IMPACT OF COASTAL PROCESSES ON RESOURCE DEVELOPMENT WITH AN EXAMPLE FROM ICY BAY, ALASKA

Bruce F. Molnia
U.S. Geological Survey
345 Middlefield Road
Menlo Park, California 94025

This paper was presented at the 1978 Circum-Pacific Energy and Minerals Conference.

Honolulu, Hawaii
August 1978

U.S. Geological Survey Open-File Report
79 - 1693

Impact of Coastal Processes on Resource Development with an Example from Icy Bay, Alaska

by

Bruce F. Molnia, U.S.G.S.
Menlo Park, California

Abstract

The coastline of Alaska is dynamic and continually readjusting to changes in the many processes that operate in the coastal zone. Because of this dynamic nature, special consideration must be made in planning for development, and caution must be exercised in site selection for facilities to be emplaced in the coastal zone. All types of coastal processes from continuously active normal processes to the low frequency-high intensity rare event must be considered. Site-specific evaluations considering the broad range of possible processes must precede initiation of development.

An example of the relation between coastal processes and a proposed resource treatment facility is presented for Icy Bay, Alaska. Icy Bay is the only sheltered bay near many of the offshore tracts leased for petroleum exploration in the 1976 northern Gulf of Alaska OCS (Outer Continental Shelf) lease sale. Consequently, it has been selected as a primary onshore staging site for the support of offshore exploration and development. The environment of Icy Bay has many potentially hazardous features, including a submarine moraine at the bay mouth and actively calving glaciers at the bay's head which produce many icebergs. But most significant from the point of view of locating onshore facilities and pipeline corridors are the high rates of shoreline erosion and sediment deposition. If pipelines or any onshore staging facilities are to be placed in the coastal areas of Icy Bay, then the dynamic changes in shoreline position must be considered so that man-made structures will not be eroded away or be silted in before the completion of development.

INTRODUCTION

The shoreline, the transition between the Earth's two major environments, the marine and the terrestrial, is the single most dynamic area on the earth's surface. The development of resources in the beach environment and the inner continental shelf, the transportation of resources collected offshore to onshore treatment facilities, and the marine shipment of processed resources to consumers are all subject to interaction from shoreline processes. The beach system is in dynamic equilibrium with continually changing local conditions. Onshore structures, pipelines that cross the beach zone, and offshore drilling platforms, all must be designed not only to withstand seasonal changes but also aperiodic severe storms and slow continuous changes throughout the life of the entire resource-development operation.

Numerous physical processes in the coastal zone can have an impact on efforts to develop resources. Some, such as storm concentration of heavy metals as erosional lags can simplify efforts to procure precious metals. Others, such as storm surge or tsunamis, can greatly hamper or curtail attempts at resource development. Because of the unpredictability of processes in the coastal zone, a knowledge of the variety of processes that can affect the shoreline must be gained and caution must be exercised in site selection before any structures, developments or facilities are emplaced in the shore region.

In the Gulf of Alaska, a region intensely studied by the U.S. Geological Survey, areas such as Icy Bay (Molnia, 1977) show rapid shoreline retreat ($\sim$4 km in 50 yr) and spit growth ($\sim$6 km in 50 yr). Deposition of over 10^7 m^3/yr of sediment may render unusable Moraine Harbor, an area strongly considered as an onshore staging site. Other processes in Alaska and other high-latitude areas that affect the location of resource development sites include rapid breakout and draining of glacier lakes, icebergs, shore-fast ice, ice gouging, permafrost, and glacier advances.

In addition to the high-latitude processes, the coast of Alaska is subject to tsunamis, storm surge, seismicity and its related problems, longshore currents that could cause erosion or deposition, and harbor shoaling. Many coastal areas are subject to tidal currents and extreme tidal ranges, mass movement, and volcanic activity.

This paper briefly discusses the processes that affect the coastal areas of Alaska and cites an example from Icy Bay, Alaska.

COASTAL PROCESSES

Processes that affect the coastline of Alaska can be divided into two major categories: (1) Processes that occur worldwide, but may have special effects in the coastal zone; and (2) Processes unique to the coastal zone. Examples are given in Tables 1 and 2.

Ubiquitous processes can be further subdivided on the basis of whether the process is active or passive. For instance, the presence of permafrost in the coastal zone by itself does not alter the characteristics of the coastal area where it exists. However, a poorly designed resource development operation can significantly change that coastal area by causing melting of the permafrost. On the other hand, even the most carefully designed resource development operation cannot always stave off the effects of volcanic eruptions, large-magnitude earthquakes, or high-discharge flooding. Active processes must be anticipated in the design of the development site, but their magnitudes and frequencies cannot always be predicted. Passive processes generally preexist in a particular area and can sometimes be avoided in site selection. The effect of the development on these processes can often be mitigated by careful planning and design.

CASE HISTORY: PROPOSED DEVELOPMENT AT ICY BAY

Icy Bay, Alaska (Fig. 1), a north-trending fiord adjacent to the Gulf of Alaska, lies 20-80 km from most of potentially petroleum-rich offshore tracts leased in the April 1976 Northern Gulf of Alaska Petroleum Lease Sale (OCS Sale #39). It also offers the only shelter from storms for marine traffic between Yakutat Bay 90 km to the east and Prince William Sound 295 km to the west. The location and the protection it can offer have made it a candidate for an onshore staging area for the development of Gulf of Alaska oil and gas.

On June 2, 1976, the Chugach Natives, Inc., applied to the Alaska District Army Corps of Engineers (NPA 76-124) for a permit to dredge and fill and to construct dock and shiphandling facilities in the Moraine Harbor area north of Point Riou Spit and Riou Bay (Fig. 2). Other plans include housing, fuel storage areas, warehouses, water storage and supply, power generation facilities, a sewage treatment site, and an 1800 m (6,000 ft.) airstrip capable of handling jet traffic. Cecil Barnes, the president of Chugach Natives, Inc., is quoted in the July 21, 1976 "Alaska Scouting Service Report" as envisioning a new town at Icy Bay that could have a population of 2,500 in 7 to 10 years. Bomhoff and Associates, Inc., an Anchorage engineering firm, has prepared a feasibility study that was submitted to the State of Alaska in November, 1976.

In 1974, the U.S. Geological Survey began investigating shoreline erosion as one of many potential hazards that might complicate or adversely affect normal petroleum operations (Molnia and others, 1976). Icy Bay, because of its recent dynamic history, was one area selected for detailed evaluation.

HISTORY OF ICY BAY

As recently as 1904, today's Icy Bay did not exist. In 1974, when the explorer Vancouver surveyed the Gulf of Alaska coast, a large lobe of the Malaspina Glacier system, Guyot Glacier, extended several kilometers out to sea, occupying the area of present-day Icy Bay. A second bay, now filled in by glacial, glacio-fluvial and glacial marine deposits, located east of Icy Bay in the present Malaspina Foreland (Fig. 2), was open at that time. Vancouver named the eastern tip of the bay Point Riou. The infilling of this second bay (referred to as Vancouver's Icy Bay by Alpha, 1975) is not well documented, but on the basis of Belcher's (1843) observations, Vancouver's Icy Bay no longer existed by the middle of the last century.

Tebenkof (1848) published a series of charts based on data compiled by Russian explorers between 1788 and 1807 which generally agreed with Vancouver's description of the first Icy Bay. They show a triangular bay about 12 km long and 8 km wide at its mouth. By 1837, when Belcher examined the area, the bay had completely filled in, and Guyot Glacier had receded, opening up the mouth of the present bay (Belcher, 1843). Water depths in the old bay as shown on Tebenkof's chart were as much as 27 m (90 ft). Calculations show that over 0.5 km^3 of sediment would be needed to fill the bay charted by Tebenkof. The infilling must have occurred between 1807 and 1838, or within about a 30-year period.

By 1886, Guyot Glacier had again advanced (Seton-Karr, 1887) to a position more than 10 km seaward of the 1977 shoreline position. A terminal moraine (Fig. 2) at the mouth of Icy Bay marks the limit of this advance. The moraine is thought to date from between 1904 and 1909 (Tarr and Martin, 1914). Ice retreat, which began prior to 1910, has continued to the present, (Fig. 3).

with about 40 km of retreat through 1977. In 1913, Tarr and Martin named the opening bay Icy Bay.

After ice retreat began, and probably prior to 1910, longshore sediment transport began building a spit complex on the east shore of Icy Bay at the point where it meets the Gulf of Alaska. The spit, today called Point Riou Spit (Fig. 2), has continued to develop to the present time. (The modern Point Riou is not the same point named by Vancouver.) As the spit complex has grown, it has hooked to the northeast and isolated a portion of Icy Bay between it and the Malaspina Foreland. This body of water is known as Riou Bay. (Fig 2).

CHANGES AT ICY BAY

The development of the Point Riou area was evaluated from vertical and oblique aerial photographs, U.S.G.S. topographic maps, and from National Oceanic and Atmospheric Administration nautical charts dating from 1922 to the present. Between 1941 and 1976, the Gulf of Alaska shoreline of the eastern shore of Icy Bay receded at least 1.3 km. Between 1922 and 1976, the same shoreline receded as much as 1.5 km (Fig. 4).

Point Riou Spit began developing as soon as Guyot Glacier began retreating (about 1904) and continued to grow until at least 1957, when its length was 6.86 km. Sometime between 1957 and 1970, a large storm breached the eastern end of Point Riou Spit and detached Severed Bar. This increased the area of Riou Bay and also increased the distance across the mouth. Point Riou Spit has continued to grow and, as of 1976, had reached a length of 6.6 km. Between 1922 and 1957, the width of Riou Bay's mouth and its area have steadily decreased. Since the major storm, Riou Bay's area and width have again been decreasing. Since 1941, Riou Bay's width has decreased from 3.73 km to 2.54 km, a decrease of 32 percent. In 1957, the width had decreased to 2.20 km. It is likely that the damaging storm had a recurrence interval of 50 to 100 years.

The western shoreline of Icy Bay has also changed significantly. Between 1922 and 1976, the shoreline has retreated as much as 4.8 km, with a loss of more than 8.2 km^2.

The lower part of Icy Bay, which has an area of about 200 km^2 has accumulated more than 2.0 km^3 of sediment between 1922 and 1976. This amount averages out to an accumulation of slightly more than 10 m of sediment for the entire basin (Fig. 5). Maximum thicknesses of sediment accumulation are greater than 75 m. Deepening at the mouth of the bay is partially related to melting of ice in the 1904 submarine moraine.

Vancouver's Icy Bay, which existed until about 1837, was filled in with sediment in less than 40 years. Calculations based on Tebenkof 's (1848) chart indicate that about 5×10^8 m^3 of sediment would be needed to raise the bottom to mean lower low water. The growth in Point Riou Spit between 1922 and 1975 would require more than 3.56×10^7 m^3 of new sediment. Both of these sediment volumes are small when compared with the quantity that has accumulated in lower Icy Bay.

The sediment being added to Point Riou spit comes from two sources, the eroding Malaspina Foreland and the streams draining the Malaspina Glacier system. Sediment is transported into the Point Riou system by longshore drift and wave action.

EFFECTS OF SHORELINE CHANGES AND SPIT GROWTH ON PROPOSED DEVELOPMENT

The sediment transport schemes for the eastern shore of Icy Bay can be characterized as: (1) longshore transport from the east and then continued longshore transport into Icy Bay along the margin of Point Riou Spit; and (2) washover sedimentation by storm waves, which drive sediment into southern Riou Bay, onto the Malaspina Foreland, and onto the inner curve of Point Riou Spit. Longshore transport has kept Point Riou elongating since its inception and, if allowed to continue without storm breaching, will probably close off the mouth of Riou Bay completely. The distance between Moraine Island and the tip of the spit has decreased from 5.52 km in 1922 to 2.54 km in 1976. Continued growth at the present rate would connect the two points in less than 20 years, thus closing off Riou Bay. Then, new sediment that previously had been deposited in deep water adjacent to Point Riou Spit, had been attached to the spit, or had entered Riou Bay would continue along the face of Moraine Island and enter Moraine Harbor, the major site for proposed development (Fig. 6). Moraine Harbor will fill in within 15 years if sedimentation continues at the rate calculated for Point Riou Spit between 1922 and 1976. Human intervention could prolong the life of Riou Bay and Moraine Harbor but has not been considered in the calculations. Even before the attachment of Point Riou Spit to Moraine Island, the increase in sediment would affect moorage sites for tankers and platforms and also loading and unloading areas for other marine traffic.

CASE HISTORY - SUMMARY

The preceding example shows how the interaction of many different coastal processes had produced a situation in which a proposed development would be rendered useless long before it had fulfilled the function for which it was designed. The interaction of weather and climate, glacial advances and retreats, erosion, deposition, longshore transport, and storm surge and tidal processes has shaped the long-term changes at Icy Bay. The record is readable here as it is at many other sites. Because of the dynamic nature of the coastal zone, an effort must be made to read the coastal history record and achieve an understanding of the processes active at each site being considered for resource development. Otherwise, selection of sites similar to Moraine Harbor may occur elsewhere. Fortuitously for the developers of Moraine Harbor, while they were obtaining additional geologic data before beginning construction, exploratory offshore drilling failed to find developable petroleum reserves. Consequently, development at Moraine Harbor has been curtailed, at least for the present time.

The future of development is uncertain, but the action of coastal processes will continue.

TABLE 1 Examples of Processes that Occur Worldwide But May Have Special Effects in the Coastal Zone

Active processes:

- Seismicity
- Volcanism
- Flooding
- Mass Movement
- Isostatic readjustments
- Tectonics
- Glacier advance and retreat
- Glacier lake breakouts
- Stream mouth offsets
- Weather and climate

Relict or passive processes:

- Permafrost
- Buried ice
- Water content and bearing strength of sediment

TABLE 2 Examples of Processes Unique to Shoreline and Coastal Regions

Shorefast ice
Tidal range
Storm surge
Tsunami run-up
Longshore transport
Low frequency-high amplitude waves
Shoreline erosion and deposition
Delta channel readjustment

REFERENCES

Alaska Scouting Service, 1976, July 21, 1976, Petroleum Inf. Corp. Anchorage, Alaska, Vol. 22, No. 29.

Alpha, T. R., 1975, The evolution of Icy Bay, Alaska, in principal sources and dispersal patterns of suspended particulate matter in near shore surface waters of the Northeast Pacific Ocean, by Paul R. Carlson et al., U.S. Geol. Survey Rept. prepared for NASA, Goddard Space Flight Center, National Tech. Info. Service, E75-10266, pp. 4-9.

Belcher, Capt. E., 1843, Narrative of a voyage round the world, performed in Her Majesty's Ship Sulphur during years 1836 - 1842: London, Henry Colborn, Vol. I, p. 79-80.

Bomhoff and Associates, 1976, Moraine Harbor feasibility study; unpub. rep. submitted to the State of Alaska for Chugach Natives, Inc., Anchorage Alaska.

Molnia, B. F., 1977, Rapid Shoreline Erosion and Retreat at Icy Bay, Alaska - A Staging Area for Offshore Petroleum Development, Proc. Offshore Tech. Conf. V. III, p. 115-126.

Molnia, B. F., Carlson, P. R., and Bruns, T. R., 1976, Report on the Environmental Geology, OCS Area, Eastern Gulf of Alaska, U.S. Geol. Surv., Open File Rept. 72-206, 46 p.

Seton-Karr, H. W., 1887, Shores and alps of Alaska: London, Low, Marston, Searle, and Rivington, 248 p.

Tarr, R. S., and Martin, L., 1914, Alaskan glacier studies: Washington, Natl. Geog. Soc., 498 p.

Tebenkof, Capt. M., 1848, Hydrographic atlas and observations, with 48 charts: St. Petersburg (Chart published in Tarr and Martin, 1914).

Figures

Figure 1. Map of Alaska showing the Gulf of Alaska coastline surrounding Icy Bay.

Figure 2. Sketch map of the Icy Bay area showing names of local geographic features. The triangular area east of Point Riou Spit represents the outline of the bay described by Vancouver in 1794.

Figure 3. Sketch map of Icy Bay showing the location of glacier termini at selected intervals since 1794. After 1960, the retreating Guyot Glacier had separated from Tyndall and Yahtse Glaciers to form four separate retreating ice tongues.

Figure 4. Sketch map of the Point Riou area showing the position of the Gulf of Alaska coastline and Point Riou Spit in 1922, 1941, 1957, and 1975. The size and location of Severed Bar in 1976 are also shown. Shoreline positions are based on aerial photographs and nautical charts. (Molnia, 1977).

Figure 5. Sketch map of Icy Bay showing changes in bathymetry in lower Icy Bay between 1922 and 1976. The shaded areas at the bay mouth represent locations where water depth has increased, possibly as a result of melting of ice in the 1904 moraine. North of the bay mouth, changes in depth are primarily due to accumulation of sediment. Between 1922 and 1976, the 460 km^2 of the lower bay accumulated 4.8 km^3 of sediment, an average sediment increase of slightly over 10 m. More than 75 m of sediment accumulated at Crested Point of Point Riou and more than 60 m accumulated just east of Claybluff Point.

Figure 6. Sketch map of Riou Bay and Moraine Harbor areas showing the location of proposed developments. Black shaded areas represent the location of warehouses, housing complexes, commercial facilities air strips, and roads.

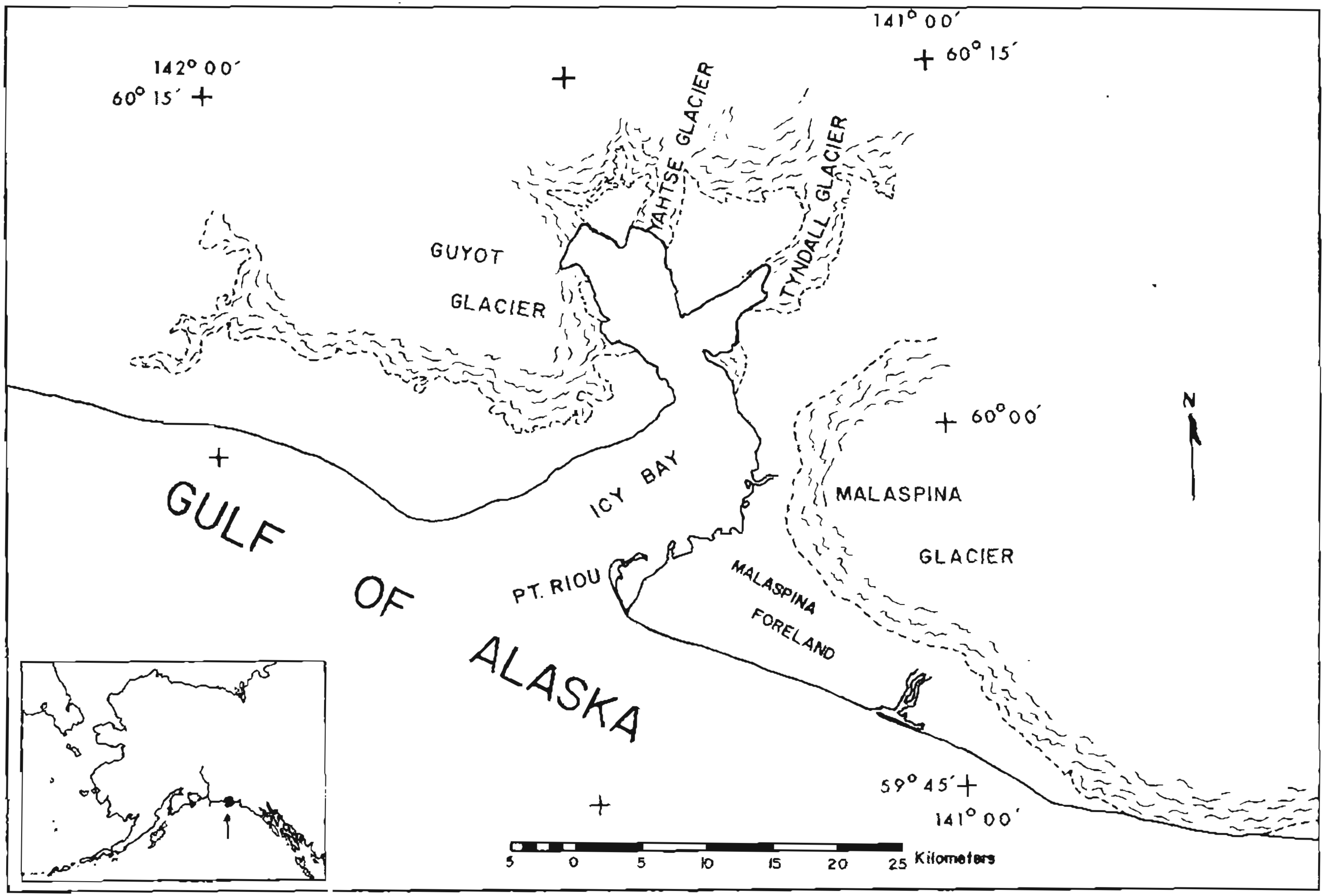

Figure 1. Map of Alaska showing the Gulf of Alaska coastline surrounding Icy Bay.

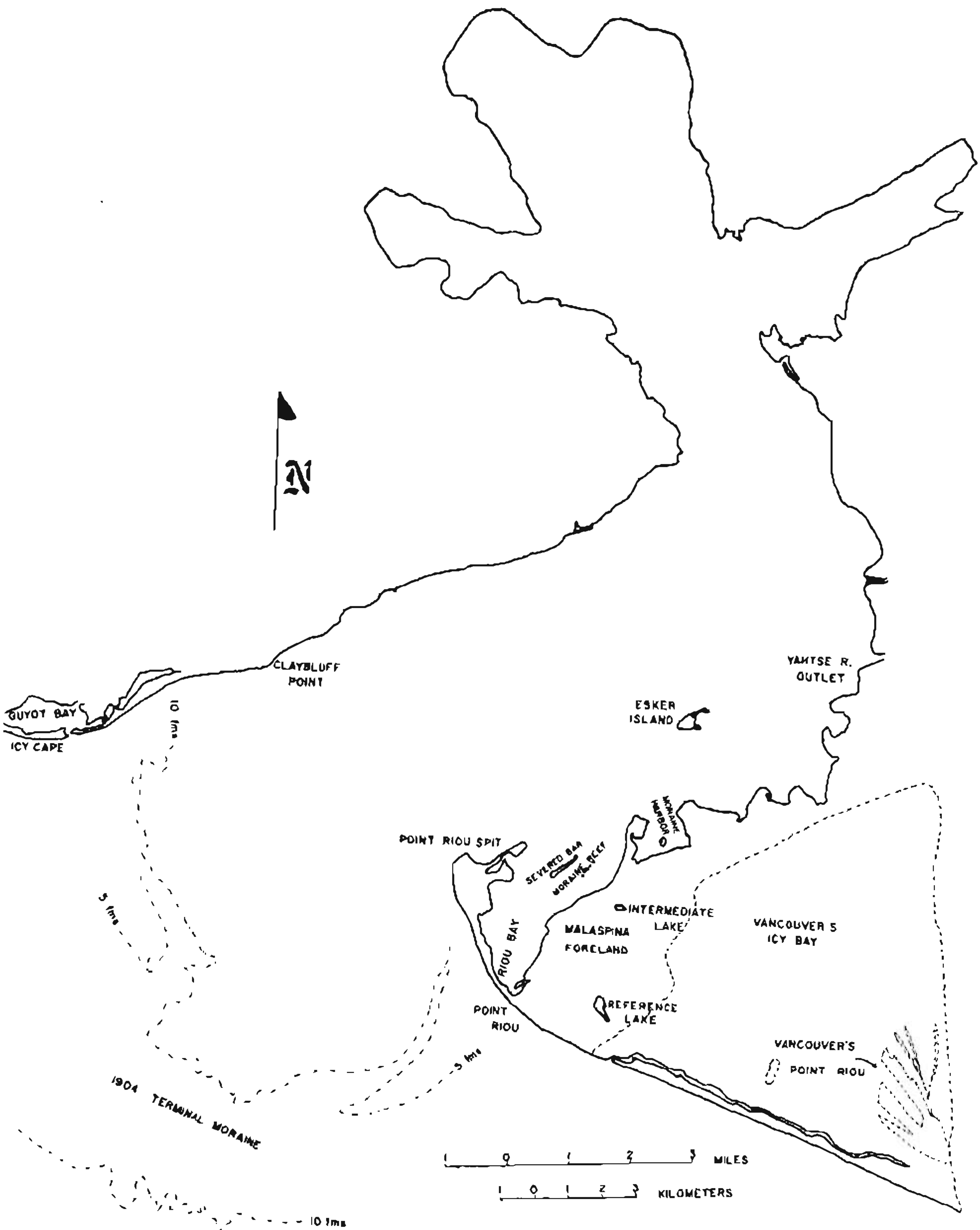

Figure 2. Sketch map of the Icy Bay area showing names of local geographic features. The triangular area east of Point Riou Spit represents the outline of the bay described by Vancouver in 1794.

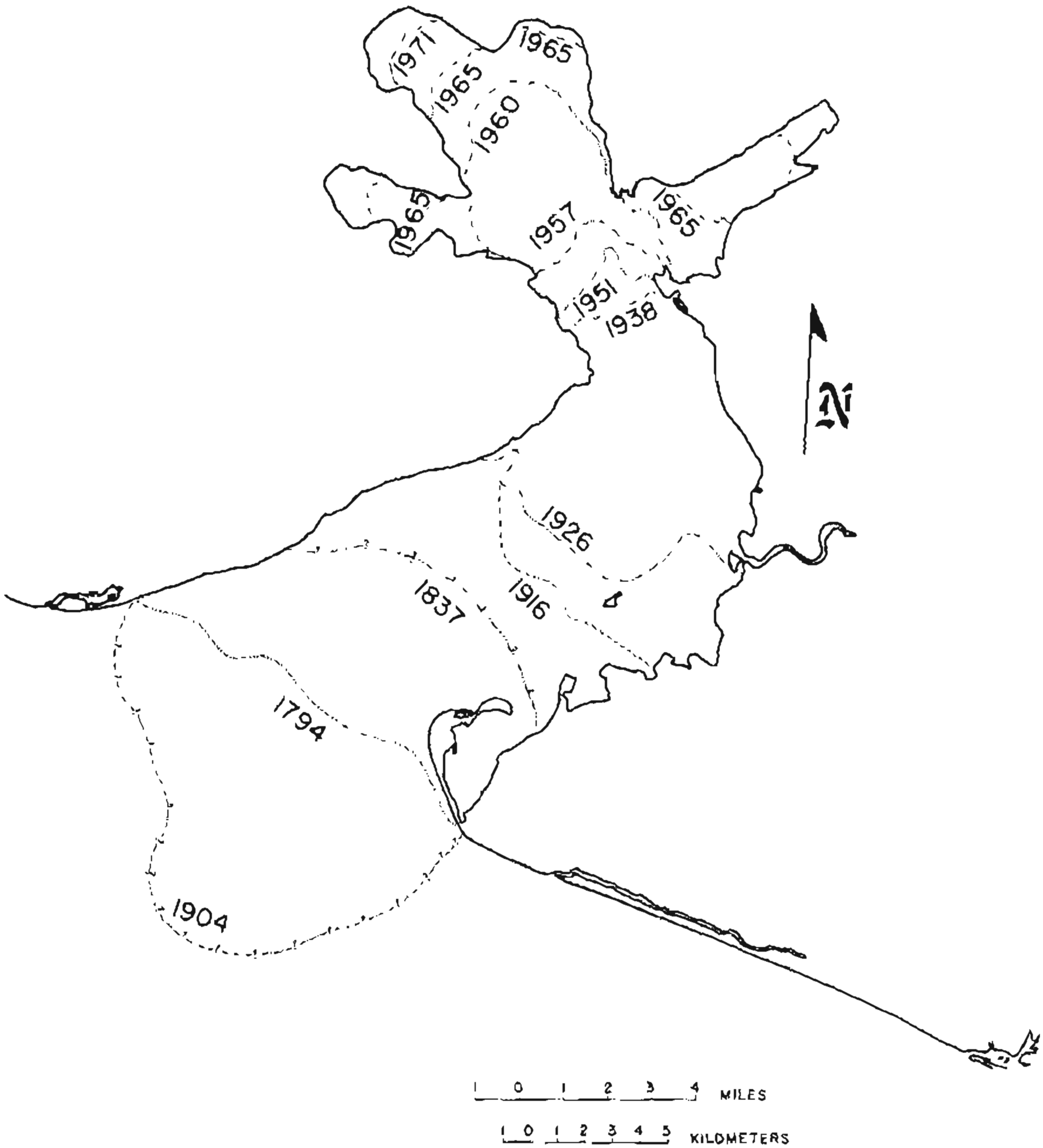

Figure 3. Sketch map of Icy Bay showing the location of glacier termini at selected intervals since 1794. After 1960, the retreating Guyot Glacier had separated from Tyndall and Yahtse Glaciers to form four separate retreating ice tongues.

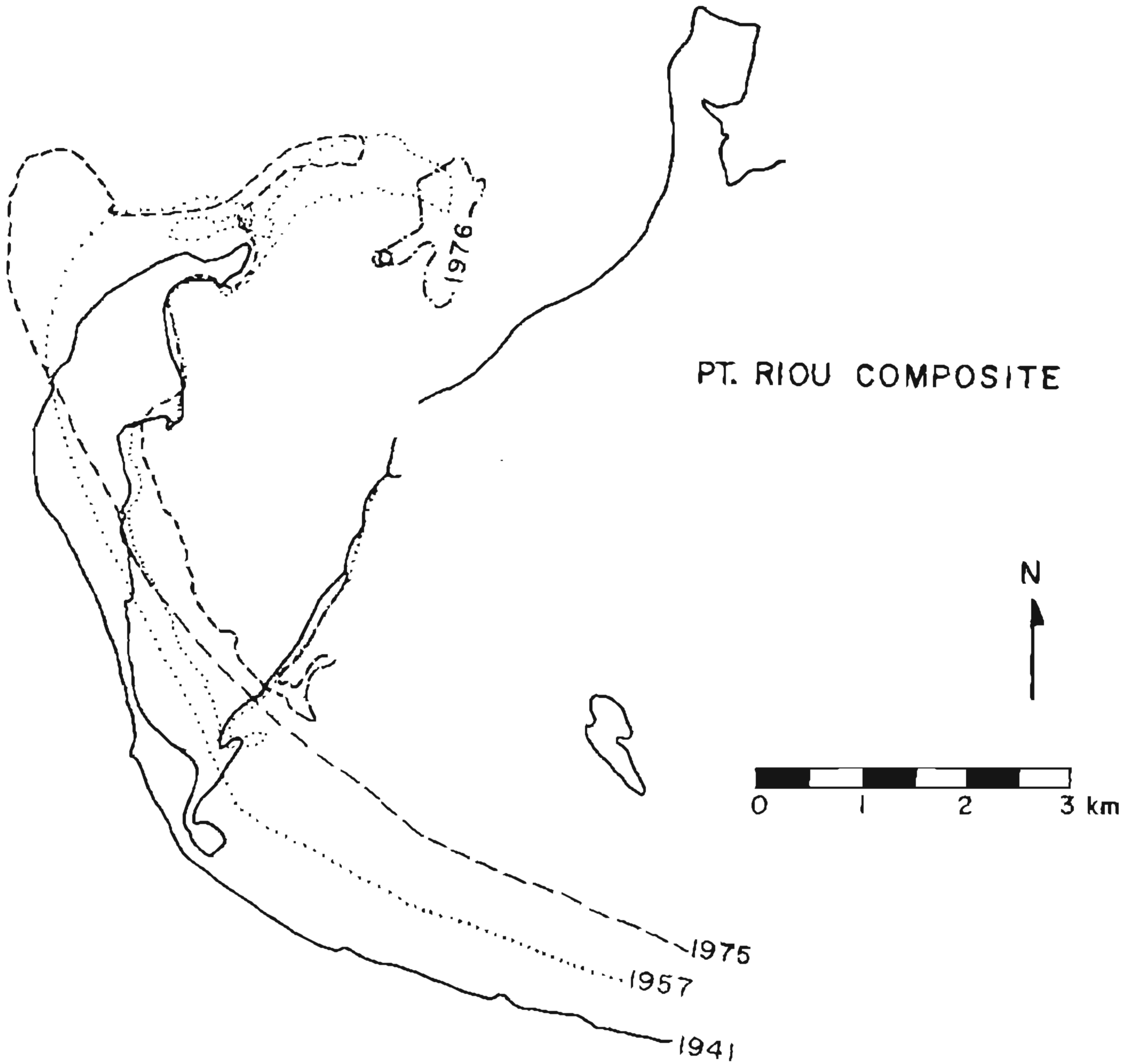

Figure 4. Sketch map of the Point Riou area showing the position of the Gulf of Alaska coastline and Point Riou Spit in 1922, 1941, 1957 and 1975. The size and location of Severed Bar in 1976 are also shown. Shoreline positions are based on aerial photographs and nautical charts. (Molnia, 1977).

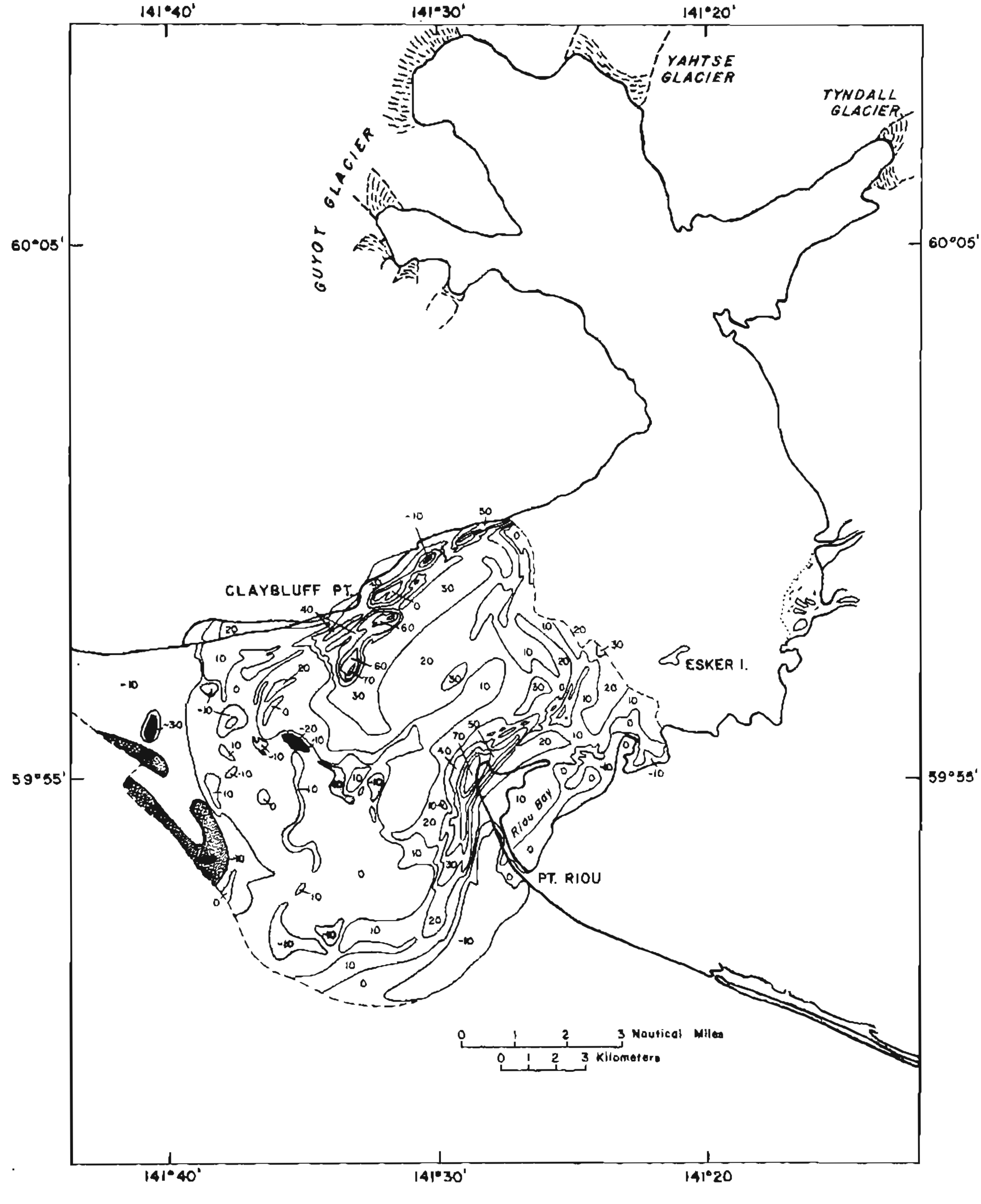

Figure 5. Sketch map of Icy Bay showing changes in bathymetry in lower Icy Bay between 1922 and 1976. The shaded areas at the bay mouth represent locations where water depth has increased, possibly as a result of melting of ice in the 1904 moraine. North of the bay mouth, changes in depth are primarily due to accumulation of sediment. Between 1922 and 1976, the 460 km^2 of the lower bay accumulated 4.8 km^3 of sediment, an average sediment increase of slightly over 10 m. More than 75 m of sediment accumulated at Crested Point of Point Riou and more than 60 m accumulated just east of Claybluff Point.

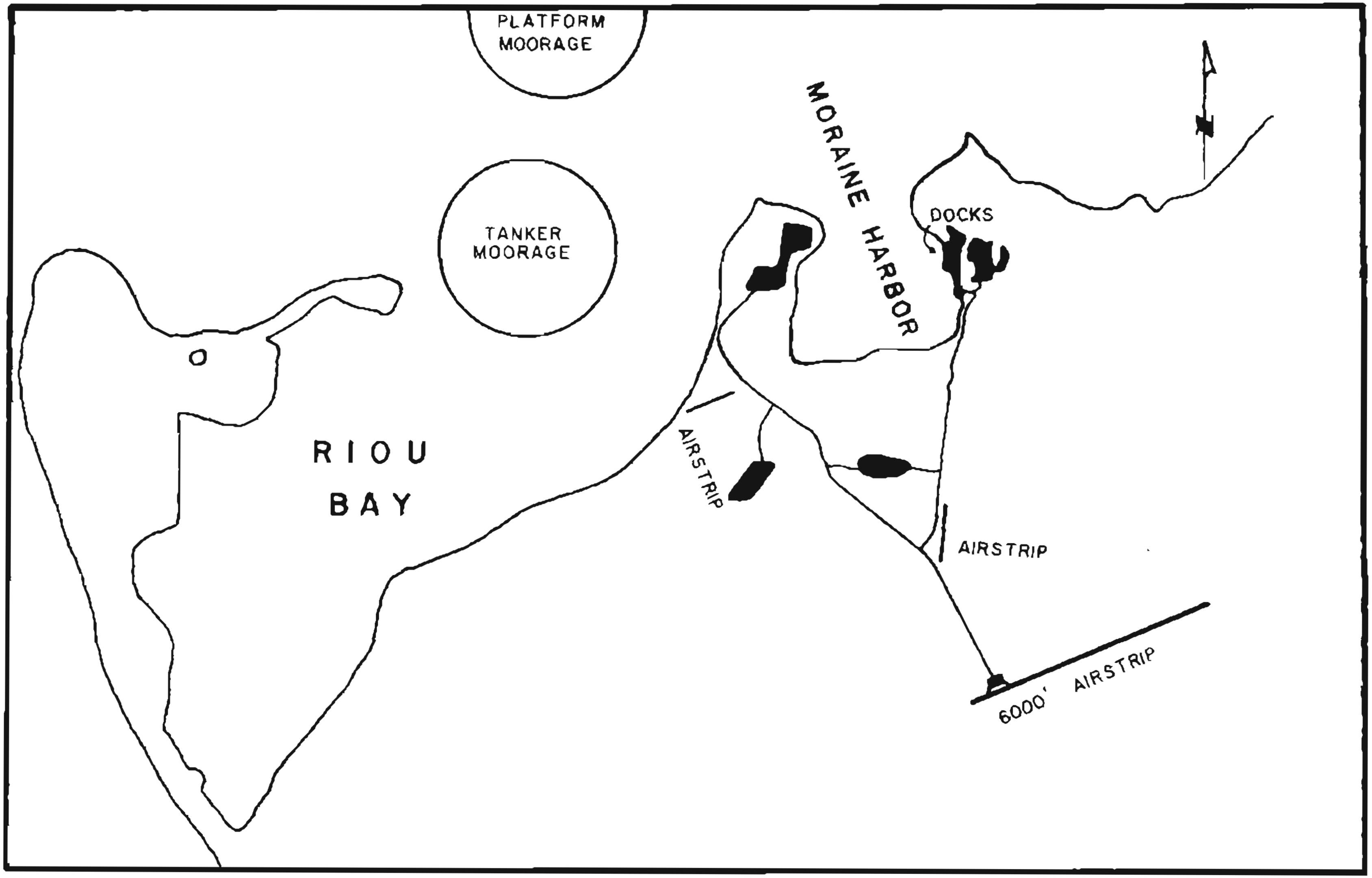

Figure 6. Sketch map of Riou Bay and Moraine Harbor areas showing the location of proposed developments. Black shaded areas represent the location of warehouses, housing complexes, commercial facilities air strips, and roads.