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OCCURRENCE OF OIL IN OFFSHORE BOTTOM SEDIMENTS AT THE *AMOCO CADIZ* OIL SPILL SITE

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ABSTRACT: *A diving survey was undertaken during August 1978 to ascertain the vertical and horizontal distribution of oil incorporated into bottom sediments of the bays of Morlaix and Lannion within the* Amoco Cadiz *spill site of Brittany, France. A total of 80 hand-held, 15-cm-long box cores was taken at 20 stations and analyzed for visual oil content and sedimentary characteristics. Chemical samples also were taken and now are being analyzed.*

Preliminary investigation revealed a significant amount of oil incorporated into the bottom sediments within both areas, although the mechanisms of deposition probably were different. Generally higher oil concentrations were found in muddy sediments, sediments containing Lithothamnium, *and in samples taken offshore of heavily oiled beaches. The depth of oil penetration was usually less than 7 cm (possibly related to the depth of biological reworking), except in the more porous* Lithothamnium *sediments, or in those areas close to heavily oiled beaches.*

Hand-held box coring techniques are more advantageous than other shipboard methods in that the problems associated with grab sampling are avoided, and complete control is maintained over the sample at all times. In addition, direct observations of bottom sediment variability and visible oil accumulation can be made.

Oil that sinks and becomes incorporated into bottom sediments during a spill in marine waters poses the single greatest threat for long-term oil pollution of the marine environment. The sinking of oil with associated contamination of offshore bottom sediments has been demonstrated for several spills, including the Santa Barbara blowout,[11] the *Arrow,*[10] and the *Florida.*[1] However, the exact mechanism of the deposition of oil on the bottom and the frequency of occurrence of this process during spills remain unresolved.

Our purpose here is to present preliminary results of a diving survey to investigate bottom oil deposited during the spill of the *Amoco Cadiz* (March-April 1978) in the coastal waters of Brittany, France. This project emphasizes oil/sediment interactions from a geological point of view. Additional studies of the impact of the bottom oil on indigenous biota are in progress by French biologists.[4]

The *Amoco Cadiz* spill

The Liberian tanker, *Amoco Cadiz,* which had a load capacity of 233,690 tons, lost steering on March 16, 1978 off the Brittany coast. The ship drifted in a storm for 12 hours. At 2104 on the March 16, the tanker struck some rocks approximately 3 km off Portsall, and soon thereafter began to spill oil. Eventually, the entire load of 223,130 tons of cargo plus 4,000 tons of Bunker oil were lost.

Strong westerly winds pushed the spilled hydrocarbons to the east. By March 22, the region of Roscoff and the Bay of Lannion (Figure 1) were heavily oiled. On April 3, L. Cabioch and associates of Station de Biologie at Roscoff observed hydrocarbons in the fine sandy sediments of the Bay of Morlaix at a depth of 18 m. Later in April, a wider distribution of the bottom oil was noted by means of underwater television. The bays of Morlaix and Lannion were especially heavily polluted. Thus, these areas were chosen for the focus of our field studies.

Sedimentological setting. The distribution of bottom sediments off the Brittany coast is related primarily to the tidal current patterns and bedrock geology. Tidal currents greater than 2.5 knots, which are generated by the large tides in the area (average of 6 to 7 m), are common everywhere up to 12 km from the coast. These currents are weakened inside the bays of Morlaix and Lannion.[4] There is a general decrease in grain size from the tidal-current swept bottoms offshore, which are coarse-grained (pebbles), to the sheltered bays, where some fine-grained sands and muds are deposited. There are numerous rocky outcrops scattered throughout the area. In some sheltered areas, accumulations of coarse calcareous sediments composed of the remains of the free arbuscular Corallinaceans *(Lithothamnium)* dominate the bottom sediments. Bottom sediment maps for the two bays investigated are presented in Figures 2 and 3.

Related studies

Beach studies. Studies of the oiled shoreline by D'Ozouville, Gundlach, and Hayes,[6] and Gundlach and Hayes[7,8] revealed the overall pattern of oil distribution on the surface and within selected beaches, as well as the effects of cleanup at specific sites. In many localities, specific morphological features controlled oil deposition. Among these were crenulate bays, tombolos, scour pits around boulders, jointing

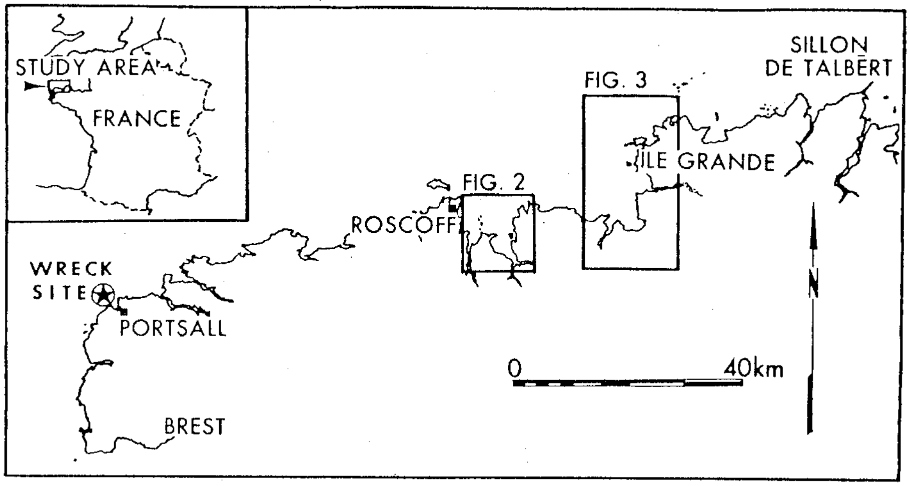

Figure 1. Location of bays studied within the *Amoco Cadiz* spill site, Brittany, France—The Bay of Morlaix is labelled Figure 2 and the Bay of Lannion is labelled Figure 3; at the time of the spill, March-April 1978, oil extended from near Brest to Sillon de Talbert.

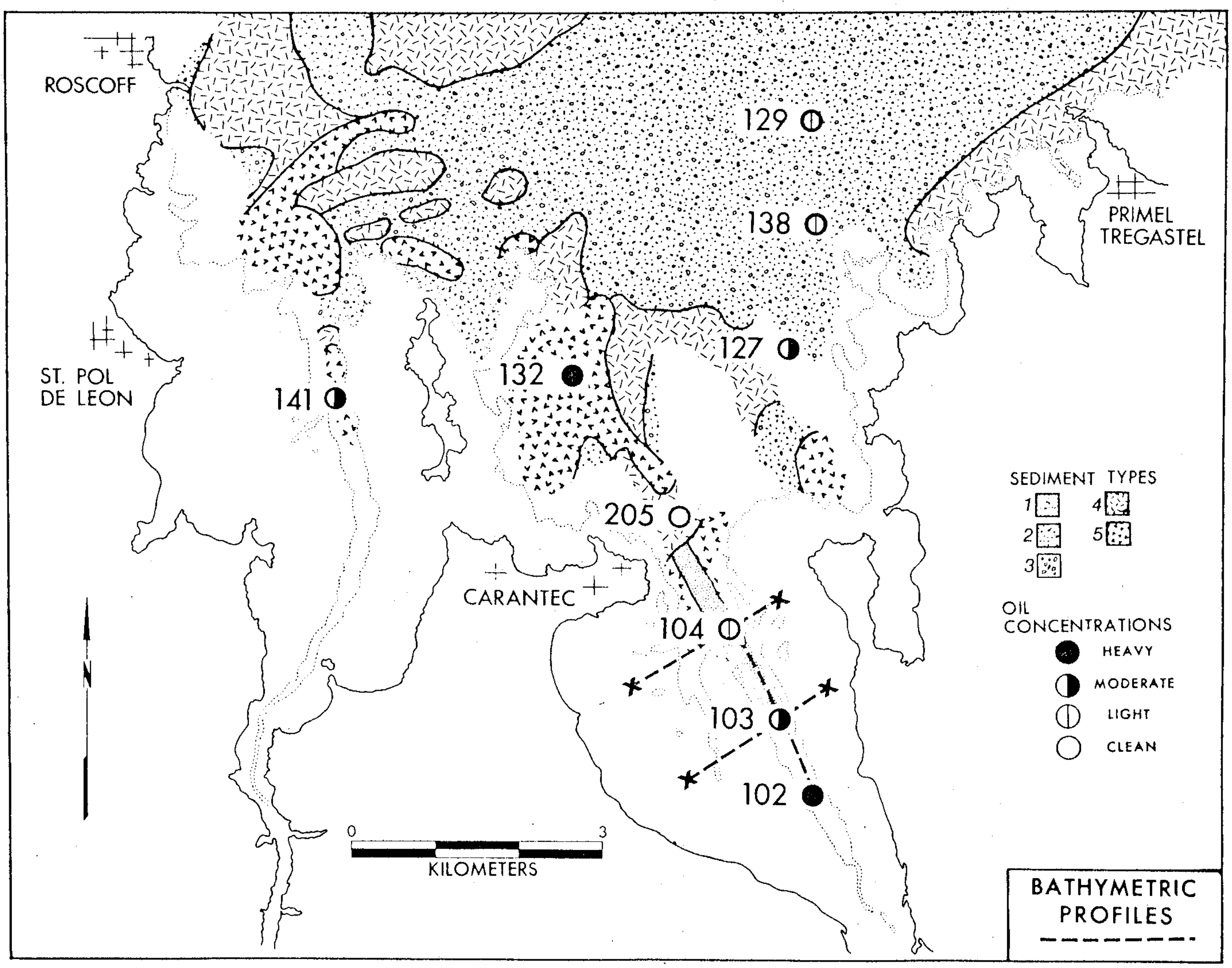

Figure 2. Bay of Morlaix—Bottom sediment type is simplified from Boillot;[2] location of diving stations and estimates of oil content are indicated; dashed lines show locations of batyhmetric profiles presented in Figure 6; sediment types: (1) fine-grained sand or mud, (2) coarse-sand, (3) gravel, (4) rocks, and (5) *Lithothamnium* marl.

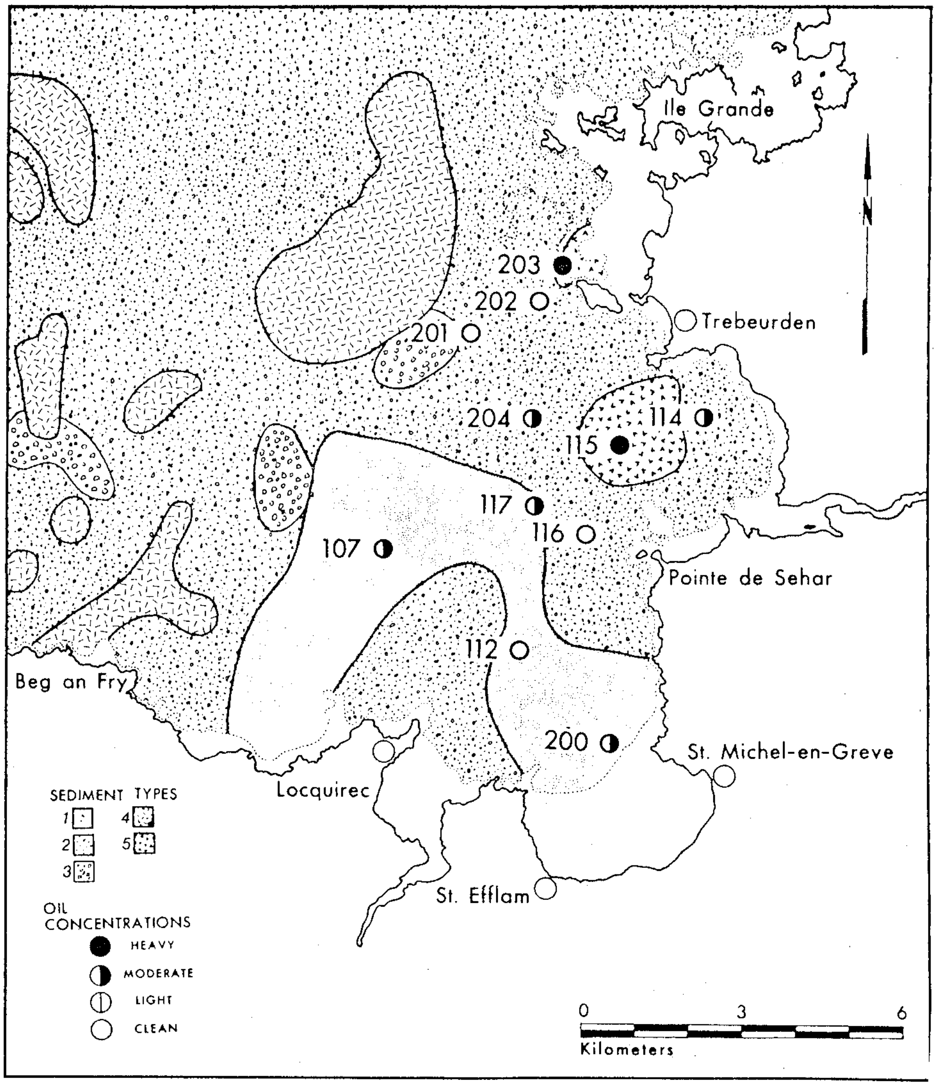

Figure 3. Bay of Lannion—Bottom sediment type interpreted from Cabioch;[3] location of diving stations and estimates of oil content are indicated; sediment types: (1) fine-grained sand or mud, (2) coarse-sand, (3) gravel, (4) rocks, and (5) *Lithothamnium* marl.

and bedding patterns in bedrock, and low-tide terrace, ridge-and-runnel systems. Large quantities of oil were removed during the erosional phase of the beach cycle, as determined by repetitive beach profiles.

Estimates of the total quantity of oil along the shoreline were made by measuring mousse thickness and the thickness of buried oiled-sediment layers, and integrating this value over the entire section of oiled beach. Buried oil in the intertidal zone was measured in trenches and was included in the estimates of oil on the shoreline. Based on values derived from 18 representative stations, the average oil content per km of shoreline was multiplied by the total length of oiled shoreline. It was found that slightly less than one-third of the spilled oil (62,000 tons) initially went onto the beaches. Within two months after the spill, the total along the shoreline was reduced by 85 percent through a combination of natural processes and an extensive cleanup operation.

Chemical surveys revealed uneven weathering of oil on both large (km) and small (m) scales due to continued leakage of oil from the grounded tanker in combination with diverse environmental conditions.[5]

Water column studies. Chemical analysis of offshore water samples revealed that *emulsified* oil was mixed into the water column.[5] Within the l'Aber Vrach'h estuary, oil concentration was vertically homogeneous. Further offshore, higher concentrations were found near a rocky shoal area, suggesting that wave activity was responsible for mixing the oil into the water column. Vertically, higher concentrations were commonly found near the bottom.[5,12] The cause of this phenomenon was attributed to the use of dispersants or sinking agents.

Biological studies. An abundance of baseline data have been collected in the impacted area by French biologists, most notably Cabioch and Mora of Roscoff and Chassé of Universite de Bretagne Occidentale. This information will allow for an accurate accounting of the biological impact of the spill. The most striking immediate effect on the offshore biota was the virtual elimination of the amphipods of the genus *Ampelisia,* which accounted for approximately 40 percent of the biomass in the offshore fine-sand areas.[4] Onshore, massive mortalities of heart urchins, razor clams, and other invertebrates were observed.[9]

Methods of study

Field work on this project was conducted between July 23 and August 2, 1978. Cabioch served as principal advisor for all phases of the field work. A total of 20 diving stations were established (Figures 2 and 3) on the basis of recommendations by Cabioch who had sampled the area in detail by grab sampling and scanned much of the bottom with underwater television. Stations were selected to show oil in a variety of bottom types.

At each diving station, a center point was established and the diver located four equally-spaced stations (north, west, south, east) around the perimeter of a circle with a radius of 8 m. At each sampling site, an

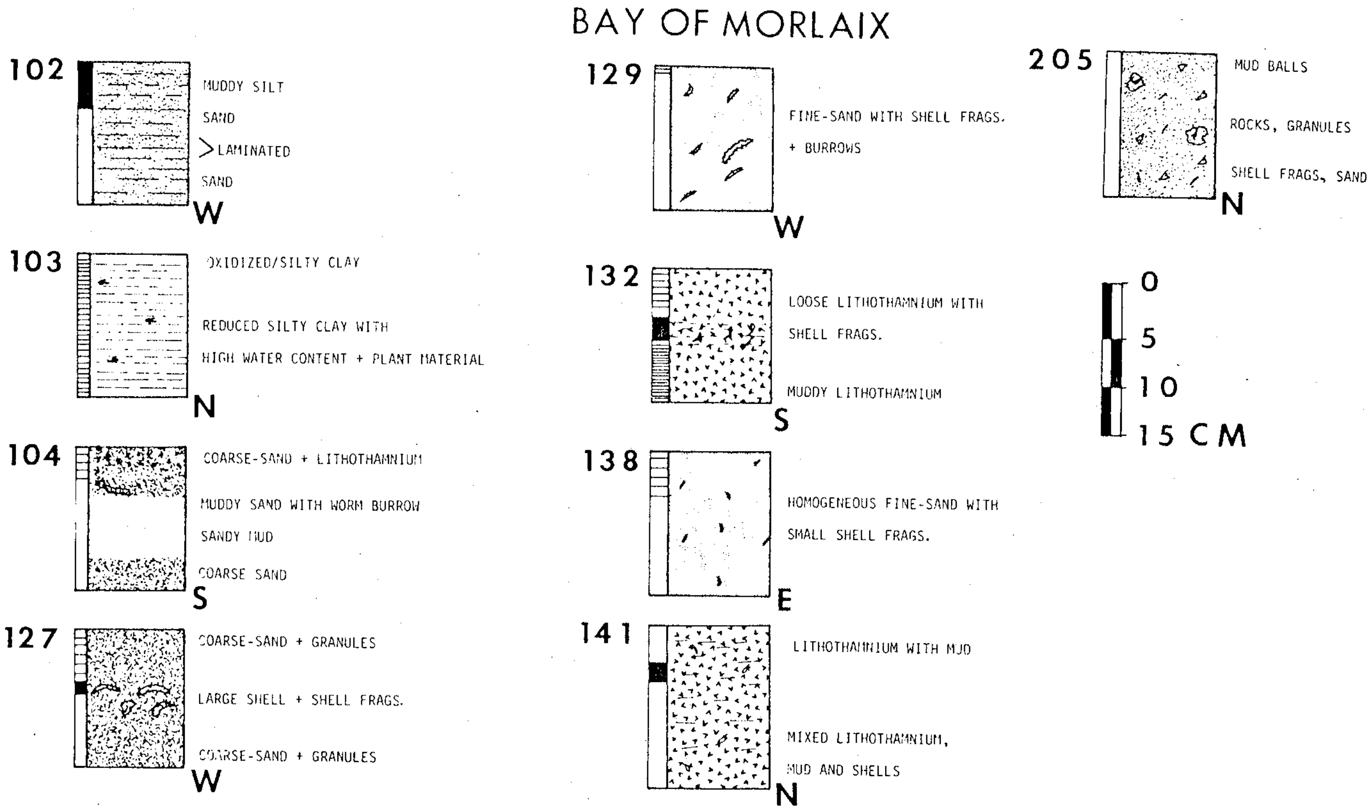

Figure 4. Bay of Morlaix core descriptions—Oil concentration is indicated to the left of the sediment type; the letter at the bottom corner of each core indicates which of the four (north, east, south, or west) cores is depicted.

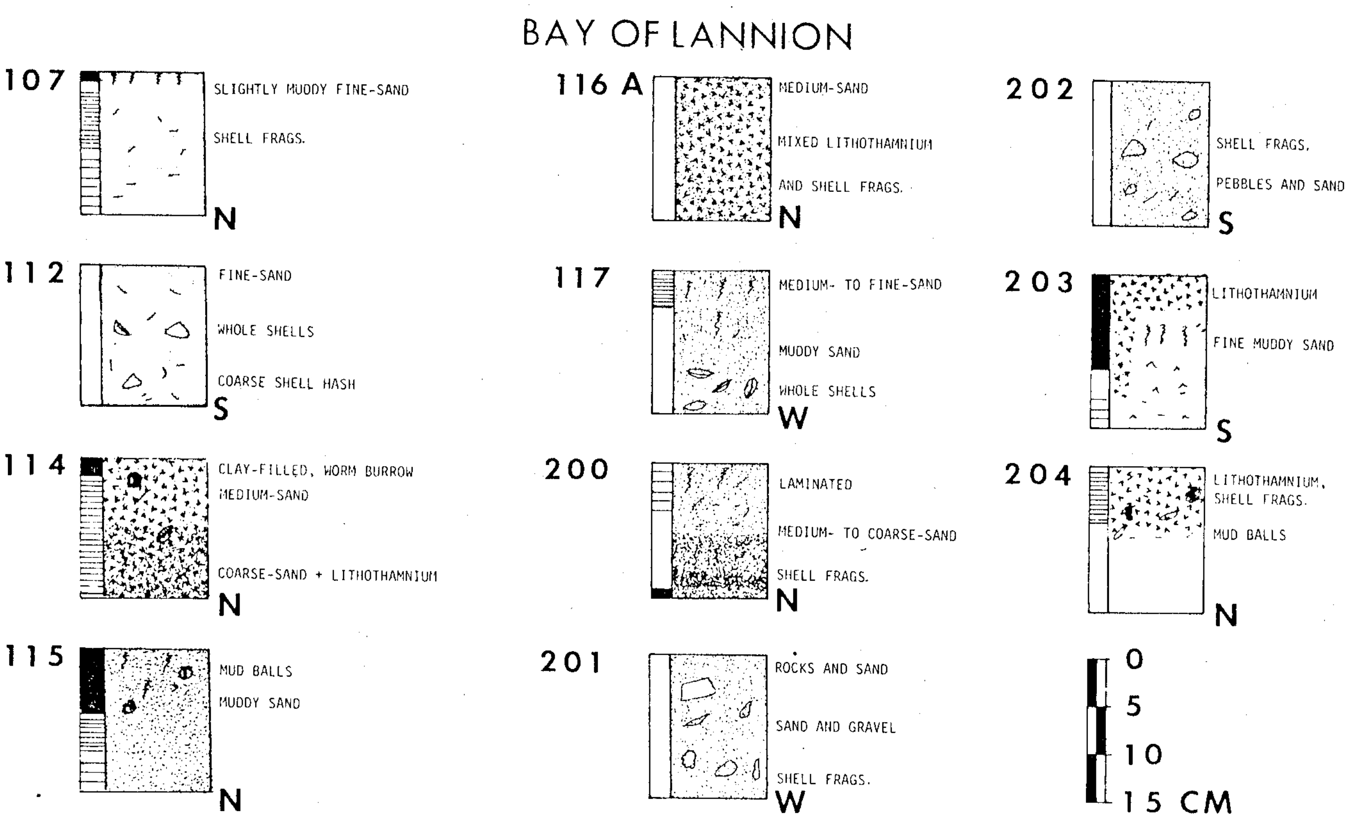

Figure 5. Bay of Lannion core descriptions—Oil concentration is indicated to the left of the sediment type; the letter at the bottom corner of each core indicates which of the four (north, east, south, or west) cores is depicted.

undisturbed core 15 cm long with a diameter of 8 cm was collected with a hand-held, cylindrical coring device. While on the bottom, the divers made other observations such as size and orientation of bedforms, sediment and biological characteristics of the bottom, and nature of bottom oil (if visible).

Once the core was extruded onboard ship, a detailed description of each core was recorded as to sediment type and visual oil content. (These descriptions are shown graphically in Figures 4 and 5.) Sediment samples were saved for textural and chemical analyses. The chemical samples were stored in a pretreated, aluminum foil-sealed glass jar and stored on ice until transferred to a freezer. Chemical analyses of the sediment samples, to show oil concentration and structural components, are scheduled to be carried out by M. Marchand at the Centre Oceanologique de Bretagne.

Continuously recording current meters were deployed at two stations in both bays. The meters were placed 1 m off the ocean floor and ran for a minimum of 48 hours.

Discussion

At this stage, our results are only preliminary. Chemical analyses are being performed and will be completed in time for a detailed presentation of all data at the oil spill conference. Some of our observations and present conclusions are:

1. The oil found in the bottom sediments of the bays of Morlaix and Lannion present two different probable mechanisms for sinking. At Morlaix, no oil was found along the edge of the shoreline nor was it seen as surface sheens entering the bay. In contrast, oil within the Bay of Lannion was very heavy on the surface and along the shoreline. This suggests that oil entered the Bay of Morlaix in an emulsified state mixed within the water column. At Lannion, an area of much higher wave activity, oil may have been incorporated first into shoreline sediments that were carried offshore, as well as direct uptake of oil placed within the water column by wave action. Note the heavy concentrations within cores taken at nearshore stations 203, 114, and 115 (Figure 3).

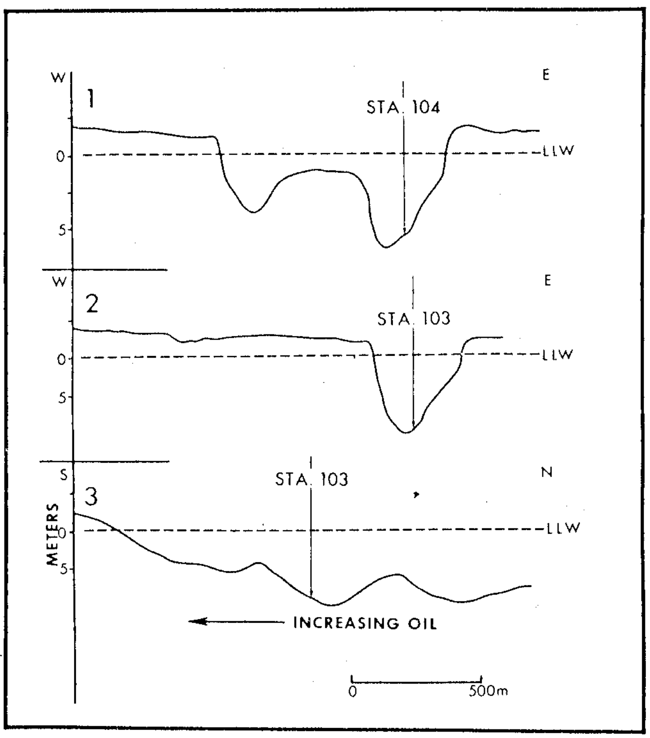

Figure 6. Bathymetric profiles from the Bay of Morlaix—For location, see Figure 2; visible oil was found only in the channels, even though oysters were severely contaminated on the nearby flats.

2. Heaviest oil concentrations were usually found within fine-grained, muddy sediments, thereby supporting laboratory evidence for increased uptake of oil by clay-sized material (note stations 102, 107, 115, 117, and 203).
3. *Lithothamnium* beds also seemed to act as oil traps (see stations 114, 141, and 203). Sinking emulsified oil would easily be able to penetrate the porous *Lithothamnium* sediment and become entrapped within the calmer interior environments of this sediment type. Often the *Lithothamnium* was associated with a small (above 10 percent) amount of clay material which would further aid oil incorporation.
4. Oil most commonly was incorporated into sediments to a depth of 5 cm to 7 cm, which may be related to the depth of reworking by bottom fauna. Deeper oil penetration (15 cm) usually was related to nearshore locality (station 115), porous sediment type (station 132), or both nearshore locality and porous sediments (stations 114 and 203).
5. Within the Bay of Morlaix, oil concentration was heaviest with channel sediments and within the calmer, depositional upper portion of the bay (Figure 6). However, oil within the water column was not limited to just the channel. Acres of oysters located on the adjacent flats became so contaminated that the entire seasonal crop had to be destroyed (even though no visible oil was present).
6. The particular impact of the incorporated bottom oil on organisms within the polluted areas will depend on the organisms present and their ability to withstand this level of contamination, as well as their proximity to reserves for recolonization. Because of the isolated nature of these fine-sediment habitats, Cabioch, Dauvin, and Gentil[4] believe that the impact of the spill on the bottom community may be long term.
7. Lastly, this sampling program was shown to be effective in sampling the distribution and penetration of bottom oil. Advantages lie principally in the diver's ability to visually inspect bottom sediment variability and physically control the sampling apparatus. The "washing" and mixing problem associated with grab sampling is completely avoided.

Unfortunately, this program was undertaken four months after the spill, so actual oil on the bottom could not be observed, nor could the mechanism of oil transport be ascertained. During future spills, it is important to begin these investigations while oil is still on the surface of the water in order to better understand this fundamental problem.

Acknowledgments

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References

1. Blumer, M., H. L. Sanders, J. F. Grassle, and G. R. Hampson, 1971. A small oil spill. *Environment.* 13, n2, pp3-12
2. Boillot, G., 1964. Geologie de la manche occidentale. *Annals of the Institute of Oceanography.* v42, 220p
3. Cabioch, L., 1968. Contribution a la connaissance des peuplements benthiques de la manche occidentale. Ed. de la Station Biologique de Roscoff. v9, n5, pp493-724
4. Cabioch, L, J. C. Dauvin, and F. Gentil, 1978. Preliminary observations on pollution on the sea beds and disturbance of sublittoral communities in northern Brittany by oil from the *Amoco Cadiz. Marine Pollution Bulletin.* v9, n10 (in press)
5. Calder, J., J. Lake, and J. Laseter, 1978. Chemical composition of selected environmental and petroleum samples from the *Amoco Cadiz* oil spill: in *The* Amoco Cadiz *Oil Spill, A Preliminary Scientific Report.* W. N. Hess (ed). NOAA/EPA Special Report. Environmental Research Laboratories, Boulder, Colorado pp21-84

6. D'Ozouville, L., E. R. Gundlach, and M. O. Hayes, 1978. Effect of coastal processes on the distribution and persistence of oil spilled by the *Amoco Cadiz*—preliminary conclusions. in Amoco Cadiz, *Premieres Observations sur la Pollution par les Hydrocarbures.* Centre National pour l'Exploitation de Oceans. Actes de Colloques No. 6, pp97-114
7. Gundlach, E. R. and M. O. Hayes, 1978. Investigations of beach processes. in *The* Amoco Cadiz *Oil Spill, A Preliminary Scientific Report* W. N. Hess (ed). NOAA/EPA Special Report. Environmental Research Laboratories, Boulder, Colorado. pp85-197
8. Gundlach, E. R. and M. O. Hayes, 1978. The *Amoco Cadiz* spill, third followup survey of oil impact on the shoreline, July 1978. Technical Report to NOAA-Environmental Research Laboratories, Boulder, Colorado. 67p
9. Hess, W. N. (ed), 1978. The *Amoco Cadiz* Oil Spill, a Preliminary Scientific Report: NOAA/EPA Special Report. Environmental Research Laboratories, Boulder, Colorado. 283p
10. Keizer, P. D., T. P. Ahern, J. Dale, and J. H. Vandermeulen, 1978. Residues of Bunker C in Chedabucto Bay, Nova Scotia, six years after the *Arrow* spill. *Journal of the Fisheries Research Board of Canada.* v35, n5, pp528-535
11. Kolpack, T. L., 1971. Summary. in *Biological and Oceanographical Survey of the Santa Barbara Channel Oil Spill, 1969-1970, Vol. II: Physical, Chemical, and Geological Studies.* Allan Hancock Foundation, University of Southern California. pp7-63
12. Marchand, M., and M. P. Caprais, 1978. Distribution et evolution des teneurs en hydrocarbures dan l'eau de mer en manche occidentale apres l'echouage de l'*Amoco Cadiz,* du 30 Mars au 15 Juin 1978. Unpublished report. Centre Oceanologique de Bretagne, Brest, France. 27p