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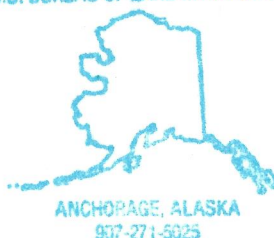


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RAPID SHORELINE EROSION AND RETREAT AT ICY BAY, ALASKA - A STAGING AREA FOR OFFSHORE PETROLEUM DEVELOPMENT

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ABSTRACT

Icy Bay is the only sheltered bay near many of the offshore tracts that were leased for petroleum exploration in the April 1976 northern Gulf of Alaska OCS 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.

The glacier that once filled Icy Bay has receded more than 40 km since 1904, when the bay was completely ice-covered. A large hooked spit, Point Riou Spit, has developed on the eastern shore of the bay mouth within the limits of the terminal moraine and has grown to a length of 6.6 km (an average growth rate of 92 m/y). The Gulf of Alaska shoreline on the east side of Icy Bay, which includes the Malaspina Foreland and Point Riou Spit complex, has been steadily eroded northward by waves and long-shore currents. Analysis of ten sets of aerial photographs taken since 1941 indicate that the eastern shoreline has receded as much as 1.3 km in this 35-year period, an average rate of retreat of 37 m/y. The western shoreline has also changed similarly; over 8.2 km² have disappeared, including all of Guyot Bay.

Field observations during 1976 revealed that the eastern section of Point Riou Spit is frequently washed over by storm waves and is filling in the Riou Bay portion of Icy Bay with sediment. At the point where the spit attaches to the Malaspina Foreland, a forest with trees at least 90 years old is being undercut by wave erosion. If pipelines or any onshore staging

facilities are to be placed in the areas of Point Riou, Riou Bay, or the Malaspina Foreland, then the dynamic changes in shoreline position must be considered so that man-made structures will not be eroded away or silted in before the completion of development.

INTRODUCTION

Icy Bay, Alaska (Fig. 1), a north-trending fiord adjacent to the Gulf of Alaska, lies 20-80 km from the majority of potentially rich offshore tracts leased in the April 1976 Northern Gulf of Alaska 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. Its location and the protection it can offer have made it a logical candidate for consideration as 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 Island 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') 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.

The U. S. Geological Survey has been 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

References and illustrations at end of paper

history, was one area selected for detailed evaluation. This paper reports on the dynamics of the erosion and deposition processes in the Icy Bay area and relates these findings to proposed developments in eastern Icy Bay.

HISTORY OF ICY BAY

The history of Icy Bay is quite dynamic. As recently as 1904, today's Icy Bay did not exist. In 1794, 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, glacial-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 this bay Point Riou. The infilling of this second bay (referred to as Vancouver's Icy Bay by Alpha 1975) is not well documented, but based on Belcher's (1843) observations, by the middle of the last century Vancouver's Icy Bay no longer existed.

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). Rough calculations show that over 0.5 km³ of sediment would be needed to fill the bay charted by Tebenkof. The infilling must have occurred between 1807 and 1838, or within about 30 years.

By 1886, Guyot Glacier had again advanced (Seton-Karr 1887) to a position over 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).

This study will examine the changes taking place in Riou Bay, Point Riou, and the eastern and western shorelines. Using the recent history of Icy Bay as a data base, projections will be made for areas being considered for petroleum-related development.

METHOD

The development of the Point Riou area was evaluated from vertical and oblique aerial photographs, USGS topographic maps, and from NOAA nautical charts. During the period 1941 - 1976, ten separate sets of vertical aerial photographs were made by various U. S. government and state agencies and private contractors. These were projected to a common scale and traced using Salzman Projectors and rephotographed to approximately the same scale. Common reference points were found (Fig. 2) and used to align overlays traced from each photograph, so comparisons of erosion and deposition could be made. Two U. S. Coast and Geodetic Survey triangulation stations originally established in 1922 (U. S. Coast and Geodetic Survey, 1922) were located. The distance between them was determined so that lengths measured on the photographs could be recalculated as true distances on the ground. Tidal heights at the time each photograph was made were determined for all aerial photographs and considered in evaluation of rates and locations of areas of deposition and erosion. Measurements were made using a compensating polar planimeter to calculate area, and these were compared to bathymetric data to calculate volume of sediment either deposited or eroded. Lengths were measured with a flexible ruler and converted to ground distance. Two separate sets of calculations were used to determine shoreline change. One set was generated from the air photographs listed below, which covered the period 1941 - 1976. The second set was based on three editions of the NOAA and U. S. Coast and Geodetic Survey Icy Bay 1:40,000 nautical chart (present number 16741, old number 8457), covering the period 1922-1971. The data from the two independent sources were then compared. A field check of the area was made in June 1976 from the Geological Survey's environmental research ship R/V Sea Sounder.

The vertical aerial photographs evaluated are as follows:

27 May 1941 U. S. Coast and Geodetic Survey
nine-lens series 05651
30 June 1948, U. S. Navy Mission SEA - 47
26 July 1954, U. S. Air Force Mission 4G - 28
11 July 1957, U. S. Air Force Mission 51 AMOI
26 Aug 1970, Alaska Dept. Lands YAK-26
7 June 1971, Nat. Ocean Survey
21 July 1972, U. S. Air Force AF 71-40
15 Aug. 1973, U. S. Air Force AF 71-40
30 Aug. 1975, North Pacific Aerial Surveys, Inc.
24 Aug. 1976, U. S. Geol. Survey 76 VI

This paper will concentrate on data from the 1941, 1948, 1957, 1971, and 1975 photographs, although information from other aerial surveys will be discussed.

The editions of the NOAA and U. S. Coast and Geodetic Survey 1:40,000 Icy Bay nautical chart used were the first (1923), third (1964), and fifth edition (1974).

DESCRIPTION OF NAUTICAL CHARTS

1923 Chart

The 1923 U. S. Coast and Geodetic Survey Chart

(Fig. 4), which is based on a Sept. 5 - 14, 1922 sextant, alidade, and lead line survey shows Point Riou Spit as being 3.18 km long and located in the area of the 1904 terminal moraine. This chart is the oldest known map that shows the eastern shore spit. The area occupied by the spit is 0.98 km² to mean lower low water (m.l.l.w.). The area of Riou Bay is 7.30 km², and the distance across its mouth is 5.52 km. This is the distance from the north-easternmost tip of the spit to the northwesternmost point on Moraine Island.

The west shore of Icy Bay, adjacent to the west side of the 1904 terminal moraine, is characteristically a low area of sand and mudflats that probably developed as part of the Guyot Glacier outwash plain. Guyot Bay is a large embayment formed by the eastward growth of a sediment spit along the shoreline and flanks of the moraine. Whereas Point Riou Spit has grown over the crest of the moraine and is growing out by infilling in deeper water, the unnamed spit on the west shore is not. This is probably due to an absence of abundant sediment migrating eastward.

The area immediately east of Guyot Bay reaches an elevation of about 12 m (40 feet) above m.l.l.w. From descriptions on the unpublished original 1922 survey (U. S. Coast Geodetic Survey 1922), it appears that this area is underlain by ice-cored moraine. The 1922 chart shows a bulbous island with a sinuous tail developing in open water at the east side of the terminus of Guyot Glacier. The morphology of the island complex resembles an esker with attached delta, and consequently the island is here named Esker Island.

Moraine Island is separated from the Malaspina Foreland by about 150 m of open water. It probably formed as a block of recessional moraine as Guyot Glacier retreated.

1964 Chart

The shoreline on the 1964 Coast and Geodetic Survey chart (Fig. 5) is based on the 1948 U. S. Navy aerial photographs. Point Riou Spit has grown to 6.02 km long and occupies an area of 2.62 km², and Riou Bay has an area of 10.65 km². The most significant changes from the 1923 chart are the growth of Point Riou Spit, the recession of Guyot Glacier, and the erosion of the spit and mudflats on the west shore of Icy Bay. The area shown as Guyot Bay (Fig. 5) is a completely different embayment than that shown on the 1923 chart (Fig. 4). The distance across the mouth of Riou Bay has decreased to 3.27 km. Esker Island is shown with an indistinct shoreline, hence no comparison to the 1923 chart can be made. Moraine Island has become attached to the Malaspina Foreland by development of a tombolo. Depths in Riou Bay are no longer shown on the 1964 chart, so no comparisons can be made or rates of infilling calculated.

1974 Chart

The 1974 NOAA Chart has the same western shoreline as the 1964 chart, but has a new eastern shoreline based on the 1971 NOAA aerial photographs. Point Riou Spit has decreased in length to 5.96 km, but a 1-km long bar, probably separated from the spit by a major storm, lies 1 km to the east of

the present spit's tip. The area of the spit has increased to 2.73 km² (exclusive of the bar).² The area of Riou Bay has decreased to 9.00 km² and its mouth is now 3.39 km across. With the exception of bathymetry measured by the U. S. Coast Guard in 1971 and the Geological Survey in 1970, the bathymetry shown on the 1974 chart is identical to that of the 1922 survey. Esker Island has been resurveyed and has essentially the same configuration as shown in 1922. Table I summarizes the pertinent data derived from the nautical charts. Figure 5 is a composite diagram showing the comparative positions of the important coastal features from the three charts. Figure 6 is a similar composite of the Point Riou shoreline drawn from three of the aerial surveys (1941, 1957, and 1975) and the 1923 nautical chart.

DESCRIPTION OF AERIAL PHOTOGRAPHS OF THE EASTERN SHORE

Although photographic coverage also exists from 1941 to 1975 for the shoreline on the west side of Icy Bay, this paper will concentrate on the eastern shore, the area proposed for petroleum-related development. Photographs that were evaluated in detail were made in 1941, 1948, 1957, 1971, and 1975. Other measurements were made on photographs made in 1954, 1970, and 1976.

1941 - The 1941 Coast and Geodetic Survey photograph (Fig. 7) was made when the tidal height was 8.3 feet (2.5 m) above m.l.l.w. This photograph is a composite from a nine-lens camera. A sketch map drawn from the photograph (Fig. 8) shows Point Riou Spit to be 5.29 km long and to occupy an area of 1.89 km². Riou Bay has an area of 9.24 km² and a mouth width of 3.73 km. Moraine Island is predominantly unvegetated and is attached to the Malaspina Foreland by a tombolo. A sandy beach a few hundred meters wide fronts the Gulf of Alaska as far as the eastern edge of the photograph at the Yahtse River. Data from the measurement of aerial photographs are summarized in Table II.

1948 - The 1948 Navy photograph (Fig. 9) was taken when the tidal height was approximately three feet (~ 1m) above m.l.l.w. A sketch map (Fig. 10) shows the length of Point Riou Spit to have increased to 5.53 km while its area increased to 2.34 km². When compared to 1941, this represents a growth rate of 34 m/yr (Table III) and a 24 percent increase in area. The area of Riou Bay has decreased to 9.14 km² and the distance across its mouth has decreased to 2.98 km. The width of exposed sandy beach has decreased by about 40 percent from the 1941 photograph.

1957 - The 1957 Air Force photograph (Fig. 11) was taken when the tide was 2.9 feet (0.9 m) above m.l.l.w.. A sketch map (Fig. 12) shows that the length of Point Riou Spit has increased to 8.86 km and its area to 2.69 km². This represents an average growth rate of 148 m/y between 1948 and 1957. Riou Bay occupies an area of 8.55 km² and its mouth width has decreased to 2.20 km.

1971 - The 1971 NOAA photograph (Fig. 13), made when the tide was 3.5 feet (1.1 m) above m.l.l.w., and the sketch map (Fig. 14) show Point Riou Spit to be broader and shorter than in 1957. A linear

bar, 1 km long, with a bulbous end to the southwest and a northwest-trending hook at its north tip, now occupies a part of the area that in 1957 was occupied by the east end of Point Riou Spit. The bar, here named Severed Bar, lies about 1 km east of the end of the spit. Observations made on June 12, 1976, indicate that a tidal height of about 6 feet (2 m) above m.l.l.w. is necessary to completely submerge the bar. Severed Bar trends parallel to Moraine Reef but appears to be separate from it.

Between 1957 and 1971, the westernmost edge of the spit has developed a rounded knob which projects out into what were open water depths of 18 - 70 m (10 - 40 fms) on the 1923 nautical chart. This area, here named Crested Point, gives the hooked end of the spit a profile similar to the head shape of the late Mesozoic dinosaur Corythosaurus. This profile continues through the present.

In spite of losing Severed Bar, Point Riou Spit has about the same area as in 1957 (2.70 km²) but has decreased in length to 5.53 km. The area of Riou Bay (8.94 km²) and the width of its mouth (3.6 km) have both increased (Table II).

No photographic coverage has been found for the period 1957 - 1970, but considering the rapid rate of spit growth and the large distance of open water between the spit's tip and Severed Bar, the storm that breached the spit and formed Severed Bar probably occurred late in the 1960's. The 1970 photo shows Severed Bar to be about the same size and shape as in 1971, but Point Riou Spit is about 200 m shorter (length 5.34 km) than in 1971. The Riou Bay mouth measured 3.25 km in 1970.

1975 - The 1975 North Pacific Aerial Survey photograph (Fig. 15) was made when the tide was 5.7 feet (1.75 m) above m.l.l.w. On the sketch map (Fig. 16), only a small area of the southwest part of Severed Bar is emergent, although its outline can be seen as a darker area on the photograph. The shape of Point Riou Spit is similar to that of 1971, with the exception that Crested Point has become more rounded and the embayment below the growing northeasternmost projection has been isolated as a saline lake that receives sea water only during storm washover. The spit has grown to a length of 6.48 km and occupies an area of 3.09 km². The area of Riou Bay (8.60 km²) and the width of its mouth (2.70 km) have both decreased but neither have returned to the pre-storm dimensions of 1957. Measurements of incomplete 1976 Geological Survey photographs show a further increase in the spit's length to 6.60 km and a decrease of the bay mouth to 2.54 km. Areas could not be calculated from the 1976 photographs.

The most striking change between the 1975 photograph and earlier ones is the absence of sandy beach south of Reference Lake. June 1976 field observations of the Gulf of Alaska coastline immediately east of Riou Bay (Fig. 17) showed waves and surf breaking on the forested Malaspina Foreland. Recently deposited sand was found carpeting the forest floor behind the southeastern extension of the spit (Fig. 18). A large number of fallen trees, generally oriented with their roots toward the Gulf of Alaska and their trunks toward Riou Bay, have eroded from the Malaspina Foreland. Three ring counts of two of the larger trees yielded ages of about 90 years.

COMPARISONS AND INTERPRETATION OF NAUTICAL CHARTS AND AERIAL PHOTOGRAPHS

Interpretations of the nautical charts and of the various aerial photographs both lead to the same conclusions but to different magnitudes. Both the aerial photographs and the nautical charts show that presently Point Riou Spit is growing, Riou Bay's area is decreasing, and the Gulf of Alaska shoreline of Icy Bay is rapidly eroding and receding northward.

Values derived from the nautical charts are consistently greater than values from the same year's aerial photographs. This is due to two factors: (1) a difference in tidal reference points; and (2) a difference in base distances.

All aerial photographic surveys were made when tidal heights were above m.l.l.w. The range is from 2.9 (1957) to 8.3 (1941) feet (0.9 - 2.5 m) above m.l.l.w. The nautical charts are based on a shoreline supposedly corrected for m.l.l.w. Consequently lengths and areas calculated from nautical chart shorelines are greater than those from the same year's aerial photographs. For Point Riou beaches, which have slopes of between 3° and 5°, a one-foot (0.3 m) reduction in tidal heights will expose 3.4 to 5.7 meters of beach. The 1941 aerial photograph, the earliest used in this study, has the highest tidal height of all. Consequently, less shoreline is exposed than would be if the tidal height were equal to that of any of the more recent photographs. Since all other photos are compared to the 1941 shoreline, this means that the numbers calculated for shoreline erosion and retreat are lower than the actual area lost.

Measurements of distances on the 1964 and 1974 nautical charts are 7 - 10 percent greater than on the 1959 USGS topographic map used for ground truth for the aerial photographs. On this map, the distance from the northwest corner of Moraine Island to the southeast edge of Reference Lake is 5.84 km and the distance from the Moraine Island to the eastern edge of Intermediate Lake is 2.62 km. On the nautical charts these distances are 6.24 km and 2.85 km respectively.

SUMMARY OF CHANGES AT ICY BAY

Between 1941 and 1976 the Gulf of Alaska shoreline of the eastern shore of Icy Bay receded at least 1.3 km (Fig. 6). Between 1922 and 1976 the same shoreline receded as much as 1.5 km (Fig. 5). The latter number is presented with less confidence than the former due to the less than precise nature of the 1922 sextant, alidade, and lead-line survey.

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 (6.60 km) had almost reached its pre-storm length. Table III summarizes the incremental growth of Pt. Riou Spit. Between 1922 and 1957 the width of Riou

Bay's mouth and its area have steadily decreased. Following the major storm, Riou Bay's area and width have again been decreasing (Table II). 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 undergone significant changes. Between 1922 and 1976 the shoreline has retreated as much as 4.8 km with a loss of more than 8.2 km². As the recent charts show no bathymetry in the area of change, no volume of sediment lost has been calculated.

Vancouver's Icy Bay, which existed until about 1837, was filled in with sediments in less than 40 years. Calculations based on Tgebekoff's (1848) chart indicate about 5×10^8 m³ of sediment would be needed to raise the bottom to m.l.l.w. The growth in Point Riou Spit between 1922 and 1975 would require over 3.56×10^7 m³ of new sediment.

The sediment being added to Pt. Riou Spit probably comes from two sources, the eroded Malaspina Foreland and the streams draining the Malaspina Glacier system. Sediment is transported into the Point Riou system by long-shore drift and wave action.

The sediment eroded from the western shoreline may have been transported into Icy Bay and deposited on the growing shoreline near Claybluff Point. It might also remain in the vicinity of Guyot Bay but be below sea level because of melting of stagnant ice underlying the western shore. The sediment that rapidly filled Vancouver's Icy Bay must have come from the Malaspina system. To date, no detailed investigations have attempted to determine its source.

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) long-shore 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 which had previously been deposited in deep water adjacent to Point Riou Spit, been attached to the spit, or entered Riou Bay would continue along the face of Moraine Island and enter Moraine Harbor, the major site for proposed development (Fig. 19). Moraine Harbor will fill in within 15 years if sedimentation continues at the rate calculated for Point Riou Spit between 1922 and 1974. (Human intervention could prolong the life of Riou Bay and Moraine Harbor,

but this has not been considered in the calculations.)

This assumption is based on the calculation of the volume of sediment added to Point Riou Spit between 1922 and 1974, and the calculation of the area of Moraine Harbor. Between 1922 and 1974, Point Riou Spit increased in area by 1.75 km². The average water depth in which the spit grew was 20.35 m (11.13 fm). This number was obtained by contouring the open water depths on the 1923 nautical chart which are now occupied by the spit. Consequently, over 3.56×10^7 m³ of sediment were added to Point Riou Spit during the period in question. This calculation is conservative because (1) the spit actually projects a significant distance above the upper limit calculated for m.l.l.w., and (2) the 1974 NOAA chart actually shows a 1971 shoreline. Available NOAA data and bathymetry from Bomhoff and Associates (1976) used to calculate the volume of Moraine Harbor indicate that 9.55×10^8 m³ of sediment would fill Moraine Harbor to m.l.l.w. Using the depositional rate calculated for Point Riou Spit, 6.84×10^5 m³/yr, the life of Moraine Harbor would be 14.0 years.

Even before the attachments 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.

CONCLUSIONS

(1) The Gulf of Alaska shorelines at either side of Icy Bay have been eroding and retreating since the deglaciation of Icy Bay began in 1904.

(2) The Malaspina Foreland shoreline to the east of the bay mouth has been eroded back more than 1.3 km since 1941 and as much as 1.5 km since 1922.

(3) The western shoreline has retreated at least 4.8 km since 1922, and between 1922 and 1976 lost an area of more than 8.2 km².

(4) Point Riou Spit began developing as soon as longshore sediment transport was able to supply sediment to the area that the ice occupied in 1904. By 1922, it had reached a length of 3.18 km. By 1957, it had grown to 6.86 km. A major storm between 1957 and 1971 shortened the spit by breaching it, and formed Severed Bar. In 1976, Point Riou Spit was 6.60 km long.

(5) If Point Riou Spit continues to grow at its present rate, it will seal off the mouth of Riou Bay within 20 years. Further sedimentation will fill in Moraine Harbor, the proposed site for the Chugach Natives, Inc., development, about 15 years after sealing Riou Bay.

(6) Between 1922 and 1971, sedimentation added over 3.56×10^7 m³ of sediment to Point Riou Spit. This included the growth of the spit into an area where previously over 40 fms (~75 m) of open water existed.

(7) Vancouver's Icy Bay was filled in by sediment probably during the period between 1807 and 1837. Available bathymetry and geography imply that this would require a sediment volume of about 5×10^8 m³.

(8) Before any attempts are made to construct major staging or related facilities in dynamic areas such as Icy Bay, the total sediment picture including areas of erosion and deposition, must

be carefully evaluated. The proposed facilities could be silted in long before the Gulf of Alaska offshore development is completed.

NOMENCLATURE

The names Crested Point, Esker Island, Intermediate Lake, Reference Lake, and Severed Bar have not as yet been formally accepted by the Board on Geographic Names. Applications have been submitted to formalize each of the above names, and their use here is in accordance with Board on Geographic Names policy.

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U. S. Geological Survey 1959, Icy Bay (D2-D3) quadrangle, Alaska, topographic map, scale 1:63,350.

TABLE I.

DATA DERIVED FROM ICY BAY NAUTICAL CHARTS

Edition	Point Riou Spit length (km)	Spit area (km ²)	Area of Riou Bay (km ²)	Width of Riou Bay Mouth (km)
1st (1922 data)	3.18	.98	7.3	5.52
3rd (1948 data)	6.02	2.62	10.65	3.27
5th (1971 data)	5.96	2.73	9.00	3.39

TABLE II.
SUMMARY OF DATA FROM AERIAL PHOTOGRAPHS

Date of Photograph	Point Riou Spit length (km)	Spit area (km ²)	Area of Riou Bay (km ²)	Width of Riou Bay mouth (km)
1941	5.29	1.89	9.24	3.73
1948	5.53	2.34	9.14	2.98
1954	6.85	2.52	8.55	2.36
1957	6.86	2.69	8.55	2.20
1970	5.34	*	*	3.25
1971	5.53	2.70	8.94	3.06
1975	6.48	3.09	8.60	2.70
1976	6.60	*	*	2.54

TABLE III.
INCREMENTAL GROWTH OF POINT RIOU SPIT, 1904-1976

1904 - 1922	177 m/yr
1922 - 1941	100 m/yr
1941 - 1948	34 m/yr
1948 - 1954	220 m/yr
1954 - 1957	3 m/yr
1957 - 1971	-95 m/yr
1971 - 1975	238 m/yr
1975 - 1976	169 m

*incomplete photo coverage.

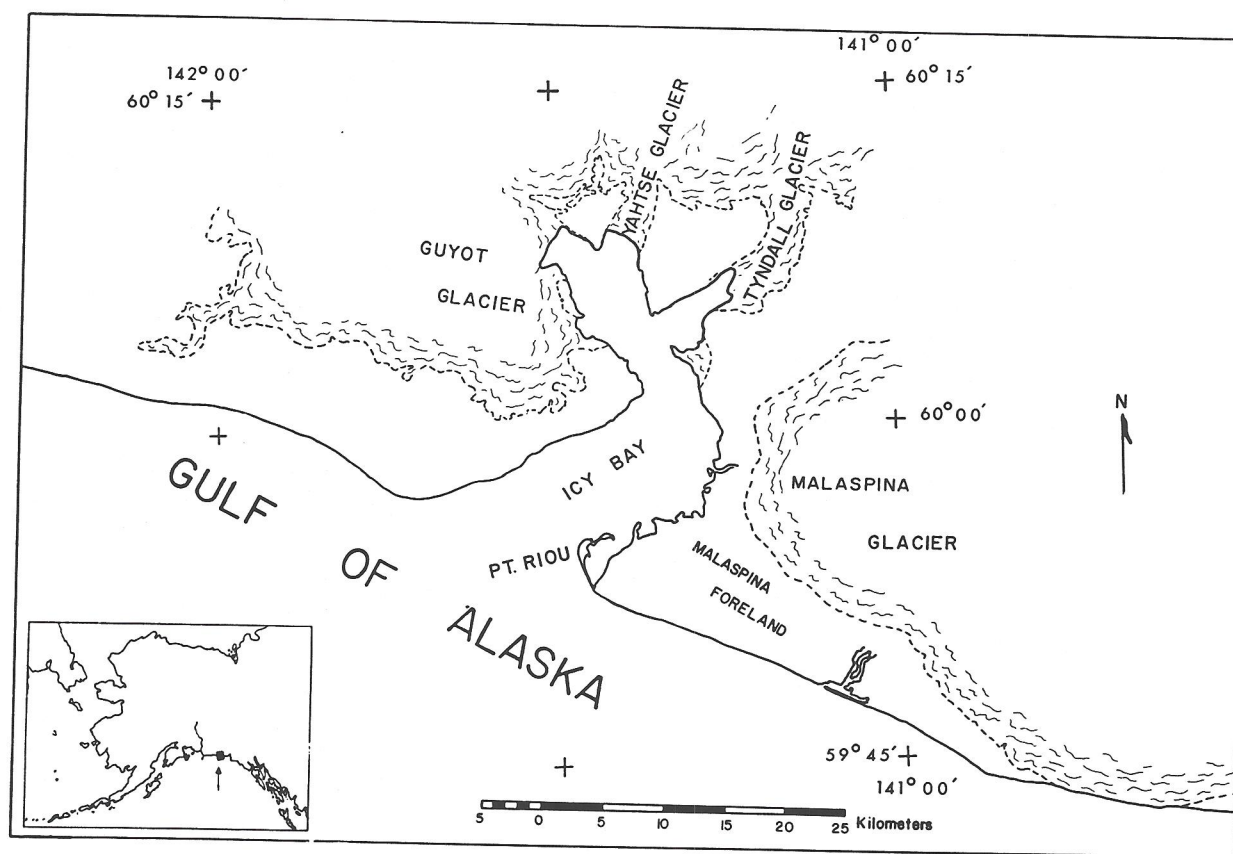


Fig. 1 - Map of Alaska showing the location of Icy Bay.

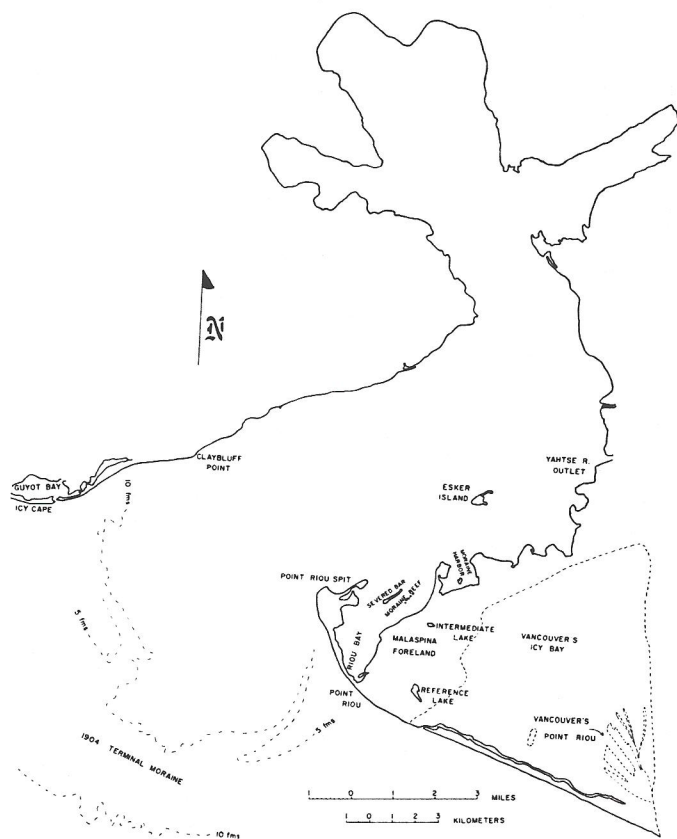


FIG. 2 - THE ICY BAY AREA SHOWING THE LOCATION OF GEOGRAPHIC FEATURES DISCUSSED IN THIS PAPER.

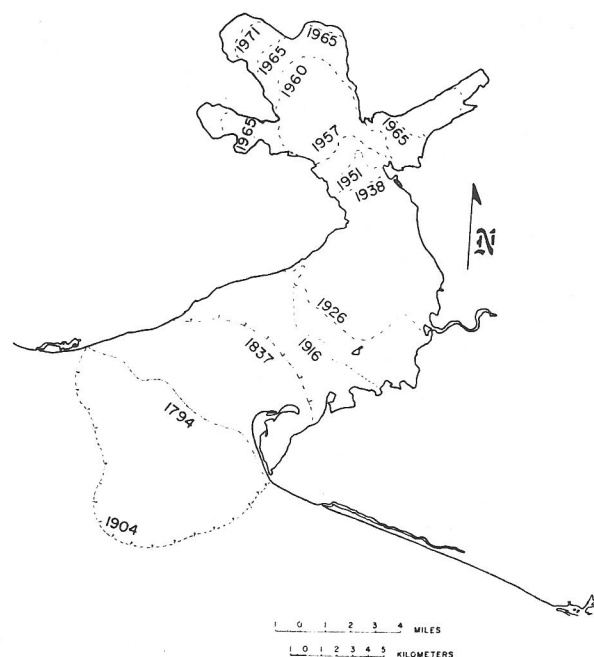


FIG. 3 - POSITIONS OF THE ICE FRONT OF GUYOT GLACIER, ICY BAY (MANY ICE FRONT POSITIONS FROM UNPUBLISHED FILES OF A.S. POST).

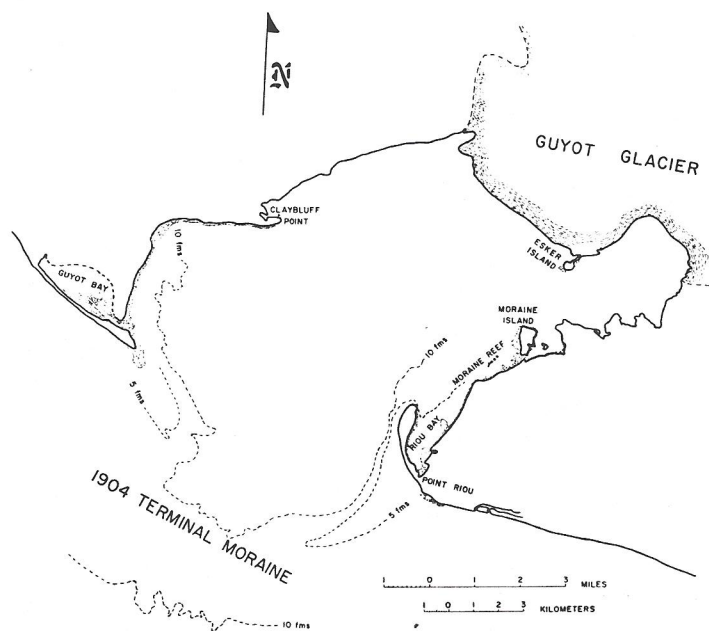


FIG. 4 - TRACING OF THE 1923 U. S. COAST AND GEODETIC SURVEY ICY BAY NAUTICAL CHART.

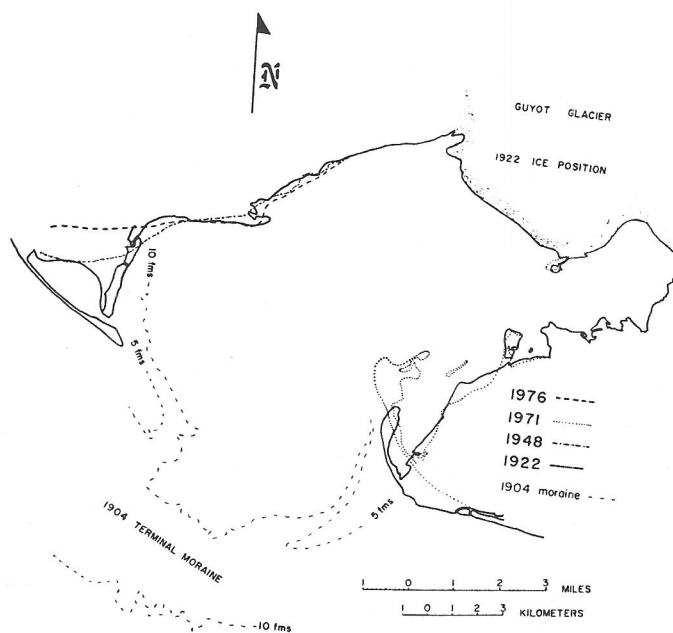


FIG. 5 - DIAGRAM BASED ON THE 1923, 1964 AND 1974 ICY BAY NAUTICAL CHARTS SHOWING THE RELATIONS OF MAJOR SHORELINE FEATURES.

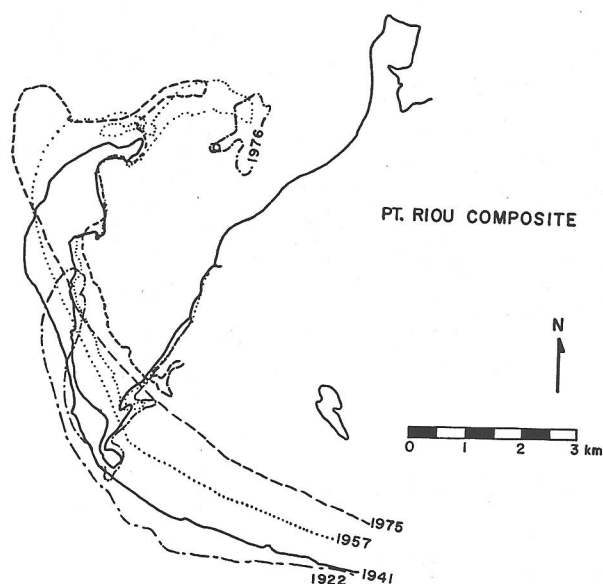


Fig. 6 - Composite diagram showing the position of shorelines determined, for the Point Riou area, from aerial photographs and the 1923 Nautical Chart.

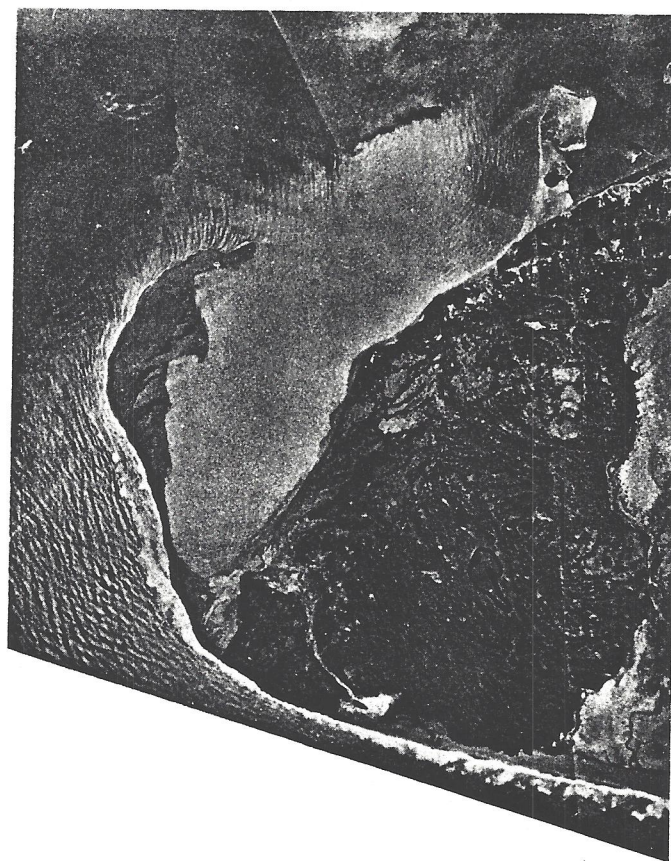


Fig. 7 - 1941 vertical aerial photograph of the Point Riou area.

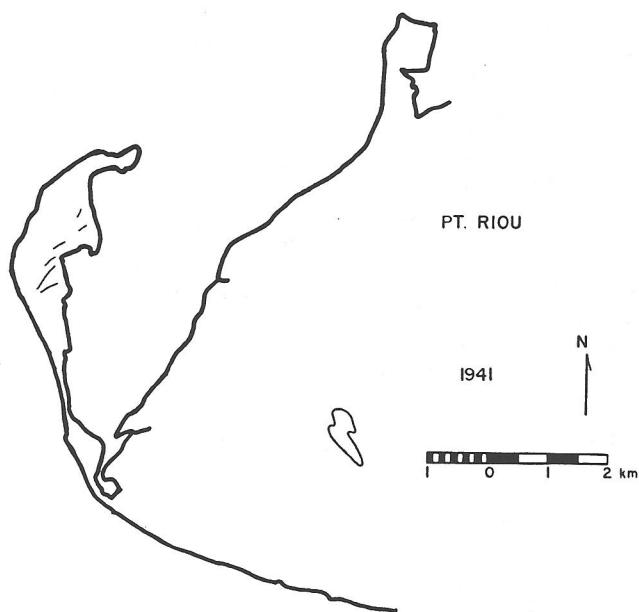


Fig. 8 - Sketch of the 1941 aerial photograph.

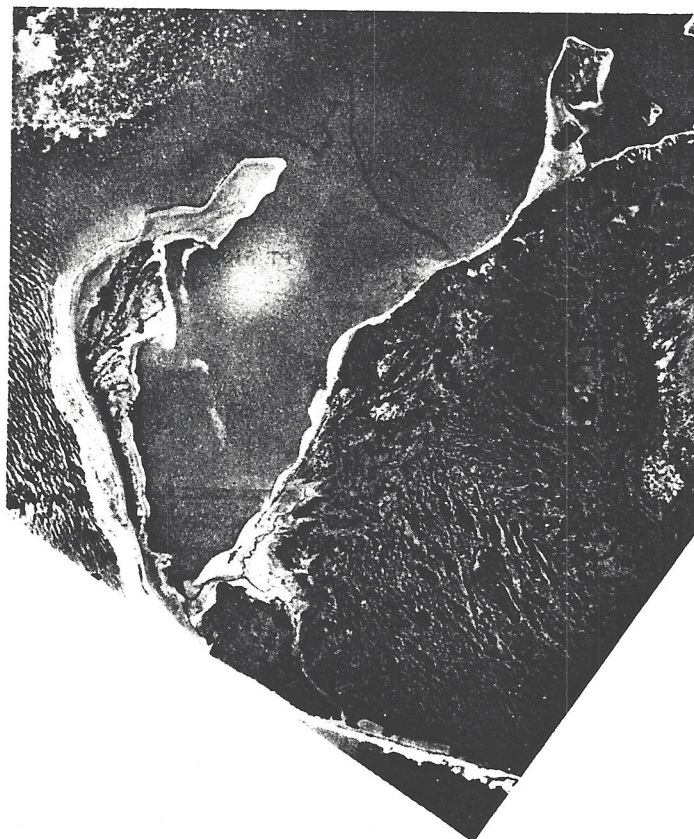


Fig. 9 - 1948 vertical aerial photograph of the Point Riou area.

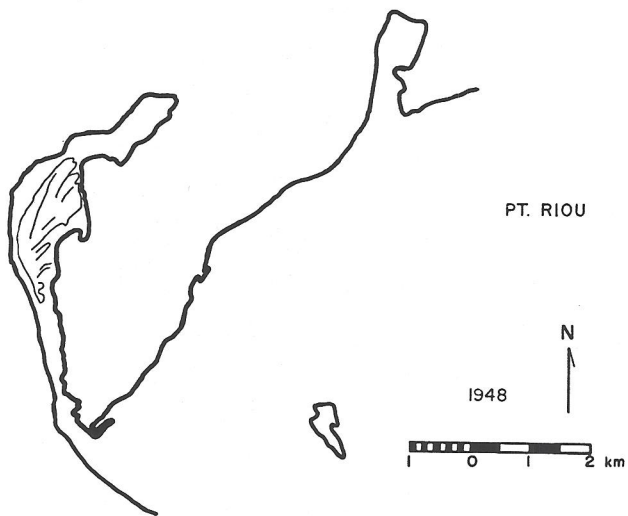


Fig. 10 - Sketch of the 1948 aerial photograph.

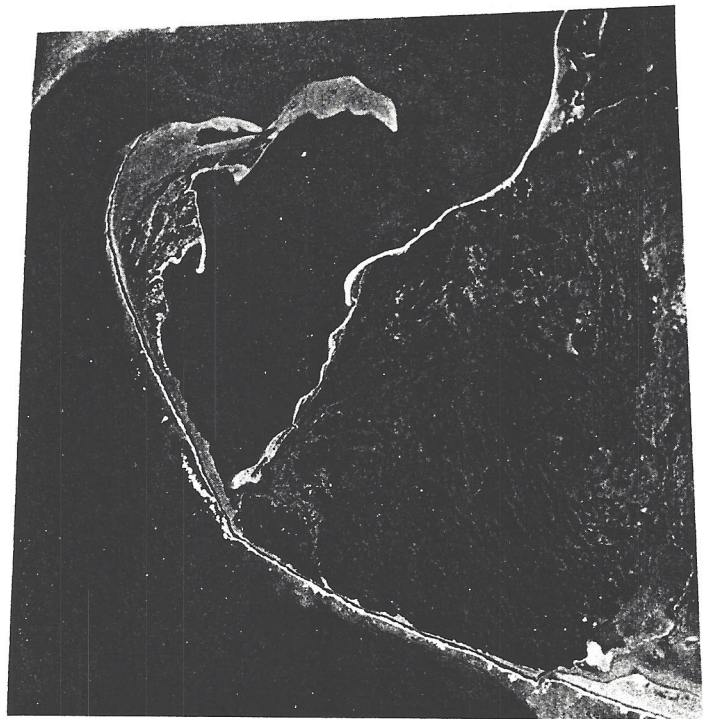


Fig. 11 - 1957 vertical aerial photograph of the Point Riou area.

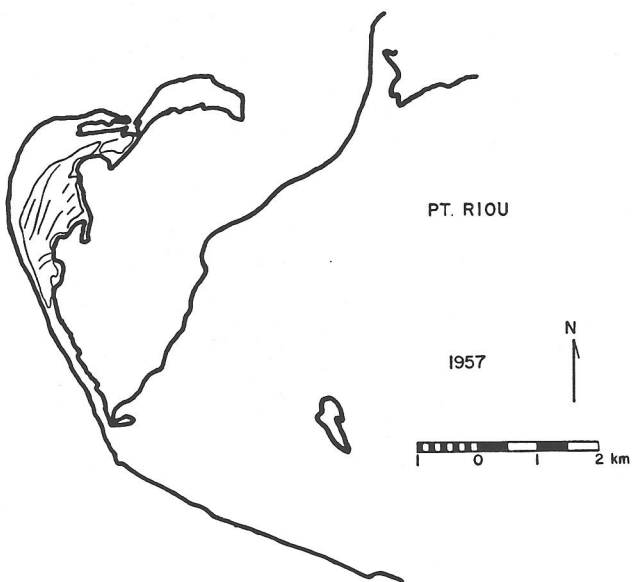


Fig. 12 - Sketch of the 1957 aerial photograph.

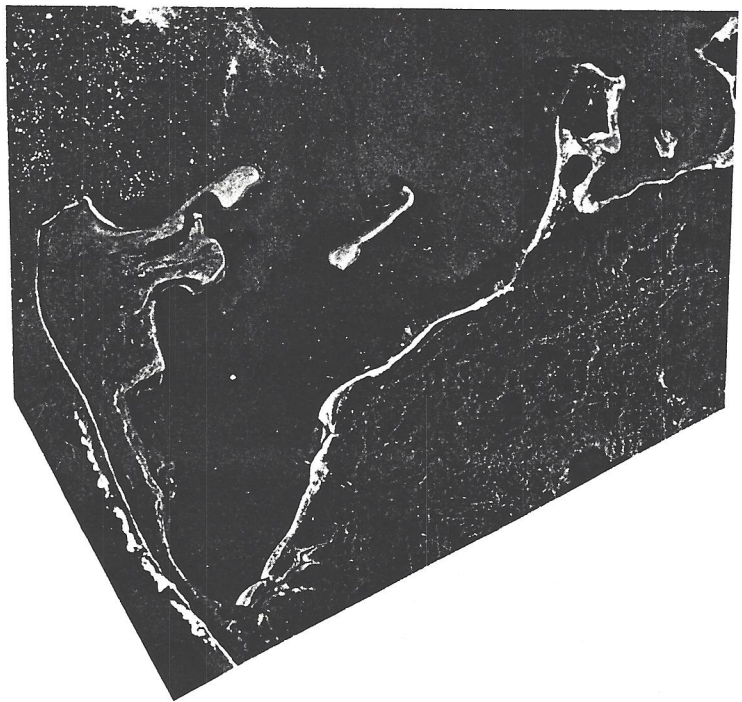


Fig. 13 - 1971 vertical aerial photograph of the Point Riou area.

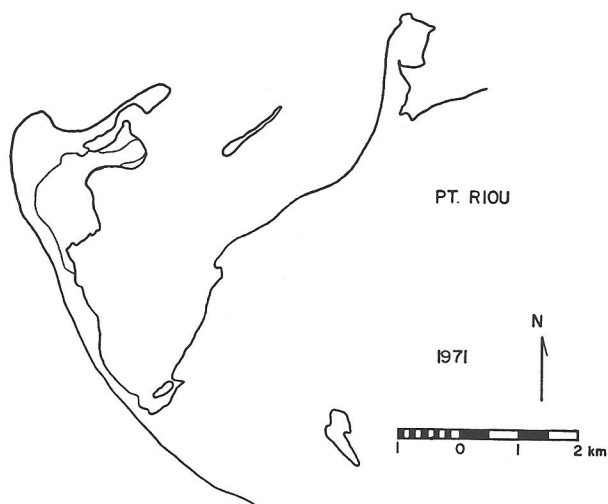


Fig. 14 - Sketch of the 1971 aerial photograph.



Fig. 15 - 1975 vertical air photograph of the Point Riou area.

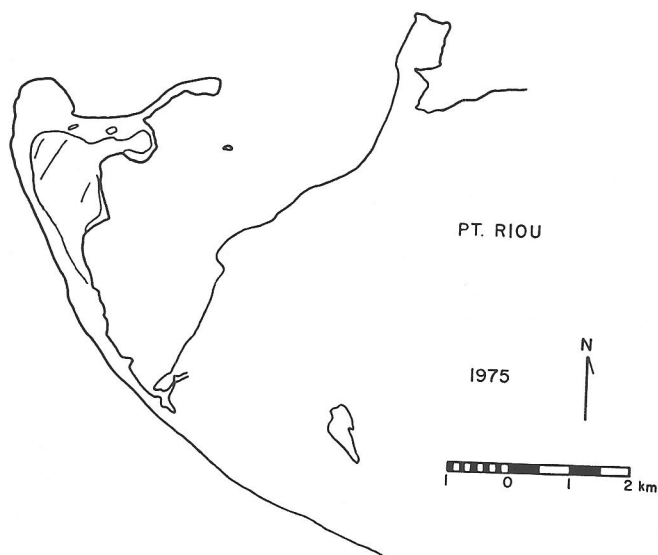


Fig. 16 - Sketch of the 1975 aerial photograph.

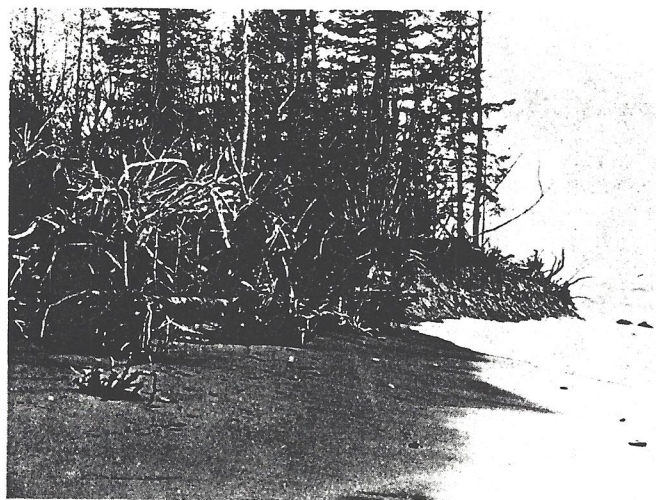


Fig. 17 - Ground view east of Point Riou showing active wave erosion (June 1976).

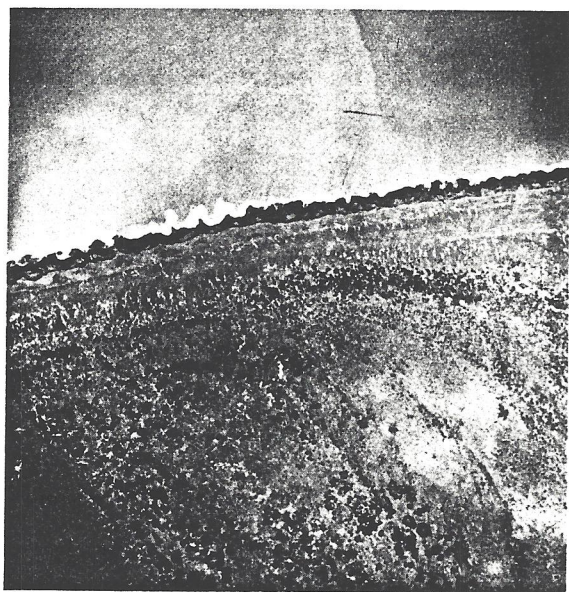


Fig. 18 - 1976 low vertical aerial photograph east of Point Riou showing wave-aligned trees along Malaspina Foreland.

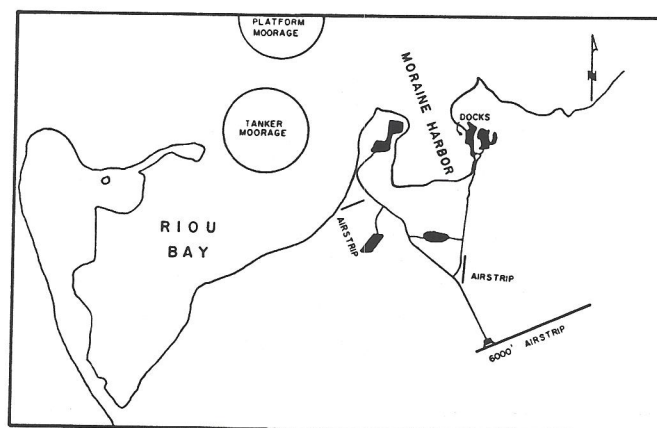


Fig. 19 - Map showing proposed development of Chugach Natives Inc., at Icy Bay (Bomhoff and Associates 1976).