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SHORELINE OIL TWO YEARS AFTER *AMOCO CADIZ*: NEW COMPLICATIONS FROM *TANIO*

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ABSTRACT: *The latest in a series of joint Franco-American surveys of the* Amoco Cadiz *(233,000 tons; March 17, 1978) spill site was conducted during May and June 1980. The purposes of this survey were to determine remaining surface oil, buried oiled sediment, oil incorporation in interstitial water, and recovery of attached macroalgae.*

Oil was found to persist primarily as tar blotches and black staining along exposed rocky shores and as oil-contaminated (indicated by surface sheen), interstitial water in previously heavily oiled, sheltered tidal flats. Less commonly, oil was present as asphalted sediment and oil-coated rocks in sheltered embayments. The cleaned marsh at Ile Grande remained significantly damaged from the oil; however, both upper and lower marsh grasses showed some recovery. At another marsh, no recovery occurred in uncleaned, heavily oiled areas. On sheltered rocky shores, heavily oiled algae showed rapid recolonization by Fucus; *however,* Ascophyllum nodosum*-dominated areas showed less recovery.*

The Tanio *oil spill on March 7, 1980 (7,000 tons lost) impacted 45 percent of the* Amoco Cadiz *spill site and severely complicated further differentiation of* Amoco Cadiz *oil in many areas. In total, 197 kilometers (km) of shoreline were impacted; 45 km were heavily oiled. Nine weeks after initial impact,* Tanio *oil occurred as patches of heavy oil along sheltered and exposed, rocky shores. Sand beaches and tidal flats were generally free of oil. Several hundred soldiers continued to pressure spray dispersants and water to clean up oiled areas, even in high wave energy and isolated localities.*

Introduction

The 2-year study of the *Amoco Cadiz* (233,000 tons of crude oil March 17, 1978) oil spill site in Brittany, France, presents an opportunity to understand the longer term impacts of spilled oil on a variety of temperate shoreline types. The extent of shoreline oiling, resulting from the offshore breakup of the 27,000-dwt tanker *Tanio* during spring 1980, is also discussed because the addition of this new oil along some of the same section of Brittany coast may severely complicate ongoing fate-and-effects studies.

Reports about the *Amoco Cadiz* are numerous and encompass a wide variety of biological, chemical, and geomorphic topics. Hess (1978), Conan et al.(1978), Spooner (1978), and a forthcoming symposium proceedings edited by D'Ozouville and Conan (in press) present the most comprehensive summary of impacts and effects. Papers particularly concerned with the persistence of *Amoco Cadiz* oil are Atlas et al. (in press), Berné and D'Ozouville et al. (1980), Gundlach (1979), and Hayes et al. (1979). Detailed investigation of the *Tanio* was undertaken by Berné (1980).

The climate of Brittany is temperate, moderated by the strong influence of its maritime setting. Low-pressure areas formed in the North Atlantic are responsible for generating strong, westerly winds and high seas. The shoreline is characterized as a low-lying, plateau-shielded coast having large protruding headlands dominated by igneous bedrock, large embayments associated with each headland, and smaller, less common, drowned river valleys (rias). Because of a 6- to 9-meter (m) tidal range, the bottom of each embayment often becomes exposed during low tide, creating a very large surface area that could be oiled. This factor was particularly important in the long-term persistence of oil in sheltered tidal flats. Lastly, tidal currents, strongly prograding from west to east through the English Channel, were extremely important in influencing the overall distribution of shoreline oil.

Methods

Visits to the spill site to determine oil persistence were made during March, April, August, and November 1978; March and November 1979; and May 1980. A total of 147 sites have been established since 2 days after the grounding (Figure 1). Two types of stations were created: (1) rapid survey stations, at which

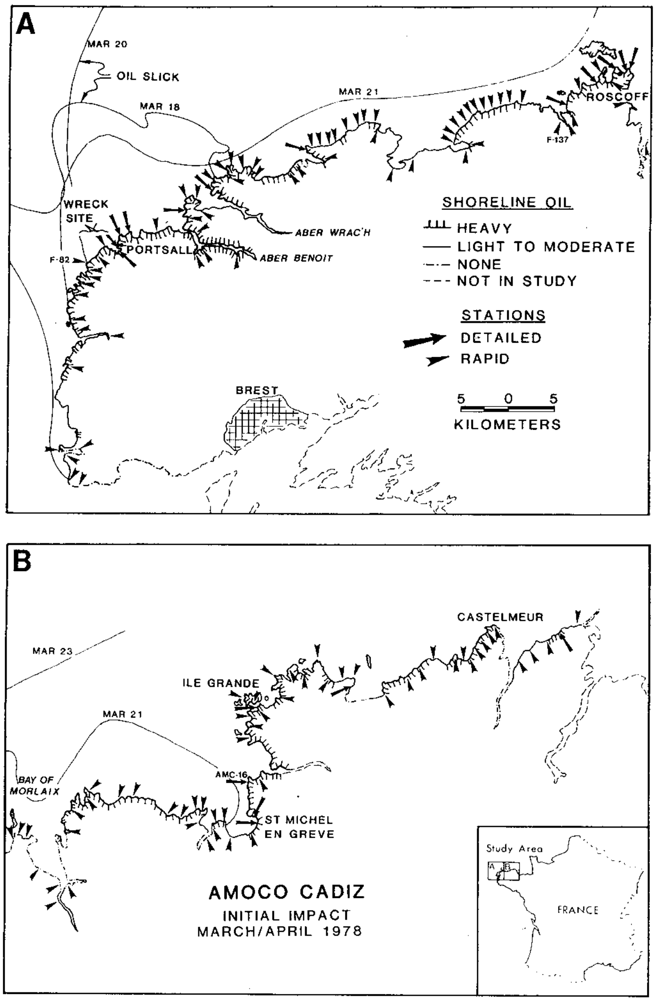

Figure 1. Oil distribution and station locations during initial impact of *Amoco Cadiz* oil (adapted from Berné and D'Ozouville, 1979).

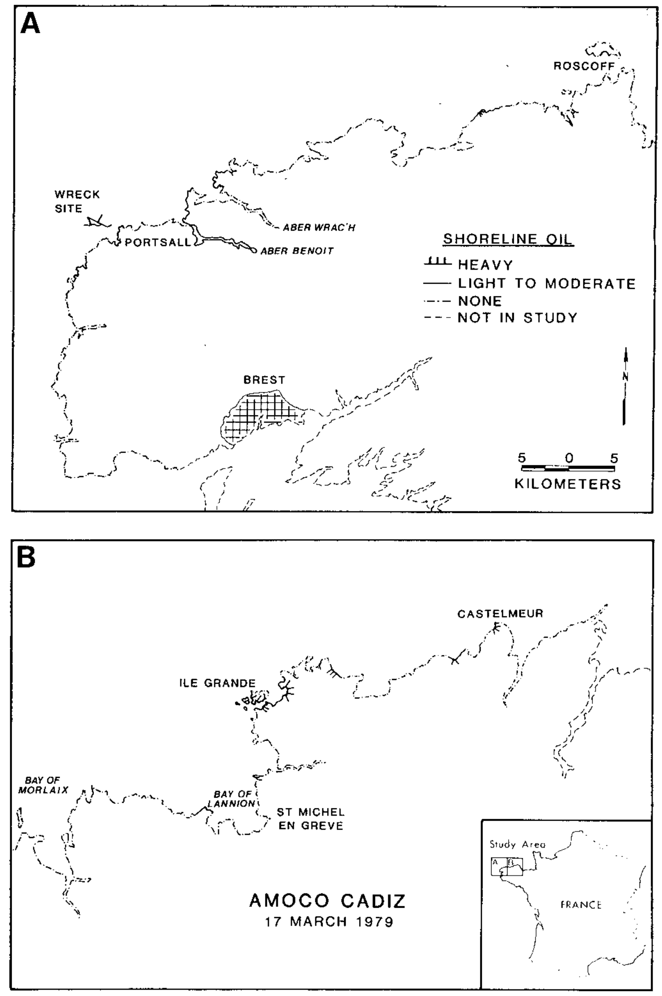

Figure 2. Shoreline oil remaining one after *Amoco Cadiz* wreck. Oil was found most commonly in more sheltered embayments (adapted from Berné and D'Ozouville, 1979).

surface and buried oil concentrations and obvious biological impact were quickly assessed; and (2) detailed study stations, at which surface and subsurface oil content were measured along a topographic beach profile and overall oil distribution was studied in detail. Numerous overflights of the spill site added understanding of initial oil distribution patterns. During the *Tanio* study undertaken from March 20, to April 21, 1980, 56 new stations were added to yield a total of 131 survey sites in this impact zone. Two aerial overflights aided in determining overall oil distribution, especially on offshore islands. Detailed analysis of algal growth, surface area coverage, and zonation were undertaken at four oil-impacted sites in Portsall during June 1979 and June 1980.

Results

Overall changes. Figures 1 and 2 show shoreline distribution of visible *Amoco Cadiz* oil during and one year after the spill. Figure 3 shows the extent of oil spilled by *Tanio*. Changes in surface oil coverage and concentration are tabulated in Table 1. As indicated, it was approximately 62,000 tons (or 26 percent) of the total *Amoco Cadiz* cargo that washed onshore during the first few weeks after the grounding. Within 3 weeks, this content was reduced to 15 percent of this (to less than 10,000 tons) primarily by natural processes. By 1 year after the spill, natural processes had diminished further the extent of shoreline still showing evidence of the spill. It was expected that by April 1980 (2 years after the spill), obvious shoreline oiling would be very limited, but the occurrence of *Tanio* greatly confused the issue.

Persistence of *Amoco Cadiz* oil on particular shoreline types. Because of the great complexity of the Brittany shoreline, initial and followup observations are discussed in terms of specific shoreline types. These environments coincide with those discussed by Hayes et al. (1980) as part of an oil spill Environmental Sensitivity Index (ESI) which ranks shorelines in terms of the potential, long-term persistence of oil. The 2-year study of the *Amoco Cadiz* site provides an opportunity to reconfirm or modify the index accordingly. The ESI is juxtaposed with observations from this study in Table 2. Environments are discussed in order of increasing oil persistence.

Exposed, rocky headlands. As first observed during the *Urquiola* spill, waves reflecting off steep, bedrock headlands kept floating oil from impacting the shore (Gundlach et al., 1978; Figure 4A). Very similar conditions existed during the *Amoco Cadiz* spill, so that these areas generally remained free of oil throughout the spill (Figure 4B).

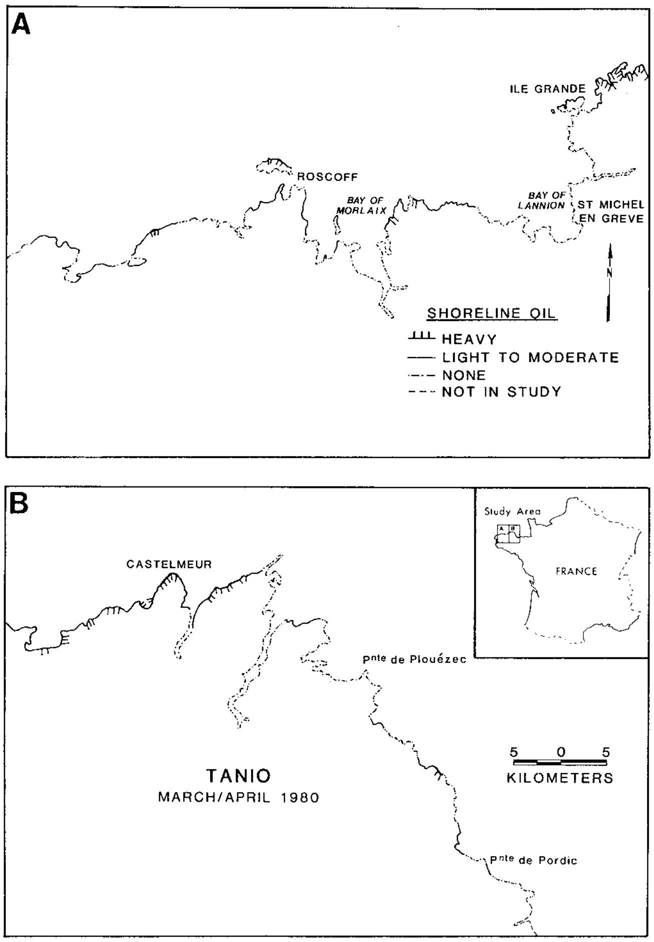

Figure 3. Shoreline impact of *Tanio* oil. Approximately 45 percent of areas previously oiled by *Amoco Cadiz* were reoiled by *Tanio*. Castelmeur and the tourist area called the "rose coast" were most heavily oiled (adapted from Berné, 1980).

Eroding, wave-cut platforms. Unfortunately, most wave-cut platforms were dominated by surface coverage of boulders or sediment, so a clear case of oil on this shoreline type is not available from this study. Where typical, well-defined platforms are present, oiling was not heavy, and high waves and difficulty of access prevented investigation.

Fine-grained sand beaches. Several typical, compact fine-grained sand beaches were present and heavily oiled in the study site (Figure 4C, D). Incoming waves rapidly removed most of the oil; burial was minor and limited to less than 30 centimeters (cm). In areas where wave activity was limited, mechanical cleanup was necessary. By July 1978, only light and scattered oil-sediment layers were evident; 1 year later no oil was visible. In one mechanically cleaned area, substantial erosion was observed 2 years after the spill; however, because of no long-term monitoring studies, natural erosion cannot be separated from that induced by man.

Table 1. Shoreline Pollution Resulting From the *Amoco Cadiz* and *Tanio* Oil Spills (March 1978 to April 1980)

	Heavy, km	State of shoreline oiling, light to moderate, km	Tons present
Amoco Cadiz			
End of March 1978	72	0	62,000
End of April 1978	175	155	10,000
End of May 1978	109	123	(a)
November 1978	54	156	(a)
March 1979	8	69	(a)
Tanio			
April 1980	45	152	6,000

[a] Difficult to determine because oil was thinly scattered along most of the shorelne.

Coarse-grained sand beaches. Less than 1 percent of the Brittany spill site can be characterized as coarse-grained sand beach. In contrast to the long, open sand beaches of the United States (e.g., Cape Cod and Long Island, the beaches in Brittany are small, semisheltered pocket beaches (Figure 4E). During the spill, extensive mechanical cleanup was used to remove heavy oil deposits. No surface oil was visible by July 1978, but several deeply buried, oiled-sediment layers were present. Because oil first impacted the shoreline during an erosional phase of the beach cycle (storm-induced), subsequent deposition of sand during calm weather caused burial of the oil/sand mixture. In fact, 2 years later, since there was no intervening period of similar erosion, oil still was found 84 cm deep at a coarse-grained sand beach near the wreck site (Figure 4F).

Mixed sand and gravel beaches. Models for this shoreline type were based on heavily-oiled, mixed sand and gravel beaches exposed to moderate-to-high wave energy at the *Metula* site (Patagonia, Chile). Such exposed beaches are not common in Brittany where, for the most part, they are located in fairly sheltered embayments fronted by large tidal flats. Oil impact on these beaches varied from light to moderate; there was little mechanical cleanup. Because of relatively low wave energy, the scattered oil formed an asphalt pavement (Figure 5A, B), which was still present 2 years after the spill.

Gravel/boulder beaches. This shoreline type comprises moderately sorted gravel, cobble, and boulder beaches. At least one good example of heavy oil impact on each was observed during the *Amoco Cadiz* spill. The historical sequence of oil persistence on a gravel beach is presented by study of station AMC-16 (see Figure 1 for location). Initial oil impact on the area was very heavy and concentrated along the upper beach face (Figure 5C). As similar deposits from the *Metula* had turned to an asphalt pavement over time, cleaning of the area was attempted, not by removal of oiled gravel, but by pushing it down the beach face into the active swash zone; this was somewhat effective. The quantity of remaining oil was reduced by November 1979, but since there were yet no major storms (generating high waves), oil was present still along the lower beach face. By the time of the next site visit in May 1980, after a particularly stormy winter, no oil remained (Figure 5D).

Station F-82 (south of the wreck site) is illustrative of the behavior of oil on exposed boulder beaches. The area was heavily impacted during April 1978 (Figure 5E) as a result of a wind shift at the beginning of the month. By November 1978, the extent of oiling was reduced substantially (Figure 5F). A year later and after several severe winter storms, only scattered blotches of tar remained. Therefore, residence time for natural degradation of oil in this environment at the *Amoco Cadiz* site was limited to 1 to 1.5 years.

Exposed tidal flats. Tidal flats exposed to moderate- to high-wave energy are present in the following two forms in Brittany: (1) as exposed, low-tide terraces fronting fine-grained sand beaches; and (2) as wide (several kilometers) sand deposits located in depositional embayments. Oil had little impact on

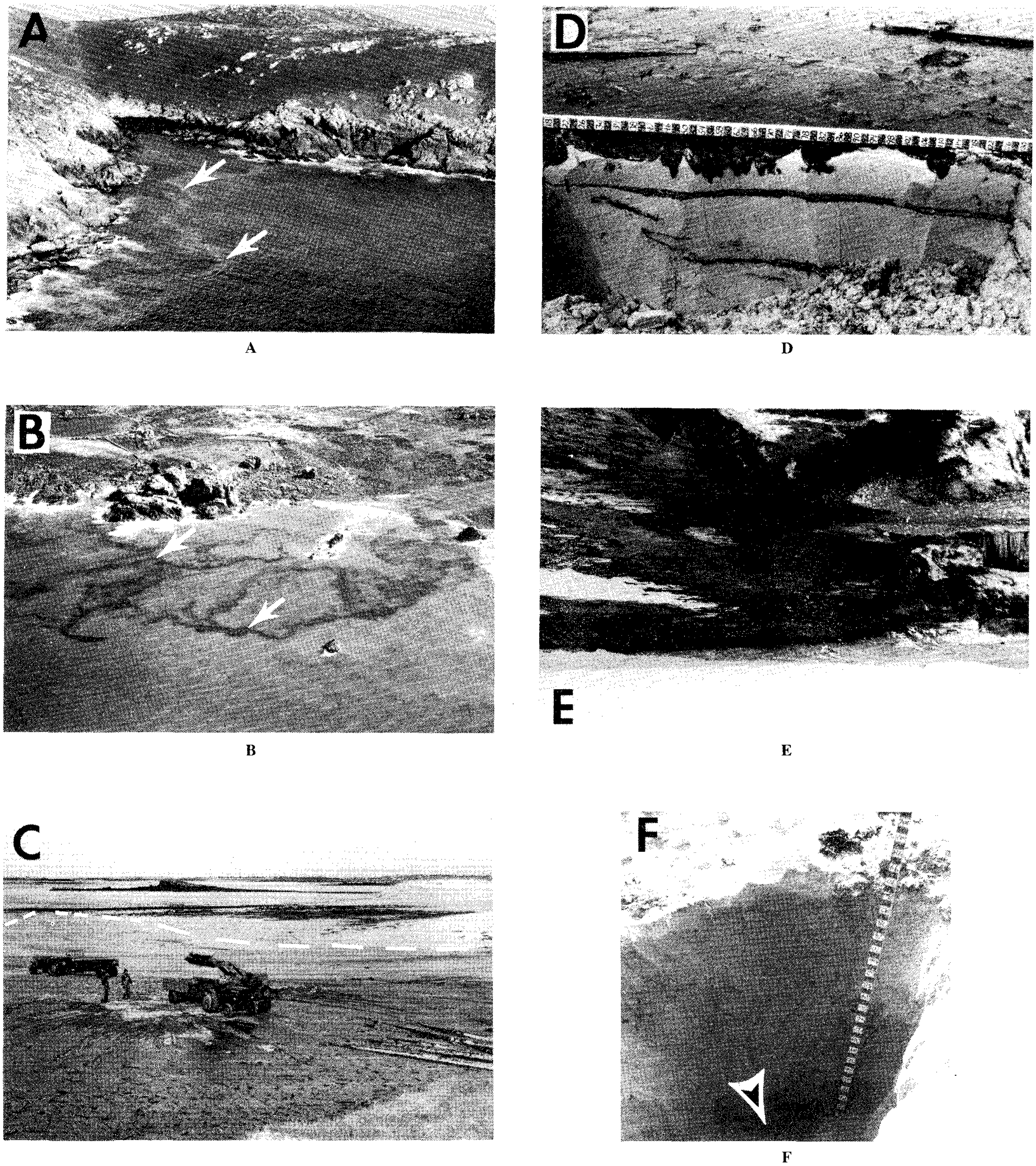

Figure 4. A. Aerial view of oil (arrows) being held offshore of steeply dipping, rocky shoreline (ESI = 1) at *Urquiola* spill site in Spain. B. Occurrence of the same phenomenon south of *Amoco Cadiz* wreck site. C. Cleanup of heavily-oiled, fine-grained sand beach (ESI = 3) near wreck site; white dashes denote oiled area. D. Oil incorporation into beach illustrated in 4C. Oil was buried less than 30 cm; penetration was limited to 3 cm. Staff across top of trench = 1.1 m. E. View of heavily oiled, coarse-grained sand beach near Portsall. F. Trench showing almost 1 m oil burial (arrow) 2 years after the spill.

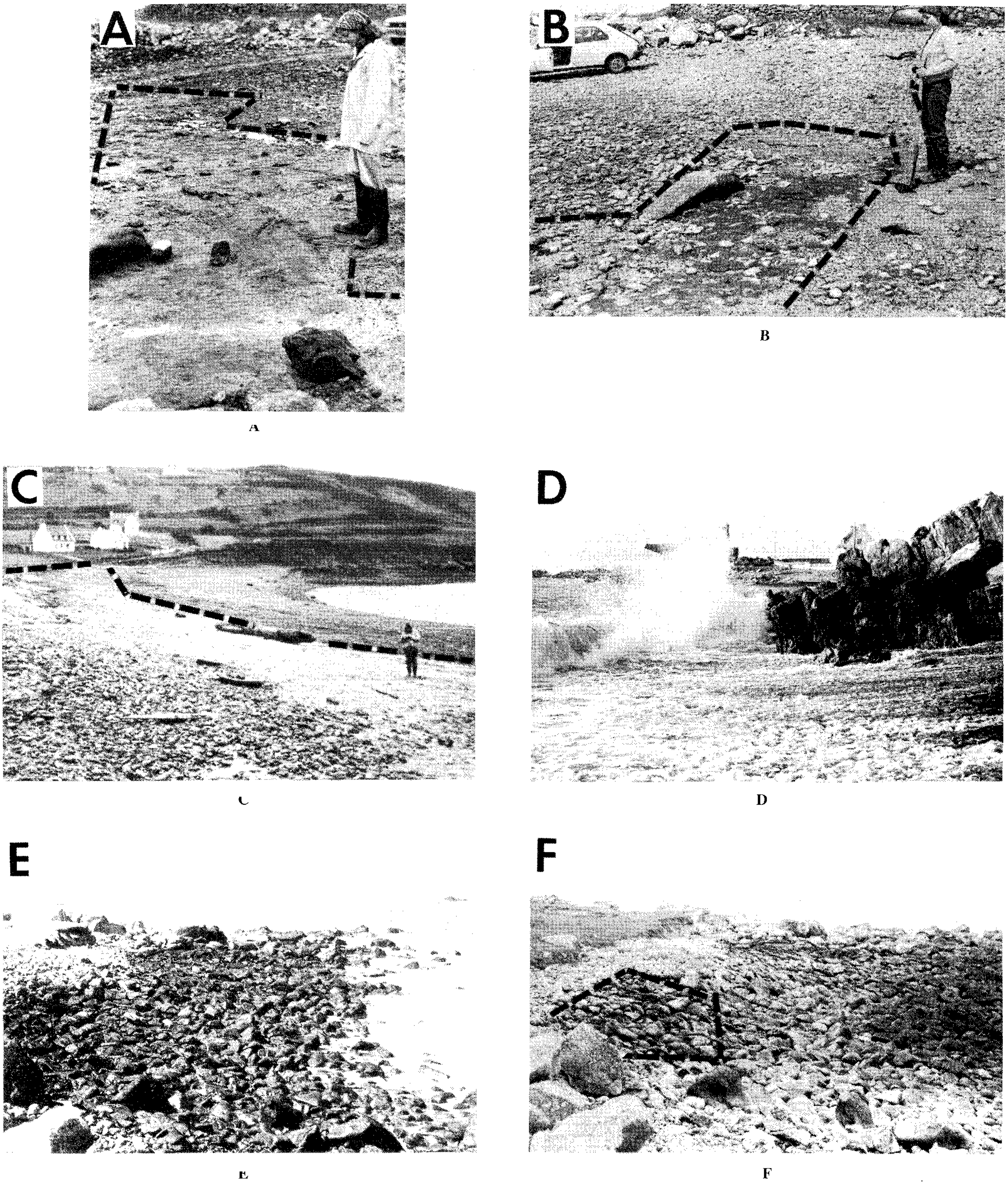

Figure 5. A. View of asphalted oil (dashed line) on sheltered, mixed sand and gravel beach (ESI = 5) on July 19, 1978. B. Same area on May 14, 1980; the extent of aspohalt was reduced. C. South view of heavily-oiled gravel beach (ESI = 6) at AMC-16 during April 1978; dashes denote heavy oiling. D. Same area (looking north) showing impinging wave action during November 1979; no oil remained. E. Heavily oiled boulder beach (ESI = 5) during initial *Amoco Cadiz* impact. F. Same area on November 7, 1978. Most spilled oil was removed rapidly by wave activity; dashes indicate remaining oil.

Table 2. Descriptions of Oil Persistence After *Amoco Cadiz* Oil Spill[a]

Sensitivity index value and shoreline type	Comments (Duration of pollution)	Observed cleanup
1. Exposed rocky headlands	Composed of bedrock with high impinging wave activity; wave reflection kept most of the oil offshore; no cleanup was needed (days or weeks)	Difficult access; natural processes sufficient.
2. Eroding wave-cut platforms	No good example of oil interaction.	Usually difficult access.
3. Fine-grained sand beaches	Exposed to moderate-to-high wave energy; little penetration into the beach because of compact sand; thin buried layers commonly persisted in depositional areas (months to 1 year)	Easy access; can be cleaned mechanically; buried layers difficult to remove.
4. Coarse-grained sand beaches	Common in semisheltered area in Brittany; greater penetration of oil due to coarser substrate; buried oil common (1 to 2 years)	Easy access; sand removal may cause beach erosion; difficult to use mechanical means.
5. Mixed sand and gravel beaches	Found within some sheltered areas of Brittany; an asphalt pavement formed in some low energy areas of oil deposition. (1 to 2 years; more in sheltered areas)	Easy access; generally hard surface permitted some cleanup of surface oil; high-pressure hosing without sediment removal recommended.
6. Gravel beaches	Showed rapid and deep penetration of oil (1 to 2 years)	Generally easy access; removal of sediment not recommended; high-pressure spraying with mechanical re-working of sediment into surf zone proved most effective.
7. Exposed, compacted tidal flats (moderate to high biomass)	Oil moved rapidly over the flat surface and was deposited along the swashline; varied biological impact: in productive areas, impact was severe (months to 1 year, oil as sheen evident after 2 years)	Easy access; compact flats cleaned easily mechanically; trenches as part of cleanup may have caused increased oiling of interstitial water (visible after 2 years).
8. Sheltered rocky shores	Oil sticks to rocky surfaces; pools of oil between the rocks eventually turned to asphalt (up to 5 years, but most obvious oil effects gone after 2 years)	Access varies, but is often difficult: high-pressure spraying removed algae and organisms as well as the oil; low-pressure washing as the oil comes onshore may be less damaging biologically.
9. Sheltered tidal flats	In areas of low wave energy, oil persisted on the surface as mixed oil and sediment patches; contamination of interstitial water persisted even if the surface was cleaned (more than 5 years)	Access difficult on soft flats; cleanup very difficult and not usually effective; heavy machinery mixed oil into the sediment.
10. Marshes	Oil pooled on the surface of the marsh, killing most flora and fauna. Oil was still very obvious 2 years after the spill. (5 to 10 or possibly more years)	Access varies; heavy equipment further destroyed vegetation and natural drainage patterns; manual cleanup not very effective, but necessary in heavily oiled areas.

[a] Listed in terms of the ESI (Hayes *et al.*, 1980) which ranks shoreline types in terms of increasing oil effects. Correlation between this system of classification and observations at the Brittany spill site is good.

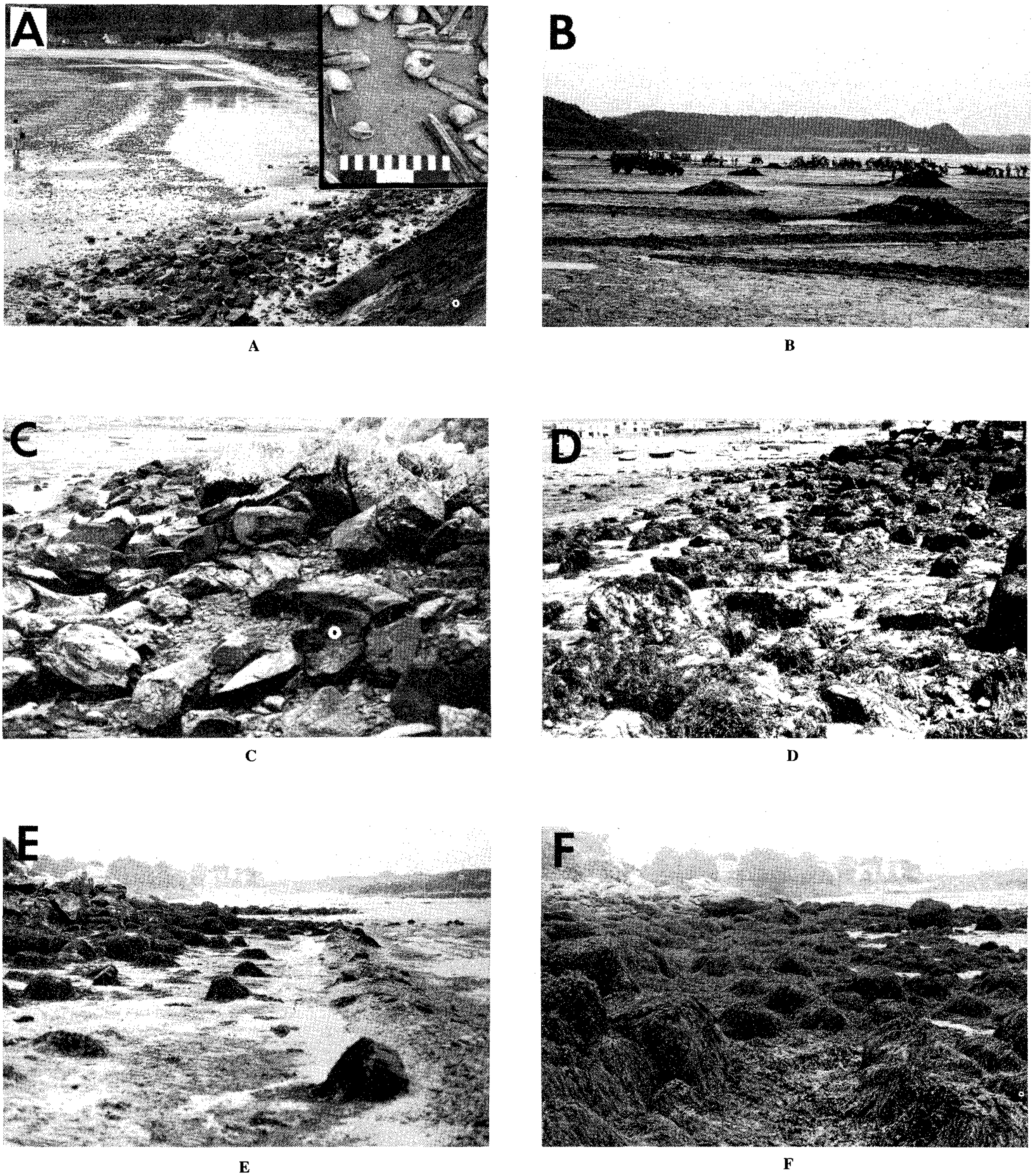

Figure 6.A. Overview and closeup of recently killed mollusks at exposed sand flat (ESI = 7) at St. Michel-en-Gréve. B. Cleanup operations of St. Michel-en Gréve. Use of oil collection pits may have increased the persistence of oil in the flat's interstitial waters. C and D. Views of sheltered rocky shore (ESI = 8) at Portsall on November 7, 1978 and June 1978 and 1980. After oiling and cleanup, much of the algae was no longer present. By June 1980, many sites still showed incomplete recolonization where *Ascophyllum,* without *Fucus,* was present. E. and F. View of north at the sheltered rocky shore at Portsall in July 1978 and November 1979 showing substantial regrowth of algae (primarily *Fucus*) during intervening year.

exposed low-tide terraces and rapidly pushed over the compact sand surface. In contrast, when oil impacted the large tidal flat at St. Michel-en-Grève (with its extremely rich, low intertidal to subtidal population of various mollusks), almost the entire infaunal population was killed (Figure 6A, B), due primarily to dispersed oil in the water column. Two years after the spill, no surface oil was visible at St. Michel-en-Grève or the adjacent beach; however, very light oil sheens were visible on the water surface in trenches in upper portions of the tidal flat. As a result of these observations, the original index was modified to "raise" high biomass, exposed tidal flats from a five to a seven to consider potential biological effects.

Sheltered rocky shores. This shoreline type is common in the many embayments of Brittany and hosts an extensive cover of fucoid algae. Portsall (close to the wreck site) provides an example of oil impact. Much of the mid-to upper-tidal fucoid algae was heavily oiled and by late summer 1978 was scraped off or lost as part of cleanup activities (Figure 6C, D). In the same vicinity, Floc'h and Dioris (1980) observed a gradual attrition of attached plants after oiling, especially at low and high tidal levels. By summer 1979, the extent of algal cover had increased substantially (Figure 6E, F); the feared suppression of reproductive viability was not long-lived (Topinka and Tucker, 1980). However the community structure had altered from *Ascophyllum nodosum* to *Fucus* dominance (as similarly observed after *Torrey Canyon* by Southward and Southward, 1978). Recolonization and growth of fucoid were aided by the presence of mature *Fucus* in the immediate vicinity.

Unfortunately, not all areas recolonized. In *Ascophyllum*-dominated sites (without nearby *Fucus*), a substantial portion of rock surface remained denuded (Figure 6E). *Fucus* propagates by releasing eggs in gelatinous masses which tend to adhere to rocks in the immediate vicinity. Without mature plants, *Fucus* colonization is restricted; *Ascophyllum* will eventually cover these bare areas again, but the process is much slower. If rock scraping and plant removal are undertaken as part of cleanup, it is best to leave some mature plants to act as sources for recolonization.

Sheltered tidal flats. Sheltered tidal flats are very common in the spill site area. Many were heavily oiled and consequently subjected to a large cleanup operation, utilizing much manpower and heavy machinery. Generally, the suface of each flat was free of oil within several months after the spill; however, subsurface contamination was a long-term problem. A moderate-to-heavy oil sheen (with oil droplets in some cases) was present on the water surface in trenches dug along upper portions of the tidal flat, usually within 50 to 100 m of the beach face. Samples of tidal flat sediments from station AMC-4 and Aber W'rach (100 m seaward of the high water line), taken from April 1978 to July 1979, had oil concentrations of 56 to 630 micrograms per gram dry weight (Atlas et al., 1980). Although the polychaete *Arenicola* was very common throughout the area after oil impacts, the continued elevation of petroleum hydrocarbon values undoubtedly affects the infaunal community.

Marshes. In contrast to the large estuarine marsh systems of the East Coast of the United States, Brittany has only small, isolated pockets of marsh grass. Two examples are as follows: (1) a heavily oiled large marsh/tidal flat complex located at Ile Grande, which was subjected to extensive cleanup activities; and (2) a much smaller, heavily oiled marsh fringe located at Station F-137, which was not cleaned. The dominant plants at Ile Grande were *Juncus maritimus, Puccinellia maritima, Triglochin maritima, Halimione portucoides,* and *Limonium*. During the spill, about 7,000 tons of oil were in the area, 3 to 5 cm thick on the marsh surface, and up to 15 cm deep in small pools (Figure 7A, B). A large cleanup operation of both men and machinery began soon after oiling. Surface and pooled oil were drained, collected, and pumped up. Both high- and low-pressure spraying of marsh grasses were used also. By July 1978, lower marsh grasses were dead; upper marsh plants survived in some areas (Figure 7C). The removal of soil-binding vegetation caused channel walls to slump into the channel (Figure 7D). The upper grasses were improving by November, although the lower grasses as yet showed no comeback. By May 1980, there was slow regrowth of the upper marsh and, finally, some appearance of new growth of the lower marsh grasses (Figure 7C). The area, in general, obviously remained oiled. Light oil patches were on the marsh surface; channel sediments were highly contaminated, and asphalt pavement was evident along the adjacent rocky shore.

The marsh at station F-137 is also dominated by marsh grasses. Oil impact was limited to a 50 × 150 m section, being heaviest (mostly 1 cm deep, with a few pools 5 to 10 cm deep) within a 10 × 50 m section. As indicated in photographs taken from April 1978 to May 1980 (Figure 7E, F), there is no evidence of recovery in areas where oil was heaviest. As at the *Metula* site, no recovery of the heavily-oiled marsh was evident 2 years after oiling. Thus, there is evidence that cleanup of very heavily oiled marshes is warranted, but it is also obvious that cleanup should be well-controlled and carefully restricted; heavy machinery and human access on the marsh surface should be limited.

Shoreline impact of *Tanio*. The tanker *Tanio* broke up on March 7, 1980, some 60 km off the Brittany coast, while carrying 26,000 tons of fuel from Germany to Italy (OSIR, 1980). The foresection sank with about 11,500 tons, while the aft section was salvage with 7,500 tons. The rest was spilled into the English Channel. Most of the oil drifted onto the Brittany shoreline from March 9 to March 21, 1980, resulting in a 45 percent overlap of areas previously oiled by the *Amoco Cadiz* (Figure 3). In total, oil impacted 197 km of shoreline; 45 km were heavily oiled. In contrast to the case of the *Ammoco Cadiz* where only one-quarter of the total lost impacted the shoreline, most of the spilled *Tanio* oil came onshore. Offshore surveys by Centre pour l'Exploitation des Oceans (CNEXO) and Station Biologique de Roscoff found only trace quantities of oil in the water column or on the bottom (Berné, 1980). The amount of oil deposited onshore by *Tanio* was roughly one-tenth that of the *Amoco Cadiz* (6,000 versus 62,000 tons).

Cleanup of *Tanio* oil began shortly after impact. Even more so than with *Amoco Cadiz, Tanio* oil impacted the "rose coast" tourist area of Brittany. Two months after initial impact, the spill site still showed light-to-moderate oiling, particularly of rocky areas. Emphasis of cleanup activities had switched from removal of major oil concentrations by skimmers and pumps to high-pressure hosing of oil-stained, rocky areas. Cleanup was not restricted to high tourism areas, but included sites well-removed from tourist traffic. Nor was it restricted to sheltered areas where cleanup by natural processes would be expected to take several years. In fact, many areas being cleaned in May were located along the exposed rocky coast where natural cleanup would be expected within 1 year. Clearly, as a cleanup policy that may (or may not) have applicability to the United States, the French system deserves more study from the technical and economic side.

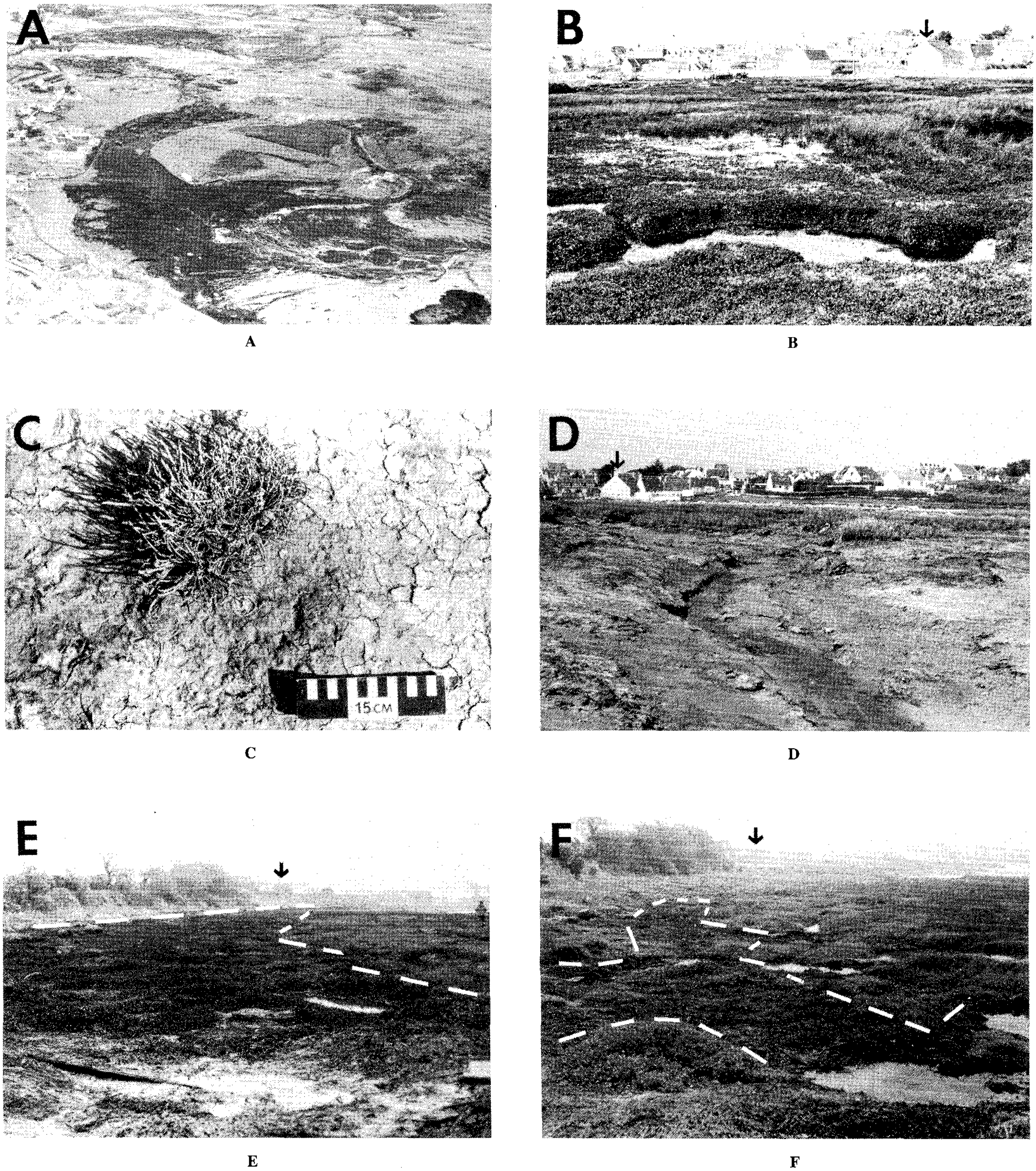

Figure 7. A. Aerial view of oiled marsh at Ile Grande during initial impact. B. Ground view of heavy oiling at Ile Grande during initial impact; pool in foreground of photo is composed entirely of oil. C. Surviving, lower marsh plants at Ile Grande, May 15, 1980. D. View of same areas as 7B on May 15, 1980; better recovery of upper marsh grass (*Juncus maritimus*) than of lower marsh plants was observed. E and F. Comparison of station F-137 on April 25, 1978 and May 14, 1980; white dashes indicate oiled areas; most heavily oiled areas have not recovered.

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