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DEVELOPMENT OF SUBMARINE PHYSIOGRAPHY  
IN THE CANADIAN ARCTIC AND ITS  
RELATION TO CRUSTAL MOVEMENTS.

by

B. R. PELLETIER  
(Geological Survey of Canada)

REPORT B.I.O. 64-16

DECEMBER 1964

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THE CANADIAN COMMITTEE ON OCEANOGRAPHY

B E D F O R D   I N S T I T U T E   O F   O C E A N O G R A P H Y  
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DEVELOPMENT OF SUBMARINE PHYSIOGRAPHY  
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INTRODUCTION

This report deals primarily with the development of submarine physiography in the Canadian Arctic (Figure 1), and is based on the hypothesis of Fortier and Morley (1956), that the Arctic Archipelago is a geological unity and that the network of inter-island channels is a submerged river system of tertiary age which previously drained a continuous land mass (Figure 2). The new soundings, and the paleontological and lithological evidence obtained with bottom grabbers and cores, offer additional support to the general theory of terrestrial erosion of a pre-existing single land mass by streams. Certain lines of topographic evidence indicate that modification of such river valleys by valley glaciers also took place (Pelletier 1961, 1962, 1963, and Horn 1963), and was followed by widespread submergence. This submergence was followed by an interval of post-Pleistocene emergence, according to the comprehensive study of relict strand lines and raised marine deposits carried out by Craig and Fyles (1960). This emergence may be continuing although the gravity data by Sobczak (1963) tentatively indicates that the western part of the Archipelago and adjacent continental shelf may be in isostatic equilibrium.

ACKNOWLEDGMENTS

The writer wishes to thank his many associates on the Canadian Polar Continental Shelf Project who gave willingly of their time and effort in affording logistical support and material aid in the undertaking of the studies carried out over the Arctic Ocean; E. F. Roots, the coordinator; F. DuVernet, the former field supervisor now deceased; C. Grant, the present supervisor; field officers of the Department of Mines and Technical Surveys, particularly the Project's former oceanographer, A. E. Collin, the senior hydrographer R. M. Eaton, surveyor F. H. Hunt, and geologists D. R. Horn and G. Vilks. Special mention is made of the crews of Autair Helicopters Limited of Montreal, Quebec, and McMurray Air Services Limited of Uranium City, Saskatchewan, who carried out the assignments of landing parties on hundreds of unprepared landing areas on the Archipelago itself, and on the ice of the Arctic Ocean. The writer owes his thanks to Captain M. V. Clarke of the icebreaker CCGS LABRADOR, and her officers and men who offered the writer every assistance during an oceanographic cruise in the autumn of 1963 into Baffin Bay, Jones Sound, and Nares Strait as far north as Hall Basin.

On the sampling operations over the Arctic Ocean, the writer was assisted by his present departmental associates: K. Abbott-Smith, A. E. Collin, D. R. Horn, R. Lahey, E. L.

Lewis, E. W. Reinhardt, and G. Vilks. On the cruise of the LABRADOR some of the writer's past associates such as, R. Cooper, J. Y. Dugas, T. Lee, P. H. McGrath, and D. Snodgrass were of considerable help in obtaining geological, geophysical, and oceanographic data. In the laboratory, bottom samples were processed by R. Cormier while some of the illustrations were prepared by Miss Sonia Pitcher, Miss Penny Wyse, and Mr. Alan Grant. Finally, acknowledgment is made to Y. O. Fortier and L. W. Morley of the Geological Survey of Canada whose original work led the writer to develop further their hypothesis upon which this report is based.



Figure 1. Index Map

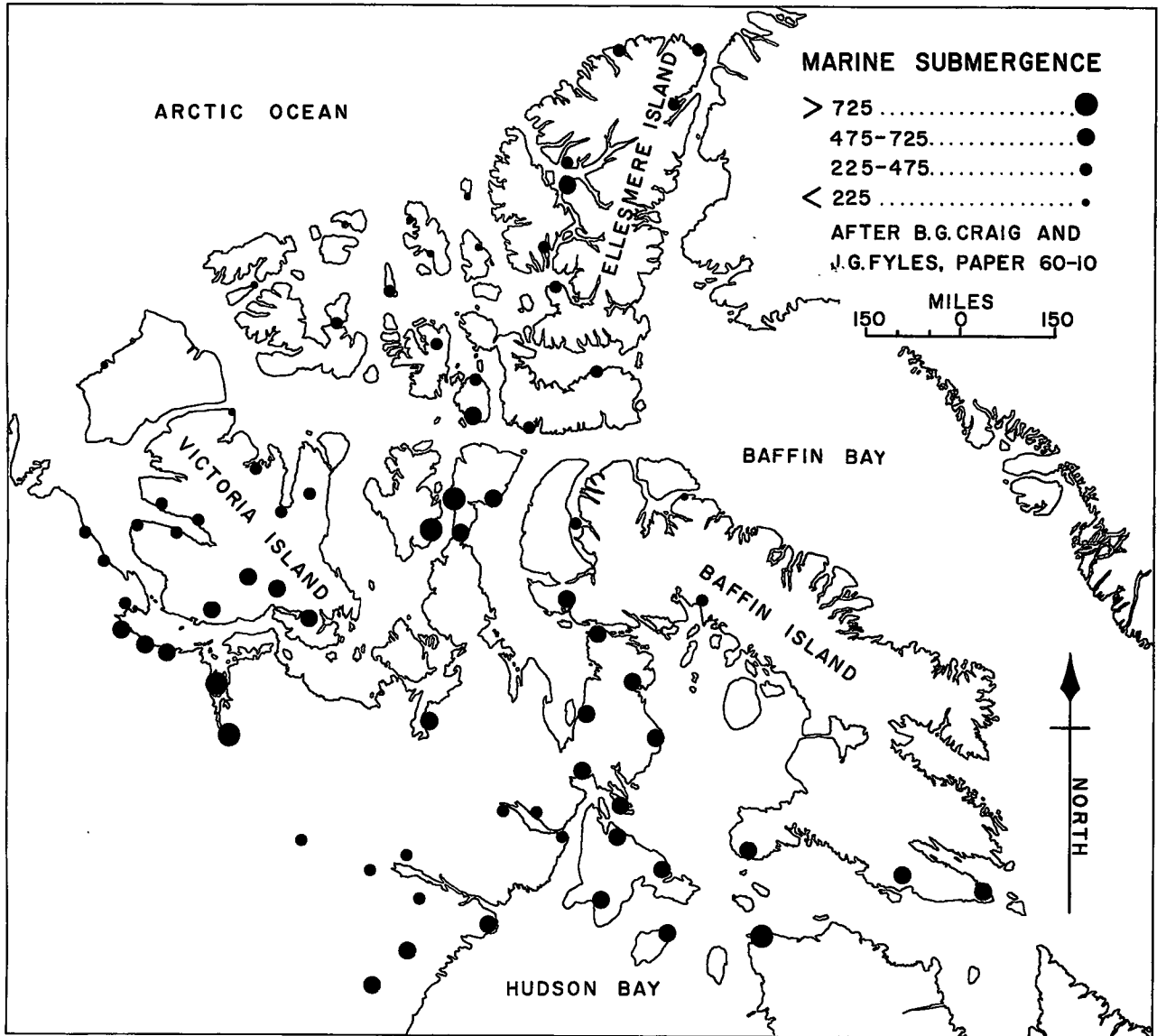


Figure 2. Tertiary drainage system. Note the major watershed passing down from north to south through the central part of the islands.

## PREVIOUS WORK

Early explorers and investigators such as Nansen, Peary, Stefansson, and Sverdrup made fundamental contributions to studies of Arctic waters and the floors beneath them during the latter part of the nineteenth century and the early decades of the twentieth century. This work was followed by the hydrographic studies of the Russian investigators commencing around 1930 when their ships penetrated many parts of the ice-covered Arctic Ocean. In 1937 the Russian oceanographic work was extended to the central part of the Arctic Ocean by means of aircraft. With this support, camps were established on the ice and occupied for periods of several months. Much of this early work, which also involved geological and geophysical investigations, is discussed by Ostenso (1962), and Collin and Dunbar (1964).

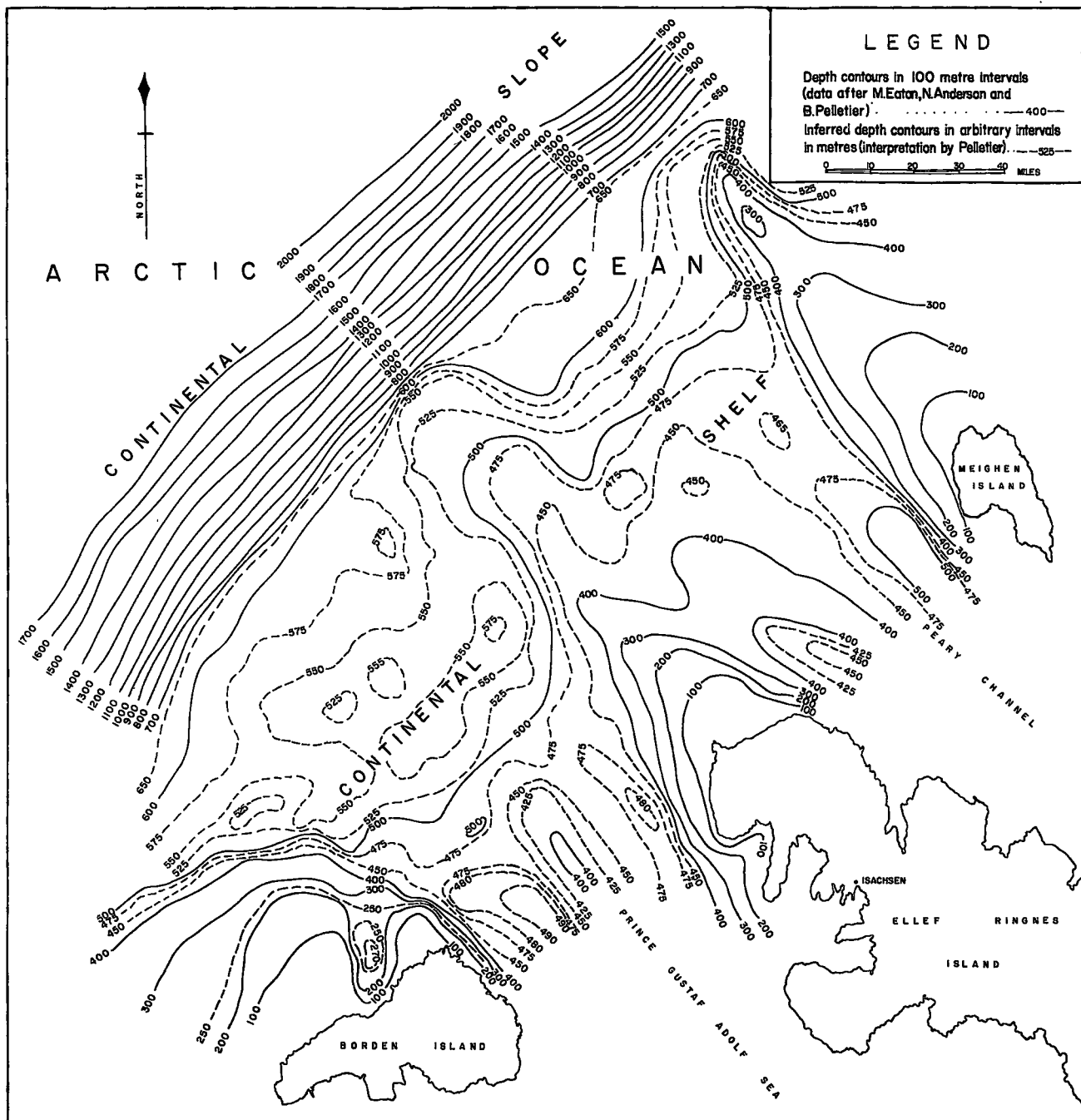
In recent years submarine physiography in the Canadian Arctic has been studied by technical teams from the Department of Mines and Technical Surveys, Ottawa, under the coordination of the Polar Continental Shelf Project, the Marine Sciences Branch and in particular, the Bedford Institute of Oceanography at Dartmouth, Nova Scotia, and the Geological Survey of Canada. Other investigators include those of the Fisheries Research Board of Canada, the Arctic Institute of North America, the Defence Research Board of Canada, the program on the American Ice Island T-3 over the Arctic Ocean, the Department of

Transport, and many other domestic and foreign institutions. This work, which is more related to the study area, is covered by Hunkins (1960), Collin (1961), Eaton (1961), Peary (1961), Pelletier (1961, 1962, 1963), Wagner (1962), Buckley (1963), Horn (1963), Manchester (1963), Marlowe and Vilks (1963), Marlowe (1964), and Vilks (1964).

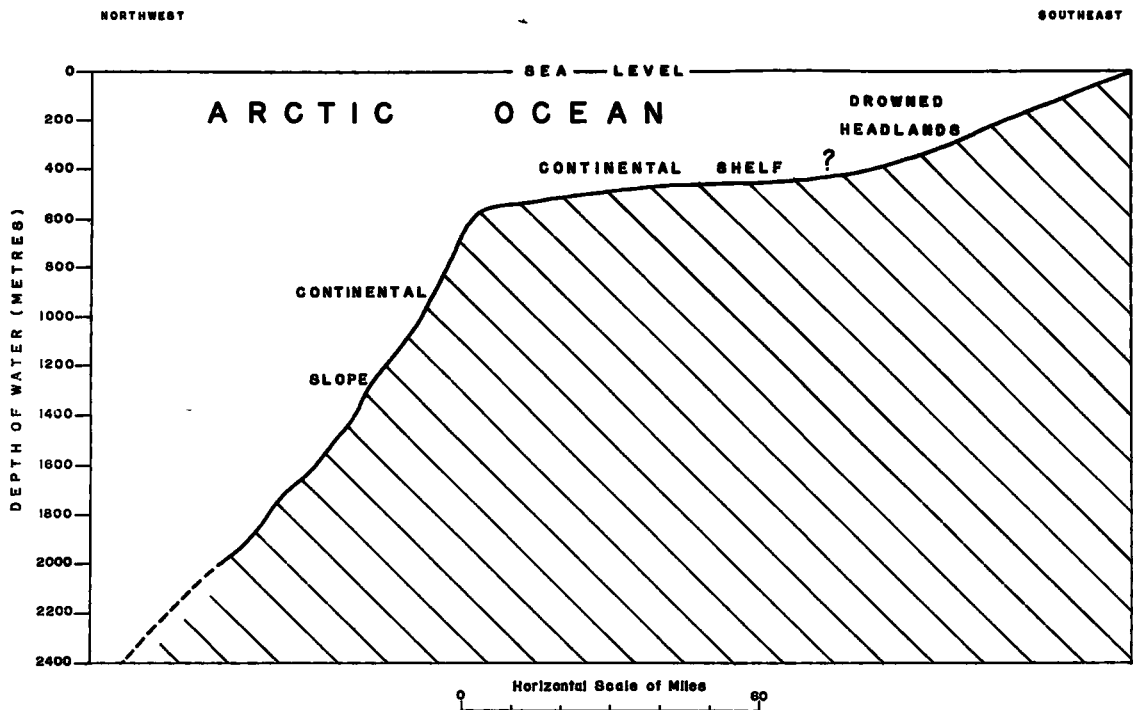
## THE WESTERN CHANNELS AND ADJACENT CONTINENTAL SHELF

Submarine physiography of the western channels and adjacent continental shelf is described by Collin (1961), Pelletier (1961, 1962, and 1963), Horn (1963), Marlowe and Vilks (1963), and Vilks (1964). The data from these investigations indicated that an unusual, or complex, physiographic development had taken place and that problems of crustal movement, glaciation, and changes in sea level were intimately involved. In connection with these inferences the most striking observations made were those on the submarine area immediately adjacent to Borden, Ellef Ringnes, Meighen and Axel Heiberg Islands. Along the channels separating these islands, the bottom profile is steep close to shore. Only a few miles offshore depths of 450 to 550 metres occur (Figures 3 and 4). Such depths are more than twice that of the continental shelves (187 metres) in most parts of the world, although some shelves are now re-defined and are about 500 metres deep (Shepard, 1963).

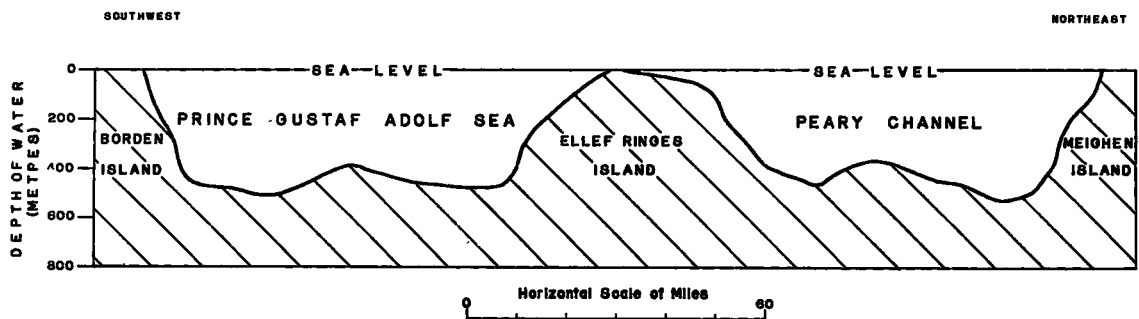
In contrast to these excessive depths in the channels, the depths of water off the seaward tips of the islands adjacent to the Arctic Ocean are shallow (Figures 3 and 4). Here the bottom slopes gently in a northwesterly direction. This gentle slope, which begins at the tip of the low-lying headlands, is broken by a series of short, steep slopes a few metres or tens of metres in height. Continuing seaward



**Figure 3.** Physiography of Arctic Continental Shelf and adjacent channels. The dominant physical influence of the headlands protruding onto the Continental Shelf is evident; also the steep submarine valleys which are characterized by median ridges and terminated seaward by hummocky terrain thought to be moraines. Topography seaward of the islands is gentle, but on the channel sides is steep.



Submarine topographic profile northwesterly from Ellef Ringes Island across the continental shelf.  
(Polar Continental Shelf Project.)



Submarine topographic profile along base-line between Borden and Melghen Islands.  
(Polar Continental Shelf Project.)

Figure 4. Physiography profiles of Arctic Continental Shelf and adjacent channels. In lower figure U-shaped valleys and median ridges of the two main troughs are evident.

this slope assumes an almost horizontal attitude about 40 to 60 miles offshore at a depth of 400 to 450 metres. The continental shelf is thought to extend to the next marked break in profile at a depth of 650 metres and at a point 110 miles offshore (Figures 3 and 4). Because the depth of water over the inner continental shelf is the same as that over much of the inland channels, and because the topography of these two major areas is contrasting, the inference was reached that a complex history was involved with respect to the physiography of the entire Arctic region.

To obtain a clearer idea of the nature of this complex physiographic development, several topographic profiles were drawn. The transverse profile of Peary Channel, as well as that of Prince Gustaf Adolf Sea, is that of a broad U-shaped valley interrupted by a median rise extending along the axis of the channel (Figures 3 and 4). At these transverse profiles the rises begin at depths up to 100 metres above the general level of the channel floors, and rise toward the southeast where they terminate as islands. The relatively deep troughs which occupy the channel floors on either side of the submerged median ridges are thought to be the original, though modified, river valleys of a dendritic pattern of streams which drained the area when the land stood higher relative to sea level. Thus the simple picture of a single submerged river valley is not entirely correct, although the hypothesis of Fortier and Morley generally stands.

The floors of the main troughs are somewhat hummocky with small disconnected basins occurring along the entire length. In some cases these basins have the configuration of cirques, especially near the eastern ends of the troughs, and in other cases the basins resemble a system of pater noster (personal communication, D. R. Horn, Geological Survey of Canada) lakes such as occur in glaciated river valleys. Along this irregular bottom, a gradual increase in elevation takes place in the seaward direction. This increase in elevation takes the form of a "toeing-up" as the channel floors rise to the level of the continental shelf about 40 to 50 miles seaward of the western entrance to the island channels. Here the troughs end in a series of hummocky ridges, lying transverse to the channel trends, and form submerged sills about 25 to 50 metres in height. Because of the transverse nature of their position relative to the troughs, and because they occur at the "toed-up" end of the long U-shaped troughs, these ridges are thought to be terminal moraines of valley glaciers which advanced down the pre-Pleistocene drainage system and modified the river valleys into their present physiographic configuration.

In accordance with this theory of glacially modified fluvial valleys, it appears that submarine tributaries leading to the main troughs have also undergone modification by the action of valley glaciers. For instance, the walls of the main troughs are steep and regular but are broken by

the entrance of submarine tributaries which also are U-shaped in profile, and hang approximately 100 to 200 metres above the floor of the main troughs. This unified pattern of submarine troughs and their tributaries is thought to represent the drainage system that existed in pre-Pleistocene times, and was subsequently modified by the action of valley glaciers.

Although the general theory that the channels are the submerged remnants of an earlier drainage system appears plausible, the idea that the river valleys extended directly to the Arctic Ocean is not entirely correct as shown in the cases of both Wilkins and Ballantyne Straits (Figure 5). Here bottom samples, which were obtained from the seaward side of these straits at depths of less than 175 metres, consist of black anaerobic mud. This indicated a lack of circulation and, possibly, non-passage of sea water entering these western channels at depths as shallow as 175 metres and perhaps less. The barrier inhibiting this flow was thought to be physical, and this was confirmed when shallow soundings of less than 50 metres were recorded in several locations at the western end of both Wilkins and Ballantyne Straits. From such observations it was concluded that, unlike the deeply submerged valleys comprising the bottom of Peary Channel and Prince Gustaf Adolf Sea, the floors of Wilkins and Ballantyne Straits do not extend from the east directly to the Arctic Ocean. This is due to the presence of a submarine ridge which separates the Arctic Ocean portion of their floors from the inland channel



portion of these floors. This ridge extends between Borden and Brock Islands, and continues southwesterly between Brock and Prince Patrick Islands. It appears to have acted as a watershed from which rivers on the west side drained directly to the Arctic Ocean. On the east side of this ridge, however, water was drained indirectly to the sea by means of a dendritic trunk system which led to the main channels that terminated along the former coast of the Arctic Ocean. Along these submerged river systems, both east and west of the drowned watershed, valley glaciation occurred and subsequently modified the topography of these river valleys.

The evidence of such glaciation is gathered from an overall consideration of the physical features both below and above sea level. This evidence is as follows: U-shaped, transverse profiles of the inter-island channels; hanging U-shaped valleys above the floors of the main channels or valleys; the presence of a hummocky terrain in the troughs; the possibility that the longitudinal series of basins in the troughs may be pater noster lakes; cirque-like features in the upland portion of the troughs and tributaries, some of which are submerged; the presence of ice-caps at the headward portion of some of the tributaries; and the longitudinal profile of the floors of the main channels which exhibit a "toeing-up" in the seaward direction together with the possibility of terminal moraines on the floor of the Arctic Ocean at the seaward end of these main channels.

Estimates of the thickness of the lobes of ice responsible for valley glaciation are based on the height of submerged terraces above the channel floors, and the difference in local relief of the so-called drowned cirques and the adjacent submerged coastal areas. It appears that tongues of ice at least 1,000 feet thick moved from ice-caps on the upland portions of the islands, through the fluvial valleys where they commonly merged with other tongues of ice, and flowed toward the sea where they terminated on the floor of the Arctic Ocean (Figure 5). Some glaciers appear to have headed on islands adjacent to the sea, and moved directly seaward. This may have been the case on the western part of Prince Patrick, Brock, Borden, and Axel Heiberg Islands. Here the cirques open toward the continental shelf at various points 20 to 40 miles offshore, and are considered to be submerged topographic features.

It is possible that a thin sheet of ice eroded the land between the river valleys but evidence of this glaciation is not substantial. Furthermore, such evidence occurring on the subaerial portion of the islands may have been obliterated by wave action during a period of a higher stand of sea level and subsequent marine regression. The fact that sinuous ridges of sand occur at low elevations and are thought to be eskers (St. Onge, 1964) is reason to suspect that some continental glaciation in the form of sheets of ice moved across the Arctic Islands. Further support to this theory is the

occurrence of isolated boulders thought to be glacial erratics which occur at various elevations. It must be stressed, however, that if an ice-sheet did exist it must have been thinner than the valley lobes as no physiographic evidence occurs which compares with the magnitude of the features impressed by the action of valley glaciers.

Estimates on the amount of present submergence are based on the depth of occurrences of the following: terminal morraines, deep troughs, a pronounced submarine topographic nick on the seaward portion of the island headlands, and terraces which flank the channel-sides of the islands. The terraces are at shallower depths in the inland portion of the channels than in the oceanic portion thus indicating that the present submergence is greatest in the area of the terminal morraines and the northwesternmost extension of the drowned headlands. In this latter area, it amounts to more than 400 metres - perhaps 440 to 450 metres would be a better approximation. Such drowning took place offshore to various distances up to 50 miles, where submerged headlands protrude upon the continental shelf. These drowned areas are shown in Figure 5, and the topographic influence of the headlands on the Arctic Continental Shelf is further shown in Figure 3.

Other evidence for drowning in the Arctic Islands is in the cores of sediment obtained on marine geology operations over the sea ice. Several cores recovered from depths of at

least 250 metres below sea level in Peary Channel contain plant fragments and carbonaceous material of terrestrial origin (Horn, 1963). One core recovered from 370 metres below sea level in Prince Gustaf Adolf Sea penetrated an ancient soil and stopped in bedrock (personal communication, J. I. Marlowe and G. Vilks, Geological Survey of Canada). The terrace from which this core was obtained extends parallel to Ellef Ringnes Island, and slopes gently seaward, where it is 30 to 50 metres deeper in the vicinity of the Arctic Ocean adjacent to the tip of the drowned headlands.

The overall evidence supports the hypothesis that at least 400 metres of drowning is present in the offshore areas of the Arctic Islands, particularly over the continental shelf. This amount appears to be progressively less in the inland areas of the channels where ancient, high areas existed. The evidence of deeper soundings in the southeastern parts of the islands, such as 900 metres in eastern Lancaster Sound, indicates that drowning may not have been uniform over the Archipelago. This lack of uniformity suggests differential movement of the earth's crust in different parts of the islands after the close of the Pleistocene epoch.

## THE EASTERN CHANNELS

Soundings of the waters of Nares Strait, which lies between the Arctic Ocean and Baffin Bay, and soundings of the waters of Jones and Lancaster Sounds revealed a similar development of topography to that of the channels of the western Arctic Islands. In the area underlying Kennedy Channel, Hall Basin, and Robeson Channel (Figure 6), the submarine topography is somewhat hummocky along the longitudinal profile. However, the regional submarine relief drops from a presumed submerged watershed (presently a sill) at a depth of 100 metres in northern Kane Basin, to a depth of 400 metres at the entrance to the Lincoln Sea on the Arctic Ocean. Submarine valleys enter from both Greenland and Ellesmere Island, and drop about 200 - 300 metres as hanging tributaries to the main valley floor, or trunk system, of the northern part of Nares Strait. These features are similar to those in the western Arctic Islands, and suggest a similar origin involving fluvial-glacial erosion and marine submergence. In connection with this physiographic similarity on both sides of the Arctic Islands, a series of basins occurs along the entire length of Robeson Channel. These basins resemble the system of pater noster lakes which Horn suggested for similar features in Peary Channel.

Kane Basin (Figure 7) is generally shallow in the eastern part where the depth of water is between 100 and 200 metres. The topography of the bottom is fairly uniform due to the

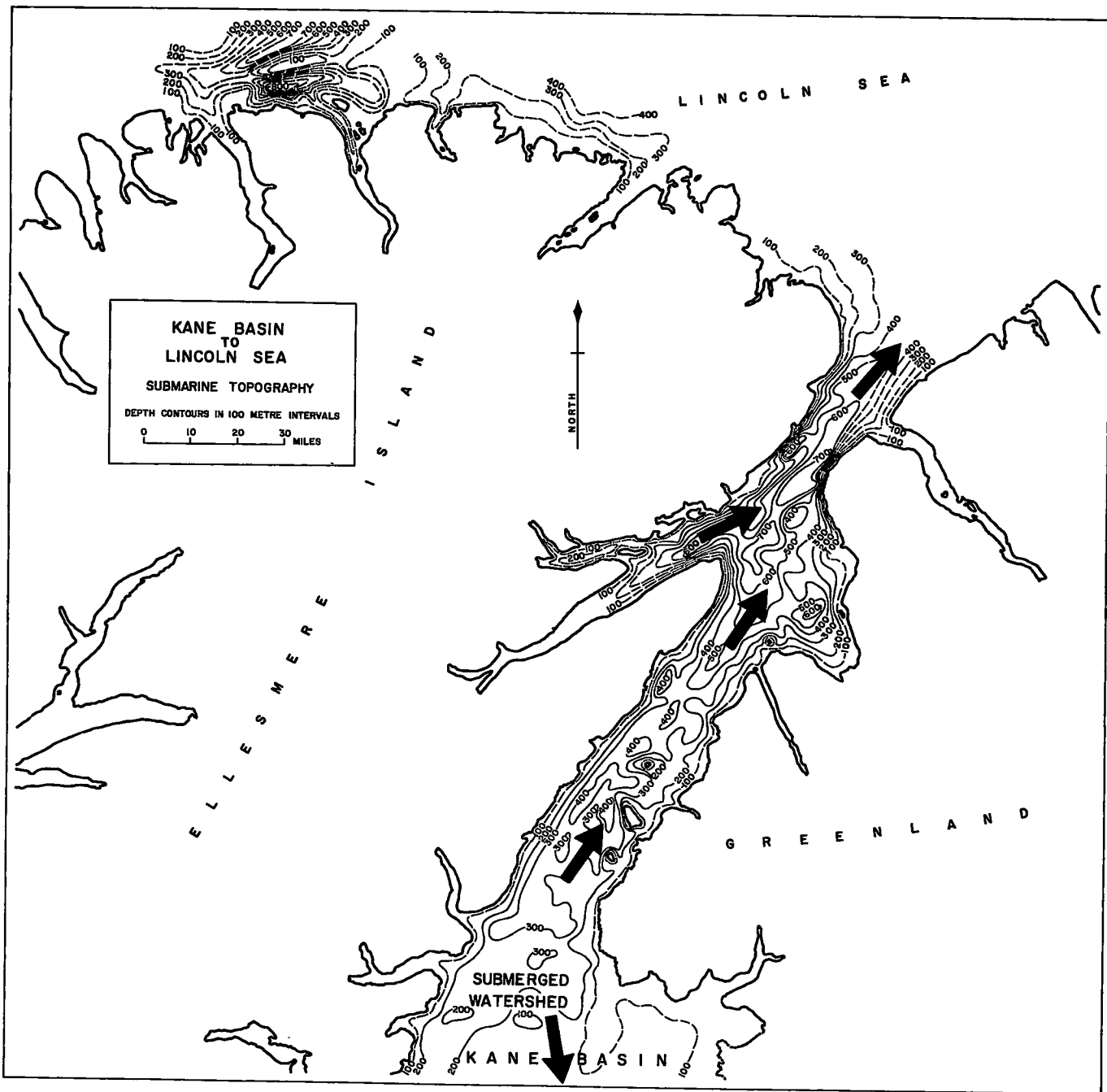


Figure 6. Upper Nares Strait. Arrows indicate direction of flow of valley glaciers from presumed watershed in Kane Basin. Sea floor drops away to north. Hanging tributaries occur about 200-300 metres above main sea floor. Sills are common at mouths of submerged valleys, and a chain of basins presumed to be former pater noster lakes occurs down the length of the channel.

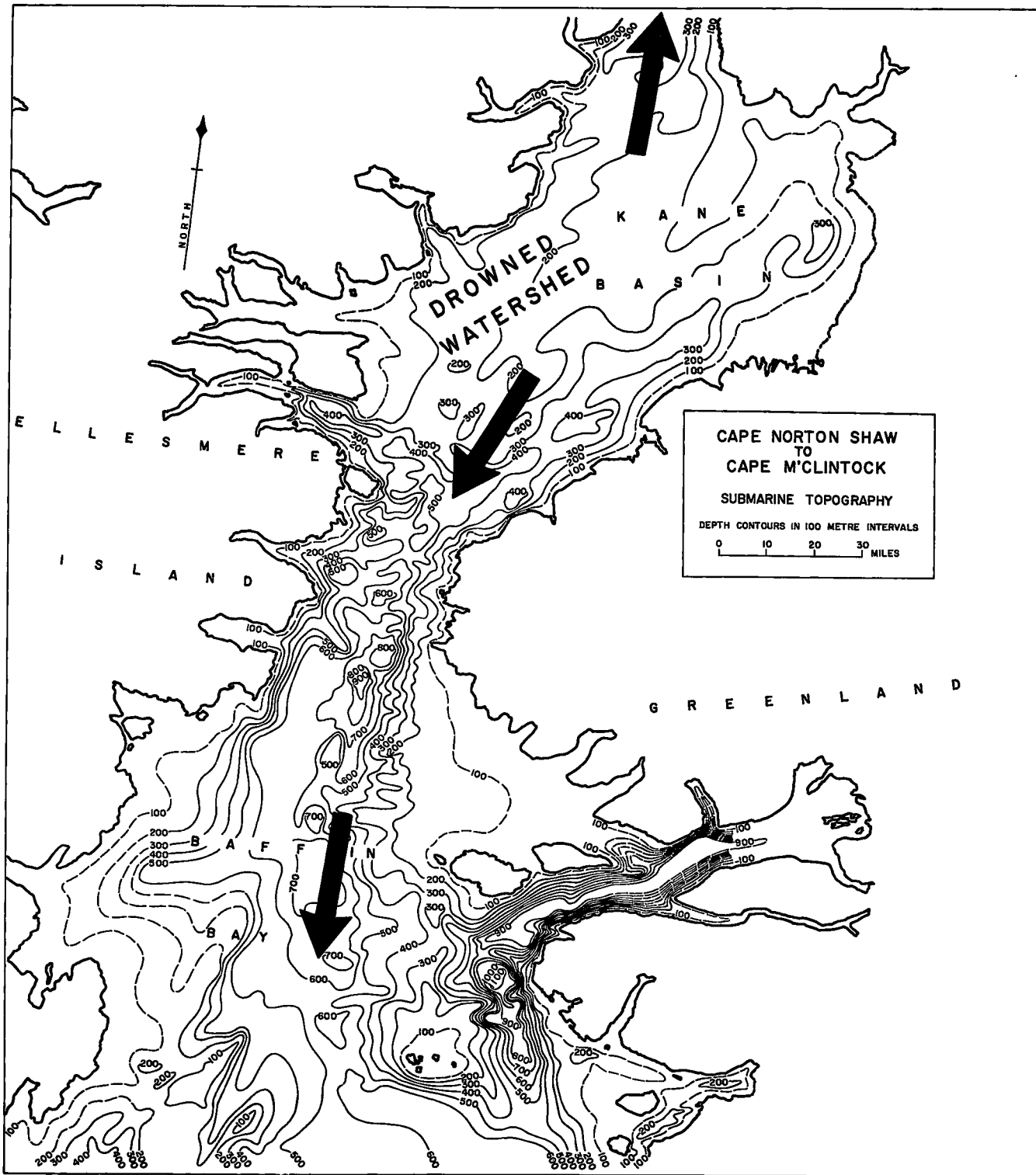
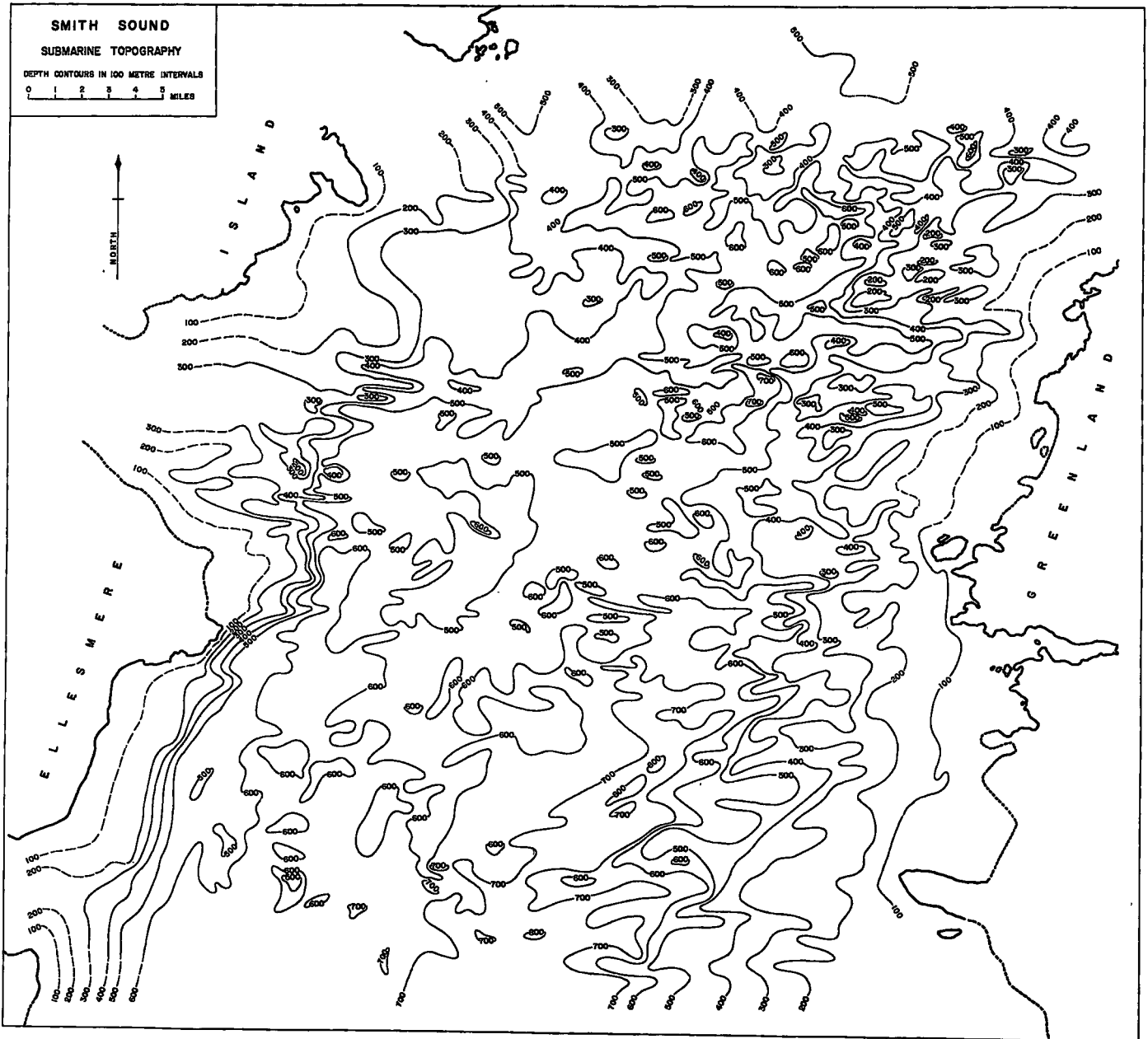


Figure 7. Submarine Topography of lower Nares Strait and northern Baffin Bay. The arrows indicate direction of flow of valley glaciers from presumed watershed in Kane Basin. Note increase in depth south of watershed, and the hanging tributaries occurring about 200 metres above main floor of the straits.

occurrence of ground moraine 20 to 30 metres thick, according to shallow seismic records. This morrainal material was deposited by the receding Humboldt Glacier to the east on the western coast of Greenland. Around the southern perimeter of Kane Basin, a trough is present at depths of 400 metres with smaller troughs leading into it from the coast of Greenland. This pattern resembling a trunk system also suggests former terrestrial erosion followed by marine submergence. On the western side of Kane Basin the submarine topography is irregular, and the regional slope drops away from the sill in the northern part at depths of 100 to 200 metres, to depths of 500 metres in the southern part adjacent to Smith Sound.

In Smith Sound the regional elevation of the sea floor continues to drop from the Kane Basin sill, and is about 650 metres below sea level at the northern part of Baffin Bay. (Figure 8). The most striking feature of the topography of Smith Sound is the east-west alignment of topographic features. This is more apparent in the eastern part where headlands and valleys extend from shore, as submarine valleys and ridges, toward the central portion of the sound where depths of 600 metres are recorded. On the eastern side of Smith Sound, a continental shelf does not appear to have developed. Here the submarine topography is a drowned portion of the western coast of Greenland. On the western side of Smith Sound, the topography of the bottom is somewhat more regular but the



**Figure 8. Submarine Topography of Smith Sound. Note the strong east-west alignment of physiography features, also the increase in depth of the sea floor from an average of 300-400 metres in the north or 600-700 metres in the south.**

600-metre depths occur closer to Ellesmere Island than to Greenland. The submarine contours suggest that a narrow continental shelf does occur off the southeastern coast of Ellesmere Island. This uniformity of depth may be due to the occurrence of flat-lying, underlying bedrock, or a former erosional surface, and thus represents submergence of an original flat-lying feature. Submergence is suggested here as depths on the east are similar to those on the west, and the topographic features could have developed under the action of subaerial erosion.

In Jones Sound, depths of water have been determined along several longitudinal and transverse lines but on the whole, coverage is inadequate. The soundings indicate that a similar type of submarine topography to that of the northern and western channels is present, (Figure 9). These similarities are as follows: a shallow headward portion which is located in the western end and appears to be a drowned watershed at depths of 100 metres or less; a long axial trough which is somewhat hummocky in profile; hanging tributaries occurring at elevations of 300 metres or so above the main channel floor; sills at the mouths of the tributaries; glaciers or cirques at the head of some of these tributaries; and a "toeing-up" of the main trough in the area of the continental shelf adjacent to western Baffin Bay. In addition submerged faceted spurs occur between the mouths of tributaries.

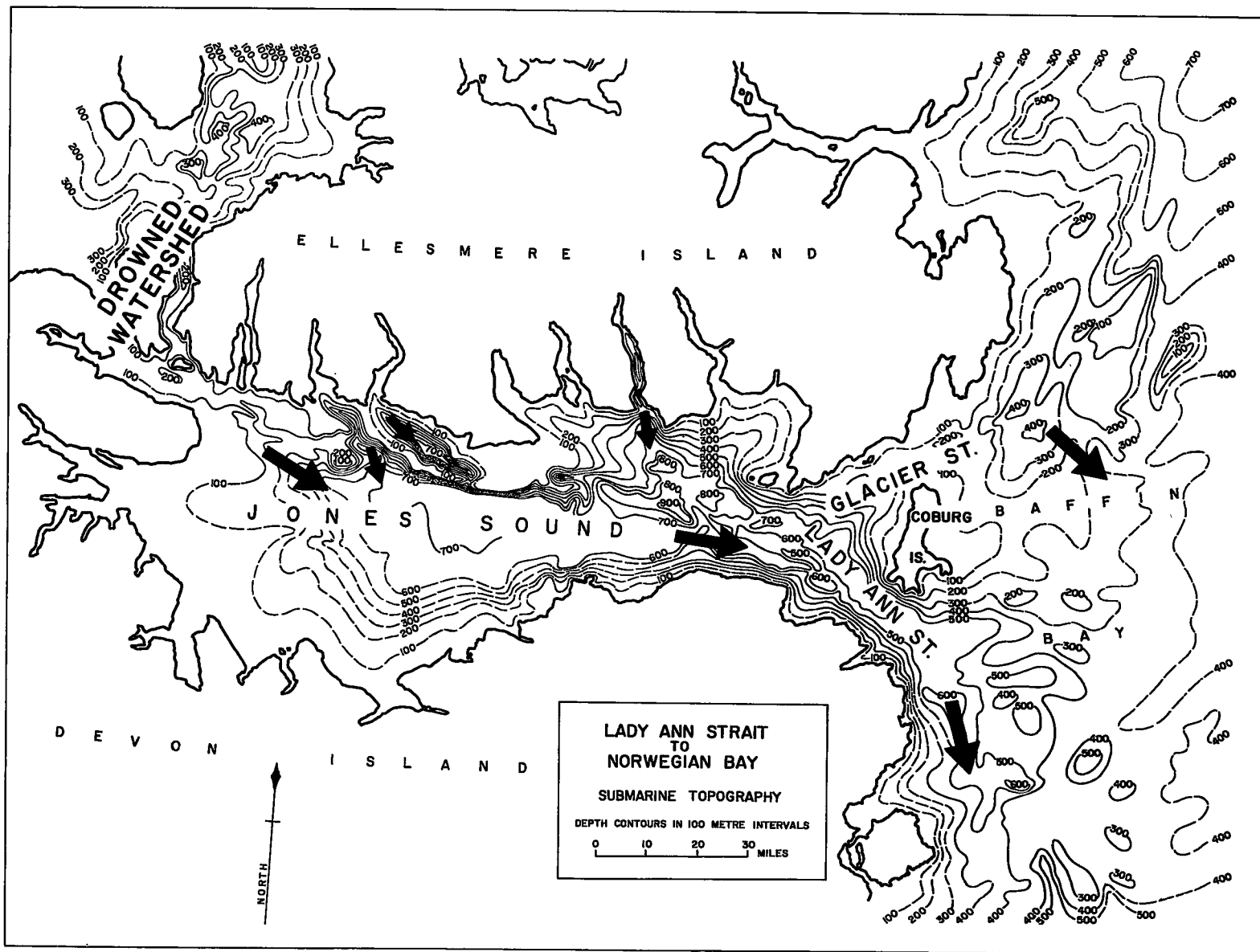


Figure 9. Submarine Topography of Jones Sound. Note drowned watershed in western part, U-shaped longitudinal valley in main part, hanging tributaries and associated sills and drowned cirques flanking both sides. Arrows indicate direction of flow of valley glaciers.

Glacier Strait, at the eastern end of Jones Sound, between Coburg and Ellesmere Islands is shallow and does not contain a deep axial trough. About 20 to 30 miles farther east, depths greater than 400 metres are present. The configuration of the bathymetric contours, together with the occurrence of this feature in a shallow area adjacent to glacial valleys, suggest that this small basin is a drowned cirque. Presumably a glacier headed in this feature and advanced easterly toward Baffin Bay.

Lady Ann Strait lies at the eastern end of Jones Sound, between Coburg and Devon Islands. It is deep close to the shores of both islands, and is the continuation of the axial trough in Jones Sound. The submarine physiography of Jones Sound and adjacent waters appears to have developed according to the following events: fluvial erosion along a pre-Pleistocene drainage system, modification of this drainage system by the action of valley glaciers, and finally submergence. As in other parts of the Arctic Islands, raised marine deposits indicate post-Pleistocene elevation of the land relative to sea level (Craig and Fyles, 1960).

In Lancaster Sound (Figures 10 and 11) the submarine topographic features are similar to those of Jones Sound. However in Lancaster Sound, faulting has occurred along the north side, which adds some complications to the interpretation. However the hanging U-shaped tributary of Admiralty Inlet which enters Lancaster Sound on the south side, and the apparent trunk

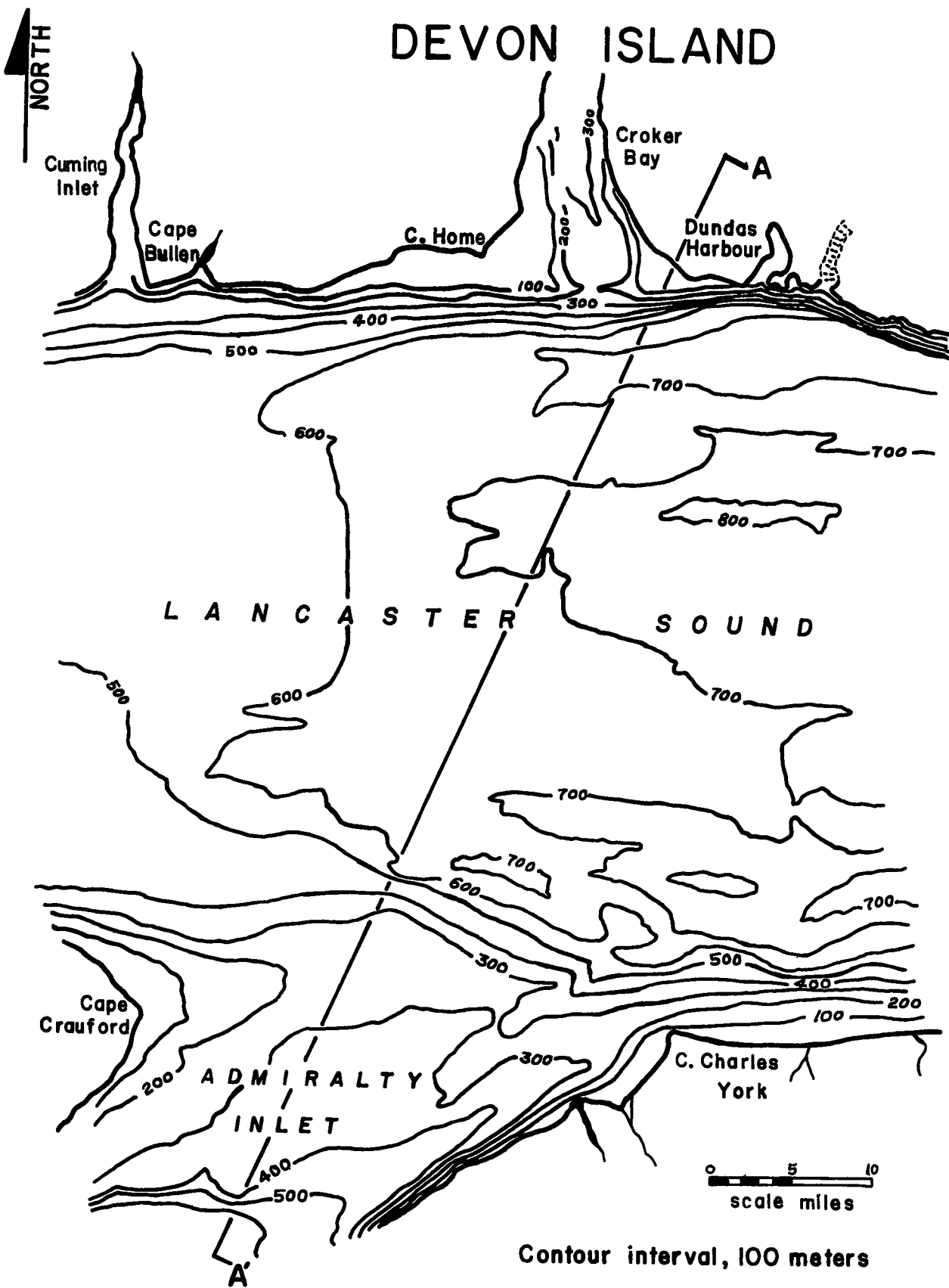


Figure 10. Submarine Topography of Lancaster Sound. Topographic gradient dips to east. Sill occurs at mouth of Admiralty Inlet which hangs more than 300 metres above floor of Lancaster Sound. Croker Bay and Cuming Inlet on northside of Lancaster Sound show similar features (after D.E. Buckley, 1963).

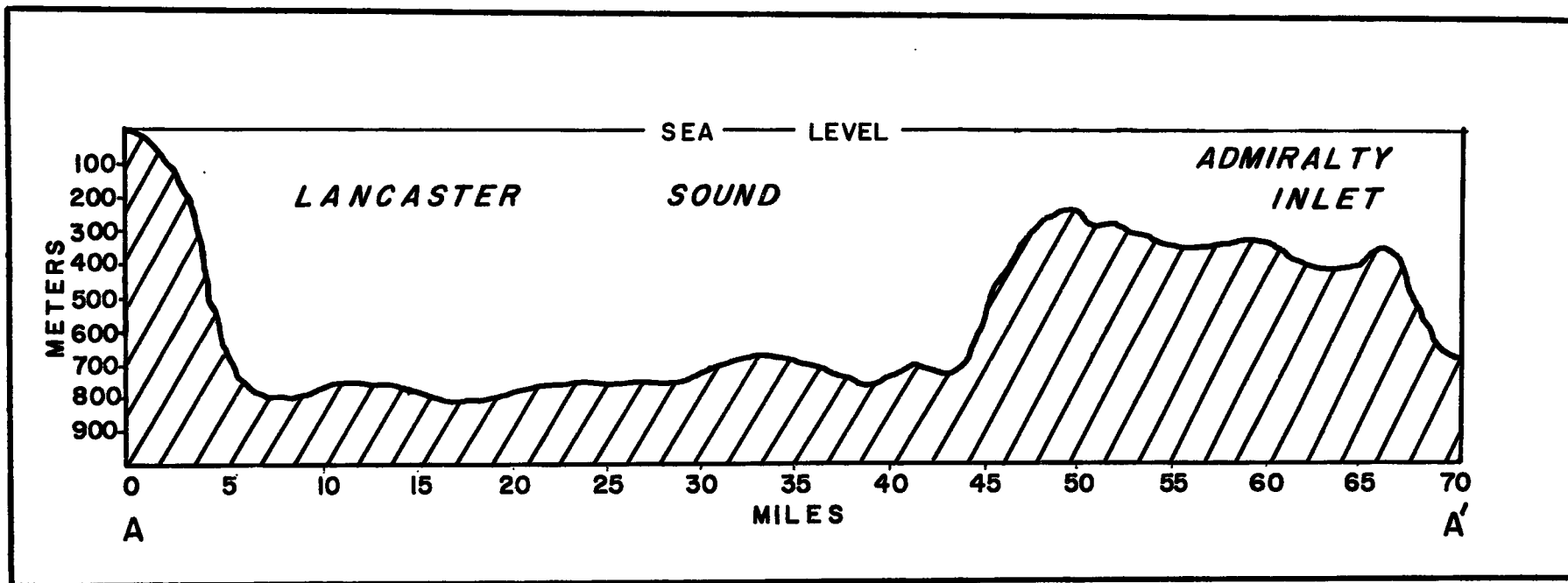


Figure 11. Topographic profile of Lancaster Sound. Sides of channels are U-shaped (after D. E. Buckley, 1963).

system consisting of the numerous U-shaped hanging tributaries on the north side of Lancaster Sound with cirques at their head and sills at their mouth indicate an origin of fluvial erosion and modification of the topography due to subsequent valley glaciation. This is further substantiated by the fact that Lancaster Sound itself is U-shaped in profile along a transverse section.

## NORTHERN AND CENTRAL BAFFIN BAY

In Baffin Bay the bottom slopes from depths of 200 to 400 metres below sea level in the northern part, where the sea floor is continuous with that of Smith Sound, to depths greater than 2,300 metres in the central part of the basin (Figures 7, 12 and 13). In the northern area, which extends south from Greenland, the submarine topography is somewhat hilly and resembles a submerged headland previously exposed to subaerial weathering. This submerged headland drops to a regular sloping surface about 140 miles from shore and at depths of 600 metres. Here it merges into a wide terrace which constitutes an outer continental shelf.

On the eastern side of Baffin Bay (Figures 12 and 13), the continental shelf is dissected by deep sinuous valleys which extend from valleys existing along the western coast of Greenland. Similarly, drowned headlands or interfluvial areas occur between these valleys and are contiguous with similar features on land. A profile drawn along a headland westerly from Greenland shows a hilly topography extending about 70 miles offshore which resembles a drowned headland, and which occurs at depths of more than 300 metres. From this point seaward the topography drops regularly to 400 and 500 metres at a point 140 miles offshore, and then drops rapidly to 2,300 metres in the central part of the basin. In the area between the steep slope and the shore, the

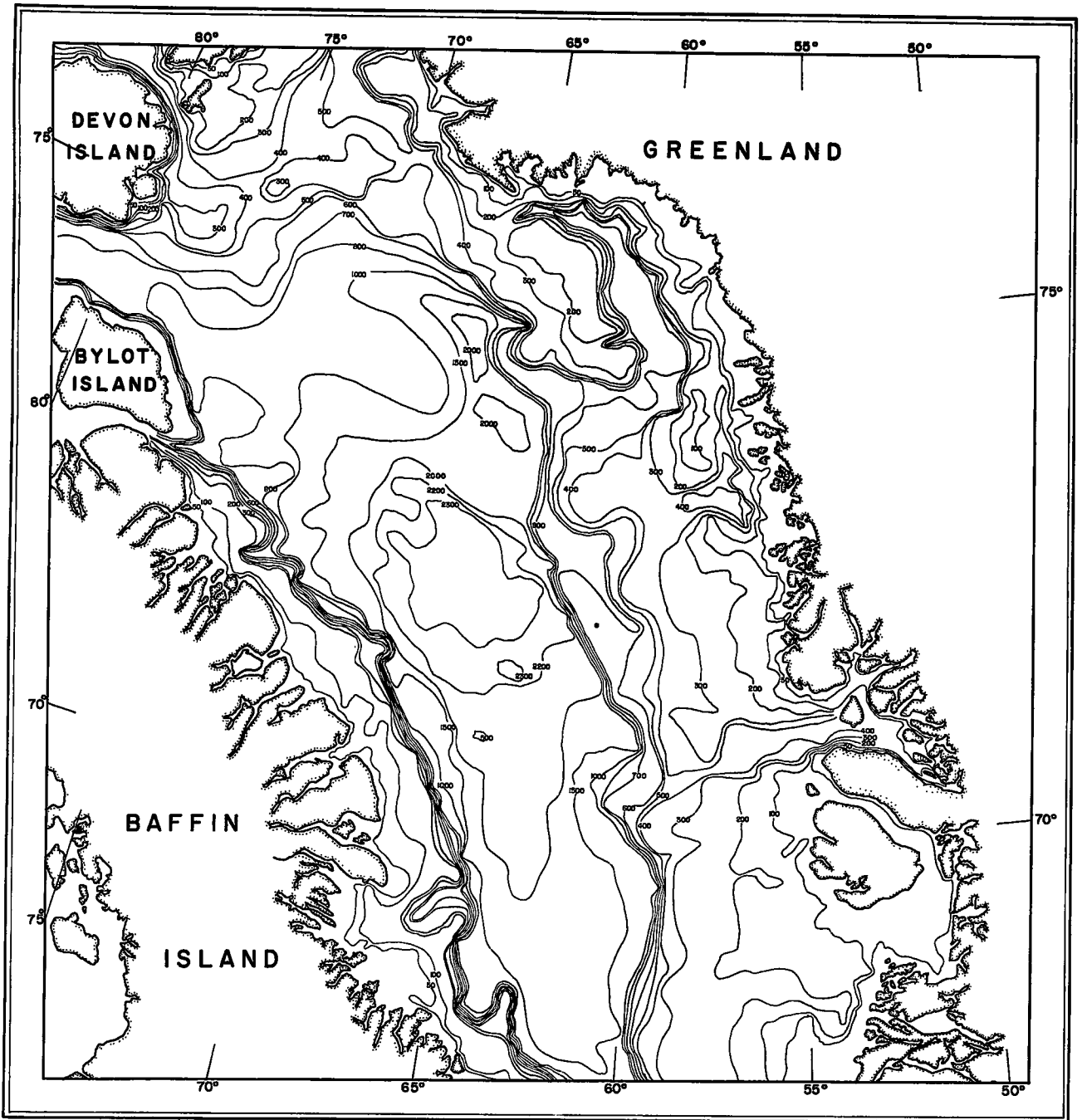


Figure 12. Submarine Topography of Baffin Bay. The low plain in the central part of the Bay is prominent where it lies between the steel-sided walls which form the Continental Slope.

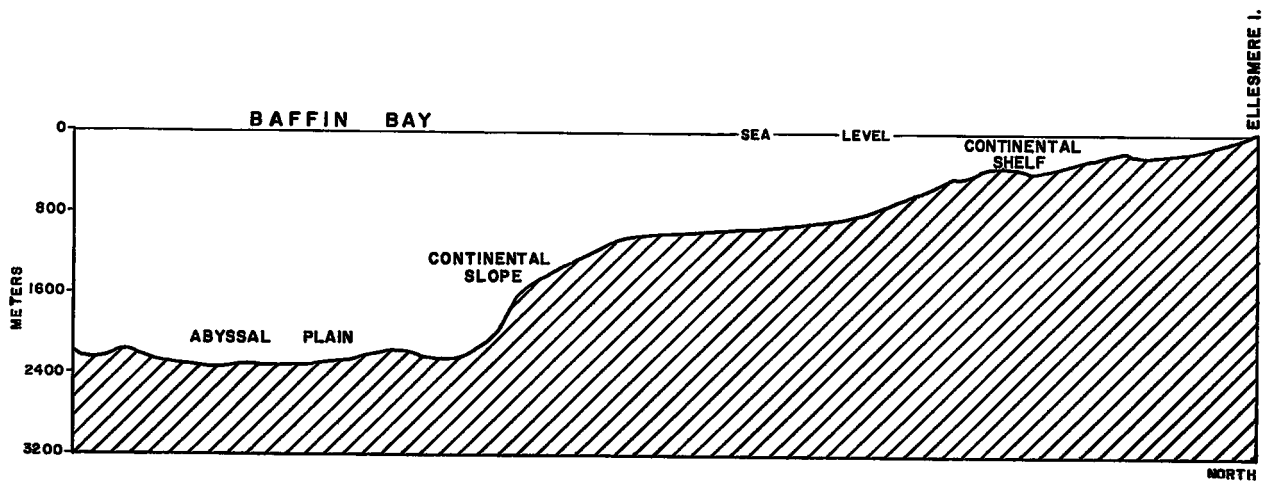
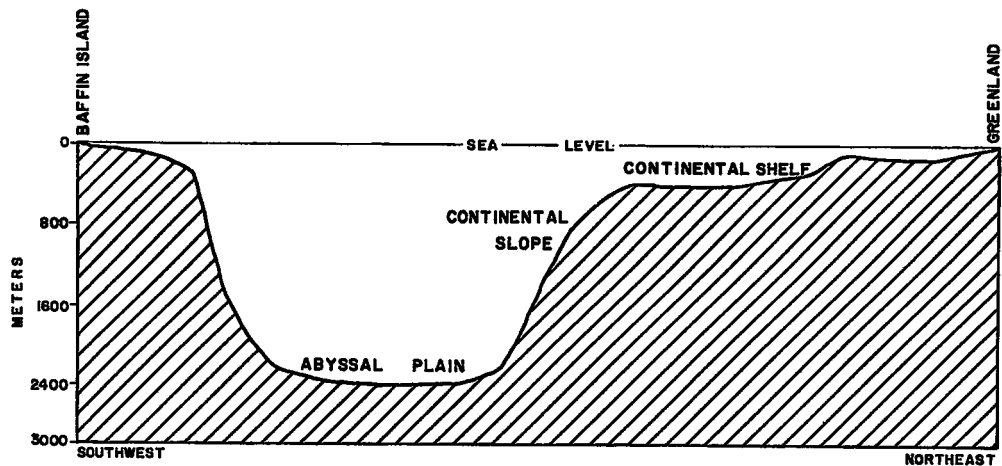
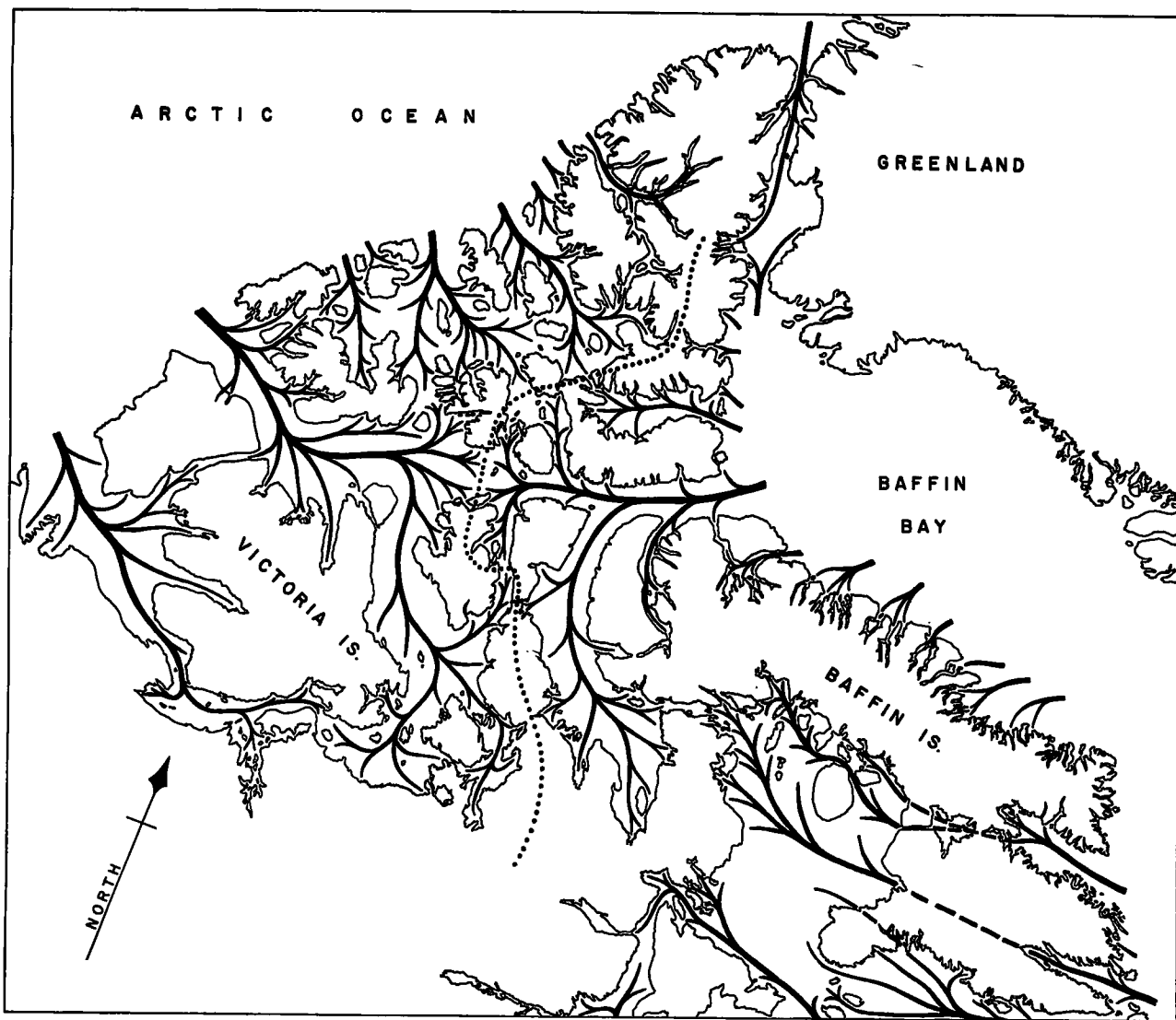


Figure 13. Topographic profiles of Baffin Bay. Top figure is a cross sectional view and lower section is a longitudinal view. The narrow shelf on the west, and the wider shelf on the east side of Baffin Bay is evident in the top figure. Both figures illustrate the steep Continental Slope.

sinuous valleys occur at depths of 600 metres. These valleys merge onto the continental shelf in the vicinity of the upper part of the steep, continental slope.

On the west side of Baffin Bay (Figures 12 and 13), the physical situation is similar except that the continental shelf is narrower and contains more morphologically irregular features. These features can be traced with some difficulty, toward headlands and valleys on the adjacent coast. This area of drowned headlands and valleys extends 5 to 70 miles offshore, but is generally 20 miles in width on the average. As in the case of the east side these submerged features, which can be traced across the full width of the continental shelf to the headlands and valleys on shore, are truncated at the seaward edge of the shelf by the steep, planar face of the continental slope.

The submarine valleys on both sides of Baffin Bay are U-shaped in profile, have U-shaped hanging tributaries leading into them, and extend into valleys on land occupied by glaciers at the valley head. Thus a development of pre-Pleistocene fluvial erosion was followed by valley glaciation which subsequently modified the river valleys. Submergence and post-Pleistocene emergence (Figure 14) appear to have been the final stages in the physiographic history of these shallow-water areas.



**INFERRED SUBMERGED TERTIARY DRAINAGE SYSTEM**

AFTER Y.O.FORTIER AND L.W.MORLEY, ROY. SOC. CAN., VOL. L, SER. 3, JUNE, 1956.

MAIN DIVIDE .....

0 150 300  
MILES

**Figure 14. Location of raised beaches, Arctic Islands.**

The central area, or basin, of Baffin Bay is approximately 5 to 10 times the average depth of all the previously discussed channels of the Arctic. Beneath the central part of Baffin Bay, the sea floor is featureless and abyssal in aspect, and bears marked resemblance to a true oceanic basin. This sea floor does not appear to have undergone extensive subaerial erosion. It is bounded on the east and west by steep slopes which, in turn, show no evidence of terrestrial erosion or of the physiographic modifications which are present on the adjacent continental shelves. In fact, these slopes exhibit no evidence of a continuation of the submerged valleys and ridges which occur on the adjacent shelves.

The origin of the central part of Baffin Bay is unknown. However on the basis of a marked contrast in submarine physiography and bathymetry, it is felt that Baffin Bay has a different origin from the island channels. This origin may be due to some form of faulting or down-flexuring of the earth's crust. Such tectonic activity may have taken place before the Pleistocene epoch as the basin floor shows no evidence of glacial or fluvial erosion, and the continental slope shows no extension of the physiographic lineation which occurs on the adjacent continental shelves.

## VERTICAL CRUSTAL MOVEMENT

Evidence of vertical crustal movement, exclusive of submergence which has been discussed previously, is seen in the following: occurrences of raised beaches and marine deposits at various elevations above sea level, a varying faunal suite in different parts of the cores of sediment recovered from the sea floor (personal communication, G. Vilks, Geological Survey of Canada), a change in texture of the sediments in different parts of the core, and the occurrence of erratic boulders on the raised beaches. The presence of raised beaches and marine deposits in the central islands (Figure 14) have been reported by Craig and Fyles (1960). Some of these beaches are dated at 8,700 years  $\pm$  400 B.P., and occur at elevations up to 800 feet above sea level. These facts, together with the decrease in elevation of younger beaches in a seaward direction, indicate that the Arctic Islands have been rising continually since the close of the Pleistocene. Some of the more seaward beaches are at lower elevations than younger landward beaches (Craig and Fyles, 1960) which would indicate differential upwarping.

Other evidence of vertical crustal movement is present in the cores of sediment obtained from marine geological operations over the channel ice (Marlowe and Vilks, 1963) in the shallower inshore areas. These cores show a coarsening in texture of the sediment from the bottom of the core to the

top which indicates the general change from quiescence to a hydrological environment of increasing energy. This change appears to have been induced by crustal uplift which produced shoaling conditions in the areas which were formerly sites of quieter, deeper-water sedimentation. Increased erosion on land, also an effect of uplift, would contribute coarser material to the depositional site. Therefore it appears that this interplay of physiographic events, the history of sedimentation as shown by the texture of the sediments, and the inferences on a changing hydraulic environment all follow as a consequence chiefly of post-Pleistocene uplift in the Arctic Islands. Further evidence from the cores, which indicates crustal uplift, is the occurrence of a fairly deep water fauna in the lower part of the core whereas the upper part contains a fauna that exists only in considerably shallower waters. Such faunal sequences generally indicate a shallowing of a few hundred metres as suggested by data from F. J. E. Wagner (1962). (See also Pelletier, 1963). This zoning suggests that the area from which the cores were taken has risen a distance of 200 to 300 metres (700 to 1,000 feet) in the past few thousand years. No accurate dating has been made on this fauna but the estimate is based on a comparison of the layers in the cores with those that have penetrated ancient soil horizons and have thereby presented a datum. This datum has been dissected by valley glaciers which retreated, according to most estimates, about 10,000 years

ago. Thus the inference is that the sea bottom together with the adjacent islands has risen several hundred feet in the past few thousand years - certainly since the Pleistocene epoch.

A further line of evidence for a rising land mass in the Arctic is the presence of granite boulders on many of the beaches and low cliffs of sedimentary formations along the Arctic coast. These boulders vary up to 3 and 4 feet in diameter, and are somewhat blocky although they may exhibit well worn edges. As there is no substantial evidence of widespread continental glaciation on the northern islands (the Queen Elizabeth Group in particular) the writer, in collaboration with his colleague, A. E. Collin, suggests that these boulders were rafted by means of fragments of an ice sheet which had broken away from the northern parts of the Archipelago.

Both the writer and Collin have landed on ice which has broken from an ice shelf and observed the exceptionally heavy mass of sediments up to boulders in size that is transported by shelf ice. On one occasion the writer noted a series of boulder ridges on the ice, each ridge successively higher than the ridge situated toward the margin of the ice that formerly faced the land. Because these are seasonal types which form after a spring run-off from land, and because sea ice ablates on the upper surface and grows on the lower surface, thus raising the elevation of the first

boulder ridge, the evidence of several years' accumulation is therefore present on this shelf ice.

It is this shelf ice which breaks away from the coast, drifts with the main Arctic circulation, and which may eventually pass through to the Atlantic Ocean by means of the inter-island channels. However, along this route it may become grounded and left stranded upon a coastline or island. The writer presumes that such a series of events took place previously when sea level was higher. After melting, the coarse debris remained on the beach. As raised beaches extend for a considerable distance toward the centre of the Arctic Archipelago, it is probable that such rafting took place over a wide area of the islands. This would also account for the presence of coarse, unsorted boulders and other sediments lying upon the well-washed highly sorted beach sands and gravels. As sea level dropped, sufficient wave energy would be available to remove the finer material but not the coarse. The latter would remain as a lag deposit.

An independent line of evidence exclusive of sampling and physical observations involves research in the field of geophysics. Gravity measurements by Sobczak (1964) over the Arctic Continental Shelf indicate that the area is in isostatic equilibrium, and that no further uplift is expected that would be attributed to ice unloading. This suggests that, although the gravity results are by no means conclusive

as yet, the position of the presently submerged areas of the continental shelf and adjacent channels is probably not due to ice loading but rather tectonic activity. If submergence is due to ice loading then there remains to be explained the existence of more than 400 metres of water which has been added to the continental shelf since the close of the Pleistocene.

In terms of the raised beaches and the drowned shelf, there may be as much as 600 to 700 metres (or about 2,000 feet) of vertical movement which must be considered. Therefore it seems likely that, although some movement is a result of sea level fluctuations due to loading and melting of ice, most of the vertical movements of the earth's crust must be ascribed to forces that are presumably internal and, perhaps, continental in magnitude.

## SUMMARY AND CONCLUSIONS

In summary there appears to be ample evidence that a tertiary drainage system existed as suggested by Fortier and Morley, and that the present inter-island channels are the result of submergence of this ancient drainage system. The inferences that topographic modifications of this drainage system are due chiefly to the action of valley glaciers appears to be substantiated, although the action of thin sheets of ice upon the interfluvial areas has not been overlooked. Submergence is established on the basis of physiography for all parts of the coastal submarine areas. Equally strong is the evidence for emergence which is seen in raised beaches, sedimentary texture and varying fauna of the bottom cores, and stranded ice-rafted boulders.

The theory of simple ice loading and release of stress after ice melting does not appear sufficient to explain the overall vertical movement of 2,000 feet, especially in the narrow span of time allotted for such movement. Therefore, exclusive of the presumed tectonism associated with the origin of Baffin Bay, it appears that a general tectonic force acted over the entire Archipelago, and may be in operation at present.

From a physiographic and tectonic point of view, both northern Greenland and the Arctic Islands have identical histories. Nares Strait appears to be part of a former river

system complete with watersheds and tributaries, and it is likely that geological structure controlled the original drainage system. It does appear that, since the close of the Pleistocene epoch, the crustal movement of the Arctic Islands was vertical and not horizontal. This vertical movement initiated more rapid and coarser sedimentation, brought about shoaling conditions in nearshore waters, caused a relative lowering of sea level and brought the sea floor and its associated older sediments and a deeper water fossil fauna to shallower depths, and triggered the forming of raised beaches all over the islands. Therefore, by assessing the interplay of tectonic, physiographic and hydrological forces and some of the ecological conditions, it has been possible to relate the development of submarine physiography and its relation to crustal movements.

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