The *Urquiola* Oil Spill, La Coruña, Spain: Impact and Reaction on Beaches and Rocky Coasts

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ABSTRACT / The supertanker *Urquiola* grounded, exploded, and burned at the entrance to La Coruña harbor (Spain) on May 12, 1976. A total of 100,000 tons of Persian Gulf crude oil was lost, of which about 30,000 tons washed onto shoreline environments. From May 17 to June 10, 1976, the impact and interaction of oil on fine-sand, coarse-sand, and gravel beaches and on sheltered and exposed rocky coasts was monitored in detail. At 32 localities, the beach was profiled, trenched, extensively sampled, and photographed. Another 67 stations were examined for surficial oil coverage and distribution. The surficial distribution of oil on the beaches was influenced primarily by wave activity, tidal stage, and oil quantity. Heaviest accumulations formed along the high-tide swash line. Within beach sediments, oil was present at distinct oiled sediment layers, which were often deeply buried. The depth of burial was related to wave energy and sediment type. Deepest burial (1 m) was on a high-energy, coarse-sand beach ($M_z = 0.82\ \phi$). Burial on fine-sand beaches was less than 30 cm. The thickness of oiled sediment depended on sedimentary characteristics, the quantity of oil present, wave action, and capillary forces. Oil-soaked sediment, as much as 65-cm thick, occurred on coarse-grained beaches. On fine-sand beaches, oiled sediment was limited to thicknesses of 10 cm or less. On rocky shores, oil distribution was determined primarily by wave energy. Along high-energy, cliffed, or steeply dipping rocky areas, wave reflection kept the oil approximately 5 m offshore and contamination was minimal. In low-energy, sheltered areas, oil readily accumulated, causing apparent environmental damage.

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Introduction

The massive spill by the tanker *Urquiola* in La Coruña, Spain on May 12, 1976 enabled detailed observation and analysis of oil impact on various shoreline types, as well as subsequent oil–sediment interaction over the following month. This report specifically deals with the impact of *Urquiola* oil on fine-sand, coarse-sand, and gravel beaches and on rocky shores. Previous reports on oil spills that have dealt with the interaction of spilled oil on different shoreline types include work by Kolpack (1971) on the Santa Barbara blowout; Owens (1971) and Owens and Rashid (1976) on the *Arrow* spill in Chedabucto Bay, Nova Scotia and Hayes and Gundlach (1975) on the *Metula* spill in the Strait of Magellan, Chile. Each of these studies was conducted after the initial impact of oil on the shoreline (3 months, 2 months, and 1 year, respectively). This report stresses the first few weeks after the spill, when major changes occurred on the beach and decisions were made concerning the application of costly and potentially environmentally damaging cleanup techniques.

History of the Spill

On the morning of May 12, 1976, the supertanker *Urquiola* scraped bottom entering the harbor at La Coruña, Spain (Fig. 1) during spring low tide (see Fig. 5). It carried 107,000 tons of Persian Gulf crude oil. The hull was damaged, causing some oil leakage and a danger of explosion within the harbor. As a safety precaution, the ship was turned about and an attempt was made to leave the harbor. While heading through the same passage, it ran hard aground, and the crew was ordered to abandon ship. Early that afternoon, the *Urquiola* exploded. Although most of the oil burned, some still remained onboard, and an estimated 25,000 to 30,000 tons washed onto adjacent shorelines over the next few weeks. Slightly more than 7000 tons of oil were later transferred to other tankers from the *Urquiola*. In total, about 100,000 tons of crude oil were lost.

The *Urquiola* disaster was comparable to other massive oil spills. The *Torrey Canyon* lost a total of 117,000 tons off the southwest coast of Great Britain (Smith 1968); the Santa Barbara blowout involved between 11,290 and 112,900 metric tons (Foster and others 1971); and the VLCC *Metula* spilled 53,500 tons in the Strait of Magellan (Hann 1974). The *Argo Merchant*, largest tanker spill to occur in United States' coastal waters, lost a total of 26,800 tons (NOAA 1977).

Oil spilled by the *Urquiola* was transported by currents, and by June 3, approximately 215 km of coastline had been oiled (Fig. 1). Of this, 60 km of shoreline within the embayments or rias were moderately to heavily oiled. Cleanup methods were limited to application of over 2000 tons of dispersants and minor use of mechanical and manual labor. For further details on the spill and

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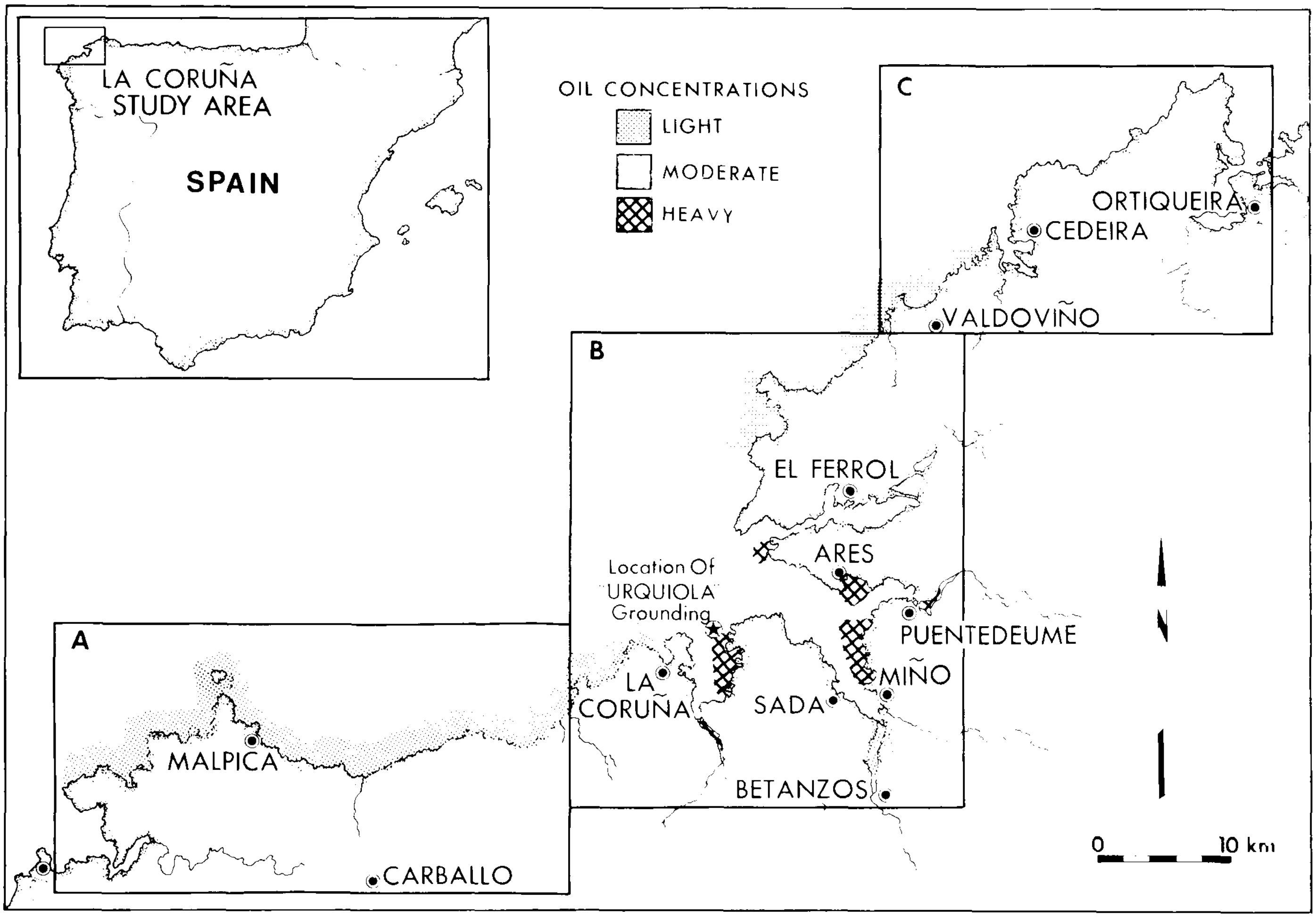


Figure 1. Location of the *Urquiola* spill site in Galicia, Spain. Approximately 215 km of shoreline were oiled by June 3, 1976. Of this, 60 km of coast within the ria embayment system received moderate (25–65% oil coverage of the intertidal zone) to heavy (more than 65% surface coverage) concentrations. Letters A, B, and C refer to Figs. 2, 3, and 4, respectively.

cleanup activities, see Gundlach and others (1977) and Gundlach and Hayes (1977).

Regional Setting

The area of the *Urquiola* spill is a ria coastline of submerged V-shaped valleys forming large embayments, or rias, sheltered from major wave activity by steep rocky headlands. The terrain is mountainous, with high cliffs along the Atlantic coast and lower escarpments inside the rias. A marsh–tidal flat system, protected by a sand spit, is located at the landward end of each embayment. Currents of approximately 2 to 4 knots are generated by 2 to 4 m tides. Rocky coasts make up approximately 60% of the oil-affected shoreline. Beaches within the rias are usually less than 1 km long and consist of fine-sand. Waves are less than 30 cm high. On the outer coast, beaches are several kilometers in length and usually contain medium to coarse sand. Waves are typically 1.5 to 2.0 m high. The climate of the area is humid temperate, with summers and winters moderated by the maritime locality. During the spill, temperatures varied from a minimum of 8°C to a maximum of 23.4°C. Rainfall averages 792 mm annually, with most of it occurring during the winter months (Aguilar 1961).

Study Methods

At 32 representative stations (UQA-1 to UQA-32, Figs. 2, 3, and 4) the beach was profiled, trenched, sampled at a minimum of four locations, photographed extensively, and described. Trenches were examined for depth of oil burial, and thickness and continuity of incorporated oiled sediment layers. Twelve of these stations were revisited at the end of our study to determine short-term changes in beach topography and oil distribution. In

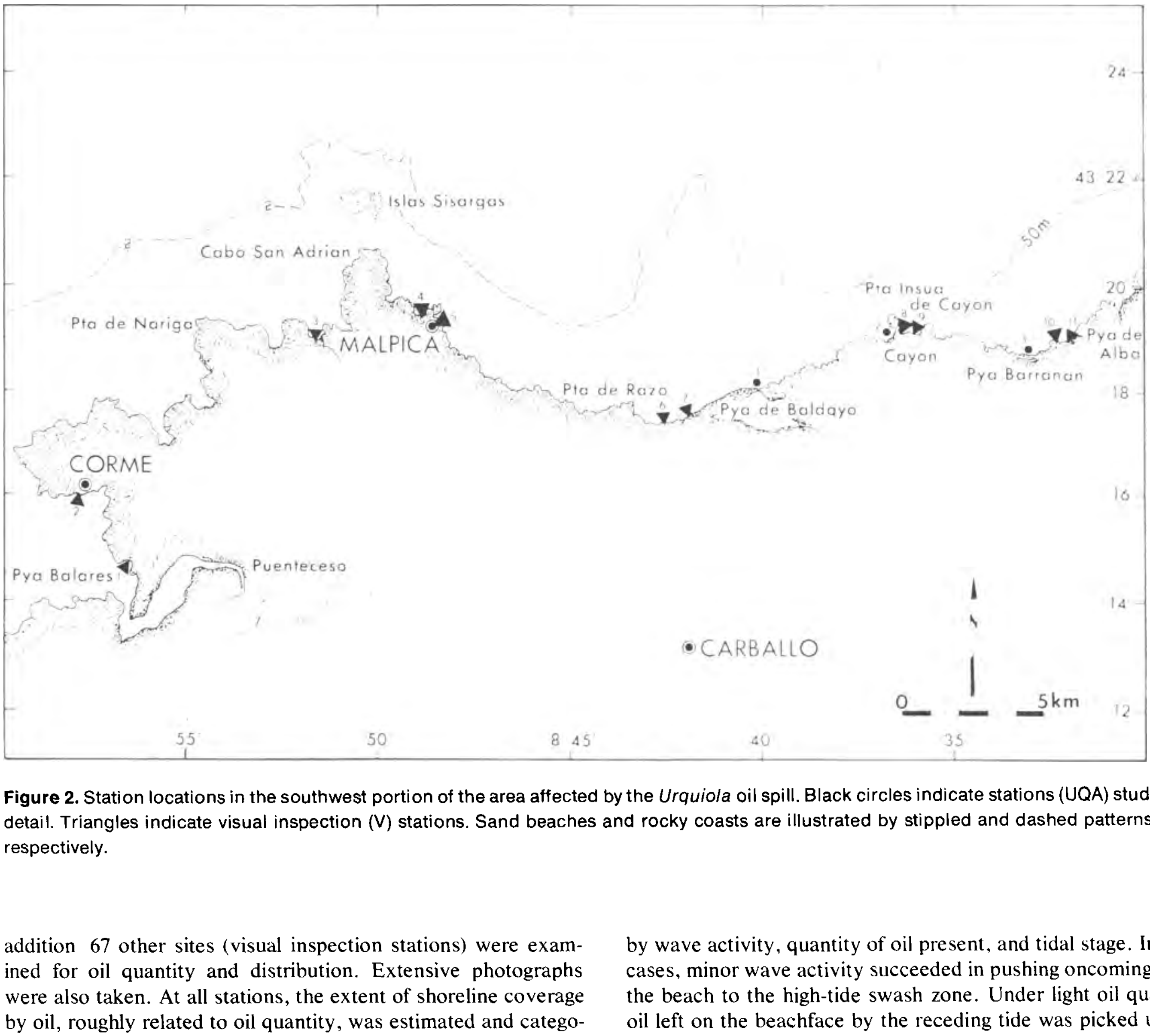


Figure 2. Station locations in the southwest portion of the area affected by the *Urquiola* oil spill. Black circles indicate stations (UQA) studied in detail. Triangles indicate visual inspection (V) stations. Sand beaches and rocky coasts are illustrated by stippled and dashed patterns, respectively.

addition 67 other sites (visual inspection stations) were examined for oil quantity and distribution. Extensive photographs were also taken. At all stations, the extent of shoreline coverage by oil, roughly related to oil quantity, was estimated and categorized as heavy (>65% coverage of the intertidal zone), moderate (25 to 65%), or light (<25%). Sediments from the midbeach face of the UQA stations were analyzed for grain size parameters by sieving at ¼-ϕ intervals ($\phi = -\log_2$ mm). Computer synthesis yielded graphic mean (M_z) and inclusive graphic standard deviation (σ_I), a measure of sorting (Folk 1968).

Results

Oil distribution on beaches

Oil was distributed in varying quantities on the surface and within the sediments of most of the beaches around La Coruña. Table 1 summarizes the extent of oil coverage and distribution and sediment type for most UQA stations.

Surficial oil distribution on beaches was primarily influenced by wave activity, quantity of oil present, and tidal stage. In most cases, minor wave activity succeeded in pushing oncoming oil up the beach to the high-tide swash zone. Under light oil quantity, oil left on the beachface by the receding tide was picked up and transported up the beachface by the following rising tide. Under these conditions, oil was found only as streaks along the high-tide swash line. As the quantity of oil increased, more oil remained along the beachface. Under moderate coverage (25 to 65% oil coverage of the intertidal zone), oil was visible as heavy streaks across most of the upper intertidal zone, with major accumulations along the high-tide swash line. Finally, under heavy oil quantity, oil covered the entire intertidal zone but again with thicker accumulations along the upper portion of the beach. Much of the oil spilled by the *Urquiola* came ashore during spring tides (Fig. 5). Oil deposited at this time was left above major swash or wave activity as the tidal range receded. Because of the lack of erosive marine processes, oil along the spring high-tide swash line has a greater potential for long-term persistence than does oil deposited elsewhere on the beach (Hayes and Gundlach 1975).

Table 1. Sediment Type, Oil Concentration, and Surficial and Subsurficial Oil Distribution for Major Spill-Affected Beaches*

Station no./ location	Oil concentration	Sediment type	Oil distribution on beach surface	Thickness of oiled sediment	Depth of oil burial
UQA-1 Baldayo	Light	Sandy gravel	Streaks along high-tide swash zone	Surficial only	5 cm
UQA-2 Cayon	Light	Med.–fine sand	Streaks along high-tide swash zone	6 cm, swash zone	20 cm, upper beachface
UQA-3 Barrañan	Light	Med.–crs. sand	Streaks—upper swash zone and very heavy accumulation at toe of beach	30 cm, sigle oil mass	40 cm, lower beachface
UQA-4 Orzán	Moderate	Sandy gravel	Heavy streaks across entire intertidal zone	Surficial only	0
UQA-7 Catalina	Moderate	Gravelly sand	Heavy along high-tide swash zone and streaks across entire intertidal	4 cm, swash zone	25–30 cm, beachface
UQA-8 Bastiagueiro	Heavy	Med.–fine sand	Heavy across entire intertidal zone	9 cm, swash zone	10 cm
UQA-9 Porto Cobo	Heavy	Sandy gravel	Heavy—high-tide swash zone, streaks across rest of intertidal zone	3–5 cm, swash zone	20 cm, swash zone
UQA-10 Mera	Heavy	Gravel	Very heavy—entire intertidal zone	65 cm, beachface	0
UQA-11 Canabal	Heavy	Sandy gravel	Very heavy—entire intertidal zone	30 cm, beachface	0
UQA-13 Veigue	Heavy	Very find sand	Heavy—high-tide swash zone, heavy streaks across rest of intertidal	2 cm, swash zone	15 cm, swash zone
UQA-14 Arnela	Moderate	Fine sand	Heavy streaks over intertidal zone	3–5 cm, swash zone	15–20 cm, swash zone
UQA-15 Sada	Moderate	Silty sand	Heavy—high-tide swash zone	2 cm	7 cm, swash zone
UQA-16 Gandario	Moderate	Very fine sand	Streaks over entire intertidal zone	Surficial only	0
UQA-17 Lambre	Light	Gravelly fine sand	Stained pebbles, light oil swashes	Surficial only	0
UQA-18 Miños	Moderate	Fine sand	Streaks over entire intertidal zone	8 cm	21 cm
UQA-19 Perbes	Moderate	Fine sand	Very heavy—high-tide swash zone, heavy swashlines, rest of intertidal zone	6 cm	25 cm
UQA-20 de Ber	Heavy	Med.–fine sand	Very thick over entire intertidal zone	25 cm	10 cm
UQA-21 Cabañas	Moderate	Fine sand	Heavy swash lines, especially along high-tide swash zone	8 cm	25 cm
UQA-22 Raso	Heavy	Fine sand	Heavy—entire intertidal zone	3–5 cm	15 cm, swash zone
UQA-23 Chanteiro	Heavy	Med. sand	Heavy—entire intertidal zone	3 cm	25 cm, beachface
UQA-25 Cariño	Moderate	Med.–fine sand	Heavy streaks—high-tide swash zone, lighter across rest of intertidal	3 cm	15–20 cm, beachface
UQA-26 Doniños	Moderate	Med.crs. sand	Heavy streaks across entire intertidal zone	15 cm, swash zone	1 m, beachface
UQA-28 San Jorge	Light	Med. sand	Streaks—high-tide swash area	Surficial only	0
UQA-29 Cobas	Light	Med.–crs. sand	Some tar balls, rocks coated	Surficial only	0
UQA-30 Frouseira	Light	Med.–crs. sand	Streaks—high-tide swash zone	Surficial only	0
UQA-31 Pantin	Light	Med. sand	Streaks—high-tide swash zone	2 cm	0

*Station locations are depicted in Figs. 2, 3, and 4.

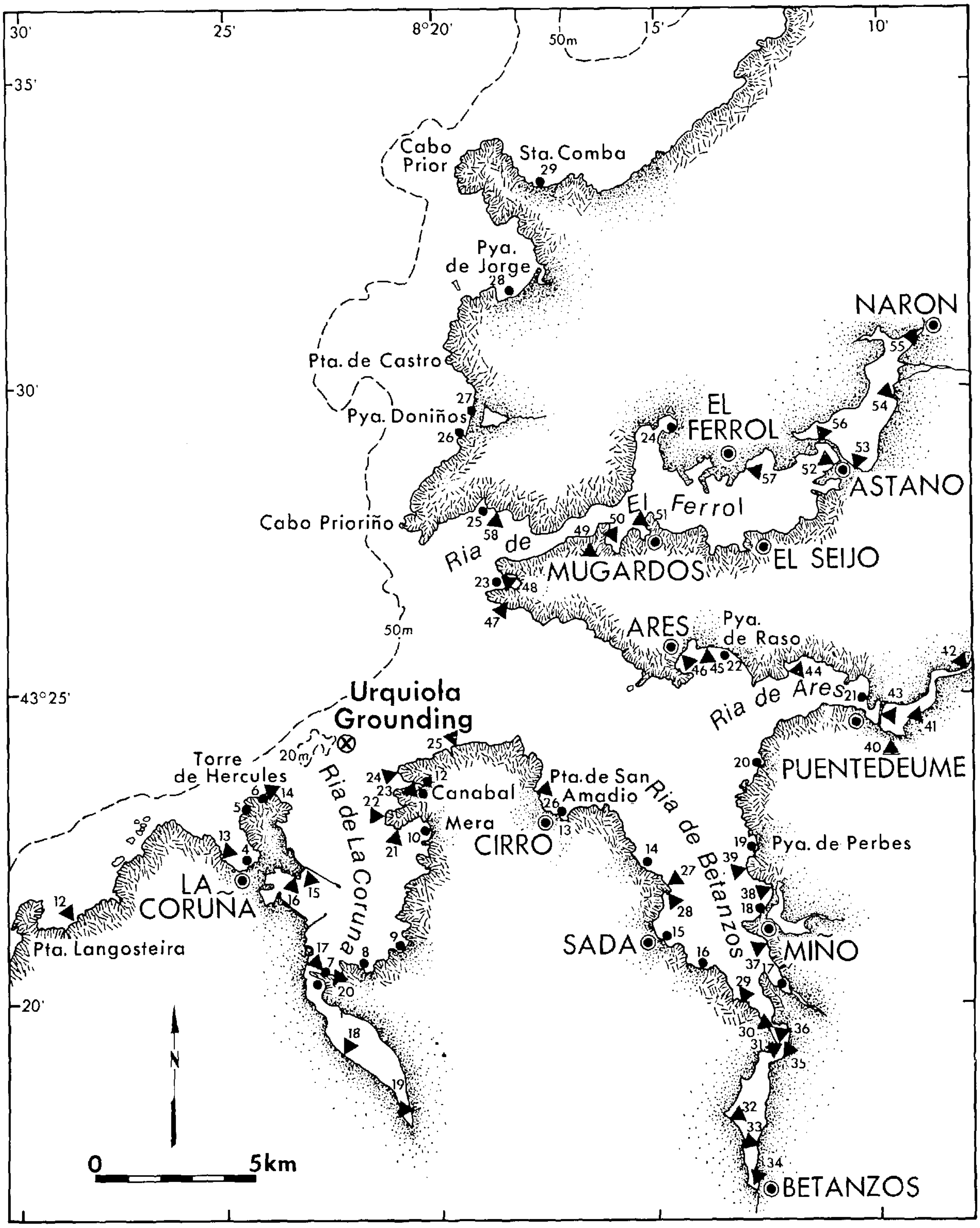


Figure 3. Central portion of the area affected by the *Urquiola* oil spill. This region received moderate to heavy oil concentrations. Black circles indicate stations studied in detail. Triangles show location of visual inspection stations.

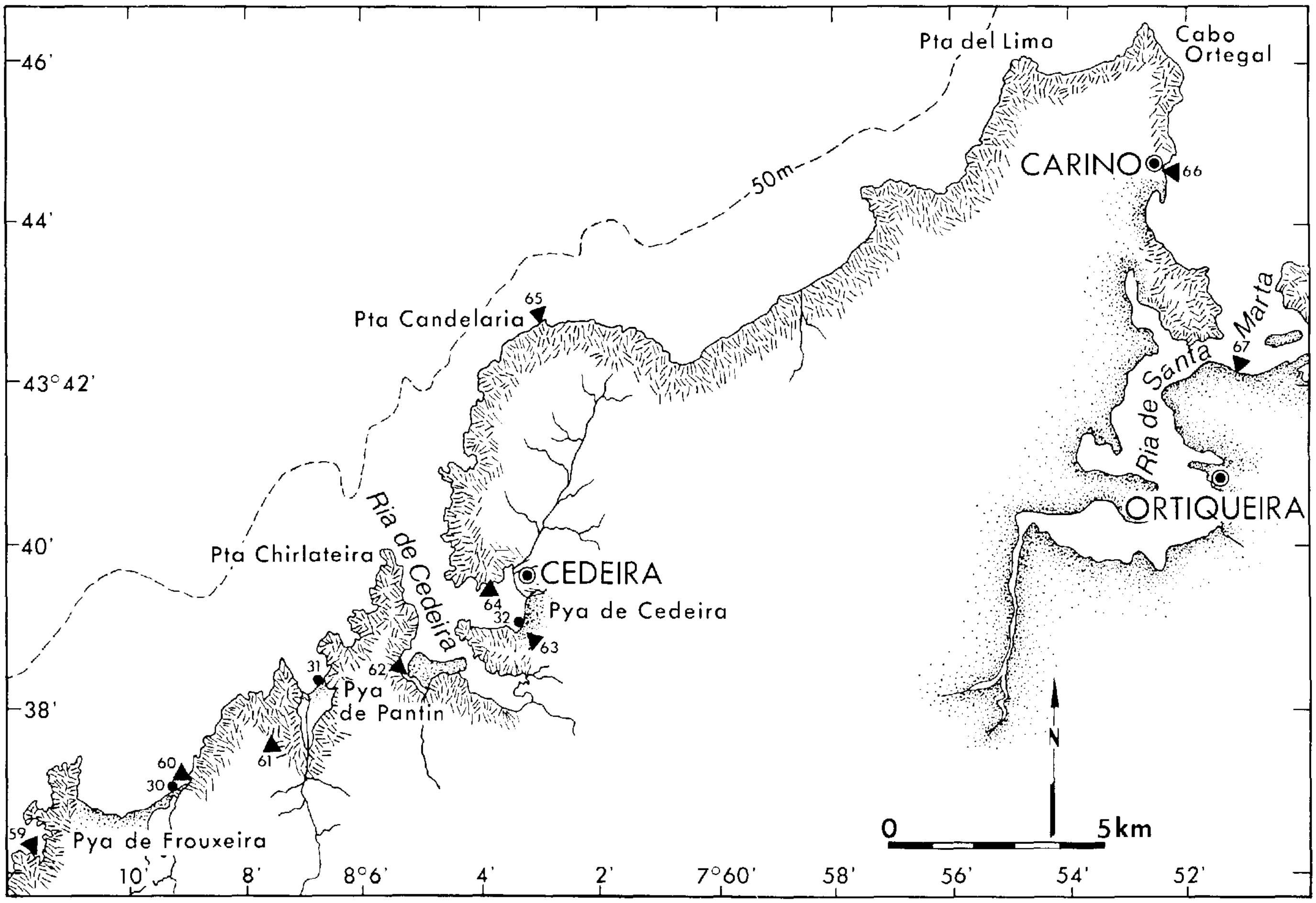
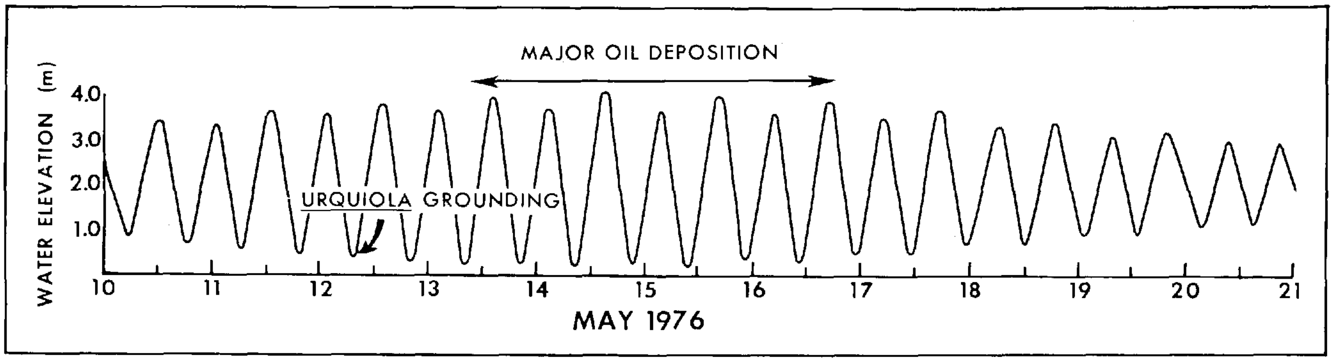


Figure 4. Northeast portion of the *Urquiola* spill site. Black circles indicate stations (UQA) studied in detail. Triangles show location of visual inspection stations.

Figure 5. Tide curve for La Coruña, Spain and time of *Urquiola* grounding. Major quantities of oil came ashore from May 12 to May 18 during spring tides. According to the La Coruña tide table (IHM 1976), the maximum tidal heights attained during May 14–16 were not again reached during 1976. Oil placed onshore during this period has a strong likelihood for long-term persistence.



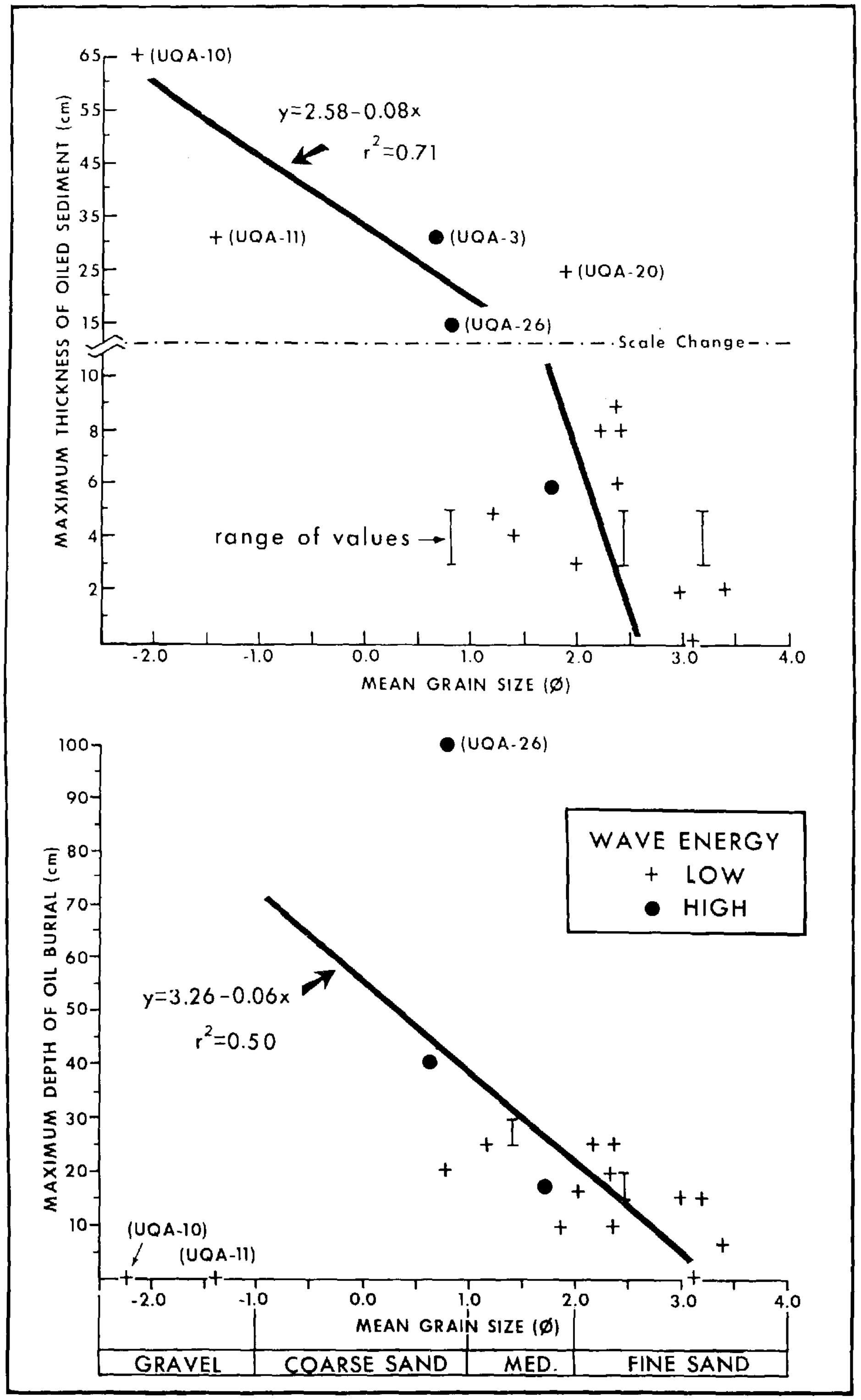


Figure 6. (a) Mean grain size versus thickness of the oiled sediment layer at 19 major oil-affected beaches. The oiled layers are caused by oil penetration, capillary forces, and mixing of oil and sediment by wave action. The indicated line of linear regression has a correlation coefficient (r^2) of 0.71. (b) Mean grain size versus maximum depth of oil burial. A trend (r^2 = 0.50) of decreased depth of burial with decreasing grain size is indicated by the linear regression line. Anomalous values at stations UQA-10, -11, and -26 are not included in the regression model for reasons discussed in the text.

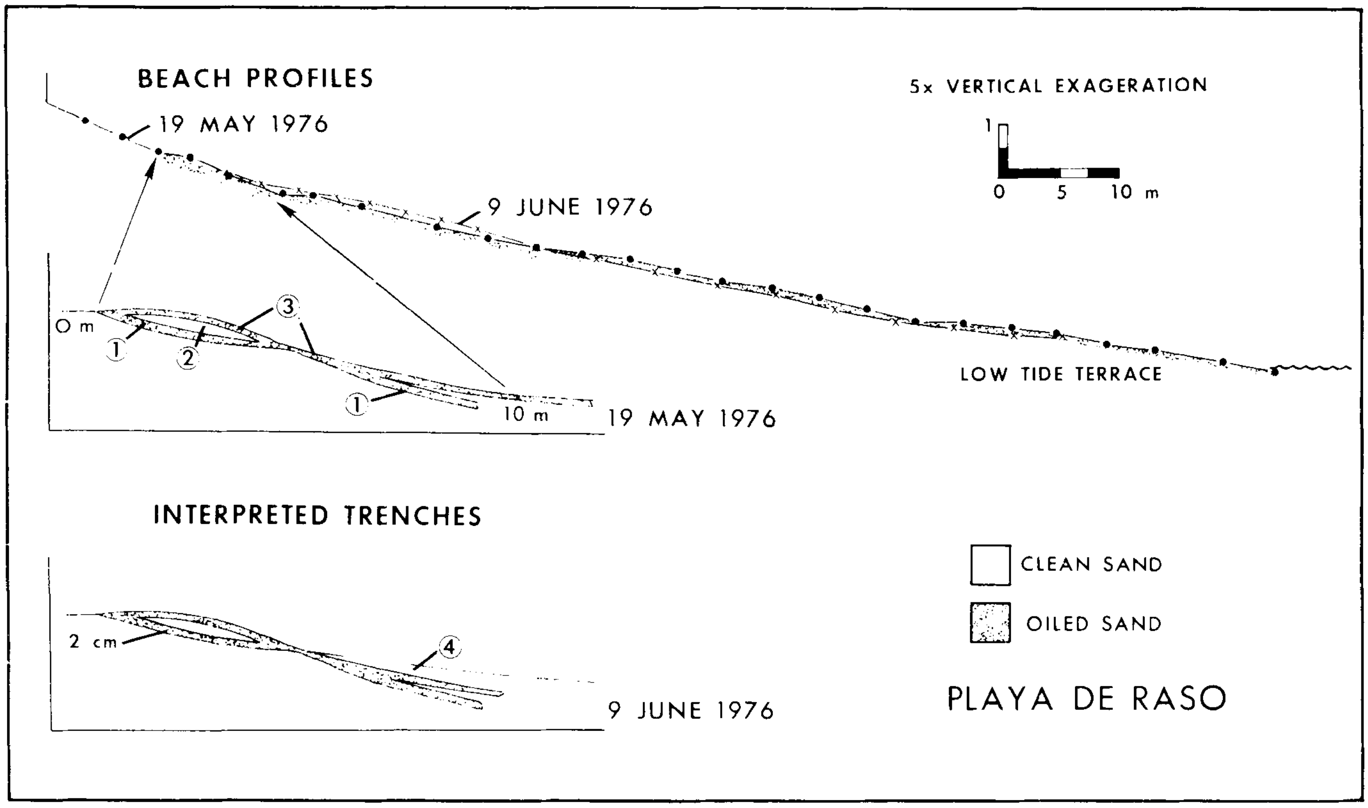
Below the surface of the beach, oil was distributed as thick oiled-sediment layers, often deeply buried. The thickness of the oiled sediment (Table 1) was a function of mixing caused by wave activity, oil infiltration, capillary action, and sediment type. Sediment size and sorting determine the permeability of the beach sediment, which affects the depth to which oil may penetrate. The amount of oil present determines the duration for which the oil–sediment mixing process can be maintained. Greater mixing and thicker layers of oiled sediment occurred the longer the oil mass remained in the near-shore zone. Additionally, oil can spread into adjacent clean sand by capillary action.

Figure 6a depicts the relation between the mean grain size of the affected beach and the thickness of the oiled sediment. Generally, as the grain size decreased, so did the thickness of oiled sediment (correlation coefficient $r^2 = 0.71$). Anomalous values are also indicated in Fig. 6a. At stations UQA-10 and UQA-11 (Mera and Canabal), wave energy was very low. The resultant layer was developed solely by percolation of oil into the sediments. In contrast, stations UQA-3 and UQA-26 are on high-energy beaches, so wave processes probably have aided mixing the oil and sand together in the swash zone. At UQA-20, the depth of oiled sediment was caused by total saturation of the sediment by oil.

The depth to which oil was buried within a beach was related to wave energy and sediment type. Greater wave energies increased the rapidity and depth of oil burial. Figure 6b presents oil burial as a function of sediment size. A trend of decreasing depth of oil burial with decreasing mean grain size is indicated ($r^2 = 0.50$). Coarse-grained beaches at UQA-10 and UQA-11 were anomalous in showing no oil burial. Large oil pools at each locality effectively eliminated most wave activity and sedimentary transport. In contrast, at UQA-26, high-energy conditions caused extremely rapid burial of the oil, as illustrated later. These three areas were not included in the statistical analysis. Generally speaking, oil was buried to a depth of 5 to 30 cm within a few weeks after initial oil impact. On coarse-grained highly active beaches, burial was usually greater. Fine-grained beaches ($<2.5\ \phi$) showed burial limited to less than 15 cm.

To clarify the method by which oil interacts with different coastal environments, the impact of oil on representative fine-sand, coarse-sand, and gravel beaches and on sheltered and exposed rocky coasts is discussed in the following sections.

Figure 7. Topographic beach profiles and interpreted trenches for Playa de Raso (UQA-26), a heavily oiled fine-sand beach. Trenches are not drawn to scale. Circled numbers refer to the chronologic sequence of depositional events (see text).



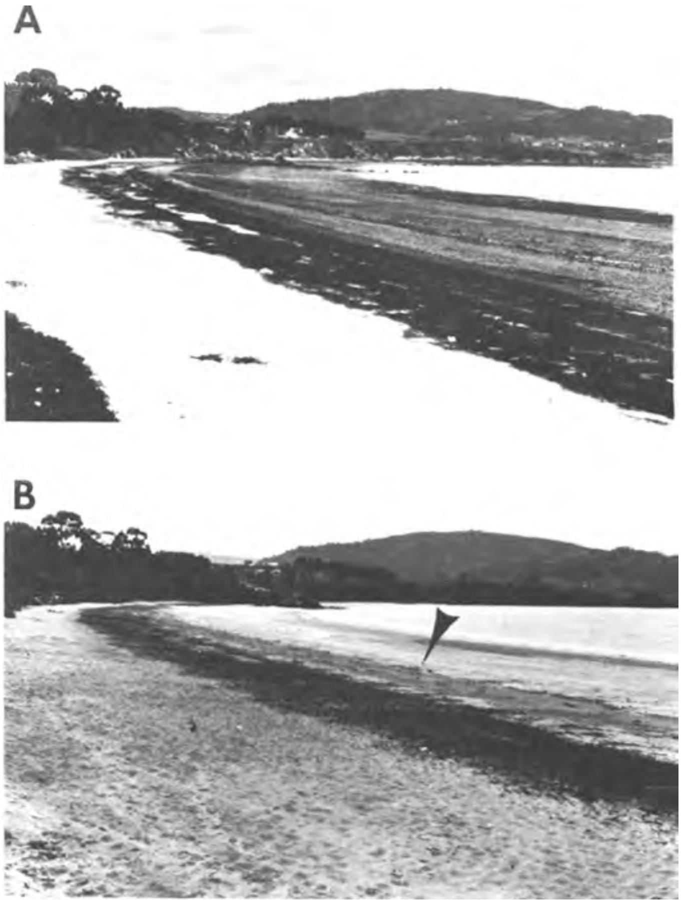


Figure 8. Playa de Raso, Spain (UQA-22) on (a) May 19, 1976 and (b) June 9, 1976. Arrow indicates the area cleaned of oil by natural processes. By June 9, oil was removed from 60 m of beach and buried along 23 m. Oil deposited in the high-tide swash zone during spring tides (May 14–16) remained unaffected.

Oil reaction on fine-sand beaches

The majority of fine-sand beaches affected by the *Urquiola* oil spill are located within the calm waters of the rias and received moderate to heavy oil accumulations. Playa de Raso (UQA-22, Fig. 3) in the Ria de Ares is typical of this beach type. It is a very well sorted ($\sigma_I = 0.34\ \phi$), coarse skewed ($SK_I = 0.42\ \phi$), fine-sand beach ($M_z = 3.2\ \phi$). The beach profile is relatively flat because of the fine grain size (Fig. 7). Figure 8 shows ground-level photographs taken of the area during site visits on May 19 and June 9.

Initially, 1 to 3 cm of oil covered the entire intertidal zone (Fig. 8a). The oil coating was strictly superficial owing to the close packing of the sediment. Comparison of the profiles taken on May 19 and June 9 illustrate minor, though important, variations in the morphology of the beach. During this time, the lower beachface lost 2 cm of sediment and oil, while the upper portions gained an equal amount of clean sediment. As a result of these subtle changes, oil was removed from 60 m to shore and buried along 23 m.

Trenches dug in the oiled zone yield substantial information concerning the depositional history of the beach during and after initial oil impact. Interpreted trenches, illustrated in Fig. 7, indicate the following depositional sequence: (1) burial of the oil deposited on the beachface before measurement of the first profile on May 19, (2) deposition of 3 cm of clean sand on the berm, (3) deposition of the thin surficial oil layer visible on the May 19 profile, and (4) deposition of clean sand over the oiled layers along the upper portion of the beach. Oil that was placed on the berm during the high spring tides of mid-May remained undisturbed throughout the study period.

Oil on coarse-sand beaches

Medium- to coarse-sand beaches commonly occur along the exposed Atlantic coast of the spill site. Playa de Doniños (UQA-26, Fig. 3) was selected for detailed study. It is a well sorted ($\sigma_I = 0.47\ \phi$), strongly fine skewed ($SK_I = +3.75\ \phi$), medium- to coarse-sand beach ($M_z = 0.82\ \phi$). At the time of the spill, Doniños received moderate oil accumulations under high wave energy conditions. Topographic beach profiles and interpreted trenches are presented in Fig. 9. Accompanying photographs taken on May 23 and June 9 are presented in Fig. 10.

Oil incorporation into the beach at Doniños was much more extensive and complex than at Raso. As oil first came ashore on May 17 or 18, the runnel behind the spring berm acted as a trap for incoming oil. Pools of oil several centimeters thick remained in the berm runnel for several weeks (see Fig. 11). As inferred from the trenches illustrated in Fig. 9, the following sequence of events probably occurred during and after initial oil impact. Alternate clean and oiled layers along the upper portion of the beach (Fig. 11) indicate that: (1) Oil slicks came ashore and were stranded during an accreting stage of spring berm development. Oil continued to come onshore as the tidal stage regressed toward neap. The neap berm (Fig. 9) formed as a result of constructional wave activity during this tidal stage. (2) Oil deposited at this time rapidly became incorporated into the accreting neap berm. (3) Oil pools formed in the neap berm runnel as more oil slicks came ashore. As the tidal cycle once again advanced toward spring conditions, after neap tides on May 20–23, the neap berm was partly destroyed and its sand distributed higher on the beach. (4) Oil previously deposited in the runnel of the neap berm was buried during this process. Remnants of this deposit are visible as discontinuous layers intersecting the beachface at high angles. During all stages, oiled sediment was continuously reworked so the main portions of the beach still appeared heavily oiled on June 9 (Fig. 10b), almost 4 weeks after the grounding of the *Urquiola*.

Oil reaction on mixed sand and gravel beaches

Gravel and sandy-gravel beaches are not common within the *Urquiola* spill area. However, two localities of this beach type, Mera (UQA-10) and Canabal (UQA-11), were subjected to

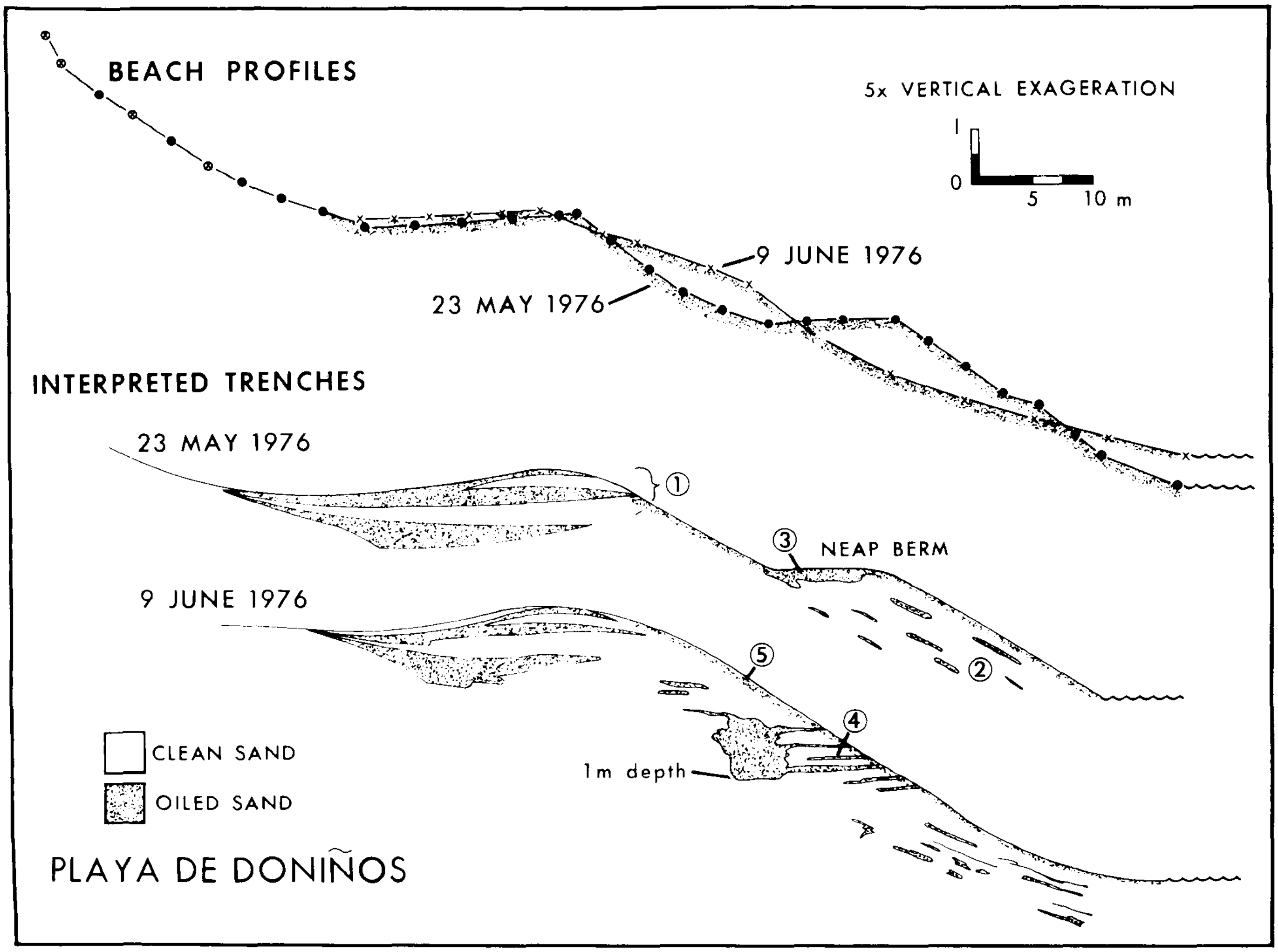


Figure 9. Topographic beach profiles and interpreted trenches from Playa de Doñinos (UQA-26), a moderately oiled medium- to coarse-sand beach. Trenches are not drawn to scale. Circled numbers refer to the chronologic sequence of depositional events (see text).

extremely heavy oil accumulations and deserve description. Mera is a medium sorted (σ_I = 0.83 ϕ) gravel beach (M_z = −2.29 ϕ), Canabal consists of very poorly sorted (σ_I = 2.51 ϕ) sandy gravel ,(M_z = −1.44 ϕ). Figure 12 contains topographic beach profiles for each locality. Ground-level photographs taken on May 20 (Mera) and May 25 (Canabal) are shown in Fig. 13.

Mera (UQA-10) is in a small embayment sheltered by a rock headland on one side and an L-shaped protective jetty on the other. The beach at Canabal is at the head of a 1-km-long, relatively narrow embayment. A thick pool of oil accumulated at each site as a consequence of close proximity to the wreck area, onshore winds, and the restricted nature of each environment. The oil pool, 15 to 20 cm thick at Mera, inhibited almost all wave activity and sedimentary transport. Oil sank deep into each beach (65 cm at Mera, 30 cm at Canabal), unaffected by mixing. Oil penetrated deeper into the sediments at Mera because of better sorting of the sands there.

The reaction of these beaches is somewhat unique. As observed at mixed sand and gravel beaches in New England, Alaska, and the Strait of Magellan, beach modification usually occurs rapidly, which can cause extensive erosion or burial of deposited oil. The lack of sediment movement on similar beaches in Spain resulted from the inhibition of nearly all wave activity by the heavy oil accumulation within these environments.

Oil reaction on rocky coasts

The majority of the shoreline affected by the *Urquiola* oil spill consists of sheltered and exposed rocky coast environments. Wave energy was the prime determinant of the extent and duration of oil impact. Along cliffed or steeply dipping portions of the

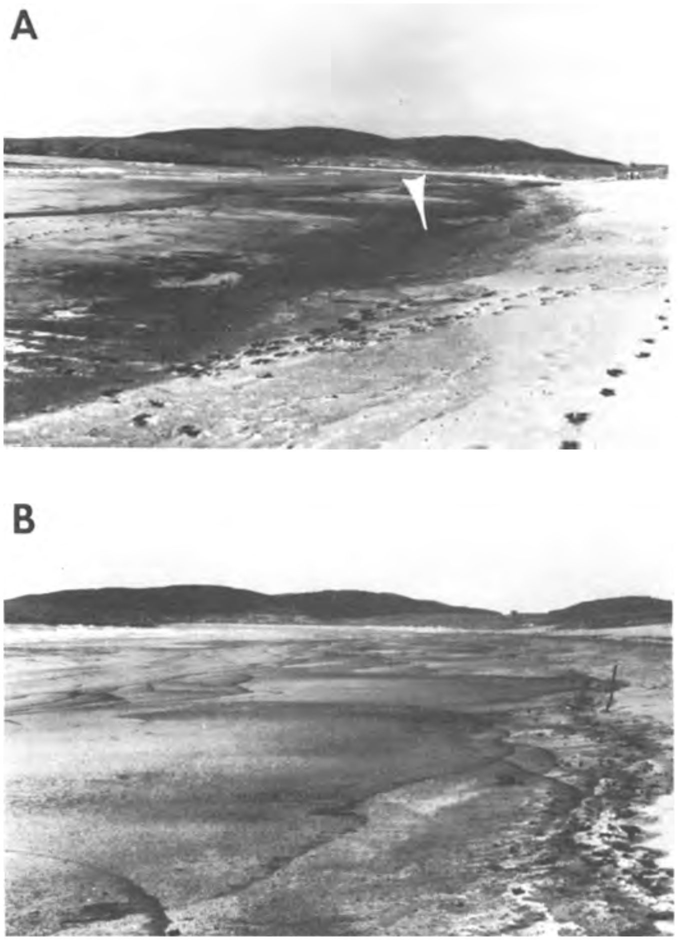


Figure 10. Ground views of Playa de Doniños (UQA-26) on (a) May 23 and (b) June 9. Arrow indicates heavy oil accumulations in the runnel of the spring berm and approximate area of Fig. 11.

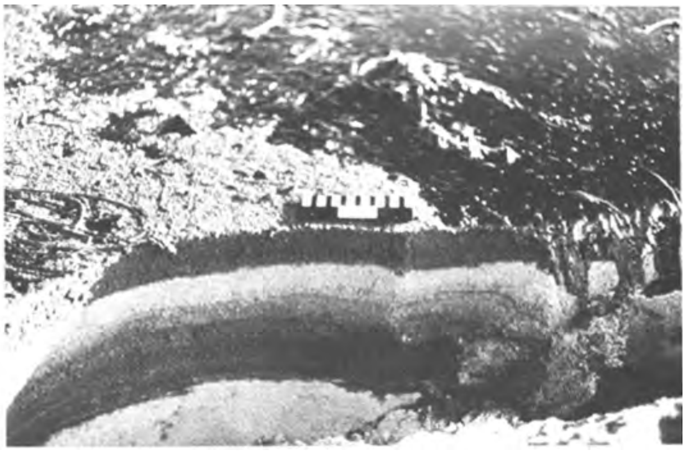


Figure 11. Photograph taken on May 23, 1976 of a trench in the spring berm runnel at Playa de Doniños (UQA-26). The ocean is located to the right of the photograph. The interlayered nature was caused by impact of different oil slicks while the berm was accreting during high spring tides.

Atlantic coast, which were exposed to high-energy wave conditions, much of the oil was held 5 to 10 m offshore by wave reflection (Fig. 14). There was little to no apparent environmental damage along these sections. However, substantial quantities of oil did accumulate in those areas (such as pockets and coves along the coast) that had low wave activity. Within the lower energy rocky environments inside the ria system, oil tended to concentrate in small embayments along the coast in response to wind conditions and tidal currents. In areas of heavy accumulation, the rocks became covered with a thick layer of oil, often killing attached algae, barnacles, and limpets.

Discussion

Fine-grained beaches are far more conducive to the mechanical removal of spilled oil than are coarse-grained beaches. Close packing of the sediment restricts oil infiltration to less than a few centimeters below the surface of the beachface. Burial of the oil is also lower in comparison to coarser beaches. A motorized grader, therefore, in conjunction with a motorized elevating scraper can efficiently clean fine-sand beaches (Sartor and Foget 1971) if adequate precautions are taken. Only the oiled surface layer should be scraped off during a single pass over the oiled area. Duplicate passes only grind the oil deeper into the beach. Additionally, near-shore waters must be free of oil before the operation commences. Inadequate understanding of these factors was clearly illustrated by cleanup activities begun at Playa de Bastiagueiro (UQA-3). During cleanup, oil still in the water repeatedly returned to oil the beach on successive tides. Mechanical scrapers, many times passing over the same area, ground oiled sediment deep into the beach. After 3 weeks of effort, most of the beachface had been lowered by as much as 1 m, and the beach still contained a large amount of oil. Large-scale removal of sediment, such as occurred at Bastiagueiro, can lead to beach destabilization and erosion.

On coarse-sand beaches, such as Doniños (UQA-26), cleanup is complicated by high wave energies and relatively porous sediments. Oil may be incorporated into the beach with extreme rapidity. Cleanup operations were not initiated at Doniños during our study; however, some of the inherent problems involved with such an undertaking are evident. Heavy machinery may churn the oil deep into the beach, become trapped in the loosely packed sand, and damage sensitive dune areas behind the beach. In order to entirely clean the beach, an enormous quantity of sand would have to be removed, substantially increasing the likelihood of serious beach erosion. On gravel beaches, such as Mera and Canabal, oil is also rapidly incorporated deep into the sediment, and it becomes extremely difficult to clean up without causing

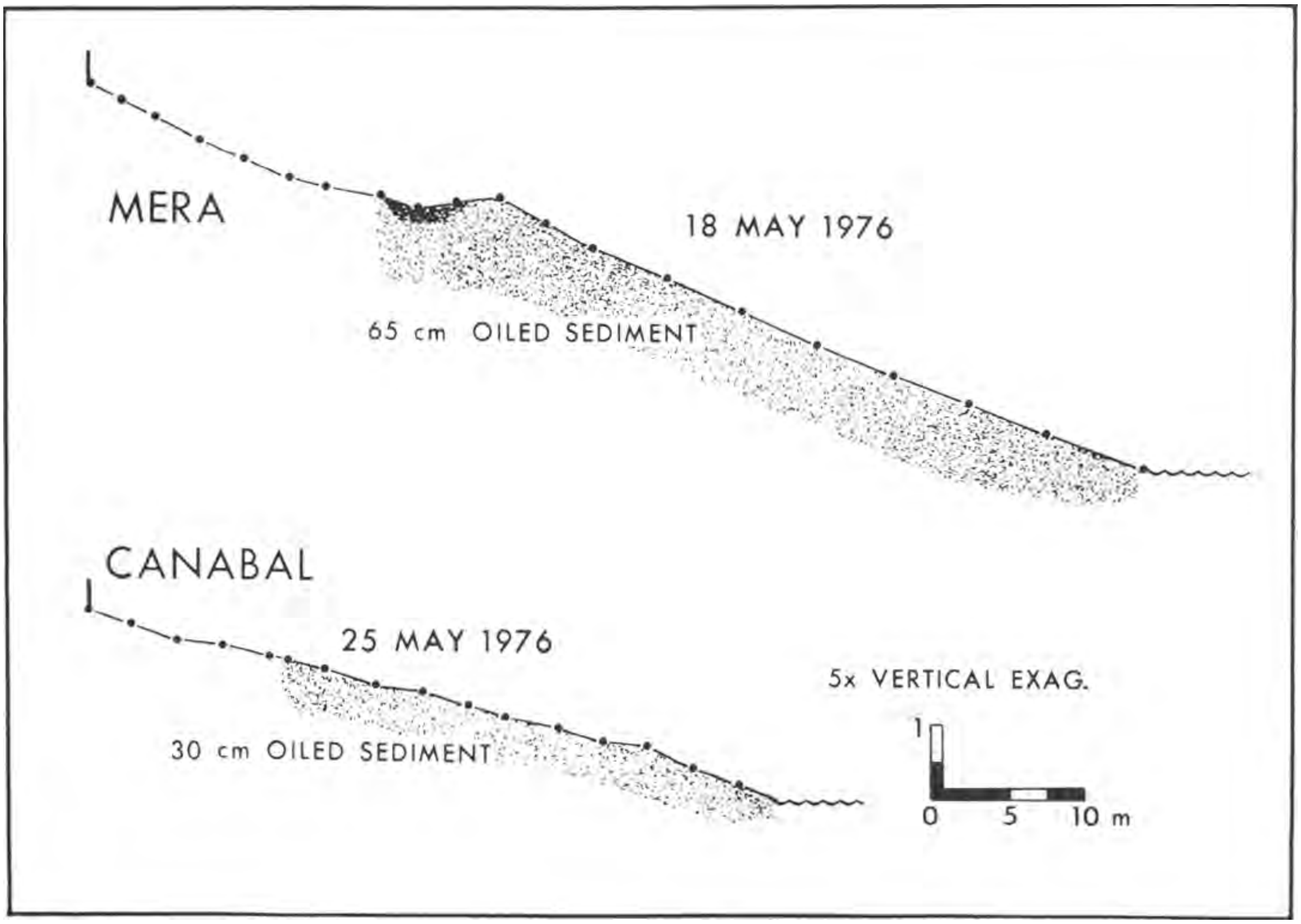


Figure 12. Topographic profiles and extent of oil penetration at the coarse-grained beaches at Mera (UQA-10) and Canabal (UQA-11). Oil penetration was caused by oil percolation in response to gravity and capillary action. Mixing of the oiled sediment and burial did not occur because of abatement of wave activity by heavy oil accumulations on the near-shore water surface.

further damage to the beach. Owens and Rashid (1976) reported that some mechanically cleaned gravel beaches eroded 20 m in the 12 months following the *Arrow* spill in Chedabucto Bay, Nova Scotia.

Natural marine processes are sometimes effective in cleaning beaches. On active beaches, the continual movement and reworking of sediment by waves along the beachface eventually will remove most of the oil from this area. Often, the greater the wave energy, the faster the natural cleaning of the beach. Because the high-tide swash area is often the location of the heaviest oil accumulation and is generally above direct wave attack, cleanup operations should concentrate on the removal of oil from this area.

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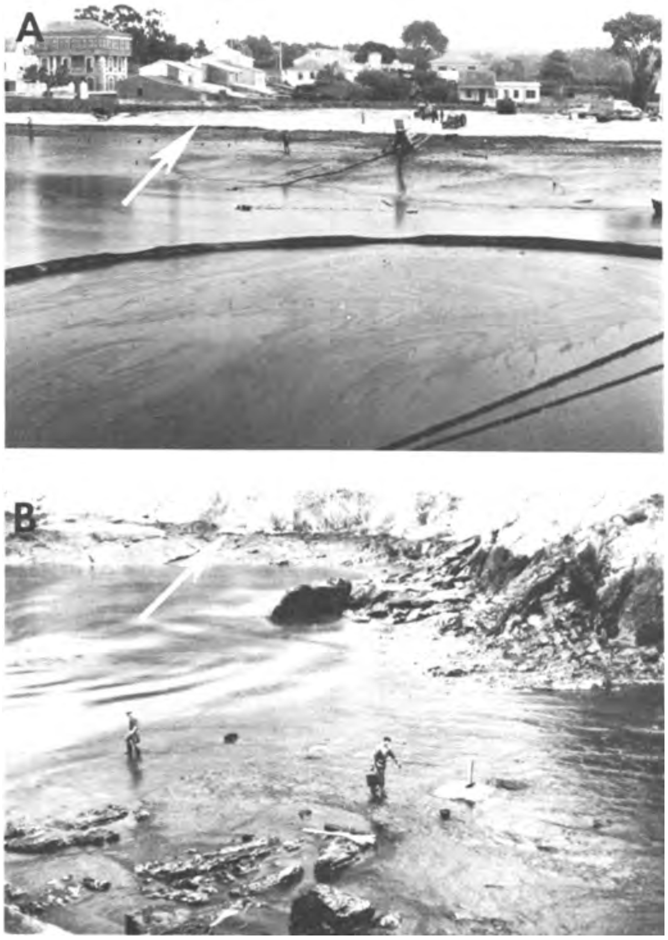

Figure 13. Views of the beach at Mera (photograph A, UQA-10) and Canabal (photograph B, UQA-11). Arrows mark the highest extent of oil coverage. Very thick oil covered the water at each locality. At Canabal, first attempts to remove the oil were limited to the use of buckets.

Turnay, Carlos Palomo, Joaquin Ros, Miguel Torre, Jorge Juan Rey, Jose Ramon de Andres, Jose Besada, and Nicholas Gonzales. Commandante Felix Bastarreche provided two helicopter overflights of the spill area.

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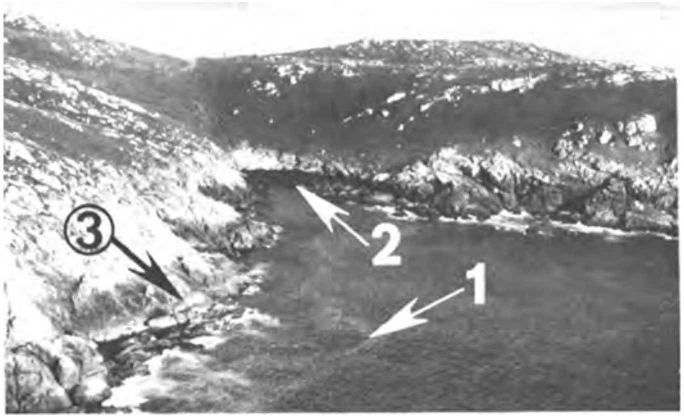

Figure 14. Oblique aerial photograph of Cabo Prioriño showing (1) oil slicks held offshore because of wave reflection, (2) a heavily oiled pocket cove, and (3) clean rocks in areas where wave reflection occurs. Coves along the coast break the uniformity of the reflected wave and are thereby subjected to oiling.

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