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FINAL REPORT

Coastal Geomorphology and Sedimentation of the METULA Oil Spill Site in the Straits of Magellan

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September 30, 1975

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16. Abstract (Limit: 200 words)

A reconnaissance was made of the Metula spill area to determine coastal morphological similarities between the affected area and future potential spill sites in New England and Alaska. Oil was still very much in evidence in the intertidal portions of the shoreline. The gravel sediments of the high beach face and the low-tide terrace were cemented by a mousse-oil mixture into layers several centimeters thick. A layer of mousse up to one centimeter thick remained on extensive areas of the tidal flats. In places, a dense blue-green algal mat was growing on the surface of the oil. The Straits dissect major Pleistocene glacial deposits, including terminal and ground moraines and terraced outwash plains. Inside the First Narrows the sediment type and beach morphology show a striking resemblance to the Pleistocene glaciated shoreline of southern New England and the present glacial shoreline of the south coast of Alaska. Tidal and wave conditions inside the narrows are laos analogous to southern New England. On the Atlantic side of the First Narrows, tidal range increases abruptly to approximately 10 m. at spring tide. At low tide, tidal flats over 5 km. in width are exposed. These tidal flats are very similar in appearance to tidal flats at Cook Inlet and in the Copper River delta region of southern Alaska.

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FINAL REPORT

TITLE:	Coastal Geomorphology and Sedimentation of the Metula Oil Spill Site in the Straits of Magellan
FOR:	National Science Foundation Ralph M. Perhac, Program Manager Advanced Environmental Research and Technology
SUBMITTED BY:	Miles O. Hayes Coastal Research Division Department of Geology University of South Carolina Columbia, S. C. 29208
COAUTHOR:	Erich R. Gundlach
DATE:	30 September, 1975

Frontispiece: View at low tide of the 7 km wide tidal flats at Banco Lomas, Straits of Magellan (Sta. 10; Fig. 2).

Objective

To conduct a reconnaissance study of the coastal geomorphology and sedimentation of the Metula Oil Spill site in order to determine whether the impact area is sufficiently similar to potential spill areas in the United States to warrant a detailed investigation of the physico-chemical effects of the spill.

Conclusions and Recommendations

1) Oil is still very much in evidence one year after the spill, especially on the shoreline of the south side of the First Narrows (Primera Angostura). Many different coastal environments have been affected, including beach face and low-tide terrace portions of the beach zone, tidal flats, marsh areas, and tidal channels. Therefore, a study of the effects of the spill on the different environments is still quite feasible.

2) The similarity between the shoreline environment of the Straits and certain parts of the United States is remarkable. The portion of shoreline west of the First Narrows bears a strong resemblance to the shoreline of New England, especially the Boston Harbor area, the south shore of Massachusetts, and the north shore of Long Island. This similarity probably results from the very similar geological histories of the two areas, as well as comparable wave and tide conditions. The beach morphology, sediment texture, and sediment composition are virtually the same for the two areas. East of the First Narrows, the tidal range increases sharply, reaching 30 ft during spring tides. Broad tidal flats are exposed at low tide (frontispiece). The morphology of these flats is very similar to the tidal flats of Cook Inlet and the Copper River Delta area of Alaska.

3) Climate. The climate of the impact area is that of a middle latitude steppe. Rainfall ranges between 250 mm and 350 mm per year. Mean monthly temperatures range between 1° and 11°C. Strong winds blow consistently from the west at velocities that commonly exceed 20 kts.

4) Oceanography. The tidal range varies greatly within the impact area, from almost 30 ft at the Atlantic entrance to the Straits to 12 ft at Bahia Felipe (inside the First Narrows). Mean tidal range drops to 3.8 ft at Punta Arenas, because of the buffering effect of the two narrows of the Straits. No wave data is available for the impact area, but no large waves were observed inside the Straits, even during strong winds.

5) Geomorphology. The eastern entrance to the Straits is flanked on either side by spectacular cuspate spits that are slowly migrating westward under the influence of Atlantic Ocean waves. Huge tidal flats up to 7 km in width occupy the south shore of the Straits to the east and west of the First Narrows. The Narrows are bordered by high cliffs in morainal till. The remainder of the shoreline is dominated by gravel beaches. The characteristic morphology of these beaches consists of one or more berms, a main beach face and a broad, flat low-tide terrace.

6) Sediments. Sediments of the beaches range in size from huge boulders to fine sand. Thirty-three beach and dune samples were analyzed for grain size. The grand means for the 33 samples were: mean size (M_z) = -1.21ϕ (2.15 mm; granule); skewness (Sk_I) = 0.10 (near symmetrical); sorting (σ_I) = 1.46ϕ (poorly sorted). A sample from the eastern edge of the Banco Lomas tidal flats was composed of 56% fine sand and 44% mud, whereas two samples from the western side of the flats were composed of 24% sand, 76% mud and 16% sand,

84% mud respectively. The beach gravel is composed predominantly of rock fragments. Point counts on ten thin sections of sand samples showed the sand to have a similar composition. Volcanic and metamorphic rock fragments make up 59% of the grains, whereas quartzose grains equal only 25% of the total.

7) We received excellent cooperation from the people of Chile, especially from the personnel at the Instituto de la Patagonia in Punta Arenas, ENAP personnel in Punta Arenas and Santiago, and Admiral Allen in Punta Arenas. We had no problems conducting our work and received every indication from many sources that future work on the spill would be welcomed by the scientists and government officials of Chile.

8) In conclusion, the rationale for U. S. involvement in a study of the Metula Oil Spill outlined by Perhac in the last paragraph of page 2 of his memorandum of 1 July, 1975, to Larry Tombaugh, Division Director, AENV, is completely justified in our opinion. Perhac's concluding statement was: "No such large spills as that in Chile have occurred in the United States, hence a study of the Chilean spill is desirable if we wish to gain information that such a calamity would provide." The field data that we gathered entirely supports this suggestion.

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ABSTRACT

On August 9, 1974, the Royal Dutch Shell supertanker VLCC *Metula* ran aground just west of the First Narrows of the Straits of Magellan and 51,000 tons of Saudi Arabian crude oil and 2,000 tons of Bunker C fuel oil were released into the waters of the Straits (Hann, 1974). Only the *Torrey Canyon* disaster spilled a greater quantity of oil.

A preliminary assessment made shortly after the spill (Hann, 1974) indicated that 40,000 tons of oil were deposited along 75 miles of shoreline, with the Tierra del Fuego side receiving the major amounts. The quantity of oil deposited on the beaches varied greatly along the coast, depending on wind, wave and tidal conditions and land configuration. Biological impact was reportedly severe (Hann, 1975).

A reconnaissance was made of the *Metula* spill area in August, 1975, to determine coastal morphological similarities between the affected area and future potential spill sites in New England and Alaska. Oil was still very much in evidence in the intertidal portions of the shoreline. The gravel sediments of the high beach face and the low-tide terrace were cemented by a mousse-oil mixture into layers several centimeters thick. A layer of mousse up to 1 cm thick remained on extensive areas of the tidal flats. In places, a dense blue-green algal mat was growing on the surface of the oil.

The Straits dissect major Pleistocene glacial deposits, including terminal and ground moraines and terraced outwash plains. Inside the First Narrows the sediment type and beach morphology show a striking resemblance to the Pleistocene glaciated shoreline of southern New England and the present glacial shoreline of the south coast of Alaska. Tidal and wave conditions inside the narrows are also analogous to southern New England. On the Atlantic side of the First Narrows, tidal range increases abruptly to approximately 10 m at spring tide. At low tide, tidal flats over 5 km in width are exposed. These tidal flats are very similar in appearance to tidal flats at Cook Inlet and in the Copper River delta region of southern Alaska.

To date, no in-depth studies have been carried out on the biological and physical impact of the spill. As long as the oil remains on the beaches and tidal flats, conditions seem ideal for an analogue study of the physico-chemical and biological effects of the spill. Information gained from such a study would be useful in planning environmental studies related to petroleum transport and terminals in the New England and Alaska areas.

INTRODUCTION

On 9 August, 1974, the Royal Dutch Shell supertanker VLCC Metula (206,000 dead weight tons; 328 m long) ran aground just west of the First Narrows of the Straits of Magellan at the southern tip of South America (Fig. 1). Forty-six days later it was refloated, but not before 51,000 tons of Saudi Arabian crude oil and 2000 tons of Bunker C fuel oil were released (Hann, 1975). Only the Torrey Canyon disaster released a greater quantity of oil (117,000 tons; Smith, 1968).

A preliminary assessment made shortly after the spill (Hann, 1974) estimated that 40,000 tons of oil were deposited along 75 miles of shoreline, with the Tierra del Fuego side receiving the major amounts. The quantity of oil on the beaches varied greatly along the coast, presumably as a function of the wind, wave and tidal conditions and land configuration. Biological impact was reportedly severe, affecting 600-2000 sea birds, intertidal mussel beds, marsh life, and nekton (Hann, 1974; 1975). However, a complete assessment was never made. Biologists at the Instituto de la Patagonia are continuing study on the biological impact of the spill with minimal financial support.

The primary purpose of this project was to conduct a reconnaissance study of the coastal geomorphology and sedimentation of the Metula Oil Spill site. The study was undertaken at the suggestion of Ralph M. Perhac, Program Manager of ANEV, National Science Foundation. In a memorandum to Larry W. Tombaugh dated 1 July, 1975, Perhac suggested that the Metula spill might provide a useful analogue for comparison with regions threatened with future spills in the United States, particularly the coasts of Alaska, New

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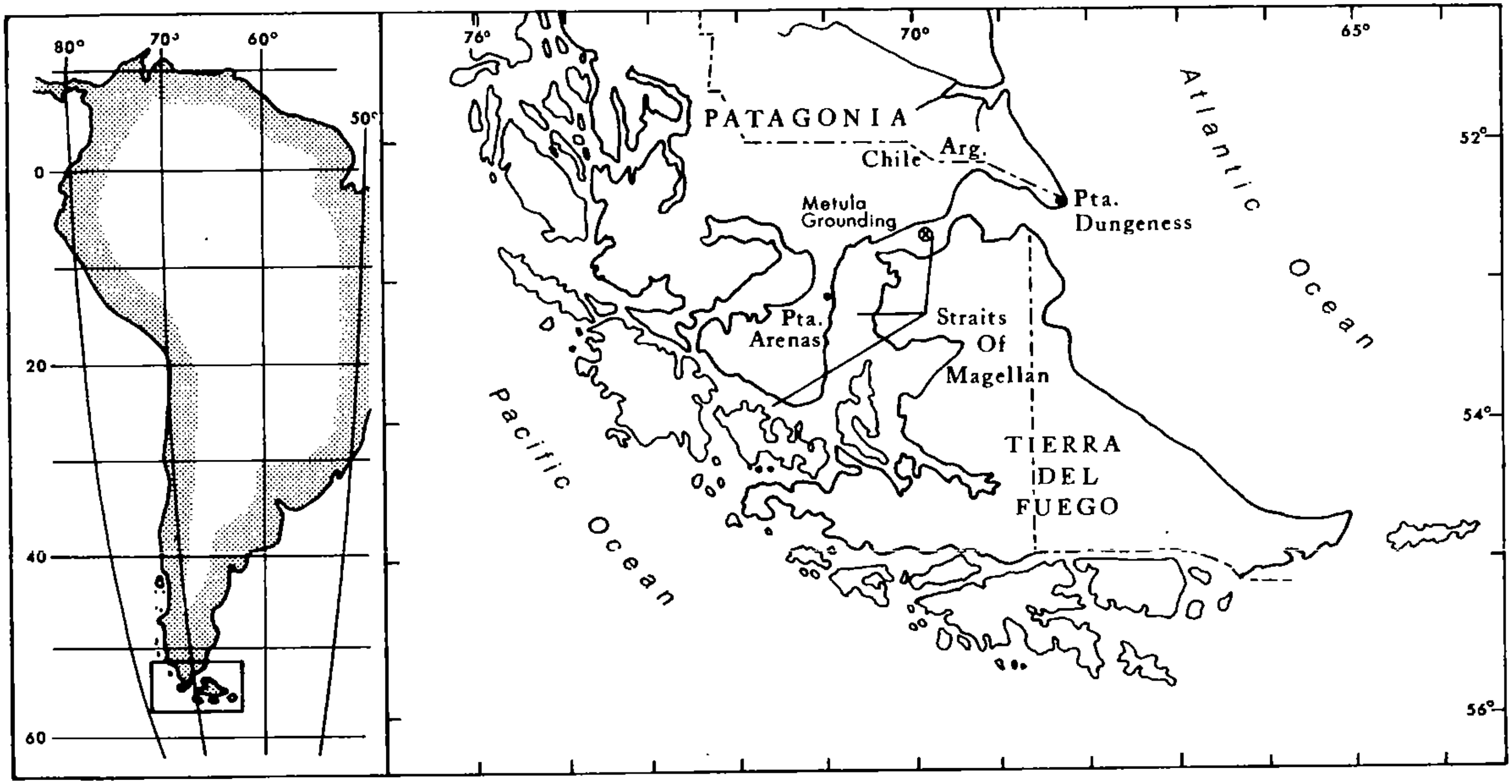
Figure 1. Location map.


80°
70°
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50°
0
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40
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76°
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65°
52°
54°
56°
PATAGONIA
Arg.
Chile
Atlantic
Ocean
Metula
Grounding
Pta.
Dungeness
Pta.
Arenas
Straits
Of
Magellan
Pacific
Ocean
TIERRA
DEL
FUEGO

England, and Puget Sound. Because he was unsure of the details of some of the geomorphological and sedimentological comparisons he made in his memorandum, Perhac asked that I make a brief reconnaissance study of the Metula site due to my previous research experience on the coasts of New England and Alaska. I was assisted in this study by Erich Gundlach, a Ph. D. candidate in the Department of Geology at the University of South Carolina, who returned last spring from a 15 month tour of duty in the Peace Corps in Valparaiso, Chile. His knowledge of the language and previous contacts with several universities and government agencies in Chile were invaluable assets to the work.

We visited the spill area between 12 and 20 August, 1975 (see Appendix I for timetable). The entire area was photographed from the air, using a chartered Cessna 172 fixed-wing aircraft. Twelve stations were visited on the ground in order to measure beach profiles and collect sediment samples. Seven additional stations were visited and photographed. Approximately 2000 photographs were taken and 50 sediment and oil samples were collected (see location of stations on Fig. 2).

ACKNOWLEDGMENTS

Special thanks are extended to the personnel of the Instituto de la Patagonia, whose help and advice were very beneficial during all phases of the field study (see Appendix I). Sr. Mateo Martenic, Director of the Institute, was especially helpful and encouraging to us. Geographer Enrique Zamora and secretary Rosa Reyes Scott assisted in the field work. Sr. Zamora's

Figure 2. Locations of stations visited during field study. Beach profiles were measured and sediment samples were collected at all the numbered stations, except tidal flat stations 9 and 10, where only sediment samples were collected. Letters indicate stations visited for photography only. See Appendix I for timetable of field work.

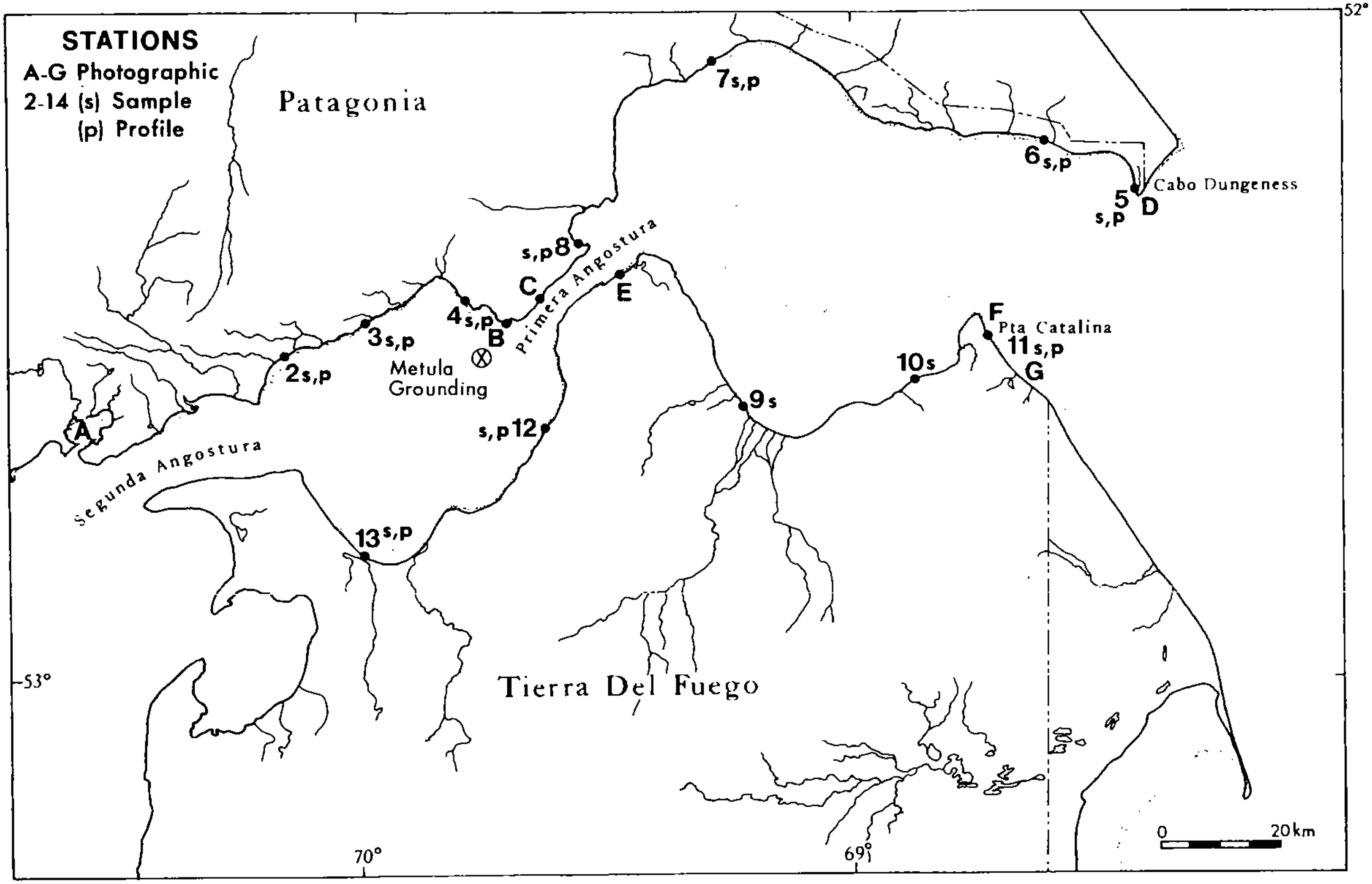
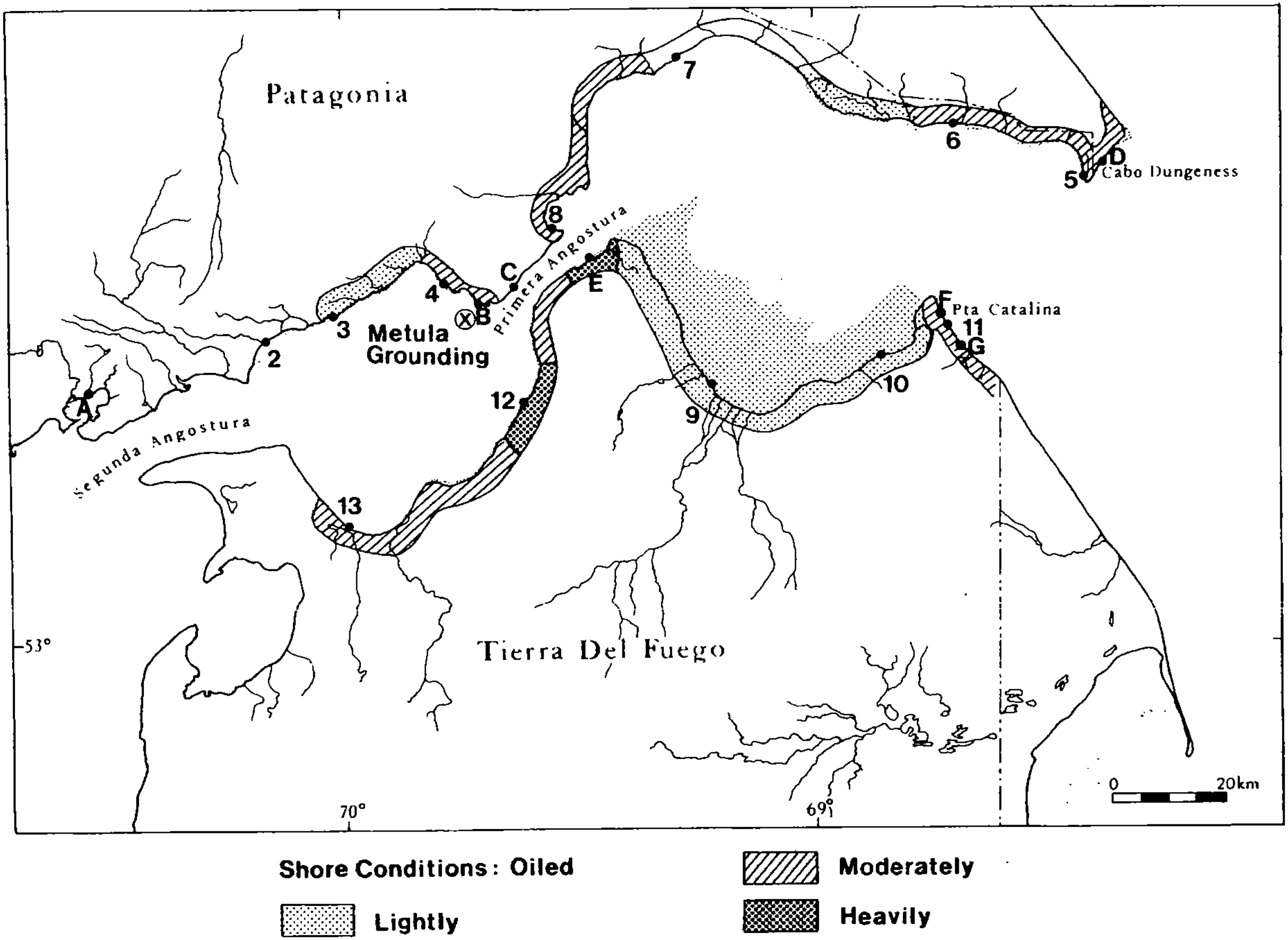

STATIONS
A-G Photographic
2-14 (s) Sample
(p) Profile
Patagonia
Tierra Del Fuego
Primera Angostura
Segunda Angostura
Cabo Dungeness
Pta Catalina
Metula Grounding
A
B
C
D
E
F
G
2s,p
3s,p
4s,p
5 s,p
6s,p
7s,p
s,p8
9s
10s
11s,p
s,p12
13s,p
0
20km
52°
53°
70°
69°

Figure 3. Distribution of *Metula* oil on the shoreline of the Straits of Magellan in August, 1975.


Patagonia
Tierra Del Fuego
Metula Grounding
Primera Angostura
Segunda Angostura
Cabo Dungeness
Pta Catalina
A
B
C
D
E
F
G
2
3
4
5
6
7
8
9
10
11
12
13
53°
70°
69°
0
20km
Shore Conditions : Oiled
Lightly
Moderately
Heavily

knowledge of the geomorphology of the area was extremely helpful.

Many Chilean organizations provided useful scientific and logistical information. Vertical aerial photographs of the study area made available to us by ENAP personnel in Punta Arenas proved to be one of our best sources of information. Special thanks are extended to Srs. Mario Mertens, Director of Operations, and Pietro Palini, Director of Engineering Operations, for providing the photographs and other information.

Other organizations and people who assisted us during our stay in Chile are listed in Appendix I.

Completion of the final report would not have been possible without the able and generous assistance of Jane Zenger, who ran the sediment analyses, and Ian Fisher, Anne Blount, Stephen Zenger, and Dorothy Attaway, who helped with the data analysis. The assistance of Carol Smith, Anne Heckel, Leita Hulmes, and Claudia Cain is also gratefully acknowledged.

OIL CONDITIONS

Oil from the <u>Metula</u> spill was present in different amounts at all the stations visited, except stations A, C, 2, and 7 (Fig. 2). Some degree of oil saturation existed along 247 km of shoreline. Figure 3 shows the areal distribution of the oil, and Table 1 gives a brief description of the oil conditions at each station.

The heaviest oil accumulation was found on the south side of the First Narrows at Punta Espora (Sta. E; Fig. 2). The aerial view of Punta Espora given in Figure 4A shows the widespread occurrence of oil over the intertidal

Table 1. Oil Conditions of the Metula Oil Spill Site in August 1975

Station*	Oil Conditions	Remarks
A	no oil	--
2	no oil	--
3	light	Minor globules and tar balls mixed with gravel and other debris of spring-high-tide swash line.
4	moderate	4 m wide zone of accumulation of oil-stained sea weed, gravel and other debris at the spring-high-tide swash line (Fig. 9).
B	moderate	Similar to station 4 but not examined in detail.
C	no oil (?)	Visited at high tide. Possibly some oil on low-tide terrace.
8	moderate	Heavy oil zones cementing gravel at spring-high-tide swash line. Thin oil layer on marsh. Apparently, broad zones of oil accumulations on tidal flats (seen from air only).
7	no oil	--
6	moderate	Extensive stained pebble zones at high tide lines. Heavy tar coatings on boulders and gravel on low-tide terrace (Fig. 10B).
5	moderate	Oil-cemented conglomerate 10 cm thick at spring-high-tide line (Fig. 11A). Tar balls in debris lines.
D	moderate	Similar to station 5, but not quite as much oil.
F, 11, G	moderate	Same as 5 and D.
10	light	In places, 1 to 2 cm thick surficial coverage of high tidal flats. Apparently, extensive oil covering on lower tidal flats (seen from air only).
9	light	Light coating on marsh surface. Apparently extensive oil coating on lower tidal flats and high marsh (seen from air only).

Table 1. (Cont'd.)

Station*	Oil Conditions	Remarks
E	heavy; heaviest of any station visited.	Heavy tar-like coating of oil on marsh surface and on estuarine tidal flats (Fig. 4A). Cemented conglomerate zones on beach face and low-tide terraces (Figs. 5A, B). Algal layers growing on oil in some areas (Figs. 6A, 6B, and 7A).
12	heavy	Heavy tar-like coatings on gravel of upper beach face and low-tide terrace (Fig. 7B).
13	moderate	Oil layers under algae in tidal flat areas. Coatings on debris at high tide lines.

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*see Figure 2 for location.

Figure 4. A. View of Punta Espora area looking west through the First Narrows. Photograph was taken at low tide on 18 August, 1975. Individual points of interest are:

1) Heavy oil accumulation on marsh and tidal flat areas of small estuary in lower left hand portion of photograph.
2) Oil accumulation on high-tide beach face which cements gravel into a conglomerate-like mass.
3) Heavy oil accumulation on low-tide terrace.
4) Location of ground views shown in Figure 4.
5) Algal mat growing on top of Metula oil (see Figs. 5A and B and 6A).

B. Low-tide view of an area in southern Massachusetts that is very similar to the Punta Espora area (above) with respect to its geomorphology, sediments and oceanographic conditions. The south jetty of the Cape Cod Canal is visible at the upper left.

A

B

zone. Figure 5 shows an oil-saturated conglomeratic zone in the upper beach face area. An intertidal mud flat covered with blue-green algae exists between the beach face and the outer gravel bar (Fig. 4A). The algae is growing on top of a 1 cm thick layer of Metula oil (Figs. 6B and 7A).

Heavy oil accumulation occurs for 40 km along the shoreline to the southwest of Punta Espora. An aerial photograph taken near station 12 (Fig. 7B) shows heavy oil at the upper beach face area and on the low-tide terrace.[1]

Oil is also found on the north shore of the Straits, but not generally in as great abundance as on the south shore. The area in the vicinity of station 4 is shown on the aerial photograph in Figure 9. There the oil occurs as a 4 m wide zone of accumulation of oil stained seaweed, gravel and other debris at the spring-high-tide swash line. The two ground views of station 6 given in Figure 10 shows oil coatings on huge gravel and boulders on the low-tide terrace.

At Cabo Dungeness (Sta. 5; Fig. 2), oil has cemented a 5 m thick conglomerate unit at the high-tide line (Fig. 11A). Badly oiled dead birds were also seen at that locality (Fig. 11B).

In summary, oil is still abundantly present in the intertidal areas of the Metula Oil Spill site one year after the spill. Two hundred forty-seven kilometers of shoreline are affected to varying degrees. Oil is especially heavy on the south side of the First Narrows. Therefore, it is still feasible to do a follow-up study on the spill.

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[1] The terms beach face and low-tide terrace are defined by the diagrammatic sketch in Figure 8.

Figure 5. A. Oil accumulation on beach face at Punta Espora (Station E, Fig. 2; see aerial view in Fig. 4A). Arrow points to location of photograph B.

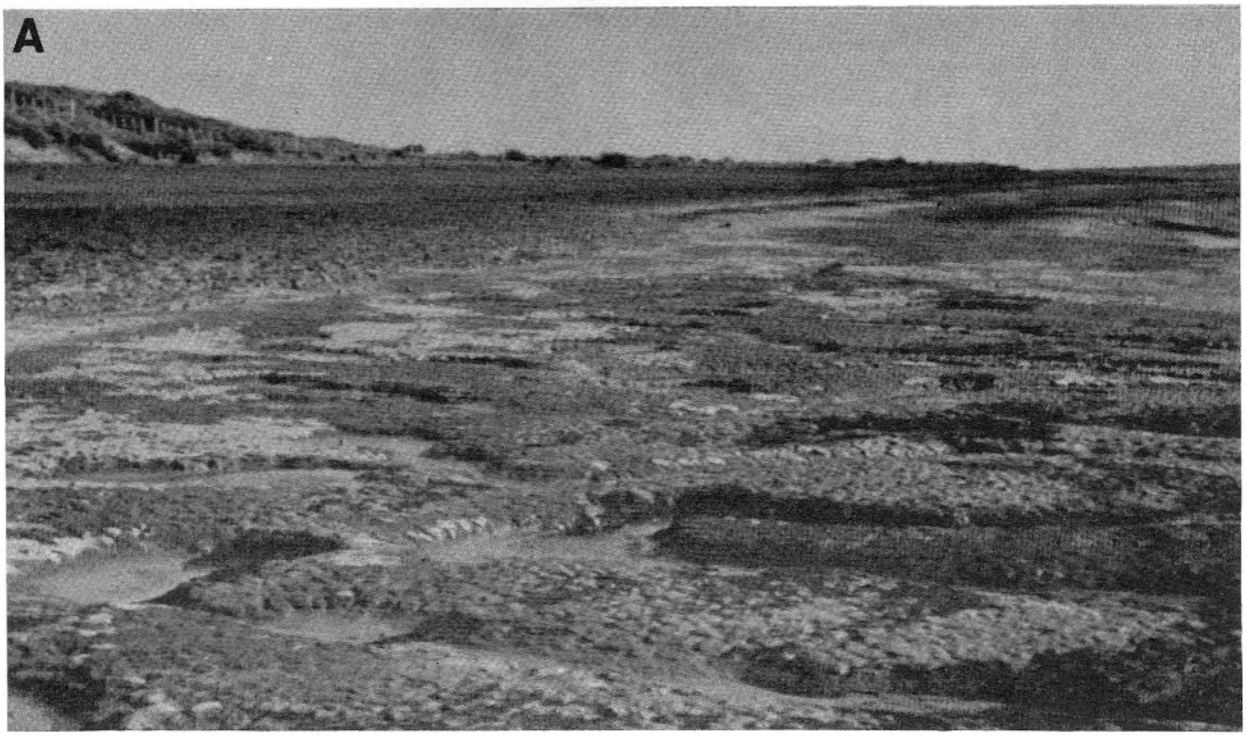
B. Close-up of oil accumulation shown in A. Surface of gravel is heavily coated with oil. Light gray material at bottom of photograph is clay substrate on which gravel was deposited. Orange brown substance is liquid petroleum that seeped out of gravel after trench was cut. Scale is 30 cm.


A


B

Figure 6. A. Intertidal flat at Punta Espora (Station E, Fig. 2; see aerial view in Fig. 4A). Note algae growing on surface of flat.

B. Trench cut in tidal flat shown in A. Greenish material on surface is blue-green algal mat which is growing on a layer of _Metula_ oil (orange brown substance). Scale is 30 cm.



B

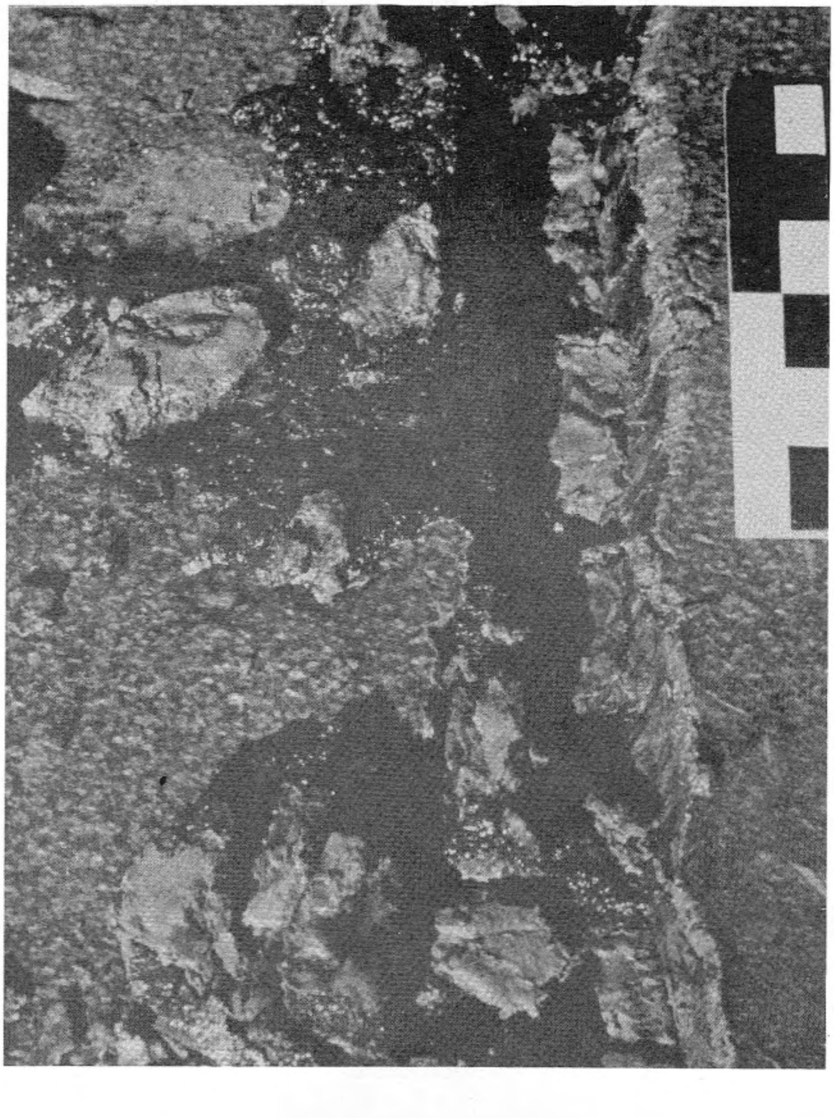
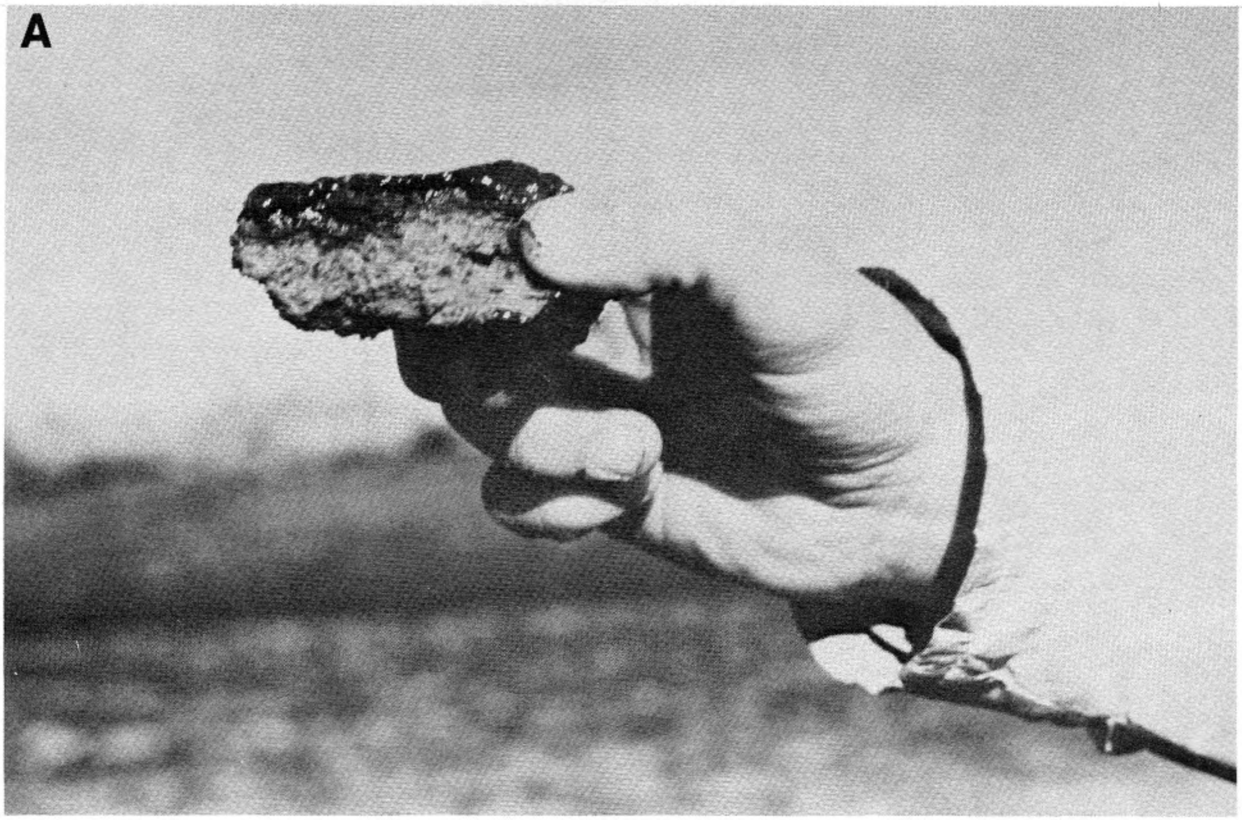


Figure 7. A. Oil layer upon which the algal mat shown in Figures 6A and B is growing.

B. Shoreline in vicinity of station 12 (Fig. 2). View looks southwest. Photograph taken on 18 August, 1975. Arrow 1 points to oil accumulation on upper beach face, and arrow 2 points to oil on low-tide terrace.


A


B
1
2

Figure 8. Typical beach profile for the Metula impact site. Letters indicate sampling localities, which are located between the upper limit of normal high waves and the low water line. B is in the center of the sampling zone, and stations A and C are located at the midpoint of the upper and lower halves of the sampling zone. D is usually a dune sample. A core sample 15 cm in length is taken at each station.

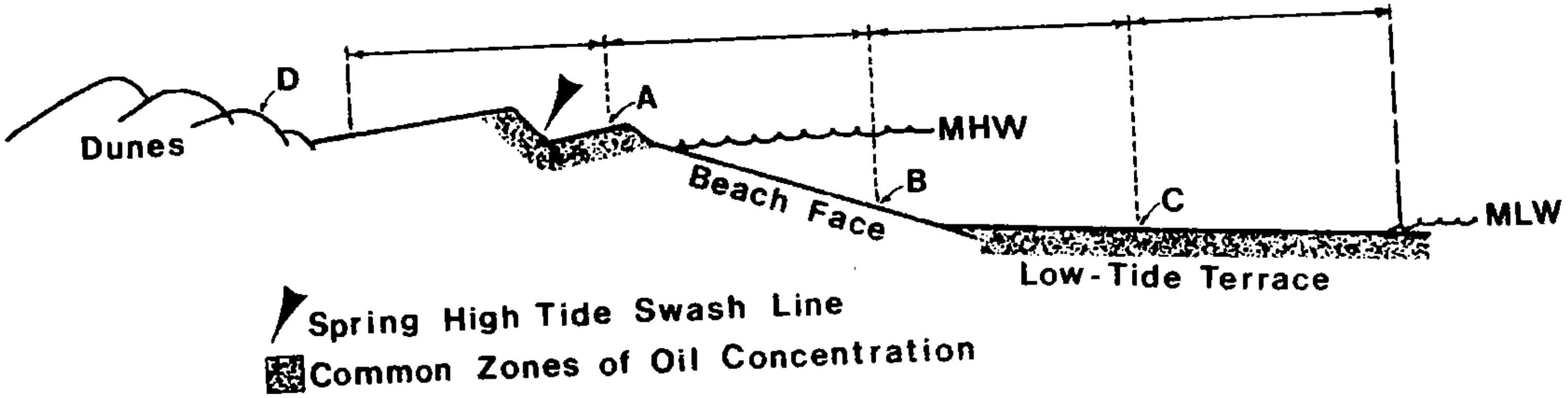

D
Dunes
A
MHW
B
Beach Face
C
MLW
Low-Tide Terrace
Spring High Tide Swash Line
Common Zones of Oil Concentration

Figure 9. Shoreline in vicinity of Station 4 (Fig. 2). Photograph taken on 18 August, 1975; view looks north. Arrow points to zone of accumulation of oil-stained debris at the high-tide swash line. Note plumes of sediment off headlands that are being transported to the north by flood-tidal currents.

Figure 10. A. Intertidal zone at Station 6 (Fig. 2).
Arrow points to location of photograph B.
B. Metula oil coating (arrows) on boulders on low-tide terrace. Scale is 30 cm. Photograph taken on 16 August, 1975.

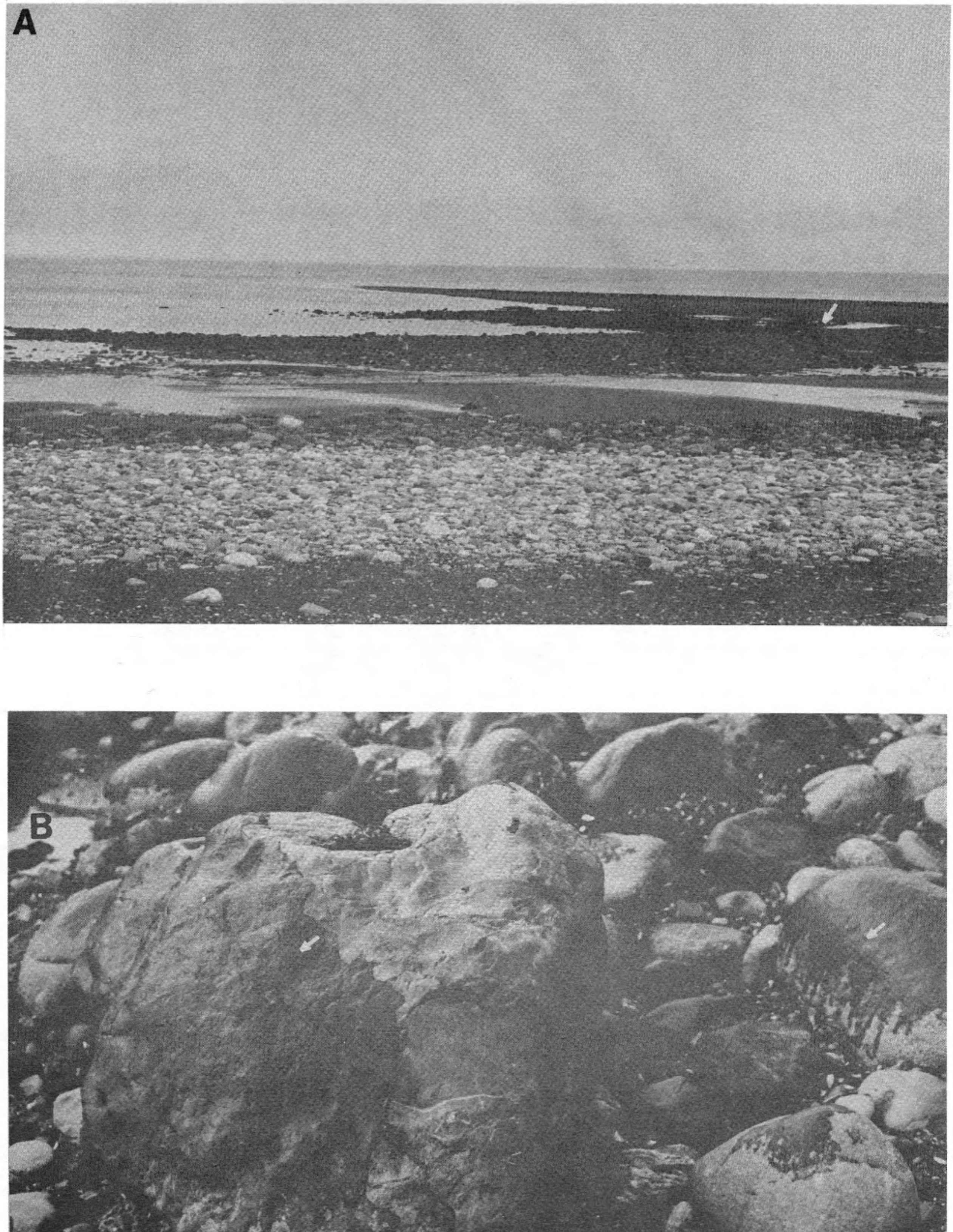
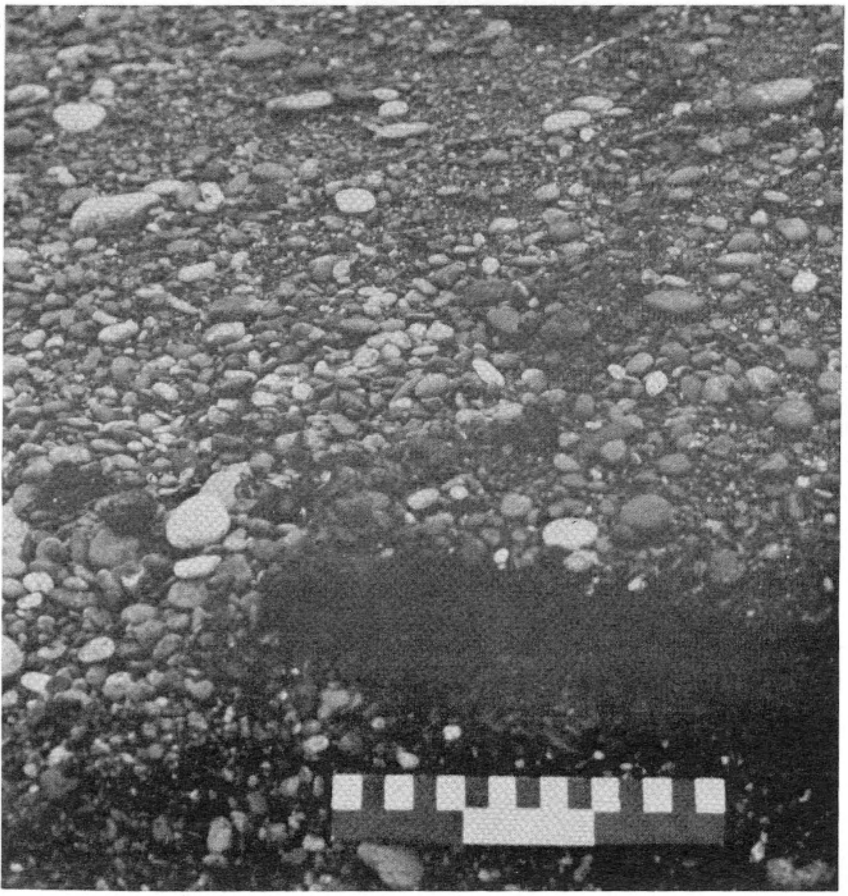
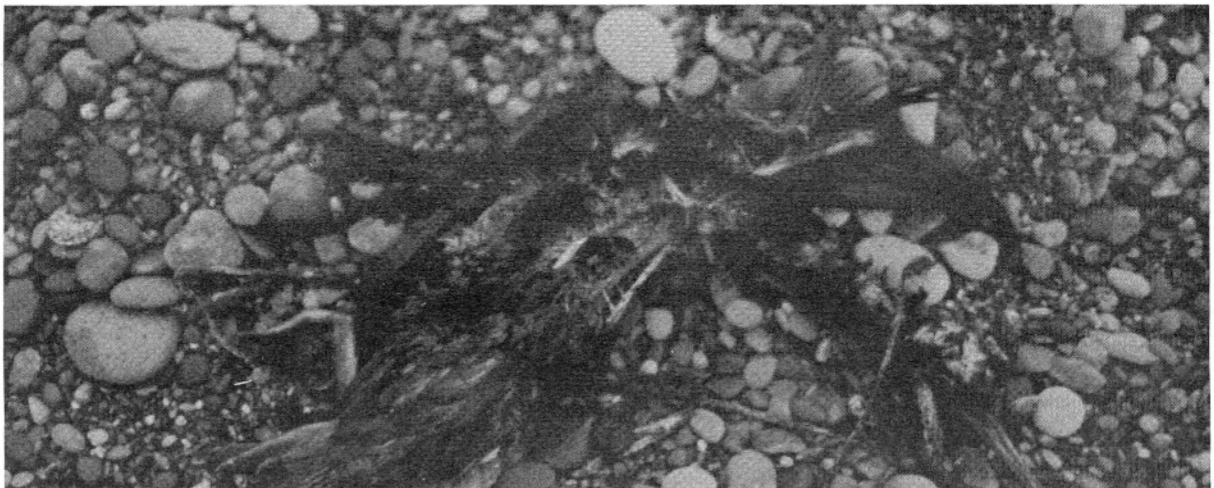

A
B

Figure 11. A. Oil cemented unit at high tide line at station 5. Scale is 30 cm.
B. Cormorant coated with oil at station 5.

A



B



GEOLOGICAL SETTING

Pleistocene glaciation has played a principal role in shaping the present coastal geomorphology of the Straits of Magellan. One of the flow centerlines of the Pleistocene glaciers is located along the main axis of of the Straits (Fig. 12). For example, the two narrows in the Straits cut across the end moraines of the Goti and Final glaciation periods (Fig. 13). According to Raedeke (1974), the glacial ice that moved through the area now occupied by the Straits accumulated in the Cordillera near the Pacific coast. The ice descended in broad piedmont tongues, the first tongue reaching all the way to the present Atlantic coast and the last stopping at the Segunda Angostura (Second Narrows). The landforms developed at the margin of the ice during the last advance are still clearly preserved in the topography of the peninsula south of the Second Narrows. Sheep now graze on a braided topography left by the outwash streams that flowed toward the northeast away from the front of the glacier.

In addition to topographical controls, the Pleistocene glaciation has been important as a contributer of sediments to the coastal environments of the Straits. Many kilometers of the Straits are lined with 20-40 m erosional cliffs of till and fluvio-glacial deposits that are actively contributing sediments to the longshore sediment transport system. A typical erosional scarp located on the north side of the Straits near station 6 is shown in Figure 14A. A close-up photograph of the till in that area is given in Figure 14B.

Caldenius (1932) published the classic work on the glaciation of this

Figure 12. Areas of ice accumulation and generalized ice movement during the Pleistocene at the southern tip of South America (after Raedeke, 1974).

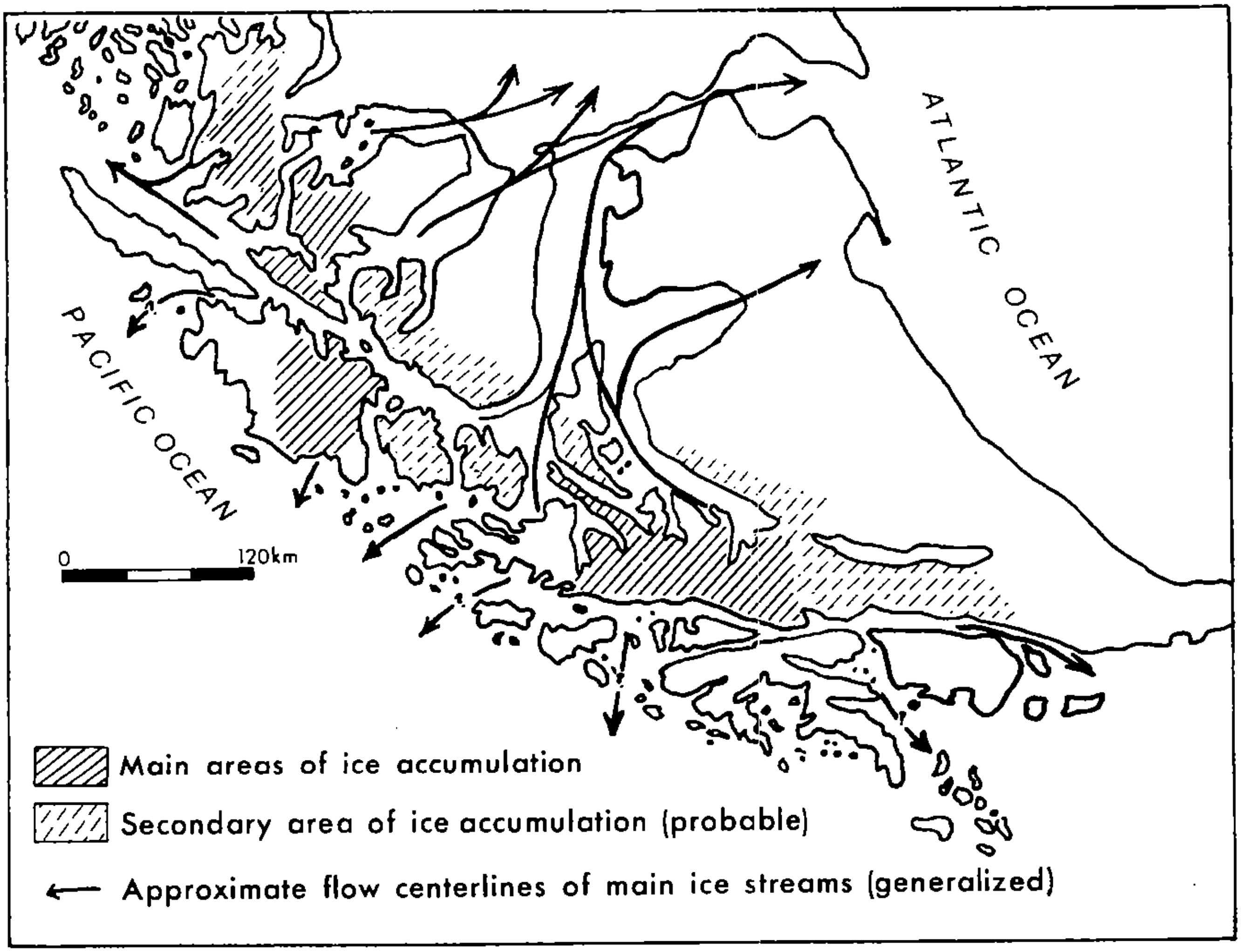

ATLANTIC OCEAN
PACIFIC OCEAN
0
120km
▨ Main areas of ice accumulation
▨ Secondary area of ice accumulation (probable)
← Approximate flow centerlines of main ice streams (generalized)

Figure 13. Occurrence of glacial sediments deposited during the four Pleistocene glaciations in the Straits of Magellan region. Note the correlation of the location of the two narrows with the limits (end moraines) of the last two glacial advances. Slightly modified after Caldenius (1932), Marangunic (1974), and Raedeke (1974).

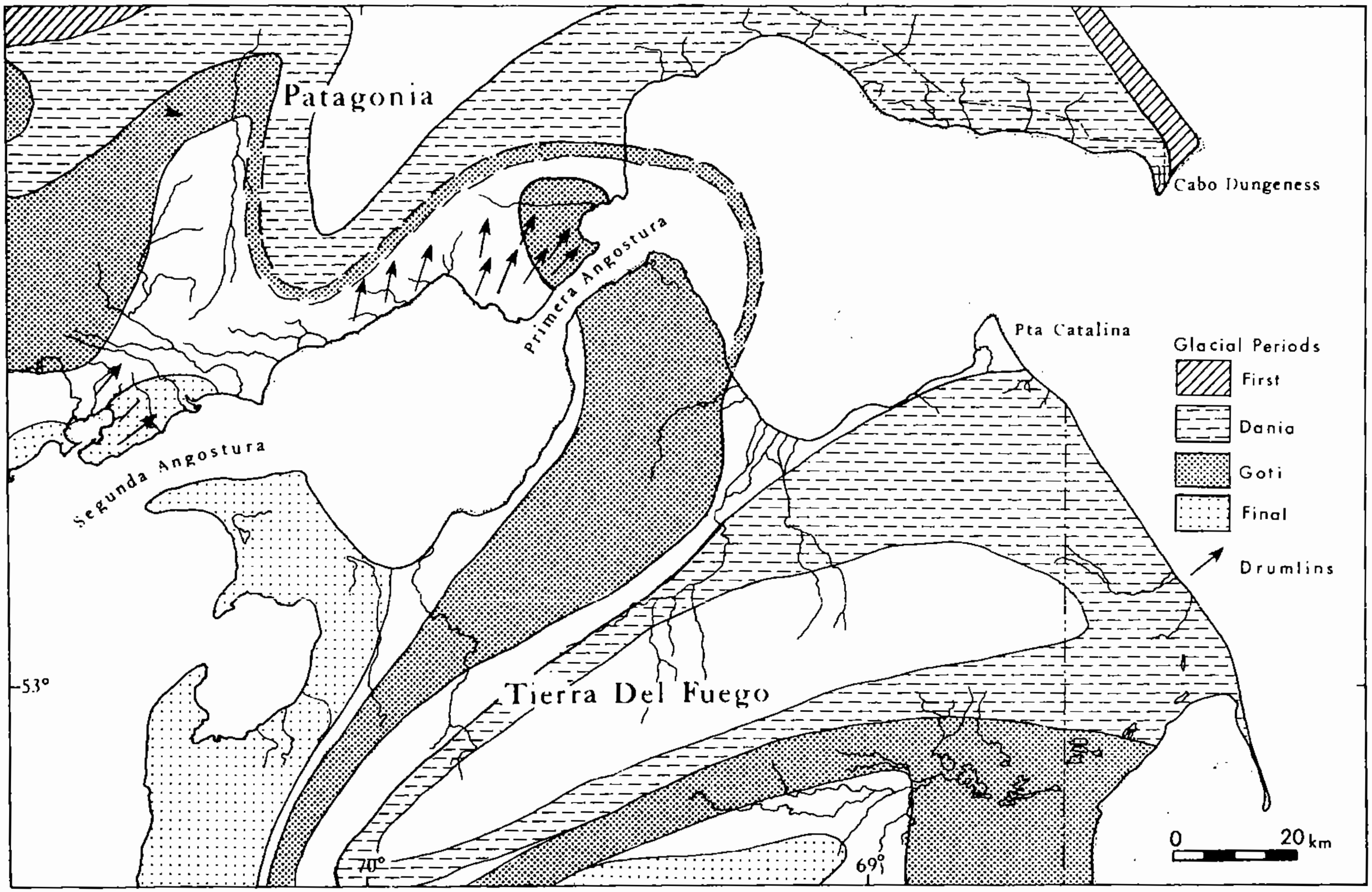
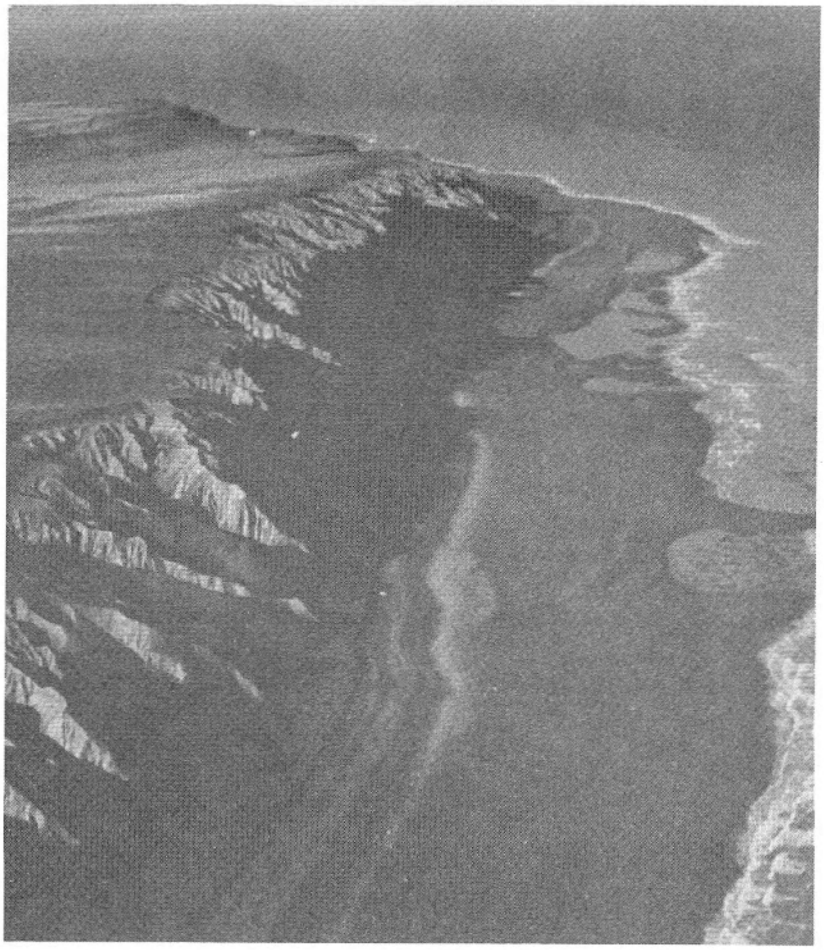

Patagonia
Cabo Dungeness
Primera Angostura
Pta Catalina
Segunda Angostura
Tierra Del Fuego
-53°
70°
69°
Glacial Periods
First
Dania
Goti
Final
Drumlins
0
20 km

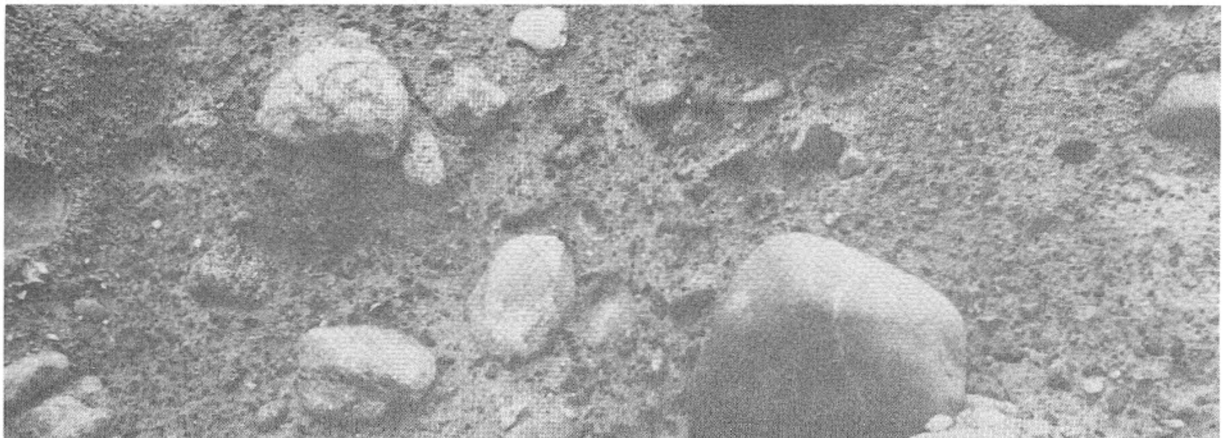
Figure 14. A. Low-tide view of cliffs in the vicinity of station 6 taken on 18 August, 1975. Note coarse material on low-tide terrace, which is essentially a wave cut platform on the Pleistocene deposits.

B. Till exposure in wave cut cliff near station 6. Scale is 30 cm.

A



B



region. Marangunic (1974) presented details of the distribution of glacial deposits on the north side of the Straits. Auer (1956, 1958) discussed regional aspects of the Pleistocene sediments and glaciation of the entire Patagonia-Tierra del Fuego area.

The whole of the eastern half of the Straits is underlain by Tertiary sedimentary rocks (Raedeke, 1974). Chile's national oil company (ENAP) has a major oil field on both sides of the Straits at the First Narrows. Fires from these wells dot the landscape of the Patagonian-Tierra del Fuego steppe. Offshore drilling in the Straits is being contemplated for the near future, according to ENAP officials in Punta Arenas and Santiago.

CLIMATE

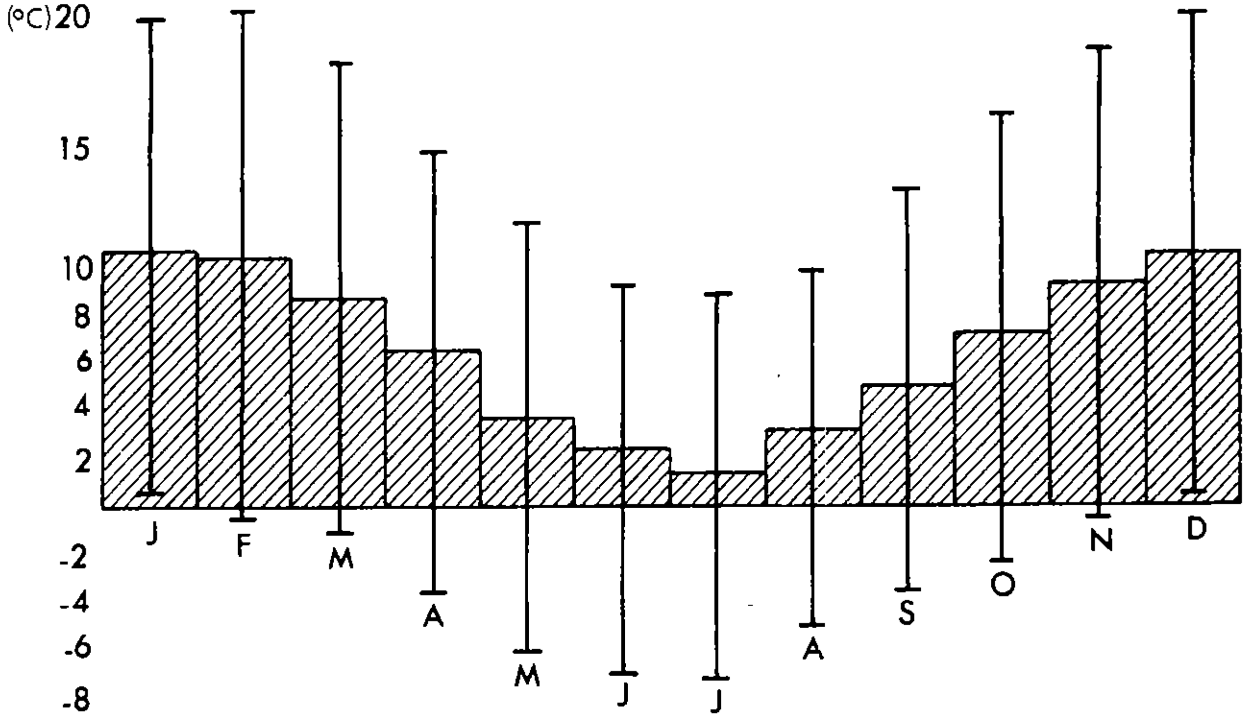
The Metula Oil Spill site is classified as a modified middle latitude steppe (BSR-SMIK) which is an area having 10 to 30 inches (250-500 mm) of rainfall per year with cold winters, by the Köppen classification. However, the temperature in this region is modified by the surrounding water masses, and mean monthly winter temperatures never go below $0^{o}C$ (Fig. 15).

The most impressive single climatic factor for a visitor to the area is the strong winds. They are highly unidirectional out of the west, averaging 13 knots (Fig. 15). During 188 days of an average year winds are stronger than 20 kts, and twelve days out of a year they are stronger than 50 kts. These winds have made a great impact on the geomorphology of the area.

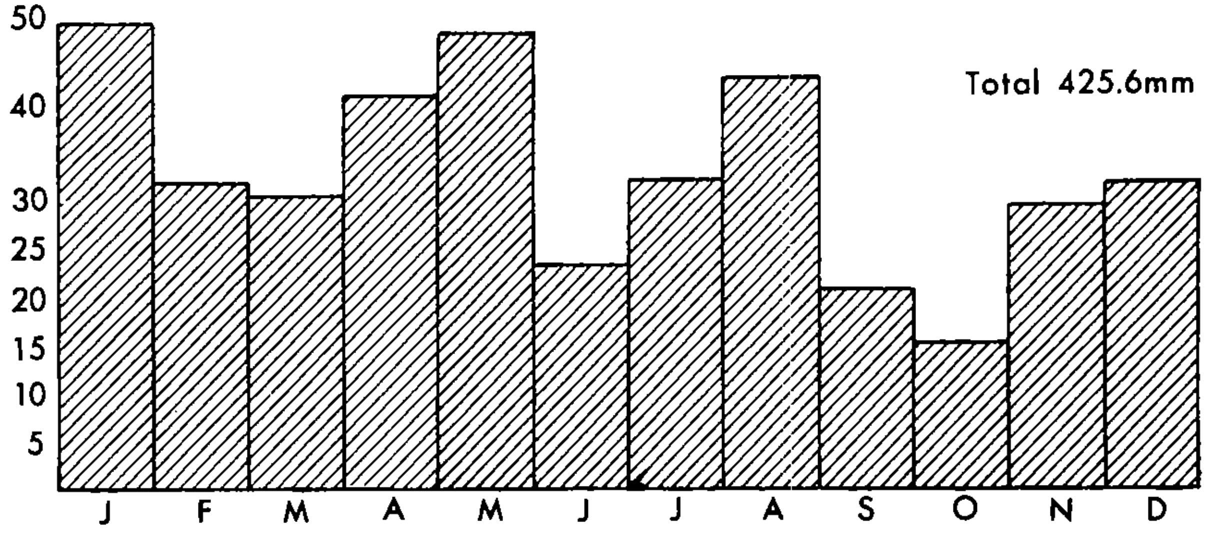
Rainfall varies from 250 mm to 350 mm within the study area (Fig. 17). Rainfall data for the Punta Arenas area, which has considerably more rainfall

Figure 15. Mean monthly temperature and rainfall data for Punta Arenas (after Ojeda, 1966).

Mean Monthly Temperatures With Monthly Mean Maximum And Minimum 1952-1961 (OJEDA 1966)



Punta Arenas

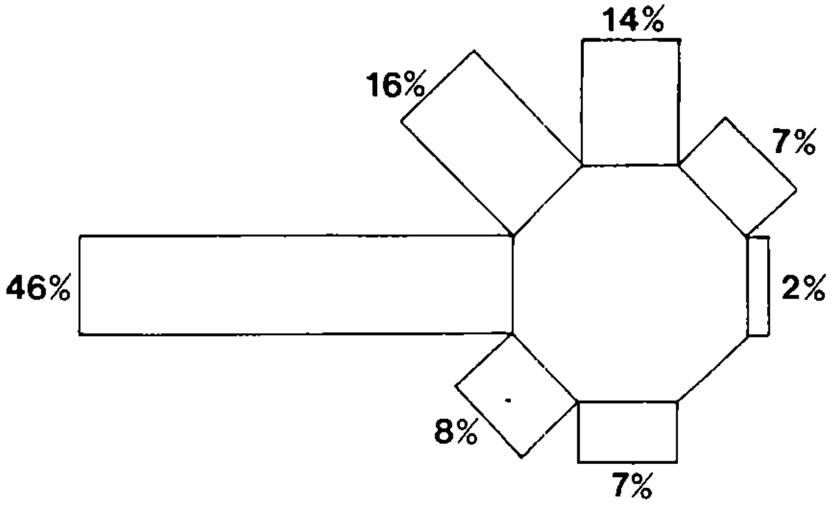


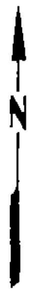
Mean Monthly Rainfall (mm) 1952-1961 (OJEDA 1966)

Figure 16. Wind conditions at Punta Arenas, Chile. Based on 9 years data (1952-61), mean monthly values (Ojeda, 1966).

Punta Arenas, Chile

Annual Wind Rose





Storm Wind Rose

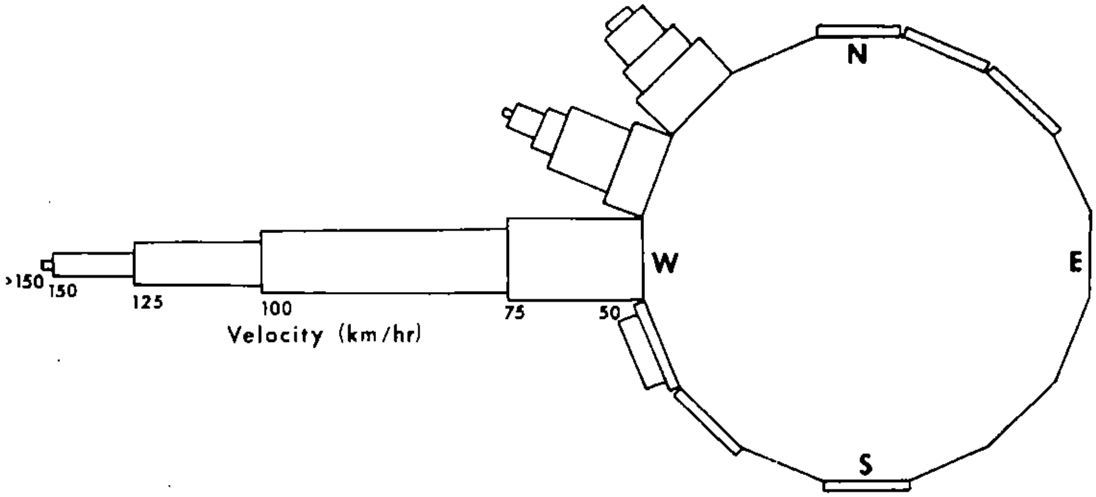
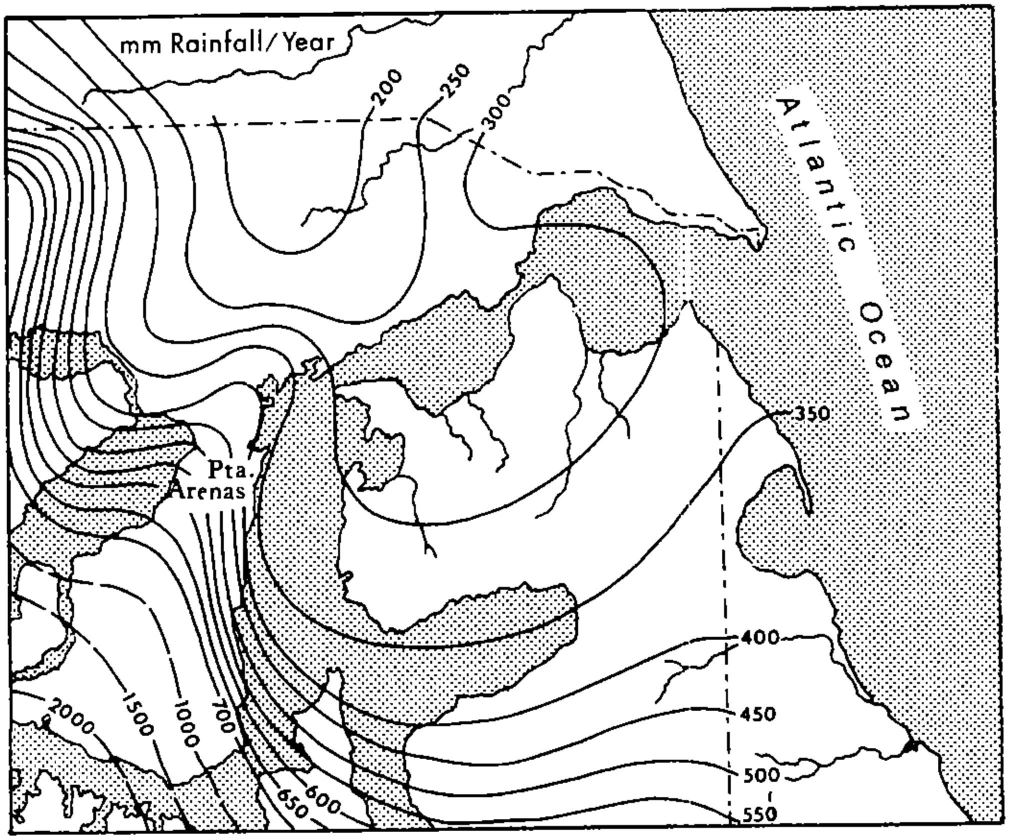


Figure 17. Contours of mean annual rainfall per year (mm) for the Straits of Magellan area (slightly modified after Jerez and Arancibia, 1972).


mm Rainfall/Year
200
250
300
Atlantic Ocean
350
Pta. Arenas
400
450
500
550
2000
1500
1000
700
650
600

than the eastern portion of the Straits (mean annual ppt = 425.6 mm; Ojeda, 1966), are given in Figure 15. Values are generally lower from September through December, with maxima occurring in January, April, May and August (Fig. 18).

No temperature data is available for the *Metula* impact area, but the temperature data published by Ojeda (1966; Fig. 15) for Punta Arenas should be analogous. Mean summer temperatures in Punta Arenas range between 8° and 11°C, and mean winter temperatures range between 1° and 4°C; however, mean monthly maxima and minima are commonly far different than the mean values (Fig. 15).

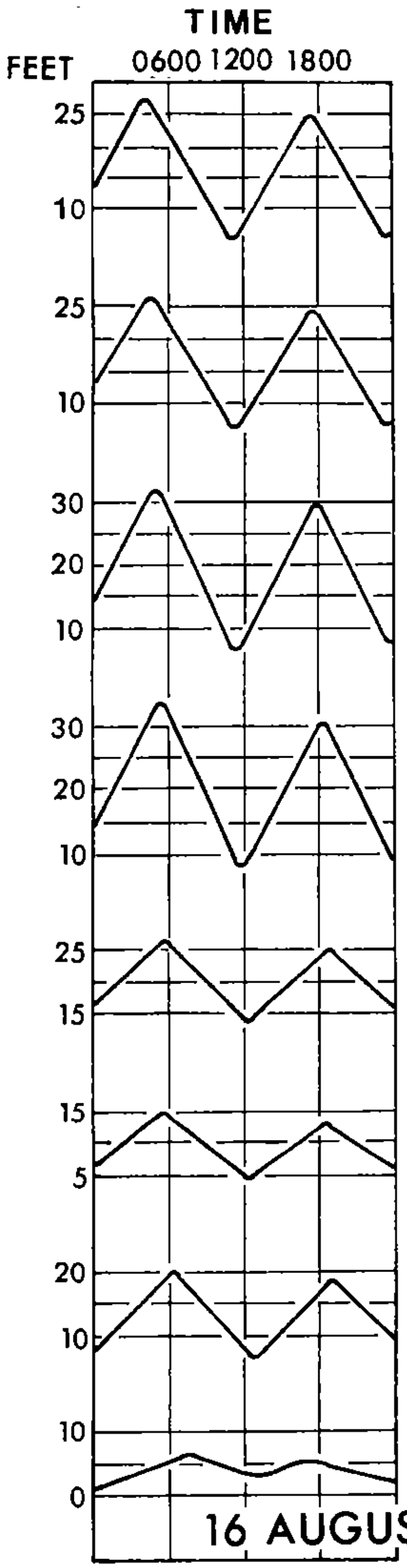
OCEANOGRAPHY

Tides

The tides of the Metula Oil Spill site are semi-diurnal, whereas they are mixed to the west of the Second Narrows (Fig. 18). The tidal range varies greatly within the impact area, from a mean of 28 ft (8.6 m) at Banco Dirección to 12 ft (3.7 m) at Bahia Felipe. Punta Arenas, which is located west of the impact area, has a range of only 3.8 ft (1.2 m). The areal distribution of tidal range is given in Figure 19. The two narrows act as tidal buffers, generally dampening the tidal effects of the Atlantic. Ranges greater than 20 ft (6.2 m) occur on the Atlantic side of the First Narrows but then drop off sharply to the west. Tidal amplitude is increased approximately 20% during spring tide (Fig. 20).

Tidal currents in the Straits are incredibly strong. According to three

Figure 18. Tides of the study area on 16 August, 1975. Mean and spring tidal ranges are also given. Stations are located on Figure 19. These are predicted, not measured, tides. Data from 1975 Tide Tables (U. S. Department of Commerce).



16 AUGUST 1975

	Time High	Time Low	Range Mean	Range Spring
			feet	
Punta Dungeness	0438 1728	1115 2325	23.8	29.8
Punta Catalina	0445 1733	1122 2332	22.8	28.5
Bahia Posesión	0512 1802	1147 2357	27.5	33.4
Banco Dirección	0522 1812	1159	28.0	34.0
Bahia Santiago	0554 1844	1235	14.0	17.8
Bahia Felipe	0555 1845	1236	12.0	15.1
Segunda Angostura	0632 1922	0010 1317	16.0	20.3
Punta Arenas	0752 1726	0019 1357	3.8	4.9

Figure 19. Areal distribution of tidal range in the eastern portion of the Straits of Magellan. First number at each station is mean tidal range and second number is spring tidal range. Data from 1975 Tide Tables (U. S. Department of Commerce).

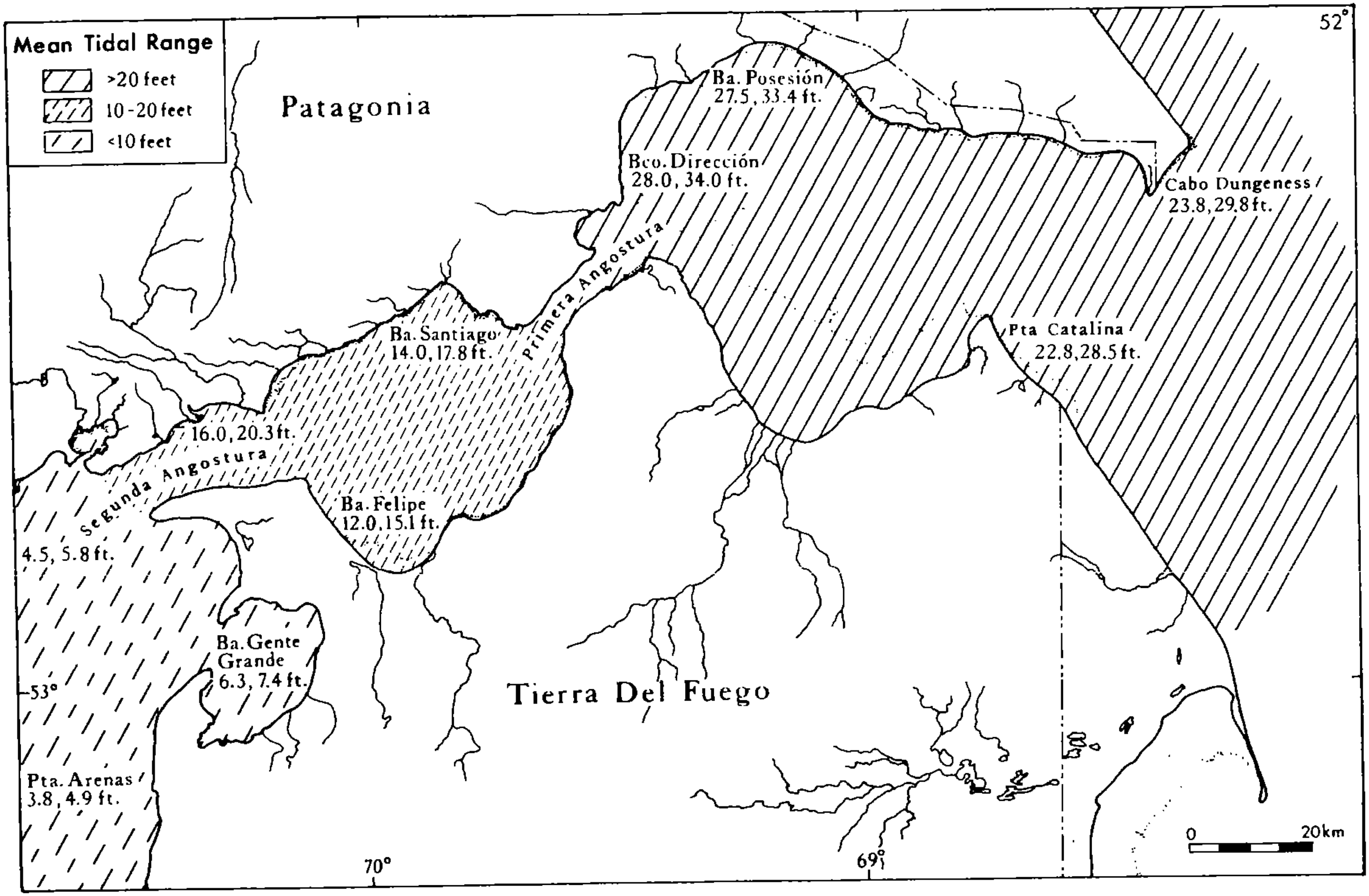
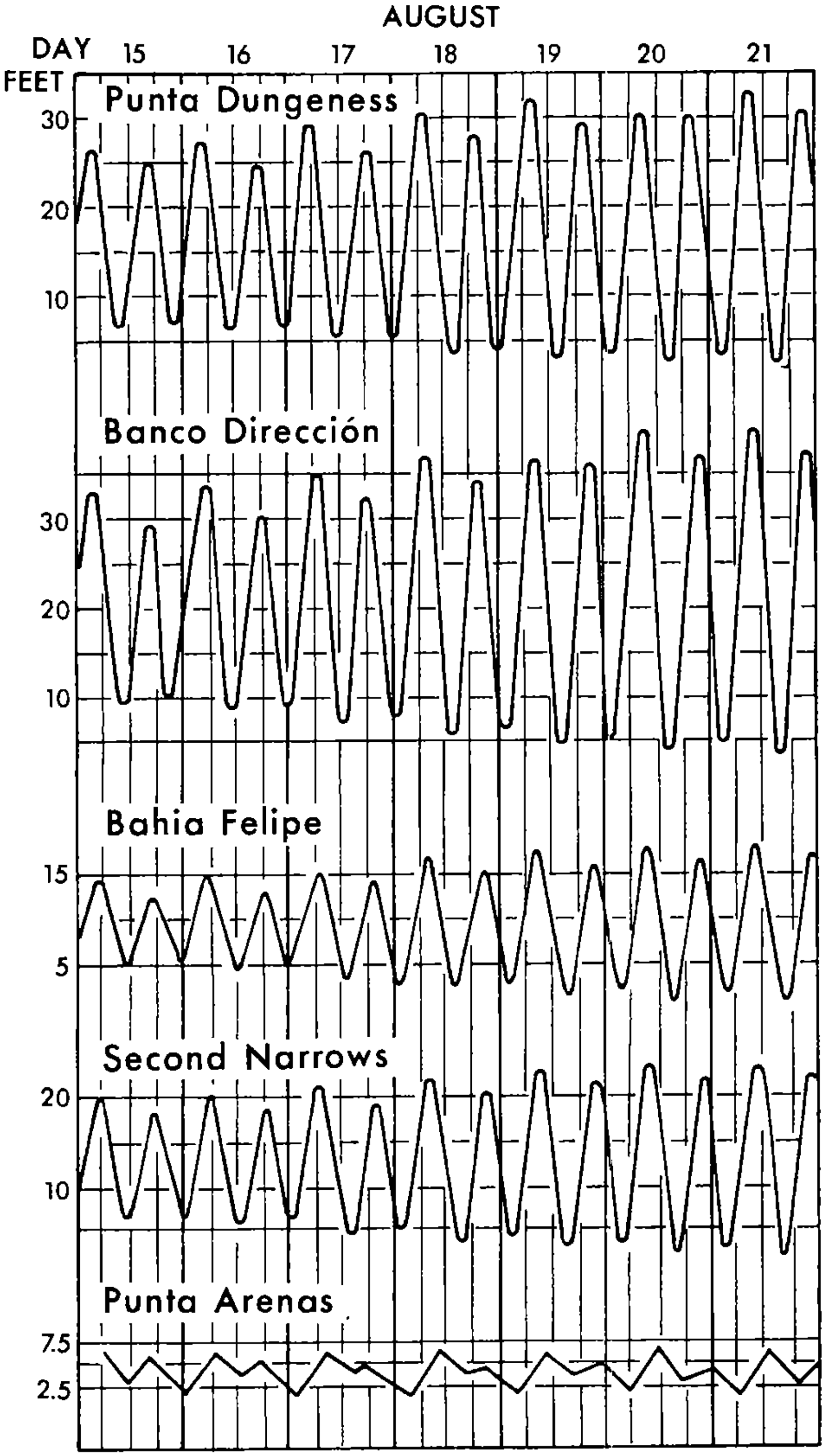

Mean Tidal Range
▨ >20 feet
▨ 10-20 feet
▨ <10 feet
Patagonia
Ba. Posesión
27.5, 33.4 ft.
Bco. Dirección
28.0, 34.0 ft.
Cabo Dungeness
23.8, 29.8 ft.
Primera Angostura
Ba. Santiago
14.0, 17.8 ft.
Pta Catalina
22.8, 28.5 ft.
16.0, 20.3 ft.
Segunda Angostura
Ba. Felipe
12.0, 15.1 ft.
4.5, 5.8 ft.
Ba. Gente Grande
6.3, 7.4 ft.
Tierra Del Fuego
Pta. Arenas
3.8, 4.9 ft.
52°
53°
70°
69°
0
20km

Figure 20. Tidal curves for the eastern portion of the Straits of Magellan during the days of the field study. Data from 1975 Tide Tables (U. S. Department of Commerce). Stations are located on Figure 19.


AUGUST
DAY
15
16
17
18
19
20
21
FEET
Punta Dungeness
30
20
10
Banco Dirección
30
20
10
Bahia Felipe
15
5
Second Narrows
20
10
Punta Arenas
7.5
2.5

sources, ENAP personnel in Punta Arenas, researchers at the Chilean Hydrographic Institute in Valparaiso, and the captain of the First Narrows ferry, currents of 8 to 9 knots are common, changing direction as the tide changes. These currents are spectacular from the air. The photograph in Figure 21 shows standing waves developed in the ocean as the flood currents spill into the Straits through the First Narrows.

Waves

To our knowledge, no wave data is available for the Metula Oil Spill site. Normal oceanic waves up to 90 cm in height were observed on the Atlantic beaches (stations D, G, 11, F; Fig. 2). However, the interior areas always had waves less than 50 cm during our visit, even under strong wind conditions (>20 kts).

COASTAL GEOMORPHOLOGY

Methods

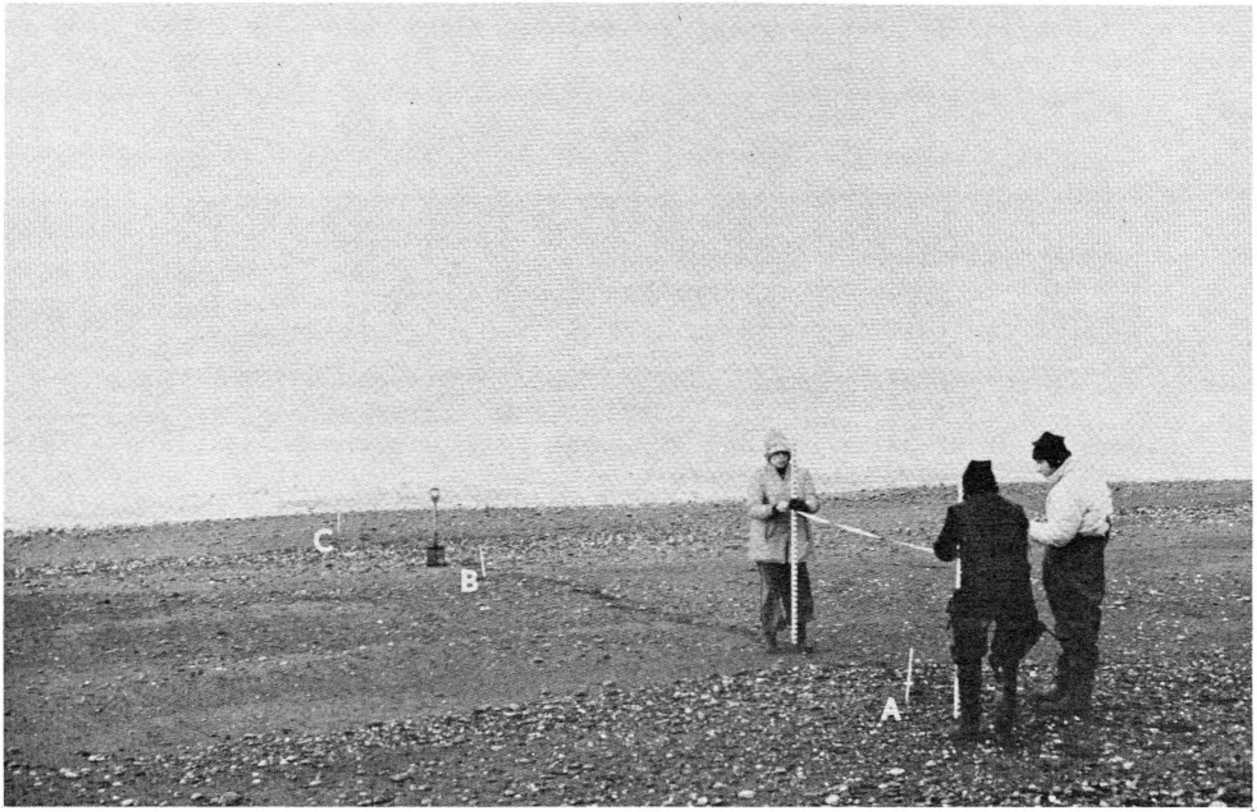
At ten of the stations visited, a beach profile was measured using the horizon-leveling technique (Fig. 22). Samples were collected along each profile, following the sampling plan outlined in Figure 8. Also, sketches were made of each profile and several photographs were taken of the beach morphology and sediments. The ten measured profiles are given in Figure 22.

Gravel Beaches

Most of the beaches of the study area are composed of a mixture of sand and gravel, with gravel predominating. The characteristic beach morphology consists of one or more high berms, a beach face with a slope of 8 to 15°

Figure 21. North shore of Straits just west of the First Narrows. Flood current flowing into the Straits is forming standing waves over the sand shoal in the lower foreground.

Figure 22. Beach profile being measured by the horizon-leveling method at station SMg 11. White stakes in beach indicate the three intertidal sampling locations (letters indicate sample designation).


C
B
A

that is washed by waves at each high tide, and a broad, flat low-tide terrace that is usually covered by coarse gravel. Figure 8 demonstrates this typical morphology, which can be seen on the aerial photographs in Figures 4A, 7B, and 14A. All but two of the measured profiles plotted on Figure 23 fit this description. Profile SMg 8 is a storm-built gravel ridge that serves as a neck for a spectacular recurved spit at the east entrance (north shore) of the First Narrows (Figs. 24A and B). A huge gravel ridge, or spit, has developed on the low-tide terrace at station SMg 13.

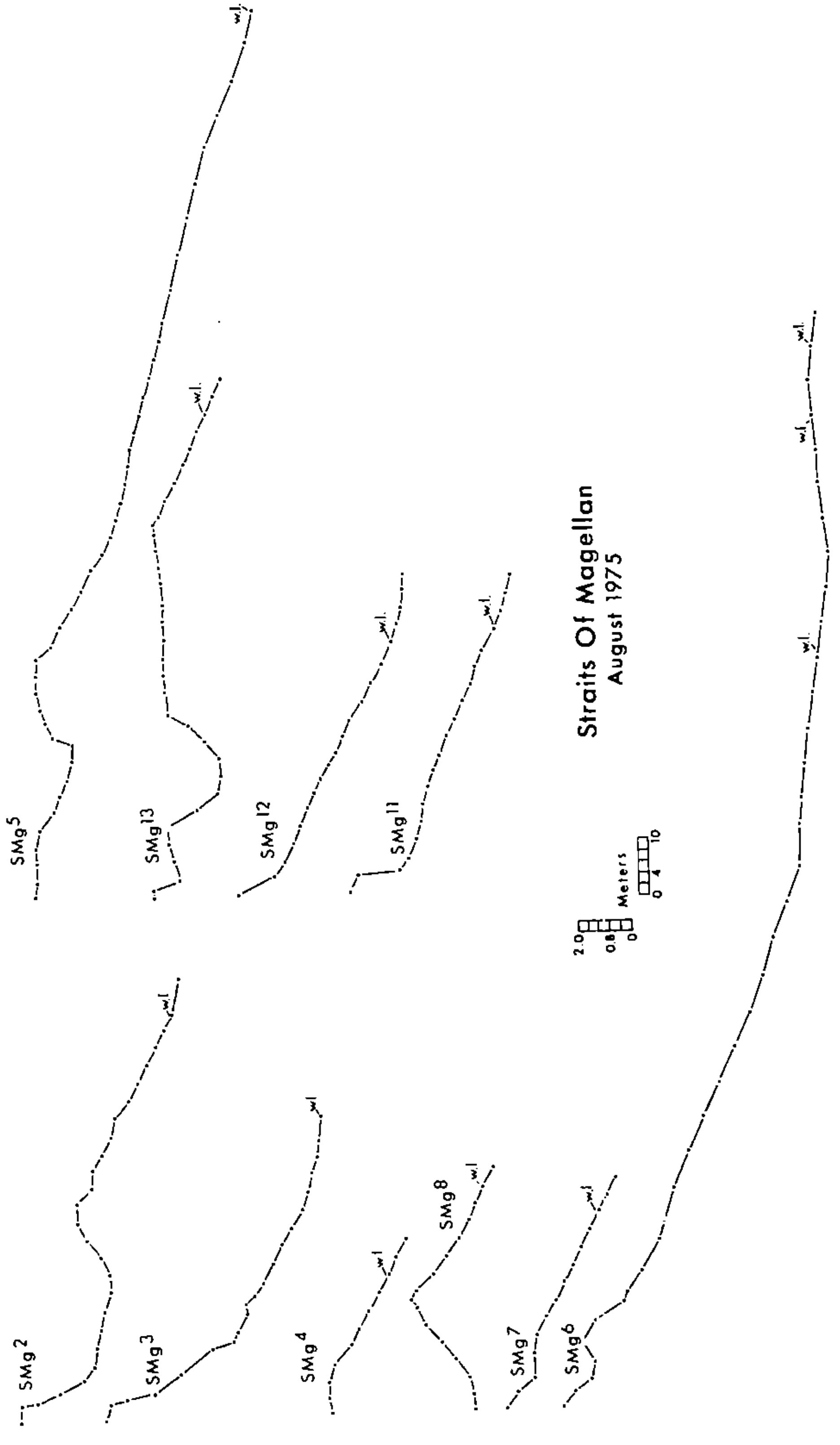
Cuspate Spits

The Atlantic entrance to the Straits of Magellan is flanked on both sides by two of the most exquisitely developed cuspate spits in the world, Cabo Dungeness on the north side and Punta Catalina on the south side. Both are slowly migrating into the Straits under the influence of waves that travel from the Atlantic into the Straits. A vertical aerial photograph of Cabo Dungeness is given in Figure 25, and Punta Catalina is shown in Figure 26. Details of the morphology of the spits are discussed in the figure captions. Both spits are made up of multiple, recurved beach ridges composed predominately of gravel. As the eastern side of the spit is eroded away, the gravel is transported around to the western side and deposited as recurved beach ridges, setting up an overall westward migration of the spits.

Tidal Flats

The combination of a huge tidal range and the development of flat

Figure 23. Beach profiles measured at the *Metula* Oil Spill site between 15-19 August, 1975. Stations are located on Figure 2. Vertical exaggeration in 5:1. W.L. = Water level at time profile was measured.



Straits Of Magellan
August 1975

Figure 24. A. Recurved spit at the east entrance to the First Narrows (north shore). Arrow indicates location of profile station 8.

B. Ground view of station 8 from top of gravel ridge looking west. Field crew is standing on marsh surface landward of the ridge.


A


B

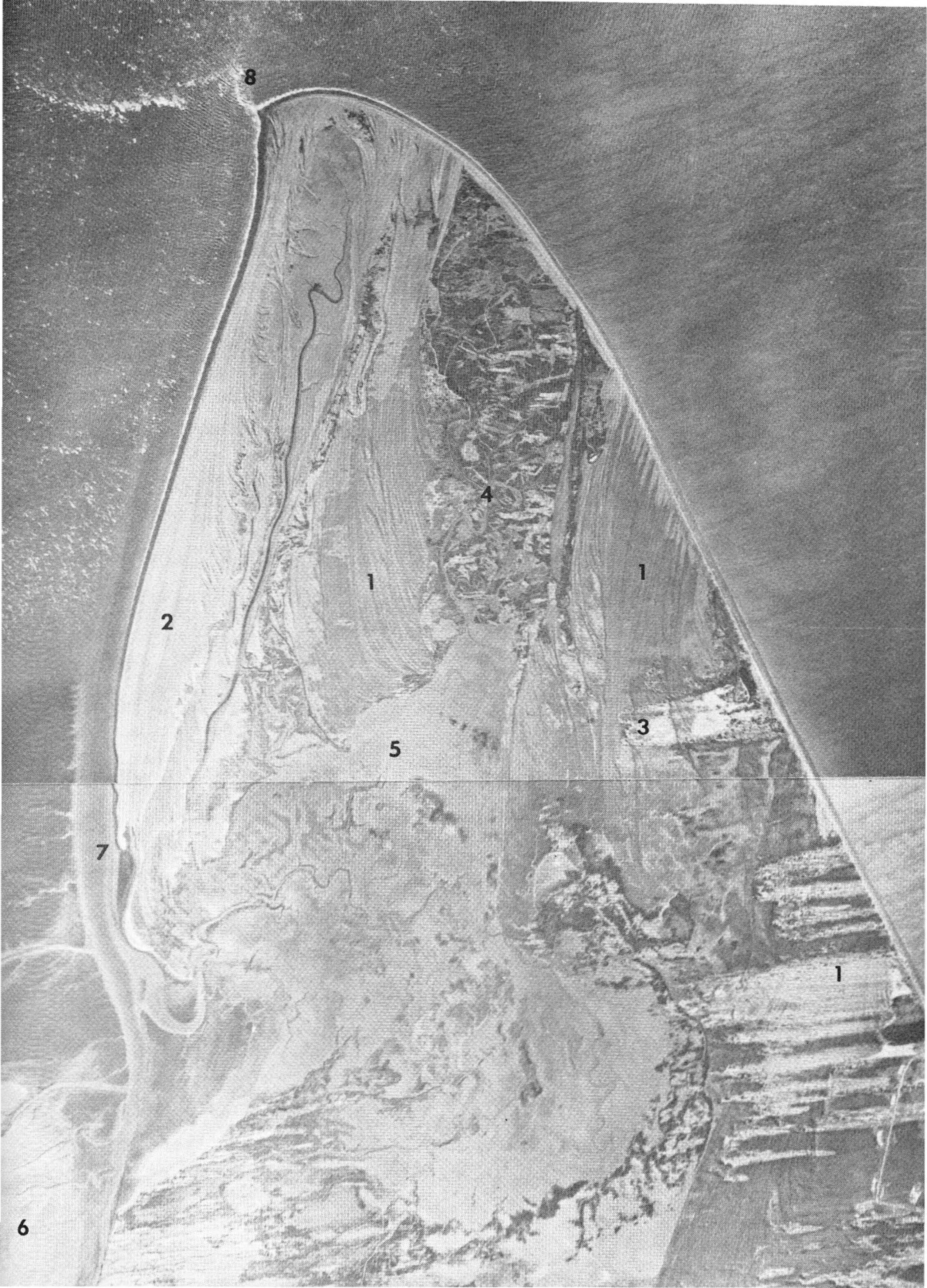
Figure 25. Cabo Dungeness (see Fig. 2 for location). This picture of a vertical aerial photograph mosaic was taken with a hand held camera in the ENAP offices at Punta Arenas. Original photographs were taken in April, 1961. Some specific points of interest include:

1) Old beach ridges being truncated as the spit migrates westward.
2) Zone of present gravel accumulation. Fine lines parallel to the present beach delineate accreting gravel beach ridges.
3) Position of former tidal channel on western margin of the spit.
4) Sampling and profiling station SMg 5.
5) Area being eroded by strong westerly winds.
6) Wind depositional features.
7) Sediment plume being transported around Cape by flood-tidal currents.


6
Exp.-16
5
1
3
1
2
4
7

Figure 26. Punta Catalina (see Fig. 2 for location). These pictures of vertical photographs were taken with a hand held camera in the ENAP offices in Punta Arenas. Original photographs were taken in April, 1961. Some specific points of interest include:

1) Old beach ridges being truncated as the spit migrates westward.
2) Zone of present gravel accumulation. Fine lines that parallel the present beach delineate accreting gravel beach ridges.
3) Area being eroded by strong westerly winds.
4) Salt marsh area.
5) Tidal flat portion of Punta Catalina.
6) Banco Lomas tidal flats.
7) Main tidal channel on Banco Lomas flats which is forced by the westerly winds to flow along the flank of Punta Catalina.
8) Tidal current rip.


8
4
1
1
2
3
5
7
1
6

outwash plain topography to the east and northeast of the end moraines at the First and Second Narrows (Fig. 13) produces tidal flats that attain widths up to 7 km (e.g., Sta. 10, Fig. 2; see frontispiece). Because of time and logistical limitations, we were not able to study these flats in any detail. Several hundred aerial photographs of the flats were collected and they are still under study. Generally speaking, the highest portions of the flats are rimmed by salt marshes up to 1 km in width. The highest portion of the tidal flats, which usually contains widely scattered meandering tidal channels (see Figs. 27 and 28), is usually more steeply sloping than the rest. Channel density increases seaward; the flats are highly incised near low water. There is a general increase in grain size from the marsh to the low-tide line. The upper flats are muddy, whereas sand bars are abundant in the lower channels.

The Narrows

In general, the two narrows are flanked on both sides by steep erosional scarps in till. The beaches are coarse-grained and narrow. Strong tidal currents flow a short distance offshore from the beaches.

SEDIMENTS

Sediment samples were collected at most of the stations visited. Beach samples were collected by the method outlined in Figure 8. Usually, three intertidal beach samples and a dune or till sample were collected. Oil samples were collected at several localities.

Figure 27. Tidal flats near station 9. Arrow points to a location similar to the one where ground photograph in Figure 28 was taken.

Figure 28. Tidal channel at station 9. Surface of flat is covered with fine mud at this locality. Note dessication cracks on mud surface.

Grain Size

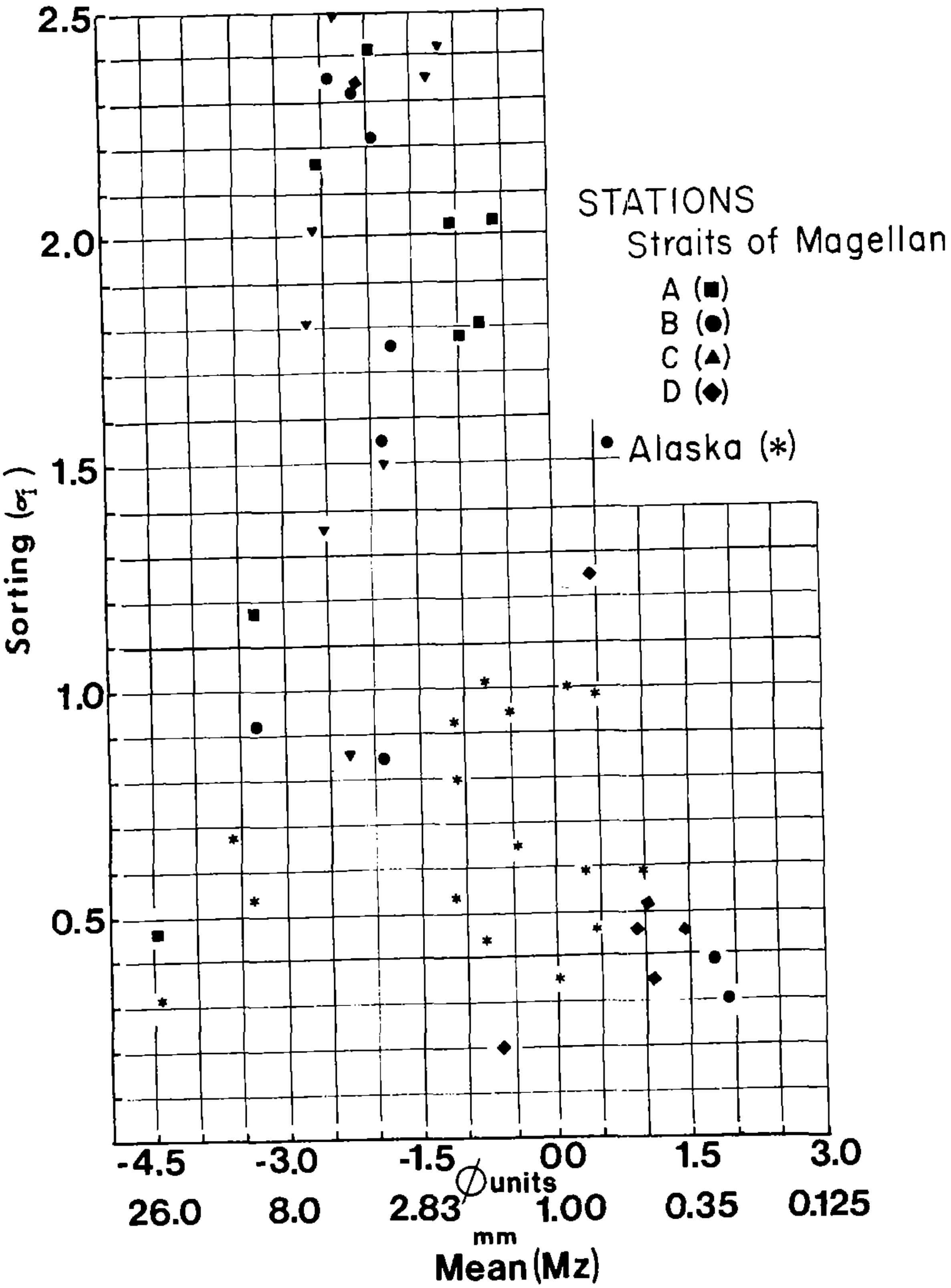
Sediments on the beaches range in size from huge boulders to fine sand. Thirty-three beach and dune samples were analyzed for grain size by seiving and settling tube. The grain size parameters of Folk (1968) were calculated for each sample (Table 3). The grand means for the 33 samples were: mean size (M_Z) = -1.21ϕ (2.15 mm; granule); skewness (Sk_I) = +0.10 (near symmetrical); sorting (σ_I) = 1.46ϕ (poorly sorted). A scatter plot of mean size versus sorting is given in Figure 29, and a plot of mean size versus skewness is given in Figure 30.

The tidal flats were sampled at stations 9 and 10 (Fig. 2), and determinations were made for sand/mud content. A sample at station 10, which is located at the eastern end of the Banco Lomas flats, was composed of 56% fine sand and 44% silt and clay. Two samples from station 9, which is located on the western margin of the flats, were composed of 24% sand/76% mud and 16% sand/84% mud respectively. This indicates a fining of tidal flat sediments in a westerly direction away from the Atlantic. This trend was clearly visible from the air.

Composition

The beach gravel is composed predominantly of rock fragments. Point counts on 10 thin sections of sand samples showed the sand to have a similar composition (Table 4). Volcanic and metamorphic rock fragments make up 59% of the grains, whereas quartzose grains equal only 25% of the total. According to the sandstone classification of Folk (1968), the sand is a litharenite, which means it is dominantly rock fragments. Most of the samples

Figure 29. Scatter plot of mean grain size (M_z) versus sorting (σ_I) for 33 sediment samples from the *Metula* Oil Spill site and 16 beach samples from the Malaspina Foreland, southern Alaska (grain size parameters of Folk, 1968). Note wide range of both mean size and sorting. Sorting is especially poor (high numbers) where the mean sizes fall between the sand and the gravel modes (-1.0ϕ to -3.0ϕ).



STATIONS
Straits of Magellan
A (■)
B (●)
C (▲)
D (◆)
Alaska (*)
Sorting (σI)
2.5
2.0
1.5
1.0
0.5
-4.5
-3.0
-1.5
00
1.5
3.0
∅units
26.0
8.0
2.83
1.00
0.35
0.125
mm
Mean (Mz)

Figure 30. Scatter plot of mean grain size (M_z) versus skewness (Sk_I) for 33 sediment samples from the Metula Oil Spill site and 16 beach samples from the Malaspina Foreland, southern Alaska (grain size parameters of Folk, 1968). There is a wide range in both skewness and mean size of samples from both areas.

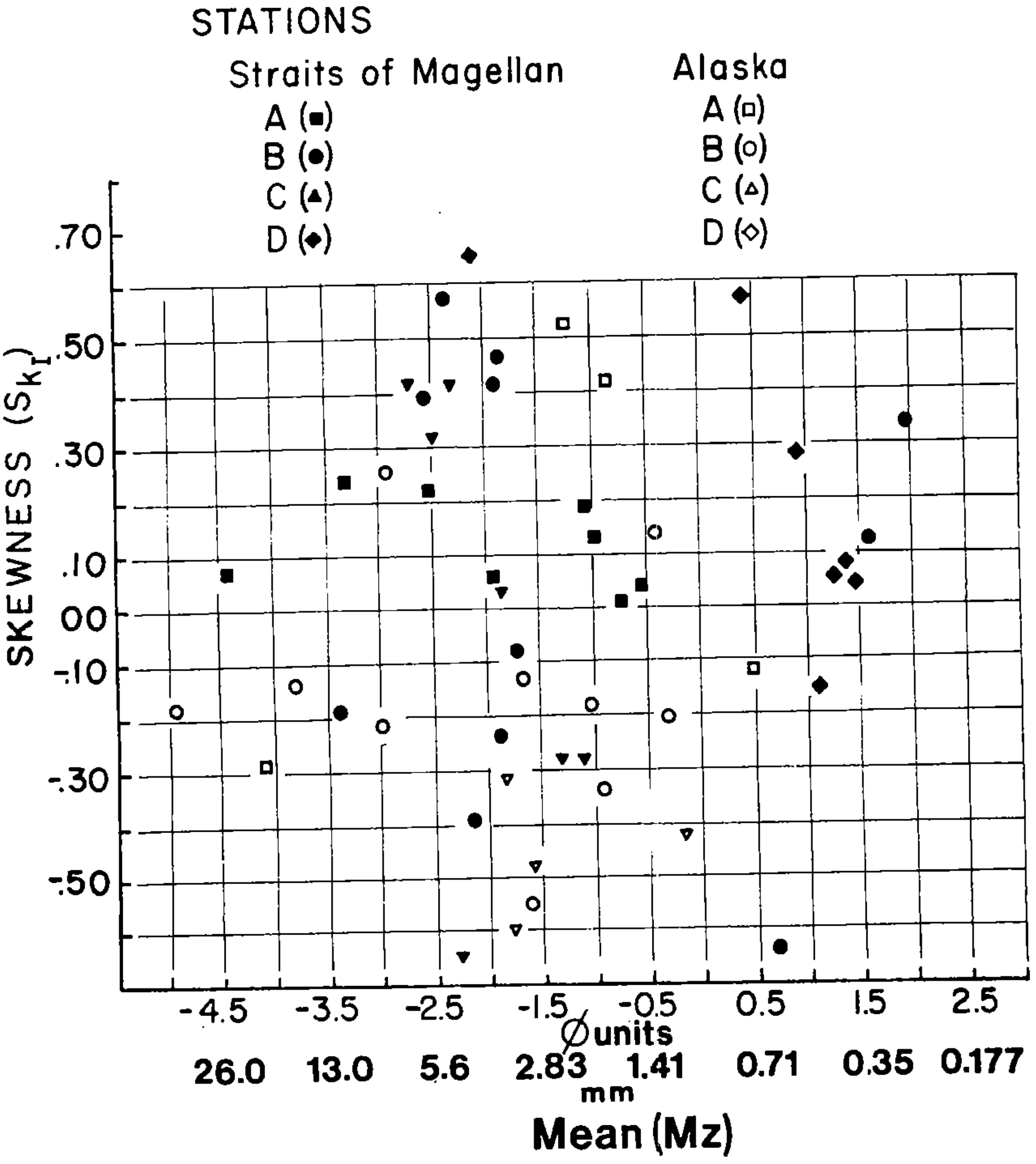

STATIONS
Straits of Magellan
A (■)
B (●)
C (▲)
D (◆)
Alaska
A (□)
B (○)
C (△)
D (◇)
SKEWNESS (S_{k_I})
.70
.50
.30
.10
00
-.10
-.30
-.50
-4.5
-3.5
-2.5
-1.5
-0.5
0.5
1.5
2.5
∅ units
26.0
13.0
5.6
2.83
1.41
0.71
0.35
0.177
mm
Mean (Mz)

Table 3. Grain Size Statistics for Metula Site Sediment Samples

Sample	Graphic Mean (M_Z)	Inclusive Graphic Skewness (SK_I)	Inclusive Graphic Standard Deviation (σ_I)	Environment
SMG-2A	-1.96	0.061	2.42	Runnel
SMG-2B	0.66	-0.633	1.54	Upper Beach Face
SMG-2C	-1.85	0.032	1.50	Mid Beach Face
SMG-2D	-2.11	0.657	2.34	Scarp (Till)
SMG-3A	-3.36	0.236	1.17	Upper Beach Face
SMG-3B	-1.75	-0.071	1.769	Mid Beach Face
SMG-3C	-2.36	0.416	2.49	Low-tide Terrace
SMG-3D	1.083	-0.153	0.359	Scarp (Till)
SMG-4A	-0.58	0.04	2.169	Stable Back Shore
SMG-4B	-2.166	0.394	2.312	Upper Beach Face
SMG-4C	.........Oil Coated Gravel.........			Mid Beach Face
SMG-5A	-2.56	0.223	2.183	Upper Beach Face
SMG-5B	-1.86	-0.227	1.55	Mid Beach Face
SMG-5C	-1.33	-0.282	2.35	Lower Beach Face
SMG-5D	Oil Covered Coarse Sand and Gravel			Berm
SMG-6A	-1.00	0.133	1.768	Lower Gravel Beach Face
SMG-6B	1.903	0.342	0.301	Till Platform Fine Sand Cover
SMG-6D	1.45	0.048	0.459	Dunes
SMG-7A	Oil Coated Gravel and Coarse Sand			Berm
SMG-7B	-2.35	0.569	2.42	Upper Beach Face
SMG-7C	-2.61	0.393	2.08	Lower Beach Face
SMG-7D	1.036	0.081	0.525	Fine Back Shore Sand
SMG-8A	-4.47	0.066	0.469	Overwash Ridge
SMG-8B	-3.35	-0.183	0.927	Upper Beach Face/Berm
SMG-8C	-1.15	-0.273	2.42	Lower Beach Face
SMG-11A	-0.76	-0.011	1.81	Berm
SMG-11B	1.56	0.125	0.329	Mid Beach Face
SMG-11C	-2.73	0.420	1.816	Lower Beach Face
SMG-11D	0.916	0.290	0.471	Dunes
SMG-12A	Oil Covered coarse Sand/Fine Gravel			Upper Beach Face
SMG-12B	-1.93	-0.469	0.853	Minor Berm/Mid Face
SMG-12C	-2.30	-0.640	0.853	Lower Beach Face
SMG-12D	0.40	0.589	0.203	Dunes
SMG-13A	-1.08	0.186	2.14	Back Shore
SMG-13B	-1.95	0.414	2.22	Middle Berm
SMG-13C	-2.53	0.320	1.353	Lower Beach Face
SMG-13D	1.26	0.052	0.477	Dunes
Mean	-1.21	0.10	1.46	

Table 4. Composition of Sand Grains (%)

Sample	Quartz %	Orthoclase %	Plagioclase %	Stretched Quartz %	Quartzite %	Phyllite-Schist %	Coarse-grained Schist %	Granite-Gneiss %	Volcanic Rock Fragments %	Chert %	Carbonate %	Mean Grain Size (ϕ)	Environment	Rock Name (Folk, 1968)
SMG-8C	7.59	3.12	0.80	3.12	10.71	12.50	5.80	8.48	33.48	14.28	0.0	-1.15	Lower Beach Face	volcanic arenite
SMG-3C	3.90	3.41	1.46	2.93	9.75	9.26	6.34	17.07	33.17	12.68	0.0	-2.36	Low-Tide Terrace	volcanic arenite
SMG-2B	10.43	6.95	2.17	2.61	10.86	11.30	6.95	16.08	26.52	6.08	0.0	+0.66	Upper Beach Face	volcanic arenite
SMG-13D	11.76	3.70	4.07	3.16	12.22	16.74	5.88	9.50	25.34	8.14	0.0	+1.26	Dunes	phyllarenite
SMG-11A	17.76	2.31	2.31	3.09	11.19	23.16	1.15	7.72	18.53	12.74	0.0	-0.76	Berm	phyllarenite
SMG-4B	8.33	2.08	2.60	7.29	14.58	11.98	3.64	7.29	35.93	10.41	1.56	-2.16	Upper Beach Face	volcanic arenite
SMG-6B	14.84	3.93	5.24	2.62	10.04	14.84	2.62	3.49	32.75	6.98	2.62	+1.90	Till Platform; Fine Sand Cover	volcanic arenite
SMG-7D	11.11	3.24	2.31	3.70	9.26	8.79	6.01	8.33	37.50	9.25	0.46	+1.03	Fine Back Shore Sand	volcanic arenite
Mean	11.00	3.00	3.00	3.00	11.00	13.00	5.00	10.00	30.00	10.00	1.00	-0.20		

are volcanic arenites, implying a predominant volcanic source, but in some samples metamorphic rock fragments are more abundant (Table 4).

COMPARISONS WITH U. S. SHORELINE

Introduction

The similarity between the shoreline environment of the Straits and certain parts of the United States is remarkable. The portion of the shoreline west of the First Narrows bears a strong resemblance to the shoreline of New England, especially the Boston Harbor area, the south shore of Massachusetts, and the north shore of Long Island. This similarity probably results from the very similar geological histories of the two areas, as well as comparable wave and tide conditions. The beach morphology, sediment texture and sediment composition are virtually the same for the two areas. East of the First Narrows, where the tidal range exceeds 30 ft during spring tides, broad tidal flats are exposed. The morphology of these flats is very similar to the tidal flats of Cook Inlet and the Copper River Delta area of Alaska.

The original proposal called for a comparison with the shoreline of Puget Sound. A brief survey of the literature and earlier flights of the area by Hayes indicate that the comparisons are much weaker there than for the New England and Alaska areas. Therefore, no further work was done on that aspect of the project.

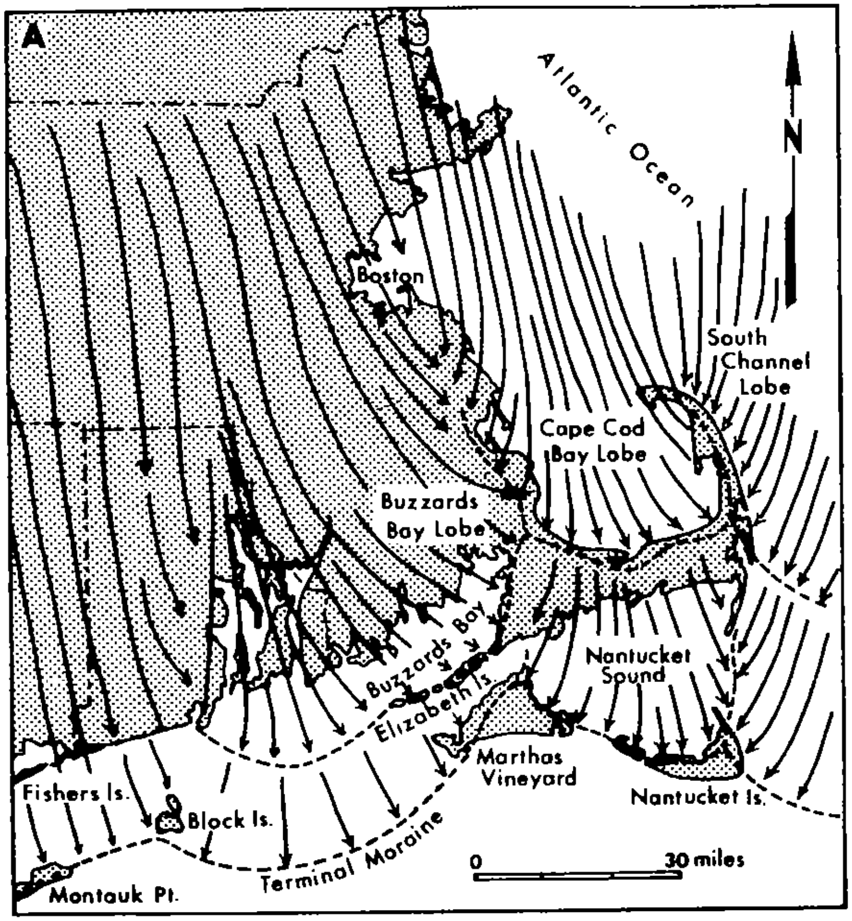
Comparisons with New England

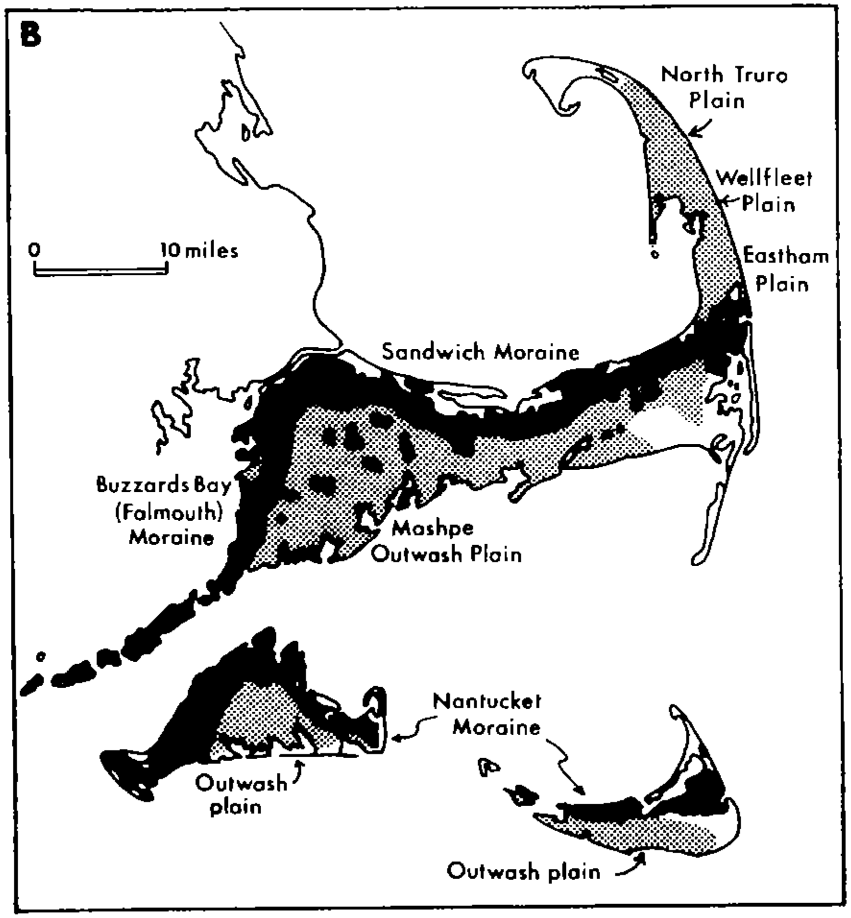
The Pleistocene glacial history of the New England coast almost duplicates that of the Straits of Magellan area (Fig. 31; compare with Fig. 12). The

Figure 31. Pleistocene glaciation in the New England area. Based on map by Woodworth and Wigglesworth (1934). After Strahler (1966).

A. Arrows show direction of flow of ice of the Wisconsin stage, as well as the two positions of ice standstill (dashed lines).

B. Moraines (solid black) and outwash plains (shaded) of Cape Cod, Martha's Vineyard, and Nantucket Island.


A
Atlantic Ocean
N
Boston
South Channel Lobe
Cape Cod Bay Lobe
Buzzards Bay Lobe
Buzzards Bay
Elizabeth Is.
Nantucket Sound
Marthas Vineyard
Nantucket Is.
Fishers Is.
Block Is.
Terminal Moraine
Montauk Pt.
0
30 miles


B
0
10 miles
North Truro Plain
Wellfleet Plain
Eastham Plain
Sandwich Moraine
Buzzards Bay (Falmouth) Moraine
Mashpe Outwash Plain
Nantucket Moraine
Outwash plain
Outwash plain

drumlin topography of Boston Harbor and the eroding glacial topography of the south shore of Massachusetts are completely analogous to the eroding till cliffs and fluvio-glacial deposits of the Straits. On the inside of the Straits, particularly west of the First Narrows, the tidal range is also similar (Fig. 32).

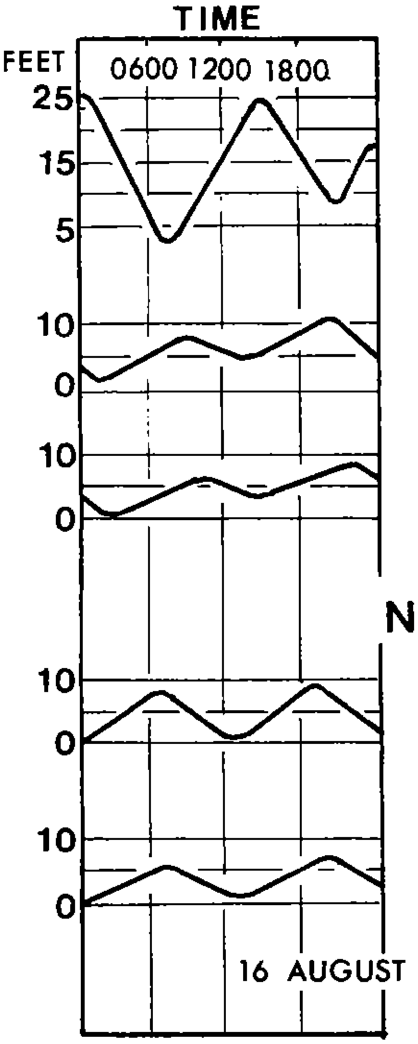
Comparisons of beach profiles for the two areas show some amazing overlaps (Fig. 33). The gravel ridge at station 3 (Fig. 22) has the same form as a gravel storm ridge at Rye Beach, New Hampshire. The long profile in front of till cliffs at station 6 overlaps completely a profile measured in front of a cliff in Pleistocene deposits near Plymouth, Massachusetts (Fig. 33). A similar overlap is demonstrated for station 12 and the beach at the north end of Nantucket Beach, Massachusetts, which is located near an eroding drumlin. Other comparisons are made photographically in Figures 34 and 35.

In conclusion, we were most impressed by the similarities we saw in the field between the New England beaches and those on the interior shoreline of the Straits. It is difficult to imagine that a closer correlation between the beach morphology and sediments of the two areas could exist.

Comparisons with Alaska

Our research group is presently conducting a research project in southern Alaska under the sponsorship of NOAA. Figure 36 shows the location of the study area, which is an area of presently active glaciation. The beaches of this region are also similar to the beaches of the Metula Oil Spill site in many ways. This likeness is demonstrated by the ground views from the two areas shown in Figure 37 and by the complete overlap of beach profiles from the two areas demonstrated in Figure 33. Sediment samples from Alaska show total

Figure 32. Tidal conditions at selected stations in Alaska and New England on 16 August, 1975.



	Time		Range	
	High	Low	Mean	Spring
ALASKA			feet	
Anchorage	0109 1443	0816 2048	26.1	29.0
Cordova	0851	0201 1351	10.1	12.4
Yakutat	0933 2051	0251 1441	7.8	10.1
NEW ENGLAND				
Boston, Mass.	0632 1855	1232	9.7	11.0
Bridgeport, Conn.	0638 1901	0300 1246	6.7	7.7

16 AUGUST 1975

Figure 33. Comparison of beach profiles of Alaska and New England with those measured at the Metula Oil Spill site in August, 1975. Note remarkable overlap in all five examples.

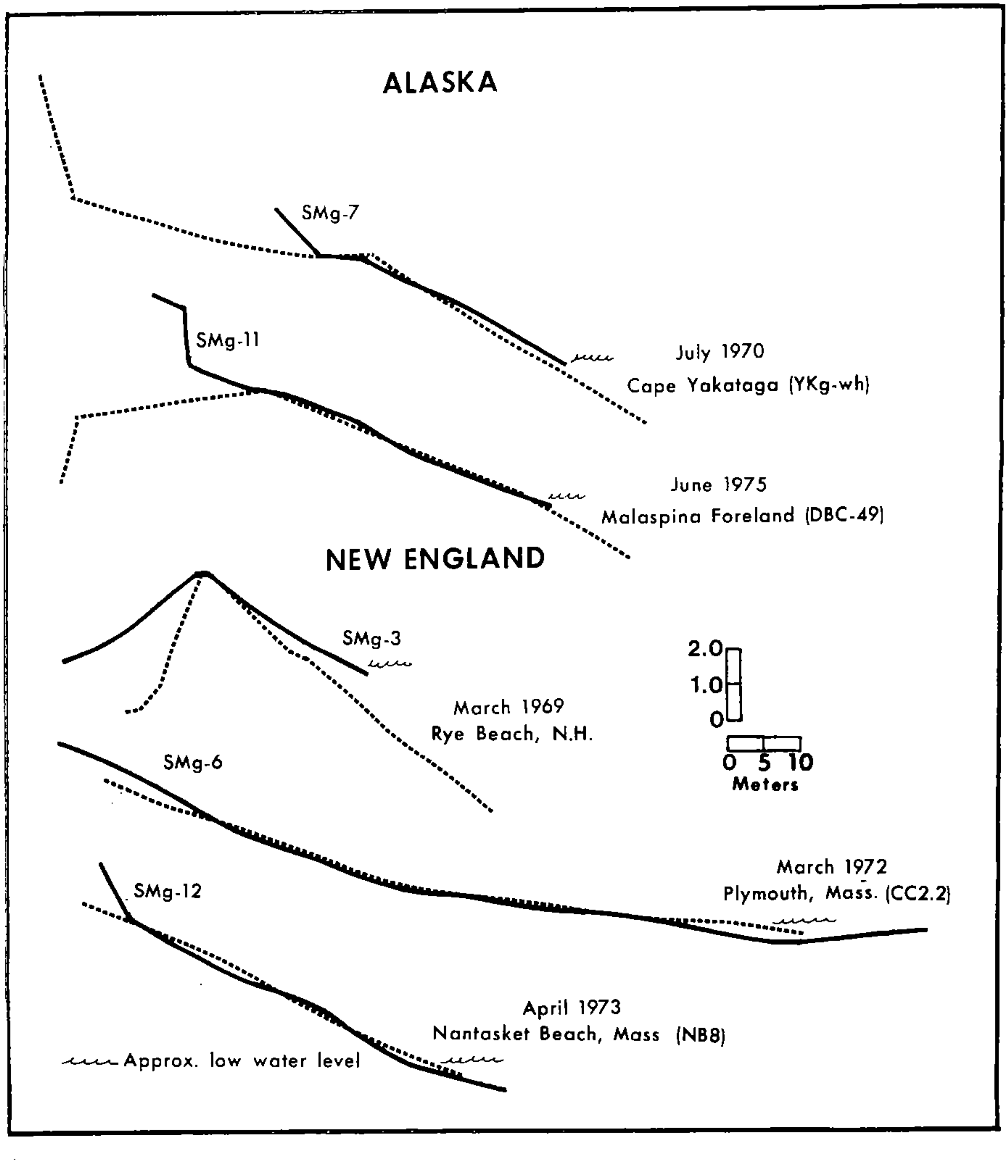

ALASKA
SMg-7
SMg-11
July 1970
Cape Yakataga (YKg-wh)
June 1975
Malaspina Foreland (DBC-49)
NEW ENGLAND
SMg-3
March 1969
Rye Beach, N.H.
2.0
1.0
0
0 5 10
Meters
SMg-6
March 1972
Plymouth, Mass. (CC2.2)
SMg-12
April 1973
Nantasket Beach, Mass (NB8)
Approx. low water level

Figure 34. Comparison of New England and Straits of Magellan beaches.

A. View of station 3 at low tide. Note well developed beach face and low-tide terrace.

B. View of Winthrop Beach, Massachusetts, at low tide.

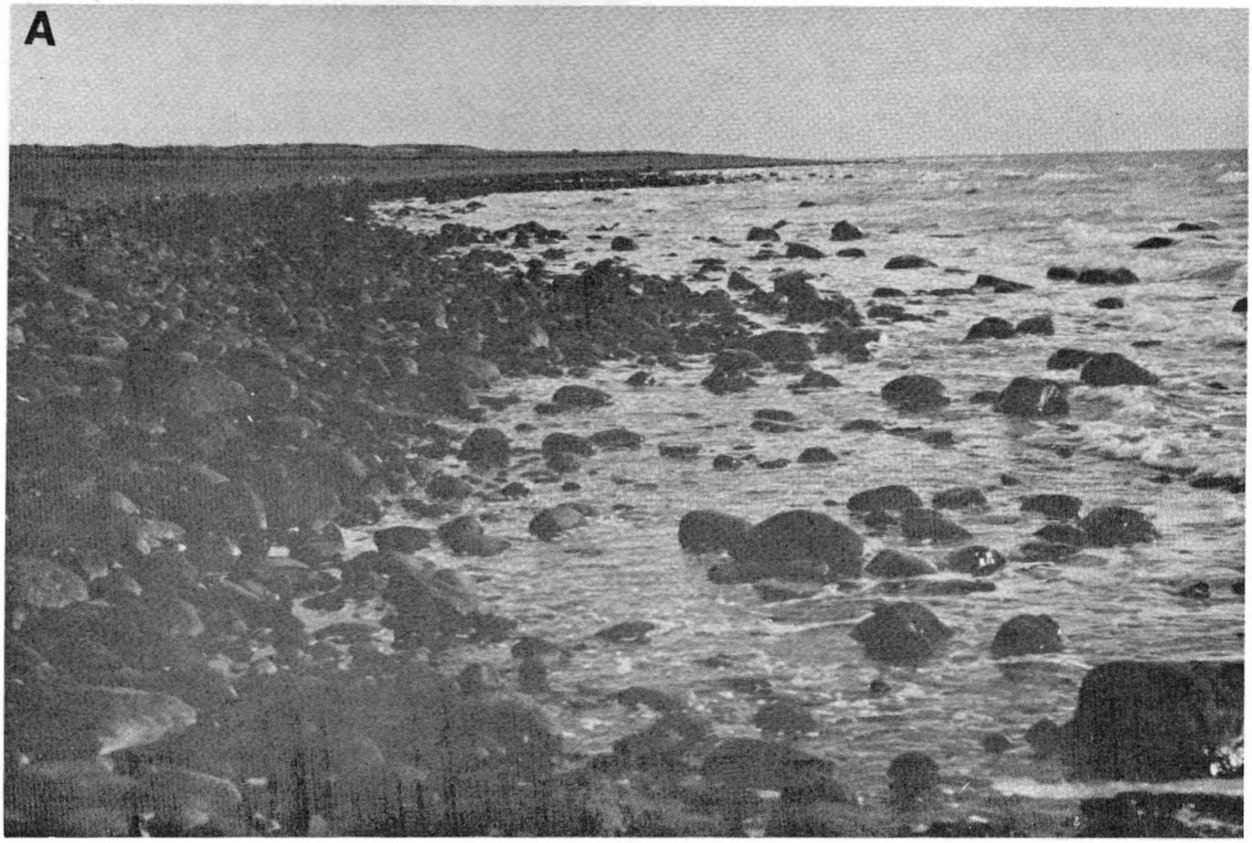
A

B

Figure 35. Comparison of New England and Straits of Magellan beaches.

A. Low-tide view across the low-tide terrace at station 12.

B. Low-tide view across the low-tide terrace of the beach zone near Wellfleet, Massachusetts.


A


B

Figure 36. Location of area in southern Alaska under study by our research group. Arrows indicate dominant longshore sediment transport direction on the basis of combined morphological and process data. Patterns indicate erosional and depositional trends. End morainal material being eroded from the area at the southern extremity of the Malaspina Glacier is being fed into the longshore sediment transport system in much the same fashion as the Pleistocene moraines of the *Metula* Oil Spill site feed sediments to the Patagonia and Tierra del Fuego beaches.

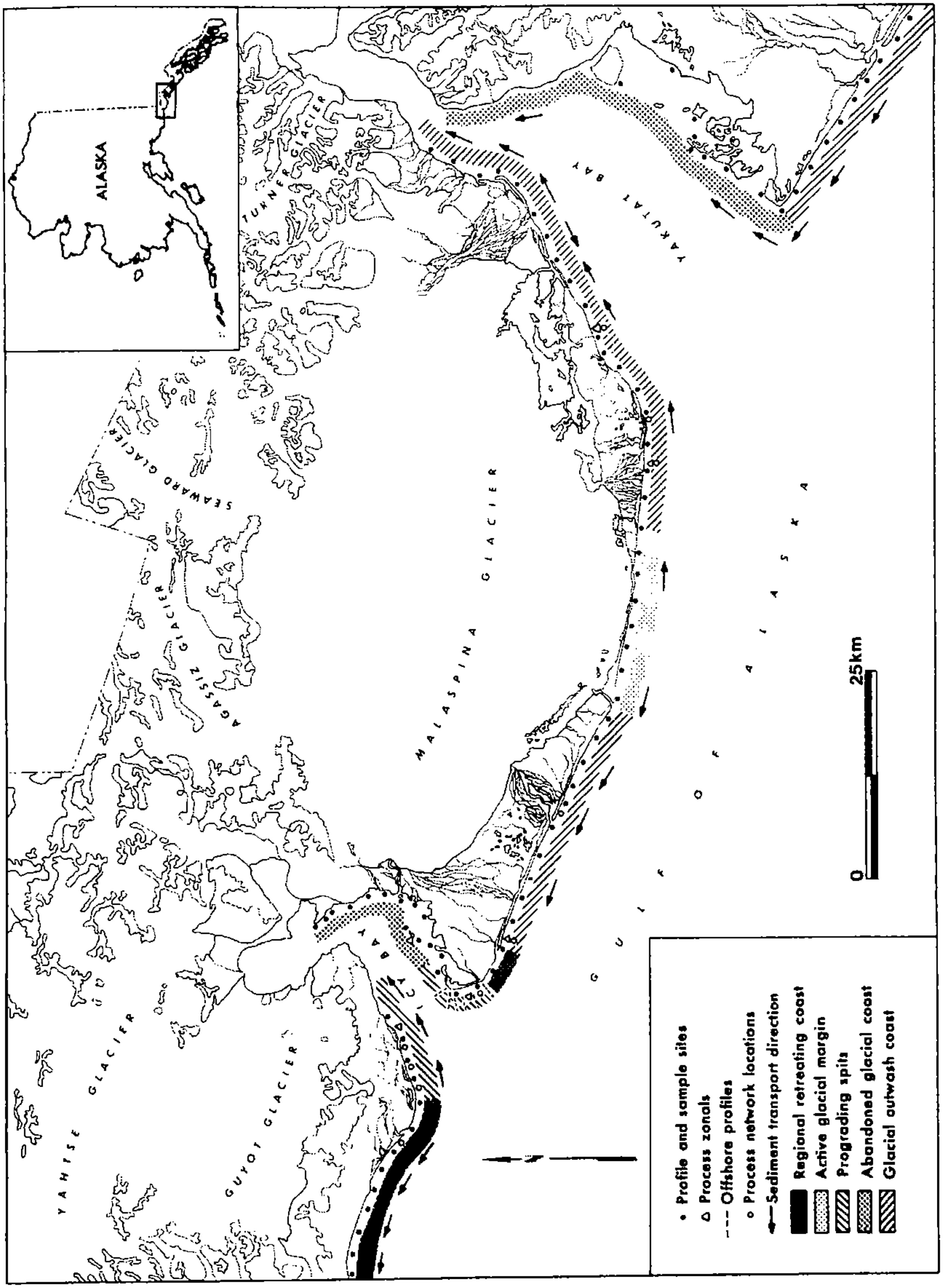

ALASKA
TURNER GLACIER
YAKUTAT BAY
SEAWARD GLACIER
AGASSIZ GLACIER
MALASPINA GLACIER
GULF OF ALASKA
YAHTSE GLACIER
GUYOT GLACIER
ICY BAY
0
25km
• Profile and sample sites
Δ Process zonals
--- Offshore profiles
○ Process network locations
← Sediment transport direction
Regional retreating coast
Active glacial margin
Prograding spits
Abandoned glacial coast
Glacial outwash coast

Figure 37. Low-tide ground view comparing a beach at the Straits of Magellan with one in Southern Alaska.

A. Station 2, Straits of Magellan.

B. Beach on north shore of Yakutat, Alaska (Fig. 36).

Note similarity of beach face slope and sediment size and sorting.


A

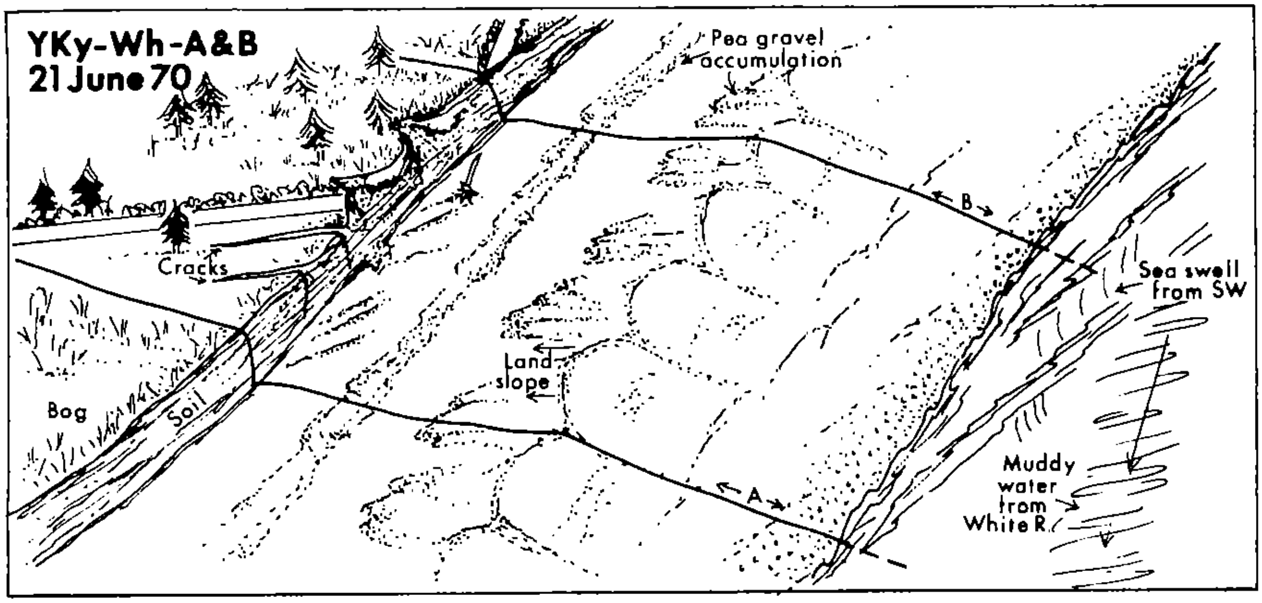

B

overlap with the Metula site samples with respect to their grain size parameters (see scatter plots in Figs. 29 and 30). The Alaska beach samples plotted on Figs. 29 and 30 were all collected around the southern margin of the Malaspina Glacier (Fig. 36).

A method we commonly use in the field is to sketch the beach profiles we measure. Comparisons of field sketches from Alaska and the Metula site are given in Figures 38 and 39. Details of the beach morphology, such as cuspate berms (Fig. 38) and depositional gravel spits (Fig. 39), are closely duplicated between the two areas.

The tidal flats of the Straits have been discussed at length above. In our opinion, two tidal flat areas in Alaska bear a strong resemblance to these flats, namely the tidal flats of Cook Inlet and those of the Copper River Delta area. The spring tidal range at Anchorage, Alaska, is 29.0 ft (Fig. 32), almost duplicating the range in the mouth of the Straits. Hayes has viewed the Cook Inlet flats many times from the air and they have a similar morphology to the flats at Banco Lomas. Inasmuch as oil is still abundant on the Banco Lomas flats, it would appear that they provide an excellent analogue for study. The tidal flats of the Copper River Delta area, which Hayes has studied in some detail, are completely analogous to the flats at the Metula Oil Spill site with respect to their morphology and sediments. Note the similarity of the two areas demonstrated by the aerial photographs in Figure 40. The Copper River Delta flats are located a few tens of kilometers from Valdez, the southern terminus of the trans-Alaska pipeline.

Figure 38. Comparison of field sketches of beach profiles in southern Alaska and the Straits of Magellan. Both areas exhibit erosional scarps and depositional cuspate berms composed of mixed sand and gravel. The Alaska station is located approximately 50 km west of the mouth of Icy Bay (Fig. 36).


YKy-Wh-A&B
21 June 70
Pea gravel accumulation
Cracks
B
Sea swell from SW
Land slope
Bog
Soil
Muddy water from White R.
A

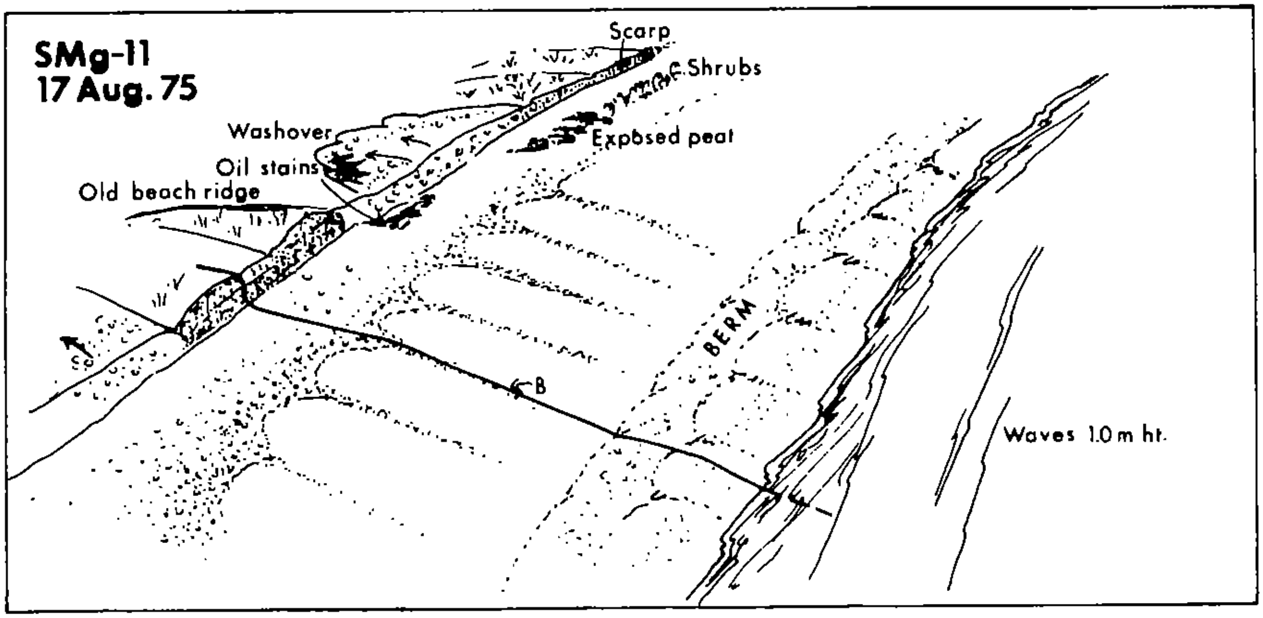
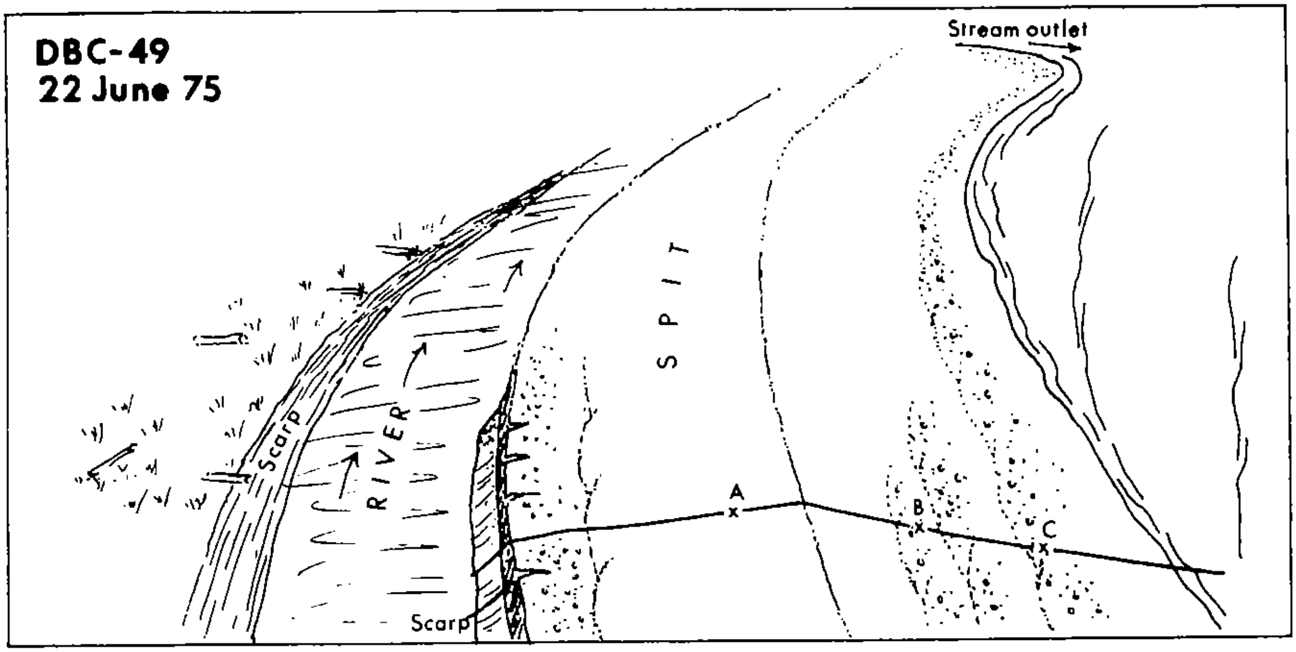
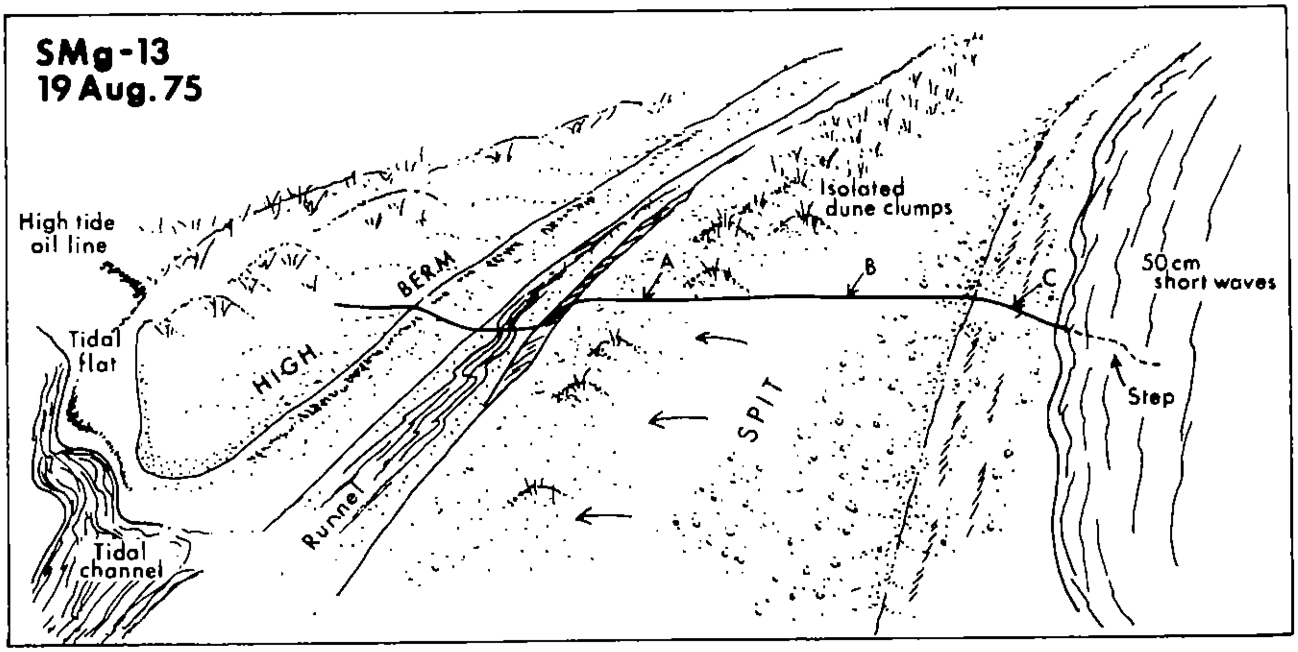

SMg-11
17 Aug. 75
Scarp
Shrubs
Washover
Exposed peat
Oil stains
Old beach ridge
BERM
B
Waves 1.0 m ht.

Figure 39. Comparison of field sketches of beach profiles in southern Alaska and the Straits of Magellan. Both areas have well developed depositional gravel and sand spits. These features are more common in Alaska than in the Straits. The Alaska station (upper) is located on the north shore of Yakutat Bay (Fig. 36).



DBC-49
22 June 75
Stream outlet
SPIT
RIVER
Scarp
Scarp
A
B
C



SMg-13
19 Aug. 75
High tide oil line
Tidal flat
Tidal channel
HIGH BERM
Runnel
Isolated dune clumps
A
B
C
SPIT
50 cm short waves
Step

Figure 40. Comparison of Straits of Magellan tidal flats (A) with those of the Copper River Delta area, Alaska (B).

A. Banco Lomas flats on 18 August, 1975. Brown coating seen in central and upper portion of photograph is thought to be oil (not visited on the ground).

B. Tidal flats of the Copper River Delta. Note incised tidal channels. Photo taken in the summer of 1969.

A

B

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APPENDIX I

Chronological Report
Coastal Reconnaissance of the Metula Impact Area in the Straits of Magellan
August, 1975

9 August	Left Columbia, S. C., for Miami and Santiago, Chile.
10 August	Arrived at Pudahuel Airport in Santiago at 3:00 p.m. Proceeded to Valparaiso/Vina Del Mar, which is located on the Pacific Coast.
11 August	Visited the Chilean Hydrographic Institute to meet with Helmuth Sievers, Director of the Oceanography Department, and Bernardo Uccelletti, Secretary of the Chilean National Oceanographic Committee. Suggestions on procedures for our immediate project, as well as future studies, were received. Purchased charts and discussed oceanographic information on the Straits gathered by Institute personnel. Met with Sergio Gonzales of the School of Fisheries and Food Sciences, Universidad Católica de Valparaiso.
12 August	Flew to Punta Arenas from Santiago. Peace Corps volunteer Bill Texera and biologist Italo Campondonico, both of the Instituto de la Patagonia, met us at the airport. Made hotel arrangements and met with Sr. Mateo Mártinic, Director of the Institute, and his staff. The purpose of our visit was explained. Sr. Mártenic was most helpful and offered to assist us with logistical arrangements for our work. Arrangements made for initial aerial flight with the local flying club.
13 August	Made the first of two aerial reconnaissance flights (2 hour duration), covering the entire north side of the study area through the First Narrows. Geographer Enrique Zamora of the Patagonian Institute made the flight with us and provided geological background information.
14 August	Visited the ENAP office (Chile's national oil company) to meet with Srs. Mario Mertens, Director of Operations, and Pietro Palini, Director of Engineering Operations. Discussions were most cordial. ENAP has serious interests in a surficial geological study of the Straits region, and access was provided to high quality aerial photographs of the area. Arrangements were made by Sr. Mario Martenic (Instituto de la Patagonia) for lodging and meals at ENAP encampments during our stay in the field. Driver Alberto Gallardo was hired.

15 August	Began field work. Field party consisted of Miles O. Hayes and Erich Gundlach (University of South Carolina), geographer Enrique Zamora and secretary Rosa Reyes Scott (Instituto de la Patagonia) and driver Alberto Gallardo. Stations 2, 3, and 4 on the north side of the Straits (Fig. 1) between the two narrows were surveyed and sampled, and additional locations were photographed. The night was spent at ENAP Camp Posesión, near Bahia Posesión.
16 August	Visited stations 5-8, as well as photo stop D, covering essentially the northeast coast of the Straits from the First Narrows to the Atlantic. Took the ferry across the First Narrows to Pta. Espora, on the Tierra Del Fuego side, late in the afternoon. Food and lodging were obtained at the ENAP camp at Cerro Sombrero.
17 August	Two tidal flat stations (9 and 10) and one gravel beach on the Atlantic side of Pta. Catalina (11) were visited, thereby covering the southern side of the Straits east of the First Narrows. Accommodations were again provided by ENAP at Cerro Sombrero. Arranged to have a small plane fly over from Pta. Arenas in order to make an aerial survey from Cerro Sombrero.
18 August	Made a second aerial reconnaissance of the area during the morning, covering the north and south sides of the Straits on the Atlantic side of the First Narrows and the south side of Bahia Felipe to Pta. Remo. Rosa Reyes Scott and Enrique Zamora returned to Punta Arenas with the plane. Station 12 on the south shore of Bahia Felipe was surveyed in the late afternoon, and the night was spent in a hotel in Porvenir.
19 August	Last day of field work. Surveyed site 13 near the former Hotel Bahia Felipe and station 14 at Punta Espora, which had by far the heaviest accumulations of oil. Crossed by ferry at Pta. Espora back to the northern side of the Straits and drove back to the Instituto de la Patagonia. The Director, Sr. Mártenic, again stressed the necessity of future biological work to be pursued in conjunction with the Institute.
20 August	Photographed and made sketches of the aerial photographs at the ENAP office and added to our bibliography of the area. During lunch, Admiral Allen stressed the strong desire of Chile for a future study and his willingness to assist us in our efforts. He also suggested that the U. S. Coast Guard might cooperate in a future study. Left Punta Arenas for Santiago at 2:00 p.m.

21 August	Went first to the offices of the Instituto de Investigaciones Geologicas, where additional reference material for our bibliography of the study area was collected. Met in the afternoon with Sr. Cedomir Marángunic, Director of the Geology Department, Universidad de Chile, a glaciologist who has worked in the Straits region. Ideas were exchanged on the Pleistocene history of the area and the direction of future research. Visited Sr. René Lagos of the ENAP Operations office in Santiago in the late afternoon to obtain physical oceanographic data taken in the Straits region by ENAP. Data was not readily available and arrangements were made for the information to be mailed to us.
22 August	Left Santiago at 10:00 a.m. for Lima, Peru.
23 August	Left Lima and returned to Columbia, S. C.