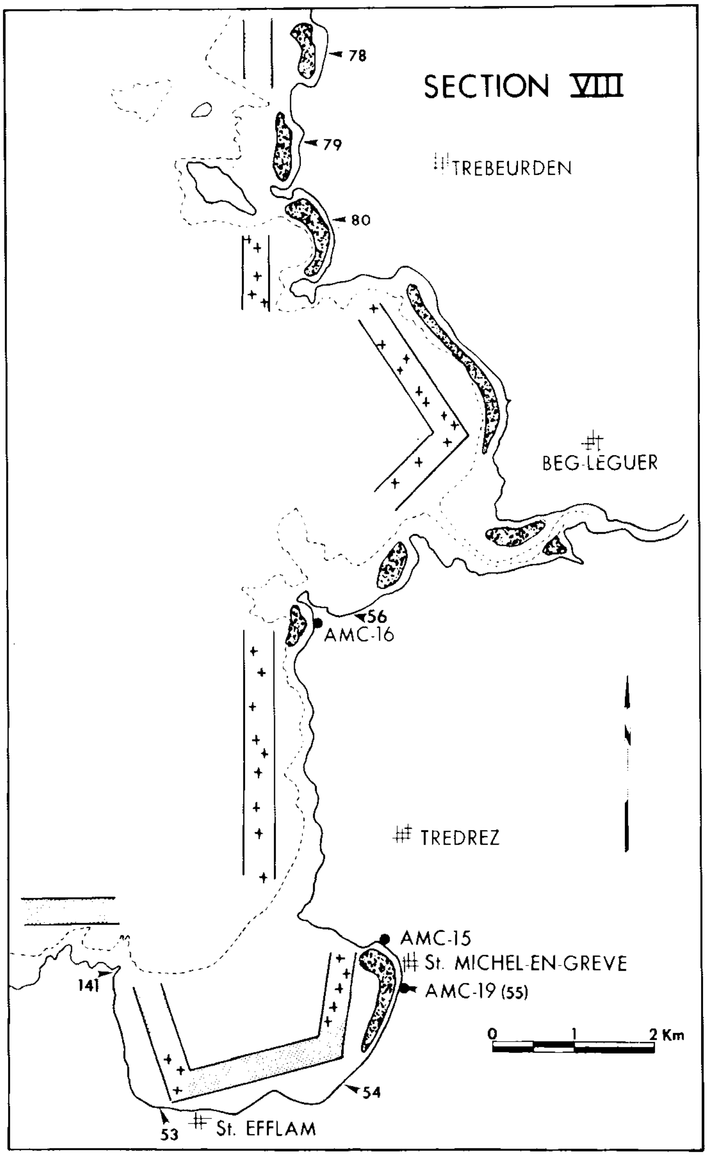

Figure 4-51. Location of survey stations in Section VIII (St. Efflam to Kerhellen). This section included the large sand flat at St. Michel-en-Grève. Oil distribution for study period one is indicated by the dark-stippled pattern. Heavy and light oil coverage during the second study period are indicated by the plus and light-dot patterns, respectively.

4.9.8 Section VIII--St. Efflam to Kerhellen

This section includes the broad sandflat called the Grève de St. Michel, as well as a cliffed, north-south trending bedrock shoreline (Fig. 4-51). The sandflat of St. Michel, which extends for over 2 km from the high tide line to the low tide line, was the scene of a massive oil-caused kill of most of the shelled infaunal organisms. For this reason, this area will be discussed in detail. The extent of oiling along the bedrock system was generally heavy, increasing toward the north. The summary of our field observations for this section is presented in Table 4-14.

Table 4-14. Field observations of oil distribution at stations of Section VIII, St. Efflam to Kerhellen.

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
F-141	27 Apr	Pointe de Plestin Exposed pocket beach consisting of medium- to coarse-grained shell material.	No oil except for very light oil splattering along the high tide swash lines.
F-53	28 Mar-	les Carrières	-no oil
	27 Apr-	Large tidal flat embayment.	-some heavily oiled rocks; no oil at the lower portion of the tidal flat.
F-54	28 Mar-	St. Michel-en-Grève (South) Large tidal flat embayment.	-oiled swash lines and some small mousse pools.
	2 Apr-		-millions of dead organisms.
	27 Apr-		-light sheen on upper tidal flat; no oil on the lower portion.
AMC-19 (F-55)	28 Mar (F)-	St. Michel-en-Grève Very large sand flat/embayment.	-heavily oiled along upper portion of beach; large clean-up operation with much manpower and many tractors; oil contaminated interstitial water.
	2 Apr (F)-		-millions of dead organisms.
	25 Apr (AMC)-		-light swashes on beach; oil buried (30 cm) in infilled collection troughs; interstitial water still oil contaminated.
AMC-15	28 Mar-	St. Michel-en-Grève (NE corner) Mixed sand and gravel beach on edge of very fine-sand tidal flat.	-80 to 100% oil coverage of the beachface and near edge of tidal flat.
	25 Apr-		-still heavily oiled beachface and rocky edge of tidal flat; signs of an extensive clean-up operation; interstitial water oil saturated.
AMC-16	28 Mar-	Pointe de Sehar Large pebble beach between two bedrock areas.	-very heavily oiled; 30 cm penetration of oil into the gravel along the upper beachface.
	24 Apr-		-still oil soaked; at least 15 cm penetration over entire beachface; presence of a bulldozer pushing oiled gravel into furrows to be rewashed by incoming tide and waves.
F-56	28 Mar	Plage de Notigou Sandy pocket beach with outcropping rocks.	Heavily oiled beach and rocks.
F-80	31 Mar-	Plage de Tresmeur	-heavily oiled.
	25 Apr-	Cobble beach leading onto a sandy low-tide terrace.	-cobble moderately oiled; low-tide terrace very clean; tractor pushing cobbles seaward so as to allow natural cleansing; high pressure hoses also in use to clean the rocks.
F-79	31 Mar-	Plage de Porz Termen	-heavily oiled.
	25 Apr-	Medium- to coarse-grained beach within a harbor.	-beachface is clean but the rip-rap walls behind the beach are heavily oiled.
F-78	31 Mar-	Kerhellen	-heavily oiled.
	25 Apr-	Coarse sandy beach with rocks on both sides.	-rocks on both sides moderately oiled; light oil along the last high tide swash line; also much burial along the upper beachface.

Oil Impact

St. Michel-en-Grève. Observations at St. Michel-en-Grève present one of the most massive kills of infauna by oil ever recorded. The initial site visit on March 28 showed extensive oil coverage within the southeast pocket of this tidal flat/fine-sand beach. A large cleanup operation was underway (see Plates 4-4, 4-5, 6-8, 6-9, 6-24), but no biological damage was evident.

By the time of our return visit on April 2, the entire 2 km of sand flat was littered with millions of shells, including empty shells of heart urchins, tissue-laden shells of razor clams, and many small bivalves (see Plates 4-6, 4-7, 5-10, 5-11, 5-12, 5-13).

Approximately 1 km from the beach, samples were taken for infaunal analysis. Living annelids and polychaetes were found. Shelled infauna were not present. The ground water was contaminated with oil.

Three estimates of numbers of dead organisms were made:

(1) A swash line of dead heart urchins (*Echinocardium* sp.) 300 m long and 25 m wide was counted, based on the number of dead organisms occurring within a one-meter wide swath measured perpendicular to the swash line. The total arrived at was 120,000 dead urchins within that one swash line.

(2) A swash line (250 m long and 6 m wide), made up predominantly of dead razor clams, was also measured using the same method as in 1. According to our estimate, there were 45,000 dead razor clams within that single swash line.

(3) At evening low tide (7:00 p.m.) on April 2, the entire intertidal area was littered with shells of dead organisms (Plate 4-4). As the tide fell, a cover of approximately 3 to 5 dead organisms/m^2 was left behind. Heart urchins were by far the dominant species. At that time, the intertidal zone was measured to be 570 m wide. Assuming that each square meter contained four dead urchins (based on several counts), a 500 m long section of the beach would have contained 1,140,000 dead urchins. Therefore, several million dead urchins were present on the surface of the intertidal zone at that time, in addition to hundreds of thousands of dead clams and worms.

Claude J. M. Chassé of the University of Brest completed an extensive Ph.D. study of this flat (and other areas) in 1972 (Chassé, 1972). Apparently, follow-up studies will be carried out under his direction.

We revisited the St. Michel-en-Grève sandflat on April 25. All dead organisms had been collected and removed from the surface of the flat. Approximately 1 km from shore, oiled rubble (mostly coarse gravel) had been placed on the flat apparently to be cleaned by wave action (similar to that illustrated in Plate 6-30). Interstitial water in the area was still contaminated with oil.

Because we wanted to monitor the effects of the cleanup operation, particularly the digging of numerous trenches in the intertidal zone, we established a new profile site (AMC-19) at St. Michel-en-Grève. The topographic profile of the beach is shown in Figure 4-52. Sediment data are presented in Table 4-15A. At the time of our survey, light oil swash lines were found on the surface of the flat. However, the oiled remains of three cleanup trenches were located (Fig. 4-52, see also Plate 6-23). A maximum of 35 cm depth of oiled sediment was measured. This profile site will be reoccupied to determine the persistence of the remaining oil. As at other sites, this could prove to be a long-term source of interstitial water contamination.

Station AMC-15 is a mixed sand and gravel beach located at the northeast edge of the St. Michel sandflat. In some parts of the beach, a thin veneer of fine sediment was deposited over compact coarser material. The beach profile and oil coverage for the station on March 28 are presented in Figure 4-53.

During the site survey on March 28, the beach at AMC-15 was heavily contaminated (see Plate 4-13). We estimate that 83 metric tons of oil were in the area (Table 4-15B). Oil extended approximately 50 m onto the sandflat. During our second survey, April 25, the beachface was still blackened in appearance, although the thick accumulations of oil were gone. The remaining quantity of oil was estimated at 4 metric tons. There were signs of a cleanup operation, so natural processes were not completely responsible for the oil removal. No oil burial was in evidence; however, the interstitial water was noticeably contaminated.

St. Michel-en-Grève to Pte. de Sehar. The coastline directly north of the St. Michel-en-Grève sand flat consists of steeply dipping, 70 m cliffs, half of which border the sandflat. Because of its north-south orientation, it became heavily oiled during the first two weeks of the spill. It was still oiled on April 28.

Station AMC-6, which is located at the northmost end of the bedrock cliffs, consists of a long, steeply dipping pebble beach (mean grain size = -4.690; Table 4-15). The topographic profile and areas of oil coverage for this site are presented in Figure 4-54. On March 28, the area was heavily oiled (see Plate 4-14). Digging into the beach, we found that taffy-like mousse had penetrated over 20 cm into the sediment (Plate 4-15). The estimated quantity of oil in the area was placed at 81 metric tons, much of which was incorporated into the beach sediment.

Returning to the site on April 24, we found the area to be little different from before. Oil was still on the beach surface and had

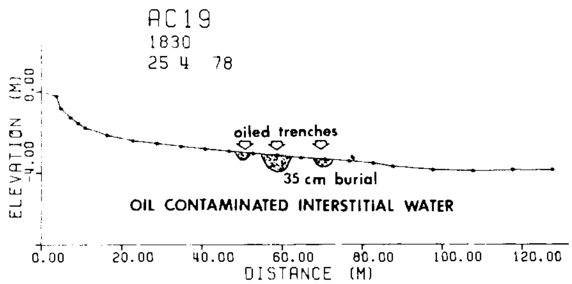

Figure 4-52. Topographic beach profile of station AMC-19 on April 25. Oiled trenches remaining from the clean-up operation are indicated.

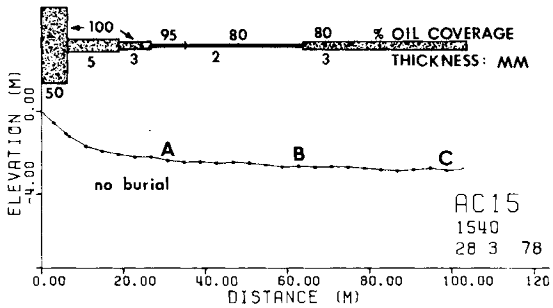

Figure 4-53. Topographic profile and oil coverage of the beach at site AMC-15 on March 28. Oil was restricted to the beach face and uppermost portion of the sand flat.

penetrated 15 to 20 cm into the sediment over the entire beachface. Our calculated tonnage of oil present was 66 metric tons, indicating little change from the previous visit.

During our earlier studies of the Metula spill site in Patagonia, we had seen similarly oiled gravel completely cemented as the mousse dried and turned to asphalt. In an apparent effort to avoid a similar situation at AMC-16, the cleanup crews used a bulldozer to push the oiled gravel seaward into furrows where the waves (at high tide) could rework the sediment, thus removing some of the oil (Fig. 4-55A). This is a valid method since sediment is not removed from the beach and it provides an artificial mechanism of mixing the oiled gravel before it becomes cemented by asphalt. In the future, wave action will probably restore the normal beach profile without marked erosion. The rapidity of beach cleaning will depend upon the amount of wave action.

The coast from Pte. de Sehar to Kerhellen. This section of coast consists of small beaches, steep cliffs, and a large ria. Some of the oil that passed by Roscoff was deposited in this area. Most of this coast was observed to be heavily oiled at the end of March. During the site surveys and aerial reconnaissance of late April, most of the area was still moderately oiled. The tidal flat leading toward Beg-Leguer was heavily oiled. Cleanup activity similar to that at AMC-16 was in progress at F-80. Oil-soaked cobbles along the seawall were being pushed onto the low-tide terrace to be cleaned by natural wave action (Fig. 4-55B).

Table 4-15A. Sediment data for AMC stations in Section VIII.

Sample	Graphic Mean	Size Class[1]	Skewness	Standard Deviation[2]
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-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

VFS = very fine-sand
CS = coarse-sand
P = pebbles

[2] Sorting

VWS = very well sorted
WS = well sorted
VPS = very poorly sorted

Table 4-15B. Estimates of oil tonnage for AMC stations in Section VIII.

Station Number	Date	Oil Present (metric tons)	Date	Oil Present (metric tons)	% Change
AMC-15	28 Mar	83.3	25 Apr	3.9	95.30
AMC-16	28 Mar	81.2	24 Apr	66.3	184.00
AMC-19	NO DATA				

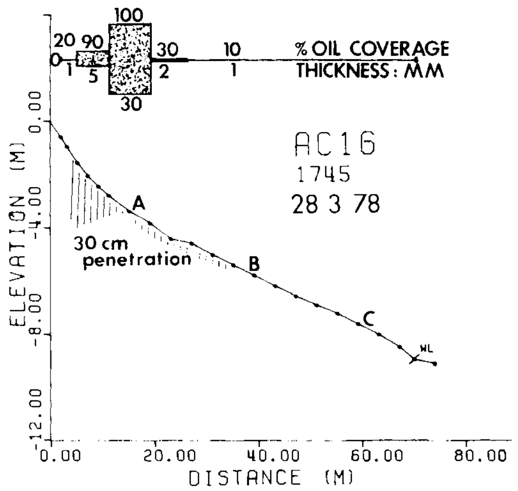

Figure 4-54. Topographic beach profile and oil coverage for station AMC-16 on March 28. Our return site survey on April 24 indicated that oil had penetrated 15 to 20 cm across the entire beach face.

Summary

The most striking observation in this area was the tremendous biological damage at the sand flat at St. Michel-en-Grève, even though it was located 87 km from the wreck. Also, the technique used to clean the heavily oiled gravel beaches may have applicability in New England and Alaska where similar beaches are prevalent, should oil spills occur in those areas.

4.9.9 Section IX--Ile Grande area

This section is one of the more important ones, because it includes a heavily impacted marsh area (Figs. 4-56 and 4-57). The general orientation of this shoreline is northeast-southwest. A large sandflat with scattered bedrock outcrops makes up most of the area. Except for the outer beaches of Ile Grande, the area is exposed to very little wave action. On a large scale map, it can be seen that this entire area protrudes out from the general shoreline trend (Fig. 4-1) making it a perfect interception point for the oil that bypassed Roscoff. Descriptions of the study sites are given in Table 4-16.

Oil Impact

All areas, except station F-76, were observed to be heavily oiled during site visits at the end of March and April. Station F-76 is an exposed, high-energy beach composed of large granitic boulders that was only lightly oiled. Sheltered areas at F-88, F-77, and F-75 had been cleaned or were in the process of being cleaned, but still appeared heavily oiled on April 25. Heavy machinery often mixed the oil deep into the beach or tidal flat sediments, which made it impossible to remove all the oil.

Figure 4-55. (A) Heavily oiled cobbles of station AMC-16 were pushed into furrows to aid cleaning by wave action. (B) At station F-80, a similar method of clean-up was in operation.

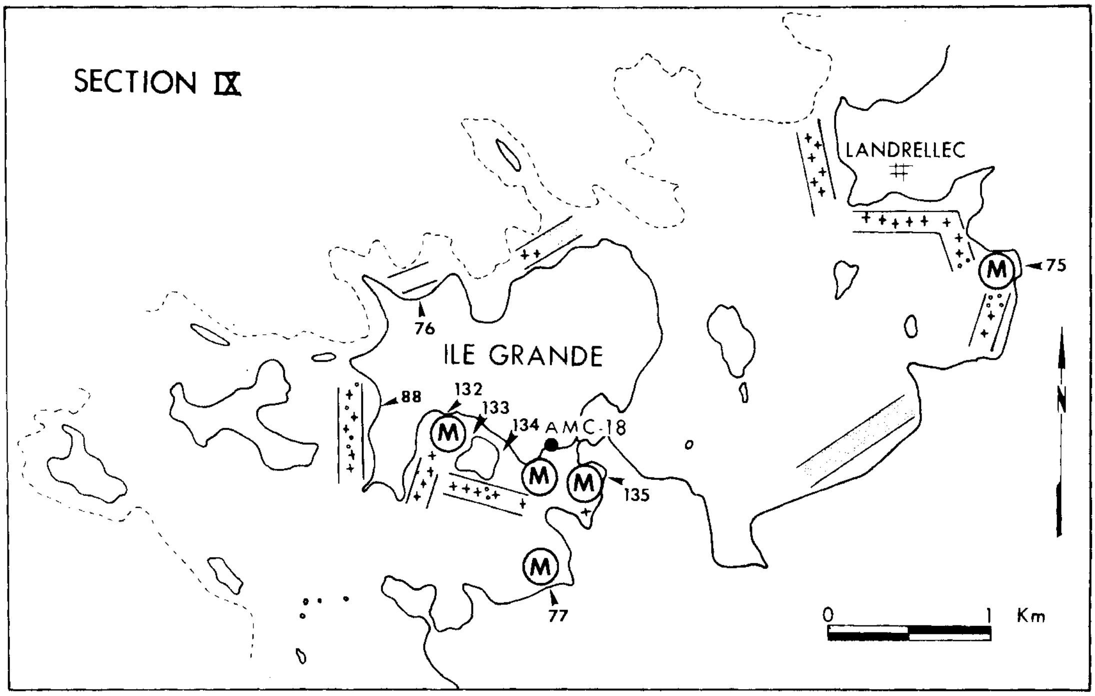

Figure 4-56. Locations of observation stations in Section IX. Oil coverage for the second study period is indicated as follows: heavy oiling--pluses, light oiling--dot pattern, and oiled marshes--circled M's.

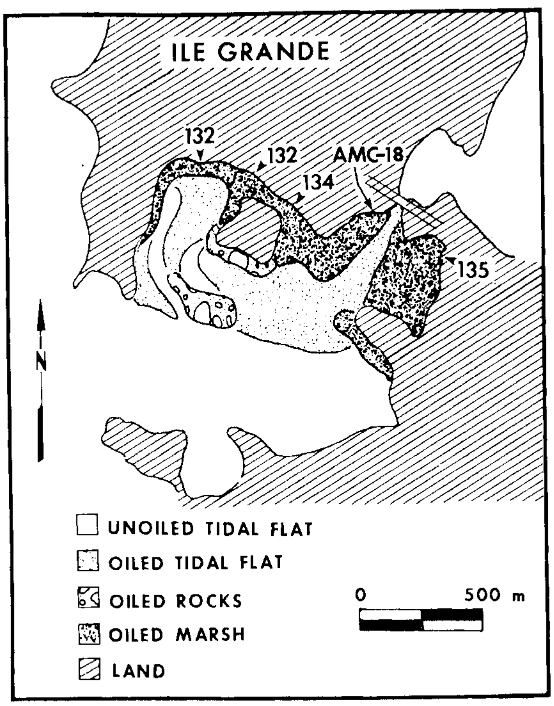

Figure 4-57. The Ile Grande marsh area observation stations and oil distribution on the tidal flat and marsh.

The marsh at Ile Grande presents the most striking effects of oil impact in the entire spill site, especially considering that the oil was transported at least 86 km (53 miles) before it came ashore. During our first survey on March 29, we found oil on the marsh grasses as well as on the tidal flat surface. Plate 4-1 shows the oil coverage at that time. Both the marsh and tidal flat were heavily oiled (Fig. 4-57). Several ground-level photographs are presented in Plates 4-2, 4-3, 5-7, 5-8 and 5-9.

This area provides an excellent opportunity for U.S. scientists to study the effects of oil on a large marsh, tidal flat ecosystem, inasmuch as the types of marsh grasses and infaunal assemblages are similar to those in the eastern U.S. The marsh grasses are distinctly segregated by topography. Figure 4-58 (station AMC-15) gives a sketch of the area, as well as the marsh plant zonation. Briefly, from the high tide line seaward, the grasses consist of *Juncus* sp., *Spartina patens* and a succulent common to northern Europe called *Sesuvium* sp.

At the time of our first site visit on March 29, 3 to 5 cm of oil covered the entire marsh area. Oil thickness and surface area coverage as measured along our profile line are shown in Figure 4-59. On the tidal flat surface, oil was approximately 1 cm thick. Within many tidal pools (approx. 3 m x 1 m) on the surface of the flat, oil reached 15 cm in thickness. In our calculations of the approximate quantity of oil within the marsh system, we assumed an average value of 3 cm of oil over most of the oiled marsh and an average of 1 cm on the flat surface. An average thickness of 5 cm was measured for the marsh at F-135. By measuring the area of each marsh as marked in Figure 4-57, we estimate that 7400 metric tons of oil were present on March 29 (Table 4-17).

At the time of our first site inspection on March 29, thousands of moribund polychaetes were found on the surface of the marsh. Many were observed wriggling on the surface of the oil pools. By the time of our return visit on April 2, the marsh was dead. Thousands of dead polychaetes littered the surface of the marsh, and collected in small saltwater pools within large (2 m x 1 m) oil pools. Crabs were found dead. Grasses were completely blackened. Four oil-covered, dead cormorants were also found.

Our third site visit, on April 25, proved to be most interesting. The French military had begun an enormous cleanup operation within the area and about 80% of the marsh on the north side had been cleaned in some manner. In addition, 90% of the tidal flat was free of oil. Cleanup activities as observed at sites F-133, F-134 and F-135 (AMC-18 and F-132 had been cleaned already), consisted of high-pressure hosing (Figure 4-60A), low-pressure sprinkling, trenching of the thick oil pools, placement of oil into buckets, and use of tank trucks to remove oil from trenches or newly created pits. Over 200 men were working when we were there. The operation was successful in ridding the marsh and tidal flat of an enormous quantity of oil. Measuring along our profile

Table 4-16. Field observations of oil distribution at stations of Section IX, the Ile Grande area.

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
F-77	31 Mar-	Runigou	-heavily oiled.
	25 Apr-	A sand flat with a rip-rap wall along the sides of the flat. A small marsh is also in the area.	-sand flat all clean; rip-rap wall still heavily oiled; marsh remains moderately oiled.
F-135	25 Apr-	Allée Couverte South side of Ile Grande Marsh; vegetation mainly Juncus marsh grass.	-very heavily oiled, cleanup operation in progress; 5 cm of oil on much of the marsh; soldiers using squeegees to push the oil into the channels where it is being pumped out.
AMC-18	29 Mar-	Ile Grande Marsh, and west side of D21 bridge to Ile Grande Large marsh with a wide, muddy sand channel.	-very heavily oiled; oil pools to 27 cm deep; average coverage about 3 cm; thousands of polychaetes worms crawling over the surface of the oil to escape.
	2 Apr-		-oil in same condition; polychaetes all dead and often found in small water pools on the surface of the oil.
	24 Apr-		-visit at hightide; only a light sheen visible on water surface.
	25 Apr-		-area has been manually cleaned; large oil pools drained; marsh still very black but some new green grass shoots appearing.
F-134	25 Apr-	West Road to Rulosquet Part of Ile Grande Marsh area.	-area oiled; extensive clean-up operation underway: light sprinkler system rinsing the marsh as well as high-pressure hosing.
F-133	25 Apr-	East Road to Rulosquet Part of Ile Grande Marsh area.	-still completely oiled; many trenches dug to drain oil; blackened; large clean-up underway.
F-132	25 Apr-	Dourlin Western side of Ile Grande Marsh--a narrow fringing marsh beside a sand flat.	-section 20 m wide remains thinly oiled after clean-up; numerous tire tracks, ditches, trenches on the sand flat as a result of clean-up.
F-88	2 Apr-	Ile Grande Beach (East Facing)	-heavily oiled.
	25 Apr-	Sheltered sandy pocket beach; wave energy usually low due to an island directly offshore.	-heavily oiled shoreline and tidal flat.
F-76	29 Mar-	Northwest Ile Grande Boulder beach.	-lightly oiled boulder beach.
	25 Apr-		-light oil coverage on boulders.
F-75	29 Mar-	(Near) Kerenoc	-small marsh and rocks heavily oiled.
	25 Apr-	Small marsh in northeast corner of large sand flat, with some rocks.	-very heavily oiled marsh grasses; some rocks with algae are completely oil covered; a large trench, dug to collect oil, causes serious oiling of the surface of the tidal flat.

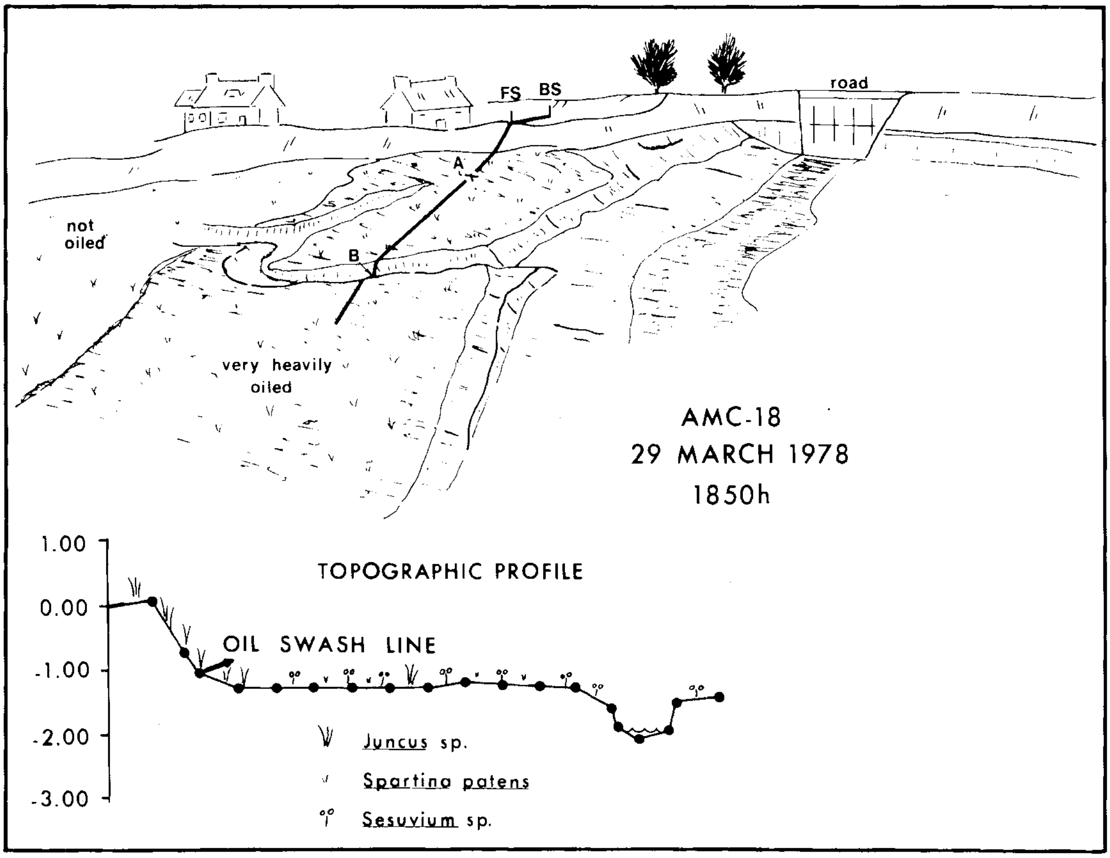

Figure 4-58. Topographic profile and oil coverage for station AMC-18 (Ile Grande marsh) on March 29. Oil distribution along the profile is indicated in Figure 4-59.

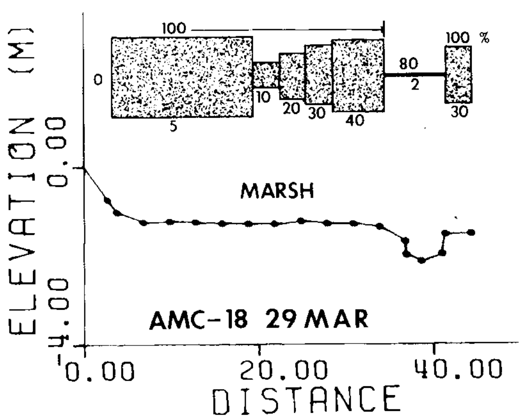

Figure 4-59. Oil coverage along profile AMC-18 (Ile Grande marsh) on March 29. The thickness of the depicted oil coverage line is roughly proportional to actual thicknesses.

Table 4-17A. Grain size data for station AMC-18 in Section IX (Ile Grande marsh).

Sample	Graphic Mean	Size Class[1]	Skewness	Standard Deviation[2]
AMC-18A	4.613	CS	-0.295	1.863 (VPS)
AMC-18B	2.100	FS	-0.134	0.934 (MS)

[1]Size Class

CS = coarse silt
FS = fine sand

[2]Sorting

VPS = very poorly sorted
MS = moderately sorted

Table 4-17B. Calculations of oil quantity at AMC-18 during first (March 19-April 2) and second (April 20-28) study periods.

Station Number	Date	Oil Present (metric tons)	Date	Oil Present (metric tons)	% Change
AMC-18	29 Mar	7400	25 Apr	2761.8	63.00

(station AMC-18), we found an average oil layer of 4 mm mostly coating the bottom sediments and grasses. We calculated the oil tonnage at this time on the following basis:

(1) 20% of the original oiling (3 cm) remained on the north side, with 80% being lightly oiled (4 mm);

(2) 5 cm oiling at F-135; and

(3) 10% of the original 1 cm oiling on the tidal flat.

On the basis of these assumptions, we estimate that 2762 metric tons of oil remained in the Ile Grande marsh area on April 25. This is a 63% reduction from our estimate for March 29 (before cleanup).

Cleanup techniques could have been improved had personnel and machinery been directed to maintain a single road or work path. The unrestricted movement of men and machinery on the surface of the marsh and tidal flat caused extra destruction of vegetation and churned oil deep into the underlying sediment (Figure 4-60B).

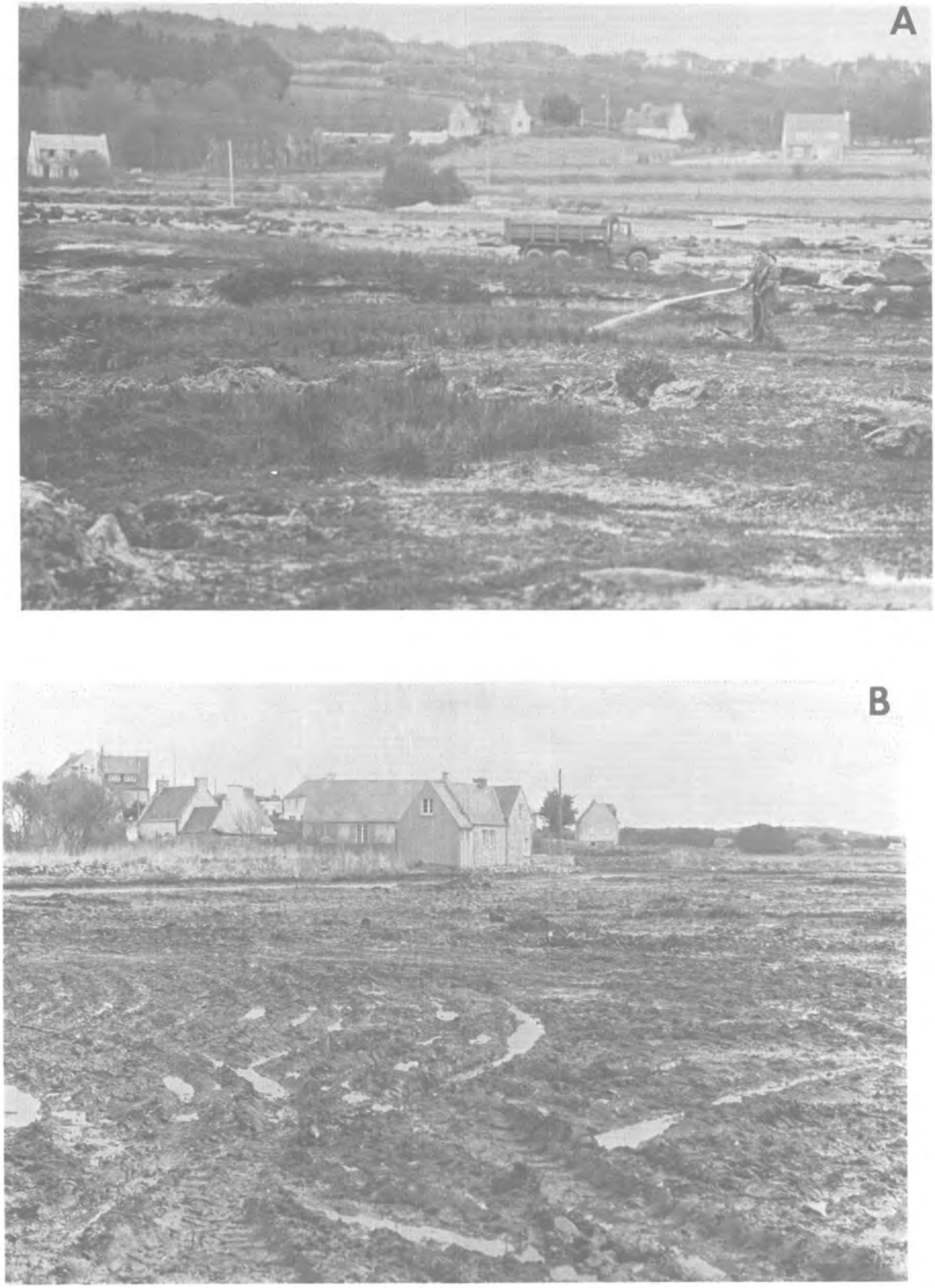

Figure 4-60. (A) High-pressured hosing of the Ile Grande marsh on April 25 (station F-134). (B) The use of heavy machinery on the tidal flat at Ile Grande tended to churn up much of the area and mix oil deep into the sediment (station F-133, April 25).

One of the best opportunities for study in this area would be a time-series investigation of biological recovery. For example, although almost all of the marsh grasses were still blackened by oil on April 25, newly sprouted green marsh grass was already visible. Live fish and crabs were also seen in tidal pools within the main channel.

Summary

The Ile Grande marsh area has illustrated the enormous impact a massive oil spill can have on a thriving marsh/tidal flat ecosystem. This marsh in particular offers an excellent opportunity to monitor marsh recovery after a major spill. It would also be of interest to compare the recovery of this marsh with that of the marsh at Punta Espora, Chile, which was impacted by a heavy dose of Metula oil in August 1973. That marsh, which was not cleaned, has been very slow to recover (Hayes and Gundlach, 1975).

4.9.10 Section X--Landrellec to Trestel

Section X is the northernmost extension of the granitic plateau of which Ile Grande is a part (Fig. 4-61). Much of the area near the coast is less than 20 m above sea level except by Ploumanac'h, where cliffs over 40 m are present. Major depositional embayments with large sand flats are located at Ploumanac'h and Perros-Guirec, where the mean tidal range has increased to 8 m. This is one of the more popular tourist areas of this section of Brittany. Individual study site descriptions are given in Table 4-18.

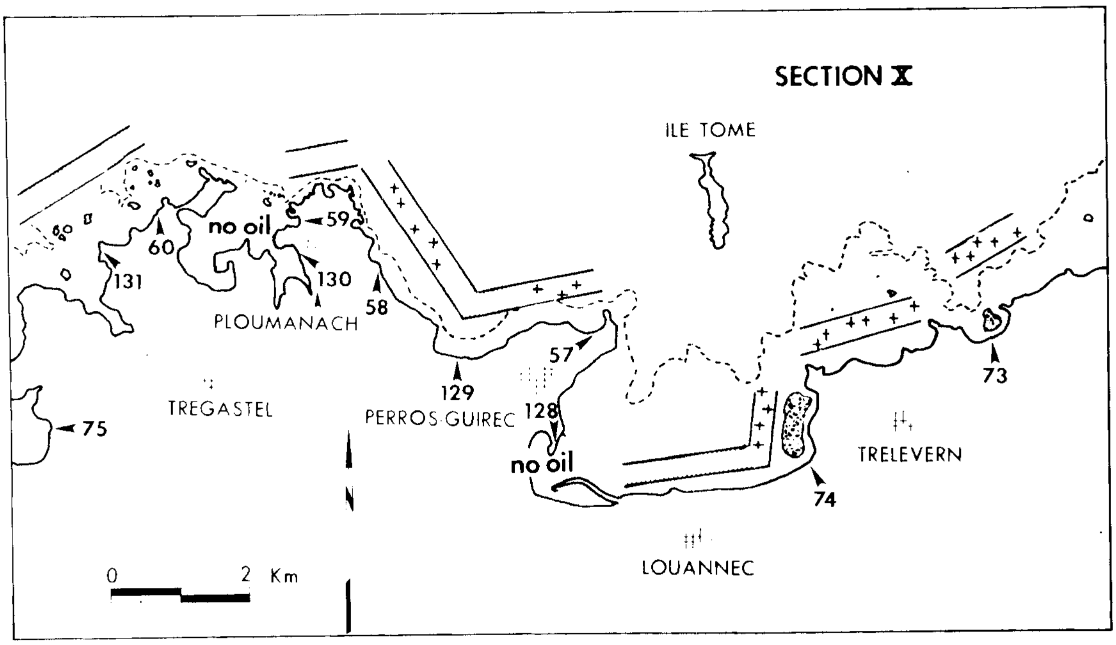

Figure 4-61. Locations of observation stations in Section X, Landrellec to Trestel. Oil distribution for the first study session is indicated by the dark-stippled pattern. For the second study period, heavy and light oil coverage are indicated by the plus and light-dot patterns, respectively.

Table 4-18. Field observations of oil distribution at stations of Section X, Landrellec to Trestel.

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
F-131	25 Apr-	la Grève Blanche Sandy beach with a large tidal flat and outcropping rocks.	-the beach is very clean with a clean tidal flat; the rocks are somewhat oiled, and are presently being cleaned by a power hose from a water tank-truck.
F-60	28 Mar-	Coz Porz Coarse-sand beach with large rocks offshore.	-lightly oiled; sand removed from beach as protection measure.
	25 Apr-		-a few isolated mousse balls on the beach; a light oiling on the offshore rocks.
F-130	25 Apr-	Ploumanac'h - South Harbor with a sandy beach.	-clean except for a few oil globs; the rocks have been artificially cleaned.
F-59	28 Mar-	Ploumanac'h - North	-moderately oiled.
	25 Apr-	Protected small pocket beach; coarse-sand and gravel.	-a clean beach; no buried oil layers, but the groundwater is oil saturated.
F-58	28 Mar-	East of Ploumanac'h Rocky coast with some small gravel and cobble pocket beaches.	-rocks clean; an oil sheen is on the water.
	25 Apr-		-the pocket beaches are heavily oiled; exposed headlands are very lightly oiled; clean-up in progress.
F-129	25 Apr-	Plage de Trestraou Large fine-sand pocket beach located between two rocky headlands which project almost due north.	-some light oil swashes on the beach; also some oiled cobbles being buried by the fine sand; a tractor is digging up the cobbles and pushing them seaward so that the waves can clean them.
F-57	28 Mar-	Plage de Trestraou Sandy pocket beach.	-very clean except for a light sheen in the water.
F-128	25 Apr-	Perros-Guirec Jetty and harbor.	-jetty lightly oiled on the ocean side; no oil in the interior of the harbor; boom across harbor.
F-74	29 Mar-	Nanthouar Large gravel beach.	-rocky area heavily oiled.
	24 Apr-		-lightly oiled swash line on the beach; rocks to the west are moderately to heavily oiled.
F-73	24 Mar-	Plage de Trestel Medium-sand tidal flat and beach.	-beach is clean; a new seawall is covered with plastic so as to prevent its oiling.
	24 Apr-		-seawall still covered with plastic, so far unoiled; a few light oil swash lines on the beach.

Oil Impact

Initial oil impact for most of the area was very light to moderate (Table 4-18). Only Stations F-74 and F-73 received major accumulations. Most of the oil still in the water drifted by without hitting the coast. Station F-60, which would have been expected to be oiled, was apparently protected by offshore rocks (see Figure 4-61). All areas on the east side of the Ploumanac'h peninsula were on the sheltered side during the westerly wind and were not initially oiled.

However, during our second study session, April 23, the coast was much more heavily oiled. Apparently, the wind shift caused the oiling of the previously clean areas on the lee-side of the headlands. Rocky areas were particularly hard hit, especially at stations F-57 and F-58. The area from F-74 to F-73 also was more heavily oiled than during the first study session. As was common at the other sections, the oil spill changed from having large oil pools at particular areas to being spread in varying quantities over the entire coastline. In many localities, the beach had become cleaner, but the rocks alongside the beach were more heavily oiled. A definite shift of oil from the beaches to within sheltered rocky areas had taken place.

Summary

Section X illustrates a standard pattern of oil dispersal for the oil spill area. Sites previously sheltered from oil deposition (e.g. F-57 and F-58) during the first two weeks of the spill, became heavily oiled after the wind shift. Beaches were cleaned much more rapidly than sheltered rocky areas. In fact, the rocks probably act as a sink for some of the oil washing off the beaches.

4.9.11 Section XI--Port Blanc to Sillon de Talbert

Section XI represents the farthest easterly extent of oil coverage that we observed (Fig. 4-62). The base of Sillon de Talbert is 130 km from the wreck site (by the most direct ocean route). On March 30, we flew the section of coast from Mont St. Michel Abbey to Sillon de Talbert and found no oil along the coast. Only a few small mousse patches were seen in these waters. Table 4-19 contains descriptions of the individual study sites.

The coastline in Section XI consists of two large granitic headlands separated by a large tidal flat/estuarine system. The tidal range reaches between 8.5 and 9.0 m. Many beaches of the area are naturally crenulate in shape (F-66, F-68 and AMC-17). The role of crenulate beaches as a localized control of oil deposition will be discussed in the following section.

Table 4-19. Field observations of oil distribution at stations of Section XI, Port Blanc to Sillon de Talbert.

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
F-72	29 Mar-	Les Dunes near Port Blanc Sand and gravel beach with a large tidal flat and dunes.	-heavily oiled gravel and rip-rap near dune area.
	24 Apr-		-minor oiling along the high tide swash line; the tidal flat is very clean.
F-71	29 Mar-	Crech Arel Sandy beach with low-tide terrace.	-clean beach but some oiled rocks.
F-70	29 Mar-	(Near) Pellinic Marsh.	-oiled marsh covered by an average 3 cm of oil.
	24 Apr-		-still very heavily oiled; no clean-up.
F-69	29 Mar-	Bugelos - Coz Castel Tidal flat surrounded by large rocks.	-oiled rocks surrounding large tidal flat.
	24 Apr-		-rocks still appear heavily oiled; no oil on tidal flat itself; marsh grasses appear oiled; clean-up operation has left area completely dug-up.
F-127	24 Apr	Anse de Gourmel Large sandy tidal flat.	Sand flat is very bioproductive; thousands of worm burrows and many cockles; beach and tidal flat are clean except for a minor oiled sea-weed swash line along the last high tide swash; rocky areas on both sides of this sand area are heavily oiled.
F-68	29 Mar-	(near) Kergonet	-tidal flat and rocks both oiled.
	24 Apr-	Sandy beach with large tidal flat.	-very heavily oiled along the upper portions of the tidal flat as well as the beachface; tidal flat itself is all soaked with oil; trenches dug to trap and pump out the oil remain heavily oiled.
F-67	29 Mar-	Porz Scaff	-oiled gravel and rocks.
	24 Apr-	Small pocket beach with a seawall behing it.	-all the cobble on the beach are heavily oiled as is most of the lower beachface.
F-66	29 Mar-	Castel Meur	-heavily oiled gravel beach; large clean-up operation underway.
	24 Apr-	Gravel and cobble beach with a large tidal flat; many cobbles outcrop on the tidal flat.	-very heavily oiled here; mousse is 1-2 cm thick on much of the beach; some of the limpets have survived but many dead cockles and crabs are seen floating in oil pools; straw used to absorb some of the oil is still on the beach and tidal flat.
F-65	29 Mar-	Porz Bugale	-no oil.
	24 Apr-	Small, mixed sand and cobble beach.	-light oiled swash line along the last high tide line.
F-64	29 Mar	Tréguier Estuarine tidal flat with a major channel flowing north.	No oil.

Table 4-19 (continued)

Station Number	Date(s) Visited	Location and Type of Environment	Description of Oil Impact
F-126	24 Apr	Luzuret Broad rocky tidal flat.	Beach area clean; rocks very lightly oiled.
F-63	29 Mar- 24 Apr-	Plage de Beni Sand and cobble beach.	-no oil. -lightly oiled swash lines.
F-62	29 Mar	Kermagen Boulder and cobble beach.	A little oil on the boulders.
AMC-17	29 Mar- 24 Apr-	Port la Chaine Coarse-sand crenulate-shaped beach between rocky headlands.	-very thick oil accummulations on beach; oil contaminated interstitial water. -light oil staining of beach sediments; some oil buried on beachface (15 cm) and on low-tide terrace; interstitial water still contaminated.
F-125	24 Apr	le Quebo Mixed sand and gravel beach.	Some minor oil blotches on the rocks; otherwise completely clean.
F-61	29 Mar- 24 Apr-	Sillon de Talbert A flying gravel spit.	-lightly oiled rocks; clean beach. -rocks lightly oiled; this is the furthest eastern extent of the oiling.

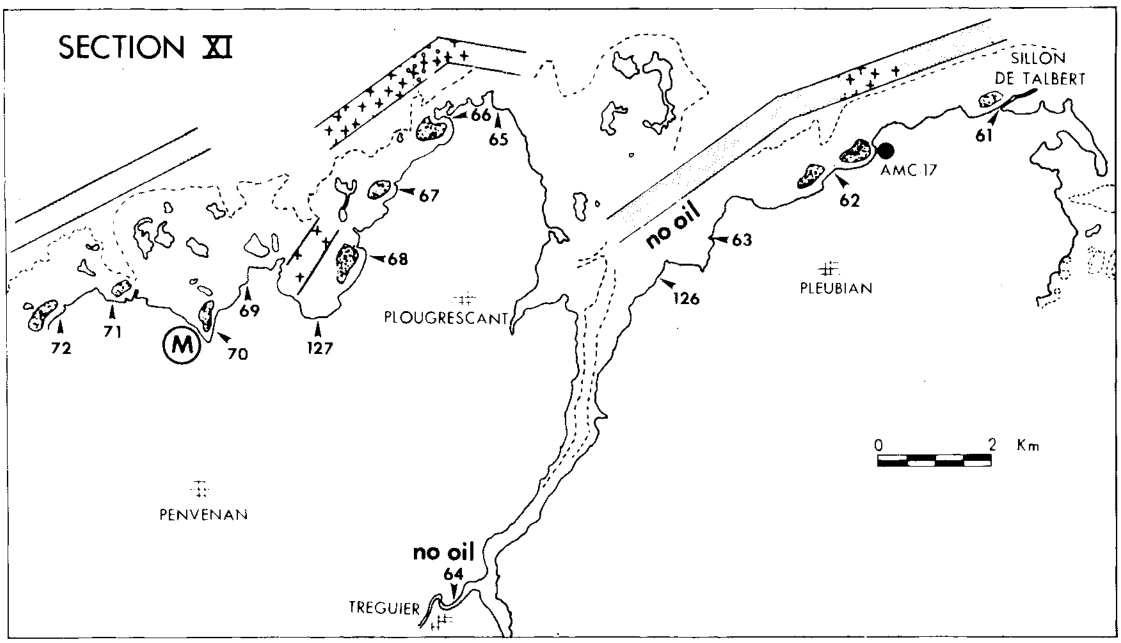

Figure 4-62. Locations of observation stations in Section XI, Port Blanc to Sillon de Talbert. Oil at the base of Sillon de Talbert represents the eastern-most extent of oil coverage observed. It is 130 km (77 miles) from the wreck site. Oil distribution for the first study session is indicated by the dark-stippled pattern. For the second study period, heavy and light oil coverage are indicated by plus and light-dot patterns, respectively.

Oil Impact

The coast from F-72 to F-66. Oil impact increased toward the north in the areas not shielded by the peninsula at Ploumanac'h (Section X). Initially, moderate to heavy oil accumulations occurred on most of these beaches. Particularly hard hit was the headland at Castel Meur (F-66) which is located at the end of the peninsula. The cobble beach and adjacent sand flat were very heavily oiled. A large cleanup operation was active during our site visit on March 29. Oil was being pushed into newly dug trenches on the low-tide terrace so it could be suctioned-up by honeywagons. Two large oil storage pits were dug nearby as collecting ponds. Upon our second visit on April 24, the area was still heavily oiled, although most of the thick oil accumulations were gone. The cobbles and boulders of the beach were still oil-blackened. The tidal flat was severely dug up. The trenches had infilled but remained severely oiled. An oil sheen was common throughout the area. Live limpets were observed on the rocks, but many cockles and crabs were found dead.

Speaking to a woman who lives by this beach, we learned that she depended on two things for her livelihood: summer tourists who come to the beach, and the collection of algae from along the swashline. Both sources of income were at least temporarily destroyed by the spill.

The coast from F-65 to Sillon de Talbert. This segment includes a large estuarine sandflat system plus the rocky coast up to the Sillon de Talbert gravel spit. To our knowledge, no oil entered the estuary during the first two weeks of the spill. During our second survey, April 24, a light oil swash was present on all these beaches.

Station AMC-17 had the heaviest deposition of oil within this section and represents the major accumulation farthest from the wreck site. It has a poorly sorted, mixed sand and gravel beachface leading onto a very coarse-sand low-tide terrace. Sedimentary characteristics are presented in Table 4-20A. The overall shape of the beach is crenulate in nature, which served as a trap for the wind-transported oil. Oil was thickly deposited (up to 12 cm) at the northern end of the beach on March 29, whereas the beach to the south was free of oil. Plate 4-31 shows the beach at this time. Oil coverage as measured along the topographic profile is presented in Figure 4-63. Penetration of oil into the beach was greatly inhibited by the compact substrate. The interstitial water of the low-tide terrace was noticeably contaminated. We estimate that 126 metric tons of oil were present at this time (Table 4-20B). The military began to clean up the beach as we finished our survey. The hard substrate made it relatively easy to shovel up the oil into buckets to be carted away by tractors.

On our second survey, on April 24, the major oil accumulation was gone, but the beach sediment and rocks appeared heavily oil-stained. In

Table 4-20A. Grain size data for station AMC-17 in Section XI.

Sample	Graphic Mean	Size Class[1]	Skewness	Standard Deviation[2]
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)

[1]Size Class

VCS = very coarse sand

CS = coarse sand

[2]Sorting

VPS = very poorly sorted

MS = moderately sorted

Table 4-20B. Calculations of oil quantity at AMC-17 during first (March 19-April 2) and second (April 20-28) study periods.

Station Number	Date	Oil Present (metric tons)	Date	Oil Present (metric tons)	% Change
AMC-17	29 Mar	136.4	24 Apr	1.6	98.80

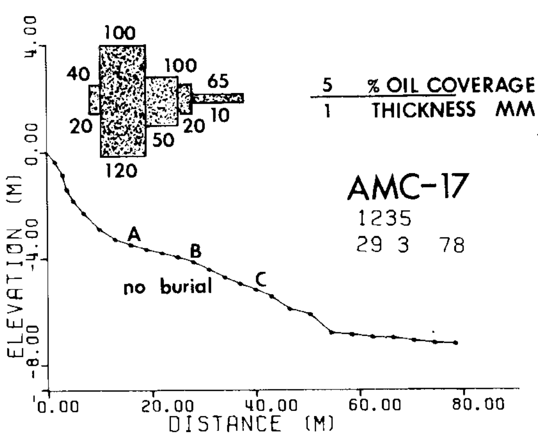

Figure 4-63. Topographic profile and oil coverage for AMC-17 on March 29.

addition, some oil was buried 15 cm by new sediment along the upper beachface. A large (100 m^2) mass of mousse also remained mixed into the low-tide terrace. The interstitial water was still contaminated, but healthy algae, snails, and limpets were found in abundance. We estimate that 1.6 metric tons of oil remained in the area (Table 4-20B). It was interesting that a large cobble beach directly to the south was significantly oiled on the second visit, whereas it had not been during the first. Apparently, some of the oil from AMC-17, or from other beaches, was redeposited in this area during the weeks between our first and second surveys.

Summary

Section XI encompasses the westernmost extent of oil pollution from the Amoco Cadiz (a distance of 130 km from the wreck). Station AMC-17 illustrates the importance of the trapping of oil along the northeast side of a crenulate bay during the first oiling and the eventual oiling of the southwest side as a result of a change in the wind direction. (According to C. J. M. Chassé, personal communication, the same thing happened on this coast during the pollution by the Torrey Canyon oil in 1967).

4.10 Preliminary Conclusions

When our second site visit ended on April 28, 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.

4.10.1 Influence of Coastal Processes and Coastal Morphology

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 first few days of the spill. The rugged and indented topography of the coast then played a major role in determining where the oil would be deposited. The shorelines facing west were hardest hit, whereas those facing east, particularly those within the larger embayments, were mostly unaffected. This process is depicted diagramatically in Fig. 4-64A. During early April, the dispersal pattern of the oil changed. Major oil accumulations were broken up and dispersed. Because of the wind shift at the beginning of April, the oil was spread far into

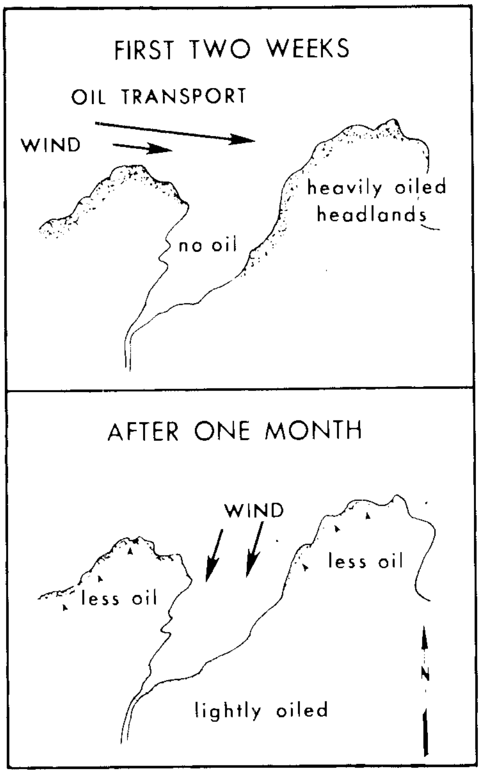

Figure 4-64. (Top) Oil pushed by strong westerly winds during the first two weeks was mainly deposited along westerly-facing headland areas. Interior embayments generally remained free of oil. (Bottom) A wind shift during the beginning of April spread a light layer of oil deep into the embayments. Previously deposited oil along the exposed headlands was greatly reduced in quantity.

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. Oil dispersal during this time period is illustrated in Fig. 4-64B.

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 because of high wave energy at that locale. Many of the exposed environments along each northward jutting peninsula were generally free of oil within 1 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-66), or at Primel-Trégastel (F-94). The marsh environment at Ile Grande illustrates an area with very low exposure to waves and, consequently, one with potential duration of oil effects.

Beaches vs. 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 attack. Thus, under similar conditions of wave exposure, a sand beach is much more likely to be cleaned by natural processes than is 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 Fig. 4-65. Where crenulate bays occur on west-facing shorelines, as at Stations F-39, -62,-68 and AMC-9 and -17, they 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 winds were westerly).

Another morphological feature, the tombolo (Plate 4-21), 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 because of the convergence of wave fronts around the offshore rocks. This process is illustrated in Fig. 4-66.

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 (see Plates 4-16 and 4-17). 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 activity (during the early days of the spill) commonly caused deep burial of oil layers in the beachface. The removal of 80% of the oil from the Roscoff area during two tidal cycles can be attributed partly to the erosional phase of the beach cycle. Therefore, a basic understanding of the beach cycle provides a good foundation for interpreting the behavior of oil on the beaches.

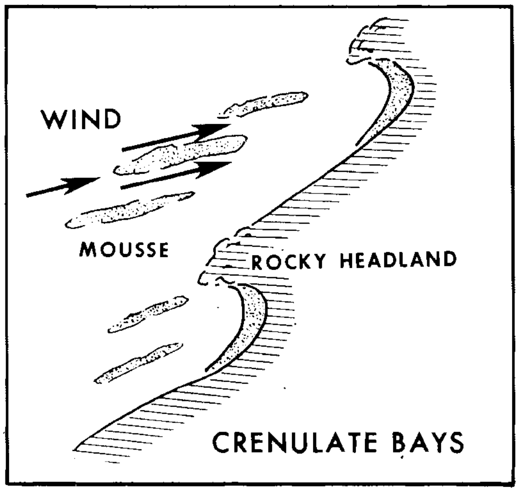

Figure 4-65. Entrapment of oil by crenulate bays. Generally, the southerly section of each bay remained free of oil.

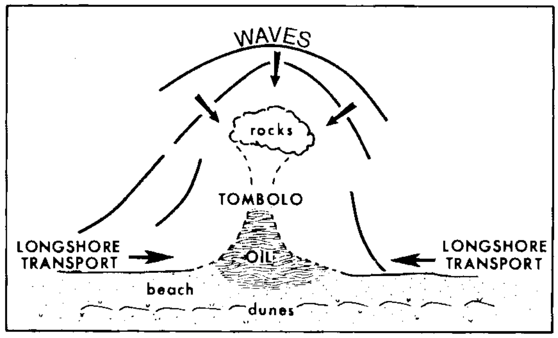

Figure 4-66. Illustration of the tombolo effect causing localized oil deposition behind offshore rocks.

4.10.2 The Vulnerability Index

On the basis of studies of the Metula and the Urquiola oil spills, we have developed the vulnerability index, a system of classifying coastal environments with respect to oil spill impacts (Hayes, Brown, and Michel, 1976; Gundlach and Hayes, 1978). 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 support some of our earlier conclusions and allow for further refinement of others.

Following is 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. A summary is presented in Table 4-21[8].

[8] It should be noted that the vulnerability index was developed in areas that could be readily classified as erosional or depositional. The Brittany coast presents a variety of sand beaches which show deposi tional cycles, but which, for the most part, are undergoing long-term erosion. Scarps of either bedrock or dune material occur back of most of the beaches, partly inhibiting formation of a truly depositional beach profile (which normally has a well-developed berm, berm-runnel, and back-beach area). This affects the classification system by some what limiting our original estimates of oil penetration and burial, and generally reducing the overall persistence of oil in these areas. Still, in terms of general oil persistence, the basic order of the index holds true.

Table 4-21. 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 (1978).

Vulnerability Index	Shoreline Type; Example	Comments
1	Exposed rocky headlands; Douarnenez to Pte. du Raz and Primel-Trégastel 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 & 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) & 12 (St. Cava) and F-38	Oil coverage and burial after one month remains at moderate levels.
5	Exposed, compacted tidal flats; La Grève 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.

(1) Exposed steeply dipping or cliffed rocky headlands

Two areas in particular fit into this category: (1) the cliff between Douarnenez and Pointe du Raz (Section I), and (2) the cliff between Primel-Trégastel and Locquirec (Section VII). In both areas, most of the oil was held approximately 10 m offshore by waves reflecting off the steep scarps. Some oiling did occur where reflected waves were dampened, as in small coves or pocket beaches. However, this is only a short-term condition since high-wave conditions will rapidly remove the oil.

(2) Eroding wave-cut platforms

A good example of this coastal type is located along the exposed coast between Trémazan (F-1) and Pointe de Landunvez (F-82) in Section II. Heavy oil accumulations that were originally found at Trémazan rapidly dissipated under repeated wave attack.

(3) Flat fine-grained sandy beaches

Fine-sand beaches are located to the southwest of Roscoff (stations AMC-9, AMC-10, F-17,-18 and-20) and to the east of Portsall (AMC-5). Each has a very broad beach/low-tide terrace. The beach profile is essentially flat. Within 1 month after being heavily oiled, each was categorized as having a light oil coverage, usually with only a minor oiled swash line. Cleanup activities at AMC-5 appeared to have caused little damage.

(4) Steeper, medium- to coarse-sand beaches

Beaches at stations AMC-4 and AMC-12 provide good examples of heavily oiled coarse-sand beaches. One month after heavy oiling, each still contained moderate to heavy oiling. Overall recovery was somewhat slower than at areas with index values of 1 to 3. Much of the beachface still contained oil or was oil-stained. Burial was also more common, but somewhat inhibited by underlying relict marsh or compact sandy gravel material. Again, this illustrates the complexity of the Brittany coast with regard to its erosional history. The coarse-sand beach at F-38, with no underlying base material, had 70 cm of oil burial.

(5) Exposed, compacted tidal flats

The large sand flat at St. Michel-en-Grève falls under this classification. Most of the oil was pushed across the tidal flat onto the beach at its edge. The flat itself was not significantly oiled; however, the enormous biological destruction caused by the oil supports its central position on this list. Perhaps, in terms of a truly biologically oriented oil spill index, this type of environment should be placed higher.

(6) Mixed sand and gravel beaches

There were no truly depositional mixed sand and gravel beaches in the spill area. Our original designation of this beach type as (6) was based on expected deep oil penetration. Each mixed sand and gravel beach in the spill area (AMC stations 1, 2, 6, 8 and 17) had an underlying material of compacted sediments that totally prevented oil penetration. Of these beaches, three were heavily oiled after 1 month, but two had only light coverage. The difference in remaining oil content is more attributable to variations in wave energy than to sediment type.

(7) Gravel beaches

All gravel beaches of the area remained heavily oiled 1 month after the spill. Typical examples are provided at F-stations 80, 95, and 129 and at AMC-16. In each case, oil penetrated deep into the beach sediment. Had cleanup not been started, it could be expected that the sediments would have become cemented together as the mousse turned to asphalt. This process was observed at the Metula site where no cleanup took place (Hayes and Gundlach, 1975).

(8) Sheltered rocky coasts

After 1 month, many sheltered rocky areas remained heavily oiled. Cleanup by hand and bucket and with water under high pressure reduces the amount of oiling but it is a slow and very tedious process.

(9) Sheltered estuarine tidal flats

Examples of this environment type are best illustrated by the sheltered environments behind Ile Grande and at Castel Meur (F-66). Oil coverage at both localities was exceedingly heavy. Clean-up activities succeeded in removing 80%-90% of the oil on the surface, but also extensively dug up the tidal flat. A large quantity of oil remains mixed into the sediment, and the interstitial water remains severely contaminated. The biological recovery of each area should be monitored.

(10) Sheltered estuarine salt marshes

The marsh at Ile Grande provides a classic example of the worst effects of an oil spill. A very extensive cleanup removed most of the 5 to 15 cm of pooled oil from the marsh, but overall biological recovery cannot yet be guaranteed.

Summary

Although the coastline of Brittany is exceedingly complex, the vulnerability index of coastal environments to oil spill damage, which was developed through studies at other spill sites, would have predicted the short-term behavior of Amoco Cadiz oil in each environment reasonably well. Environments rated high on the scale generally remain more highly oiled today (and generally represent more severe environmental damage) than those areas with low values. Thus the utility and application of this scale as part of a contingency plan for threatened areas (e.g., the coast of Alaska) seems to be clearly justified.

4.10.3 Oil Response to Tide-Level Changes

One of the questions raised by our previous oil spill studies (mainly those of the Metula and Urquiola spills) is whether the oil lifts off the bottom with every flood tide or instead becomes sediment-logged and remains 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 had sunk. 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.

4.10.4 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-Grève (F-55) provide typical examples.

The ground water within a beach rises and falls with each tidal cycle. On the receding tide, large quantities of the ground water flow out of the beach, creating a series of ground water rills. However, a significant portion remains tied up within the sediment by capillary forces.

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 oil 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?

Unfortunately, some of the methods now being employed to clean up the beach undoubtedly intensify the pollution of the ground water by the oil. The digging of large pits and trenches into the beach surface to use as catchment basins, such as those we witnessed at St. Michel-en-Grève, can only increase the contamination. Follow-up studies of beach processes and water chemistry are needed for a better understanding of this problem.

4.10.5 Cleanup Activities

Our perspective of the cleanup operation is from a geomorphological standpoint and not from the technical side. (See Chapter 6 for details on engineering techniques.) We are fortunate that our co-participant, Dr. Laurent D'Ozouville, has maintained contact with the Department of Equipment concerning the types of cleanup operations in force. Our combined suggestions follow:

(1) Restrict vehicular traffic on the beach, especially on the low-tide terrace. Oil often became deeply churned into the sediment as a result of heavy tractor usage. If tractors and trucks must be used, a single lane of traffic should be utilized.

(2) The removal of oil by manually scraping the surface layer with wood squeegees into trenches, to be suctioned off, is a valid method. However, natural infilling after abandonment of the pit often caused the deep burial of large amounts of oil. This oiled sediment should be dug up and placed in the surf zone so it can be cleaned by wave action. Long-term contamination of the interstitial water may otherwise result.

(3) The use of front-end loaders to scoop up thick layers of oiled sediment is valid in low-populated dune areas. This practice in areas that lack a readily replenishable sand supply may cause serious beach erosion problems. In general, any removal of sediment from the beach should be avoided.

(4) The use of bulldozers to plow oiled gravel into the surf zone is an excellent method for oil removal, because the sediment balance on the beach is maintained and the normal beach profile can be re-established by natural wave action.

(5) In general, the clean-up effort at Ile Grande marsh was laudable. The removal of oil from the marsh was necessary to establish any sort of biological recovery. The use of trenches to drain oil pools, as well as squeegees, buckets, and pressurized water, all seem valid from an environmental point of view. However, a problem

did arise by not limiting vehicles and personnel to certain access roads. The extensive walking and driving over the marsh may have further inhibited its recovery.

4.10.6 Where did the oil go?

Two of the primary questions usually raised during an oil spill are "Where did the oil go?" and "How did it change?". In a very basic attempt to answer these questions, we have made extrapolations from our areas of detailed study to the entire oil-affected coastline. This method has two weaknesses:

(1) Our study areas were generally limited to beaches. Thus, extrapolations 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 March 24. This could be the same oil that we encountered in the Ile Grande area on March 29.

Calculations of oil coverage were made for the morphological sections (I-XI) of the coast during each of the two study periods. The results of this calculation are presented in Table 4-22. Using 17 of the 19 AMC stations as a basis (AMC stations 14 and 19 were eliminated), we calculated the average oil quantity per km of coast.

Table 4-22. Extent of oil coverage during study periods one and two. Oil is described as heavy only during study one (March 19-April 2). During study two (April 20-28), it is described as light or moderate-to-heavy.

Section of Coast	Study Period 1 (km oiled)	Study Period 2 km lightly oiled	km heavily oiled	total km of coastline
I	0	52	39	280
II	11	5	8	24
III	16	15	8	43
IV	4	30	0	38
V	4	43	0	43
VI	8	10	4	27
VII	4	24	9	76
VIII	9	10	20	35
IX	5	4	4	16
X	2	12	6	35
XI	9	8	9	36
Total	72	213	180	653

The results of these calculations are presented in Table 4-23. In order to determine the total amount of oil on the coast, the amount of oiled coastline (Table 4-22) was multiplied by the quantity of oil per km of coastline (as determined from the individual study sites; Table 4-23). The values used were 886.5 tons/km for all oiled areas during the first study, and 55.4 tons/km for moderately to heavily oiled areas, and 5.2 tons/km for lightly oiled areas during the second study. The results are presented in Table 4-24.

Table 4-23. Oil quantity per length of beach for 17 AMC stations during study period one (March 19-April 2) and study period two (April 20-28).

		OIL CONTENT (metric tons)		
AMC-STATION	LENGTH OF BEACH	SESSION ONE	SESSION TWO	
			Light Coverage	Heavy Coverage
1	500	50.2		7.3
2	250	1.8		2.4
3	250	44.6		5.5
4	200	284.1		2.5
5	1250	1146.9	2.5	
6	200	51.8	1.0	
7	200	102.5	1.7	
8	200	9.6	0.4	
9	2000	1039.4	10.6	
10	1250	46.3	6.0	
11	450	175.2		1.0
12	400	357.7		6.3
13	550	248.3	0.6	
15	300	83.3		3.9
16	400	81.2		66.3
17	300	136.4	1.6	
18	4000	7400.0		500.0*
SUB TOTAL	12.7 km	11259.1	24.4/4.7 km	595.2/10.75 km
TOTAL (metric tons)/km		886.5	5.2	55.4

*After clean-up

Table 4-24. 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	180
km shoreline lightly oiled	-	213
total shoreline oiled km	72	393
total quantity of oil along shoreline	63,828 m tons	11080 m tons
	Total reduction between sessions = 83%	

During the first 2 weeks of the oil spill, a total of 72 km of coast was heavily oiled. Using our estimated quantity of oil per km of shoreline (886.5 tons) yields a total of 63,828 metric tons of oil (rounded to 64,000) that we are able to account for. This is approximately one-third of the total amount of oil lost from the tanker. The remaining two-thirds must be accounted for by evaporation loss, oil masses remaining on the water's surface, sinking to the bottom, and mixing into the water column.

During the second study session, 213 km of coastline were lightly oiled and 107 km were heavily oiled. Using our oil estimates for session two (Table 4-22), we can account for 10,310 metric tons of oil (a loss of 84% of the oil on shore during the first visit). This continued loss of oil from the shore can be attributed to a combination of natural cleaning processes and a very active cleanup program.

In conclusion, approximately one-third of the oil spilled from the *Amoco Cadiz* (estimated at 64,000 metric tons) went aground on 72 km of shoreline during the first 2 weeks of the spill. During the following 3 weeks, the quantity of oil along the shoreline was reduced by 84% (to approximately 10,310 metric tons). This reduction was due to natural dispersion and to cleanup activities by man. On the other hand, the amount of shoreline visibly contaminated by the oil increased to 320 km by late April. This increase was due to the break-down and dispersion of the large oil masses by waves and currents and to a major shift in wind direction (from westerlies to easterlies).

4.11 References

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