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TROY L. PÉWÉ, DANA E. ROWAN, RICHARD H. PÉWÉ,
and ROBERT STUCKENRATH

Glacial and periglacial geology of northwest Blomesletta peninsula, Spitsbergen, Svalbard

NORSK POLARINSTITUTT
OSLO 1982

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Abstract

The Blomesletta peninsula, Spitsbergen, Svalbard, is a recently deglaciated lowland less than 100 m above sea level consisting of gently dipping Paleozoic rocks. Late Weichsel glaciers receded to the north from the peninsula approximately 10,000 years ago as suggested by radiocarbon dates of mollusk shells on isostatically raised beaches. Evidence for the glaciation of the area includes erratics and southerly trending glacial grooves, striations, roches moutonnées, and side glacial channels. The Sefströmbreen, currently 7 km northwest of the peninsula, surged 6.5 km to the ESE during the late 1800's.

Subsequent to the recession of late Weichsel glacial ice, raised beaches have been cut to an elevation of 61.1 m above sea level as a result of isostatic uplift and eustatic effects. Two types of beaches occur: (1) low profile beaches consisting primarily of light grey chert gravel forming gently sloping topography, and (2) step-like beaches cut into a well jointed dolerite sill. The low profile beaches form a series of striking, regularly-spaced strandlines, whereas the step-like beaches vary in width from 1—20 m. Both beach types contain datable mollusk fragments. The post-glacial emergence rate of the area obtained from dated shell material from various beach levels compares favorably with rates from nearby areas.

The Blomesletta peninsula is in a periglacial environment with a mean annual air temperature of —5.5°C and continuous permafrost. Periglacial features include sorted and unsorted stone circles, sorted mud circles, frost-rived backscarps of marine terraces, and frost heaved dolerite joint blocks up to 1.8 m above the former glacially smoothed surface. Using emergence data, frost heave rates of the dolerite blocks have been determined to range between 0.03 and 0.18 mm/year assuming frost heaving has occurred every year at a constant rate since deglaciation.

Cryoplanation terraces are minor step-like landforms consisting of horizontal bedrock surfaces covered by a thin veneer of rock debris and bounded by ascending or descending bedrock scarps. They are formed by a series of processes including nivation, frost action, mass wasting, melt-water washing and piping and require the presence of permafrost. These terraces which form on ridges and hilltops in a rigorous periglacial environment, have been reported from the Blomesletta peninsula. We believe the reported «cryoplanation terraces» on Blomesletta are not cryoplanation terraces, but are raised marine beaches because: (1) mollusk shells occur in marine sediments on the terraces, (2) radiocarbon dates of terrace elevations correspond to regional sea level at the time of their formation, (3) rounded pebbles of differing lithology are present on the terrace treads, and (4) identical fresh terraces are currently being cut on the Blomesletta coast.

Introduction

Svalbard, a series of Arctic islands north of Norway, occupies a historic and strategic location for the study of periglacial phenomena and is currently a study site in the classic problem of the northern boundary of the late Weichsel northern European continental ice sheet. These features, plus the excellent record of dated raised marine beaches, make Svalbard a challenging site for glacial and periglacial studies. Although earth science investigations have been

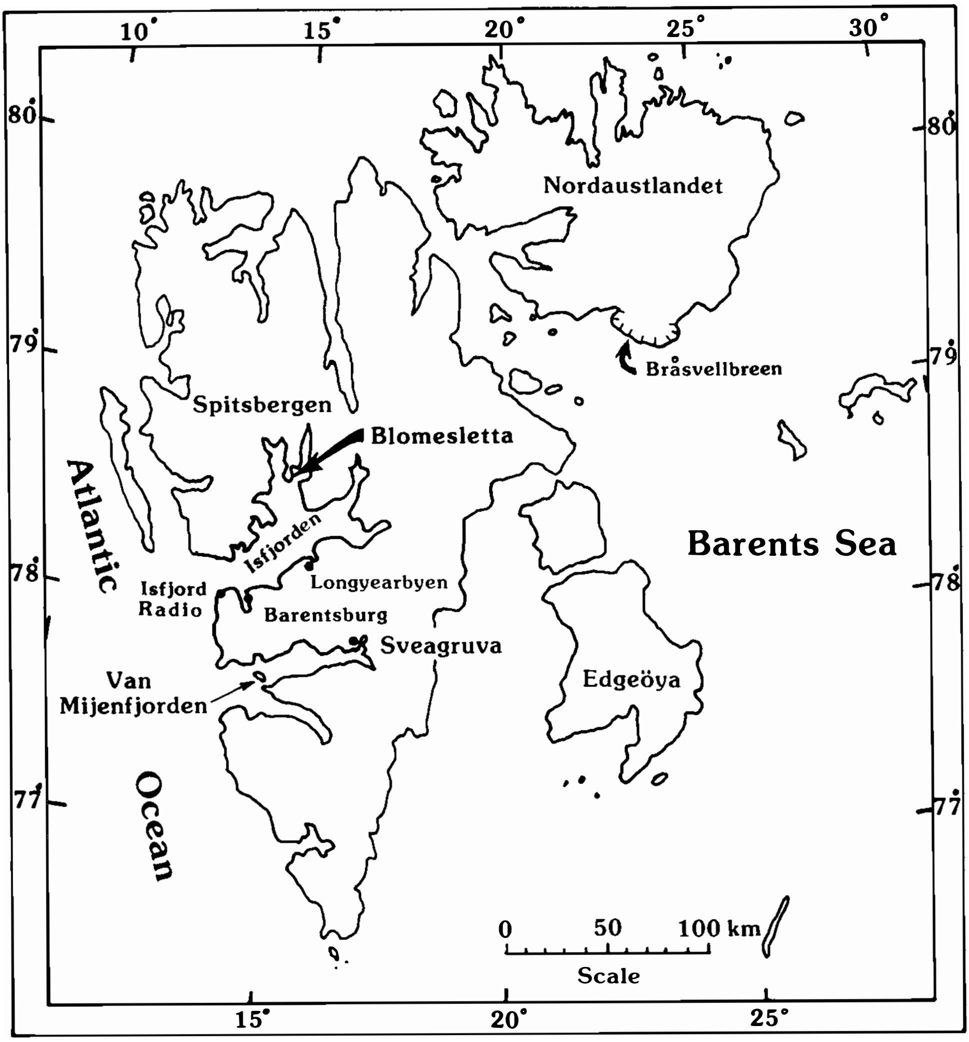


Fig. 1. *Index map of Svalbard.*

conducted in Svalbard by many countries for about 100 years, with increased year-round accessibility by air, logistic capabilities and interest in petroleum resources, both physical and biological research programs are increasing.

Troy L. Péwé, Dana E. Rowan, and Richard H. Péwé spent from 26 June to 7 August, 1979, in Svalbard conducting geological investigations on the Blomesletta peninsula, in the Longyearbyen area, and in the Sveagruva area. From 12 July to 22 July, the group examined glacial and periglacial phenomena on the Blomesletta peninsula, especially the reported active cryoplanaation terraces from this low peninsula. Inspection of the terraces, including detailed plane table mapping, revealed them to be raised marine beaches up to 10,000 years old cut into a dolerite sill. Radiocarbon dating of mollusk shells not only permitted dating of the raised beaches but allowed calculations of rates of frost heaving of dolerite joint blocks.

Fig. 2. *Oblique air photograph of the Blomesletta peninsula, Svalbard, looking east showing Ekmanfjorden, foreground, and Dicksonfjorden, middleground* (Photograph Nos. 367—368, Norsk Polarinstitutt, 1936.)

Physical setting

Geography

Svalbard is a large archipelago 800 km north of Norway bounded by the Atlantic Ocean on the west and the Barents Sea on the east. It covers an area of 62,400 km² between 74° and 81° N. latitude and 10° and 35° E. longitude (Fig. 1). Alpine glaciers carved the terrain into sharp mountains and U-shaped valleys after the retreat of the late Pleistocene ice sheet. Fjords were left by these glaciers as they withdrew from Svalbard's sharply indented coastline. Today 60% of Svalbard's total area is covered by glaciers (Royal Ministry of Justice, p. 4). The Norwegian Current, a branch of the warm Gulf Stream, flows along the western and northern coast of Spitsbergen and keeps these waters ice free between May and November (Royal Ministry of Justice, p. 4).

The Blomesletta peninsula is a north trending lowland on the island of Spitsbergen at the junction of Ekmanfjorden on the east and Dicksonfjorden on the west (Fig. 2). The peninsula is 6 km long and 2 km wide with an approximate area of 12 km². The Blomesletta peninsula has a maximum elevation of 99.6 m above sea level.[1] Raised beaches were cut into the peninsula up to an elevation of 60 m as the land rebounded when the overlying ice sheets withdrew in late Pleistocene time. These numerous old beaches now appear as parallel strandlines following the contour of the land. The peninsula is covered by fragmentary tundra that forms a thick vegetative mat of moss and low growing plants. Blomesletta, its name meaning «flower plain,» is locally covered by flowers in July, and is the nesting ground for many Arctic migrating birds.

Climate

Climate data from Blomesletta are not available, however, a permanent weather station operated by the Norwegian Government has collected climatic data at Longyearbyen 50 km to the south (Fig. 1) continuously since 1957 (Svensson 1978, p. 13) (Fig. 3). Prior to this time, sporadic data from both early coal mining operations and the German occupation during World War II were recorded. The Norwegian station was at the mouth of the Longyeardalen valley at an elevation of 53 m until 1977 when it was moved 3 km northeast to the newly completed airport at an approximate elevation of 25 m.

Svalbard has an Arctic maritime climate due to the moderating temperature effects of the surrounding Greenland and Barents Seas. The northerly flow of the warm Gulf Stream to the west of Svalbard keeps the port of Longyearbyen ice free three to five months of the year.

The mean annual air temperature (MAAT) at Longyearbyen is —5.5°C with an absolute minimum recorded temperature of —39.1°C; the absolute maximum recorded temperature is 15.8°C. The mean number of days with freezing temperatures is 261 and freezing occurs every month except July.

[1] Elevations in this report were obtained by plane table methods. Sea level was taken at 10:00 a.m. on July 15, 1979, which corresponds to 0.35 ± 0.15 m above the lowest possible low water (National Ocean Survey, 1978).

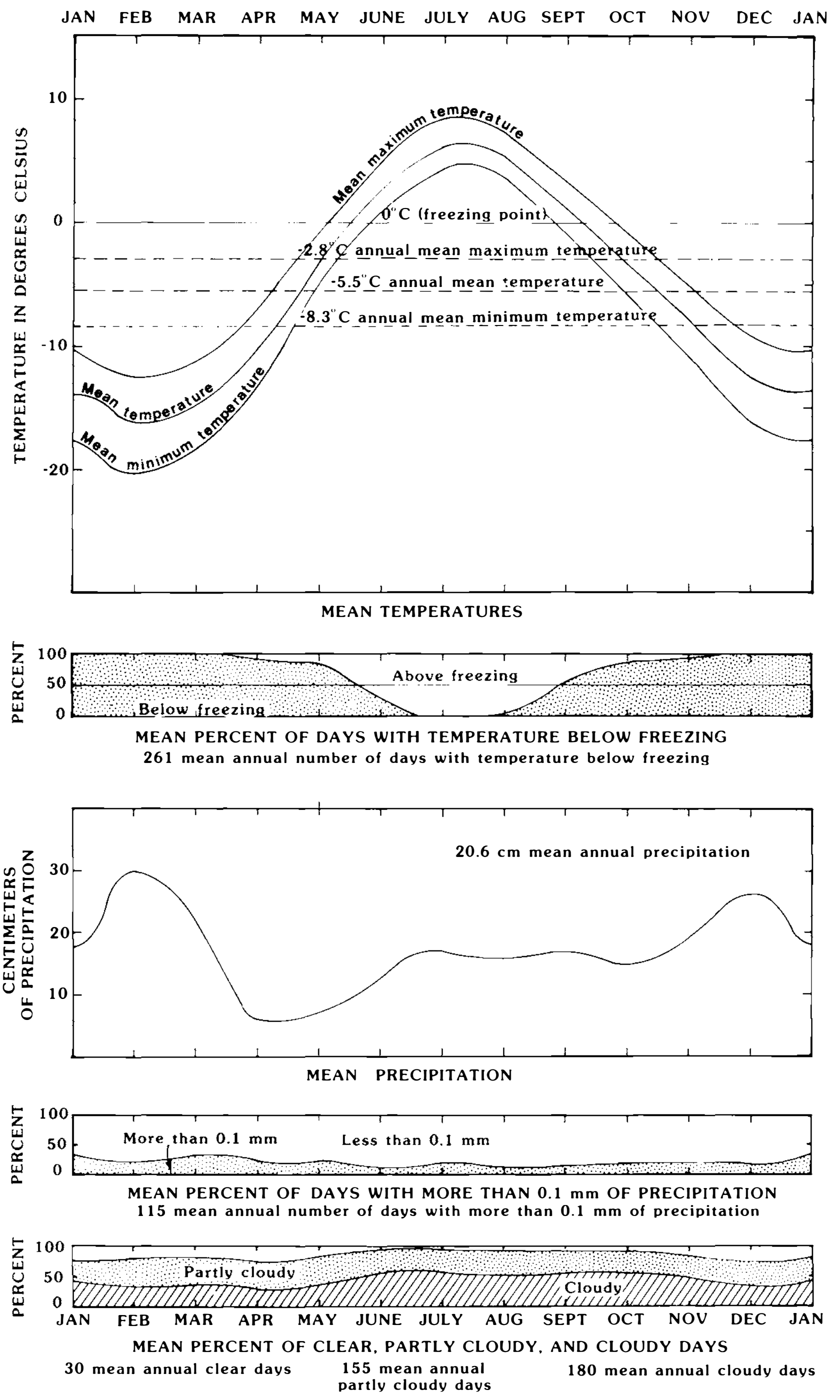


Fig. 3. *Climatic data for Longyearbyen, Svalbard (from Steffensen 1969).*

Because of its inland location, Longyearbyen has a mean annual air temperature 1.1°C colder than the coastal Isfjord radio station 50 km to the southeast (Steffensen 1969) (Fig. 1). The mean annual air temperature of nearby Barentsburg is —4.5°C (Federoff 1966).

An apparent cooling trend in the MAAT of Longyearbyen has been recognized (Svensson 1978, p. 13). Although temperature records are incomplete between 1931 and 1957, missing data have been inferred from nearby meteorological stations by the Norwegian Meteorological Institute to arrive at an estimated MAAT of —4.8°C for this period (Svensson 1978, p. 13). For the periods 1957—1968 and 1969—1979, MAAT values of —5.9°C (Steffensen 1969, p. 322) and —6.3°C (Svensson, written commun., Feb. 29, 1980), respectively, were recorded at Longyearbyen. Recent reactivization of some ice wedges near Longyearbyen tends to support this belief.

The best indicator to measure both the intensity and duration of cold temperatures is the freezing degree day index. A freezing degree day is equal to 1 degree below 0°C for the duration of one day. Therefore, one day that records an average air temperature of —10°C is equal to 10 freezing degree days. These freezing degree days are added together for an entire year to obtain the freezing degree day index.

Longyearbyen has a mean annual freezing degree day index of 2,467°C days. This measure of seasonal cold intensity for Isfjord to the east is 1,944. In contrast to Svalbard, the mean freezing index at Fairbanks, Alaska, is 2,900°C days and at Minneapolis, Minnesota, U.S.A., is 1,560°C days (Péwé and Paige 1963, p. 366).

The mean annual precipitation of Longyearbyen is approximately 200 mm with the majority falling in the winter months as snow. The summer months are mostly overcast with precipitation falling as a light to moderate drizzle.

Geology

The bedrock of the Blomesletta peninsula consists of gently dipping limestone and chert of Paleozoic age intruded by a more or less concordant dolerite sill 100 m thick (Pl. 1). The sill crops out over half the length of the peninsula lowland (Bates 1958, p. 221) and forms a north-south trending arcuate ridge.

The oldest rock of the peninsula lowland is a Carboniferous limestone 150 m thick. Bates (1958, p. 227) reports that this limestone is the upper member of an evaporite series which totals 300 m in thickness and was formed in a shallow marine environment. The limestone forms the shallow valleys of the lowland and crops out on the periphery of the dolerite sill (Pl. 1). Locally the limestone weathers to a montmorillonite rich clay.

Overlying the limestone is 150 m of dark grey chert of Permian age (Bates 1958, p. 224). Only the lower 30 m of this unit is exposed on the lowland. This

PLATE 1

Geologic map of northwest Blomesletta peninsula, Svalbard, showing C-14 sample sites, comparative photograph sites, and area of detailed topographic map (Pl. 3). Elevations and topography from plane table survey, July, 1979, by D. E. Rowan, R. H. Péwé, and T. L. Péwé. (Aerial photograph No. 3310, 1961.)

lower part is interbedded with fossiliferous limestone (Bates 1958, p. 227) which contains Productids and Spiriferids and was deposited in a shallow marine environment. The basal part of the chert crops out as pronounced cliffs along the coast and is the source of both the modern and ancient beach gravel (Pl. 1).

The dolerite sill forms an arcuate north-south ridge that cuts through the NW part of the peninsula (Pl. 1). It is stratigraphically near the chert-limestone contact, and has intruded into both the limestone and chert (Bates 1958, p. 229). The intrusion deformed the surrounding sediments as seen by their departure from regional dip near the sill. The dolerite includes no olivine; it is composed mostly of plagioclase and pyroxene, and varies in grain size from a basalt to a gabbro. The dolerite has well-developed perpendicular joint sets which dip nearly 90°. This jointing gives rise to its characteristic blocky, weathered appearance. The dolerite weathers to a red clay.

Raised beaches are present on the lowland up to 60 m (Pl. 1). The elevation is due to a combination of isostatic and eustatic effects. The angular beach gravel is predominantly chert. Glacial till occurs locally above 60 m elevation.

Glacial geology

Preliminary statement

Svalbard has been the scene of major glaciations during Pleistocene time. Evidence for these widespread glaciations is observed by the presence of well-developed U-shaped valleys, striations, rock polish, glacial deposits underlying raised beaches, and erratics.

The Quaternary glacial history of Svalbard has been treated by many investigators. Nordenskiöld (1876) suggested that an ice sheet existed in the whole area of the Barents Sea shelf in Pleistocene time. De Geer (1900) expressed a similar view suggesting that the large Barents Ice Sheet center was located to the northeast of Spitsbergen and ice from this center flowed along the eastern coast of Spitsbergen as suggested by glacial striations and erratics (Troitsky 1975, p. 226).

At the same time, however, Nathorst (1910), Andersson (1910), Drygalski (1911), and Hoel (1914) considered Svalbard as an independent center of glaciation, although believing also that the Svalbard glacial sheet extended onto parts of the continental shelf.

By dating glacial deposits that occur under Holocene raised beaches, Troitsky (1975, p. 231—234; 1979, p. 403—407) has found evidence for pre-Weichsel and late Weichsel glaciations and has outlined a Pleistocene glacial chronology of Svalbard. Since late Weichsel time the glaciers on Svalbard have withdrawn leaving many of the fjords ice free.

Recently a controversy has developed over the distribution and thickness of the ice masses which covered Svalbard in late Weichsel time. Boulton (1979, p. 50) believes that during this time, glaciation on Svalbard was limited to only the central and northeastern part of the archipelago. Grosswald (1980, p. 16), however, believes that the glacial ice masses covered all of Svalbard, and that these ice masses were part of a larger ice dome centered in the Barents Sea. Known as the Barents Ice Dome, it coalesced with the Scandinavian Ice Dome to the south and the Kara Ice Dome to the west to form a large Eurasian Ice Sheet.

Summary of the Barents Ice Sheet controversy

Two principal theories have been developed to explain the glacial history of Svalbard during late Weichsel time. Boulton (1979, p. 50—52) suggests that a glacial advance, centered in northeastern Svalbard, occurred between 11,000 and 10,000 years B.P. reaching as far south as Edgeøya and as far east as Billefjorden, 40 km east of Blomesletta (Fig. 1). The presence of this advance, known as the Billefjorden Stage, was interpreted in light of a shift of high crustal uplift rates from northeastern to southeastern Spitsbergen between 9,000 and 6,000 years B.P. Boulton further estimates the limits of Billefjorden Glaciation by sudden regional changes in the heights of the maximum terraces in central Spitsbergen (Boulton 1979, p. 49). Salvigsen (1977) reports raised beaches 30 m high on the western coast of Svalbard, outside the limits of the Billefjorden advance, dated by C-14 as being up to 40,000 years old. If glaciation were more extensive during this period, these beaches would have been destroyed. This supports Boulton's theory of limited glaciation of Svalbard during late Weichsel time.

Grosswald explains that the glaciation of Svalbard during late Weichsel time was part of a large Eurasian Ice Sheet which contained ice domes and mountain glacier complexes over Great Britain, Scandinavia, Svalbard Barents Sea, Kara Peninsula and the Putorana Plateau (Grosswald 1980, p. 16). The Barents Ice Dome is thought by Grosswald to have supplied Svalbard with glacial ice during this late Weichsel advance 11,000 to 10,000 years ago. Evidence for both the existence of this ice dome and its relationship with Svalbard takes the form of: (1) dendritic patterns of U-shaped valleys on the Barents Sea floor showing past ice direction toward Svalbard, (2) submarine outwash fans at the mouth of these U-shaped valleys, (3) glacial striae and roches moutonnées on Svalbard suggesting that ice flowed over the islands from a Barents Sea direction, (4) the occurrence of glacial drift and submarine moraines found on the Barents Sea floor, (5) high crustal uplift rates in the Barents Sea Region suggesting greatest past ice thicknesses of ice in this area, and (6) the presence of moraines off the western coast of Svalbard (Grosswald 1980, p. 3—7). Grosswald dismisses Salvigsen's 44,000 year B.P. terrace dates by stating that the dating was done on largely redeposited material (Grosswald 1980, p. 26).

Glacial geology of the Blomesletta peninsula

During late Pleistocene time, the Blomesletta peninsula was covered by a glacier formed by the coalescence of three tributary glaciers: the Holmströmbreen to the north, the Sefströmbreen and the Bardebreen to the northwest (Fig. 4). Evidence for glaciation on the Blomesletta peninsula includes south-

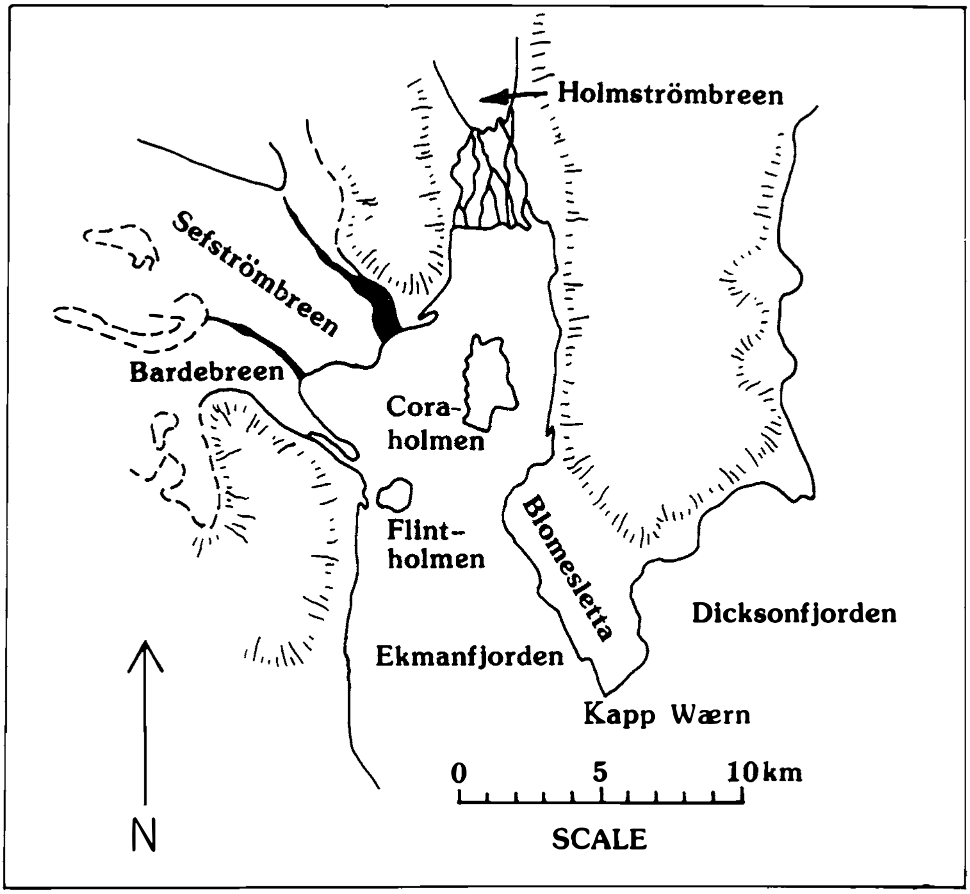


Fig. 4. *Index map of the Blomesletta peninsula area, Spitsbergen, Svalbard.*

erly trending glacial grooves, striations (Pl. 1), roches moutonnées, side glacial channels and erratics. As the glacier scoured the peninsula, the dolerite was polished forming striations on the surface of the dolerite. These were first reported by Högbom (1911, p. 36). Glacial erratics of limestone occur near the top of the dolerite ridge.

The oldest C-14 date we obtained on the peninsula was 9,780 ± 75 (SI —4308) years B.P. from specimens of *Mya truncata* collected on a 31.1 m raised beach (Pl. 1). This, along with the striations, suggests that a southerly flowing glacier was present over the peninsula as late as 10,000—11,000 years ago.

The presence of a glacial ice mass over the Blomesletta peninsula at this time neither supports nor refutes the Barents Ice Sheet or the Billefjorden Stage concepts. Glacial ice over the Blomesletta peninsula correlates well with Grosswald's Barents Ice Sheet model of glaciation; however, even though the peninsula is outside of the principal Billefjorden Stage glacial masses outlined by Boulton, one would expect that the Holmströmbreen, Sefströmbreen and Bardebreen covered the Blomesletta peninsula with ice 10,000—11,000 years ago.

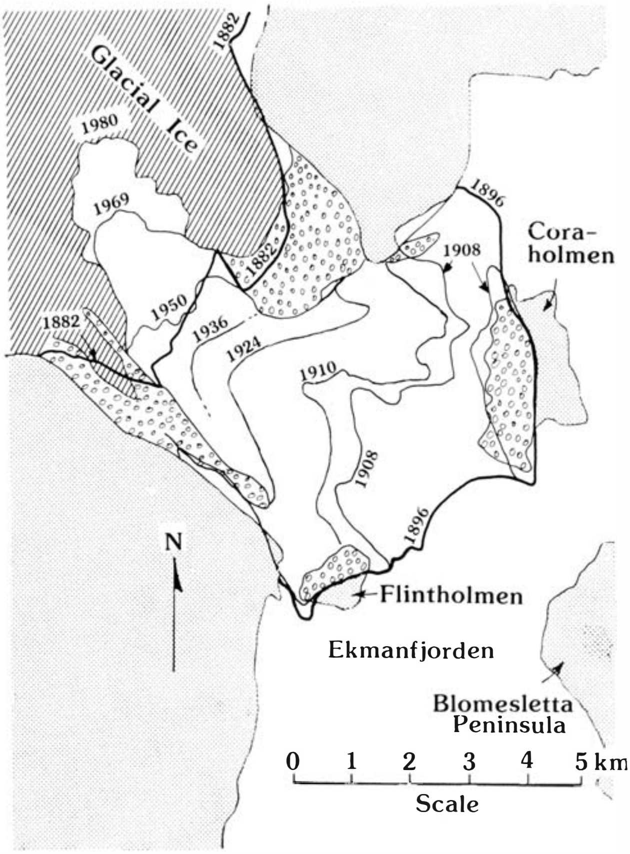


Fig. 5. *Glacial front of the Sefströmbreen in presurge (1882), surge (1896), and post-surge (1908—1980) positions (De Geer 1910; Liestøl in press). Finely stippled pattern represents land; coarsely stippled pattern represents moraine; lined pattern represents glacial ice; and unpatterned represents fjord.*

Holocene glacial surges

Glacial surges occur frequently on Svalbard and are believed to be a common form of glacial advance on the islands (Liestøl 1969, p. 895). The largest historical glacial surge occurred on Nordaustlandet (Fig. 1) between 1936 and 1938 in which the Bråsvellbreen, with a 30 km glacial front, pushed 20 km out to sea (Schytt 1969, p. 896). Although an explanation for the frequent surge behavior of Svalbard's glaciers is still uncertain, Liestøl (1969, 1976) concludes that the high frequency of surges can be explained by the steady-state flow rate of Svalbard's glaciers. Because the flow rate is insufficient to maintain a steady-state flow, ice buildup and imbalance occur. This buildup is relieved on the order of every few hundred years by surging (Liestøl 1969, p. 895). Baranowski (1977) attributes the surge behavior of Svalbard's glaciers to changes in the thermal regime of the glacier core and substratum effecting the flow properties of the ice.

The Sefströmbreen (Fig. 4), currently 7 km northwest of the Blomesletta peninsula (Fig. 5), is reported to have surged during the late 1800's (Högbom

1911; De Geer 1910). In 1882, G. De Geer visited the area and noted the extent (Fig. 5) and morphology of the glacier. The front of the main glacier was well recessed into its valley and its surface was smooth and free of crevasses (De Geer 1910, p. 16) despite the apparent recent surging of the southern side glacier which deposited a terminal moraine near the north margin of Flintholmen (Fig. 5) before 1882. Upon revisiting the area in 1896, De Geer noticed that the Sefströmbreen had advanced approximately 6.5 km to the ESE, terminating by covering part of both Flintholmen and Coraholmen. The surface of the glacier was now rough and full of crevasses, whereas the north and south side glaciers were smooth and reduced in size.

Subsequent to De Geer's observations, the Sefströmbreen has withdrawn to approximately its pre-surge position (Fig. 5) leaving mollusk-rich, fresh, ice-cored till forming steepsided knob and kettle topography on both Flintholmen and Coraholmen as evidence of its recent surge. Holocene mollusk-rich, ice-cored till has also been described by Péwé, Rowan, and Péwé (1981) on the Sveagruva Lowland 95 km to the southeast.

Holocene raised beaches

Preliminary statement

Well-preserved raised beaches or strandlines are widespread in Svalbard (Jahn 1959; Blake 1961; Feyling-Hanssen 1965; Boulton and Rhodes 1974; Moign 1974; Salvigsen 1978). Since the onset of radiometric dating, it has been possible to use raised marine beaches to determine rates of emergence in the area (Feyling-Hanssen 1965). As the great thickness of glacial ice was removed from Svalbard in late Weichsel time, great crustal rebounding occurred producing raised beaches. The current elevation of these raised beaches is a result of: (1) isostatic uplift, (2) eustatic changes caused by changing volumes of ocean water, and (3) eustatic changes caused by a redistribution of the earth's mass as the late Weichsel glaciers receded (Clark 1976, p. 310).

The individual raised beaches can be dated by radiocarbon determinations of in situ shell, wood, or bone. Dates obtained from these materials are maximum dates of beach formation and therefore may not represent the true date of the water plane (Donner and Juger 1975). Locally, contamination may result in erroneously young dates. Radiocarbon dates on material from a series of raised beaches, however, can be very useful in determining an emergent curve for the area in question.

An emergent curve for the Billefjorden area can be constructed using data from Feyling-Hanssen (1965, p. 4) and dates obtained from the Blomesletta peninsula (Fig. 6). This curve shows that post-glacial emergence occurred at a decelerating rate. Boulton (1979, p. 34—35) has plotted uplift rates of Svalbard to show differences in both the amount and shape of isobases through time. These rates are instrumental in locating past centers of glaciations since the greatest amount of crustal uplift is assumed to correlate with the maximum weight unloaded and thus the greatest thickness of ice.

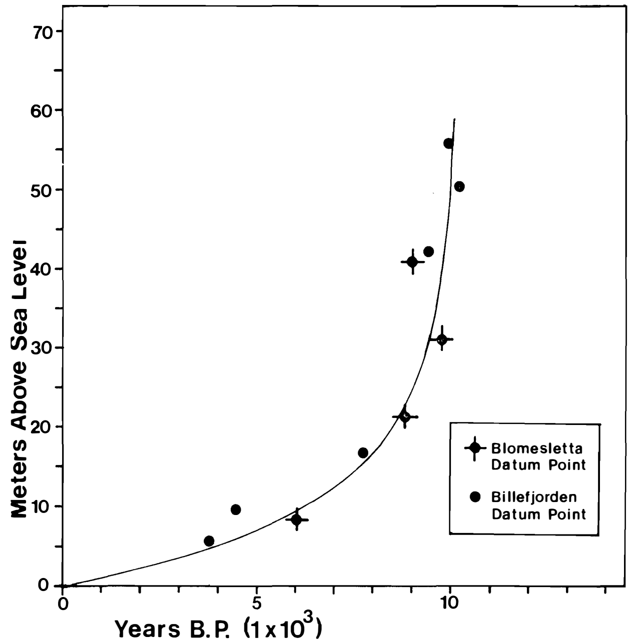


Fig. 6. *Emergence curve, based on C-14 dates, in central Spitsbergen. Data obtained from Blomesletta investigations as well as Feyling-Hanssen (1965, p. 4).*

Raised beaches on Blomesletta

Raised beaches on the Blomesletta peninsula occur from near modern sea level to 61.6 m above sea level. The beaches differ in their morphological appearances depending upon the underlying rock type. Two types of beaches occur: (1) low profile beaches of chert gravel overlying chert and limestone (Fig. 7), and (2) step-like beaches cut into the dolerite sill (Pl. 2: A, B, C).

Beaches on chert and limestone form parallel rounded berms of angular beach gravel approximately 1 to 10 m in width. The relief of the berms measured from trough to crest ranges from 0.2 to 0.3 m. These beaches are composed of predominantly angular, light grey chert pebbles ranging from 2.0 to 4.0 cm in diameter. Trace amounts of limestone, dolerite pebbles, and shell fragments occur in the beach material. Beach deposits overlying the limestone have a high amount of light grey clay. The low profile beaches characteristically form on gentle sloping topography. Since much of the gently sloping topography is formed over the limestone and chert, most of these beaches occur here (Pl. 1). They commonly occur on the dolerite where the surface expression has a gentle slope (Fig. 7).

The second type of beach forms terrace-like steps in the bedrock which are morphologically composed of a relatively flat tread and a steep back scarp (Pl. 2: A, B, C). The height of the back scarps range between 0.5 and 1.5 m. The treads range greatly in width from 1 to 10 m. The treads of these beaches contain sub-angular to sub-rounded cherty pebbles 1.5—3.0 cm in diameter and shell fragments in a silty-sandy matrix. Wave-cut back scarps that help to distinguish between different beaches are preserved only in the dolerite. These

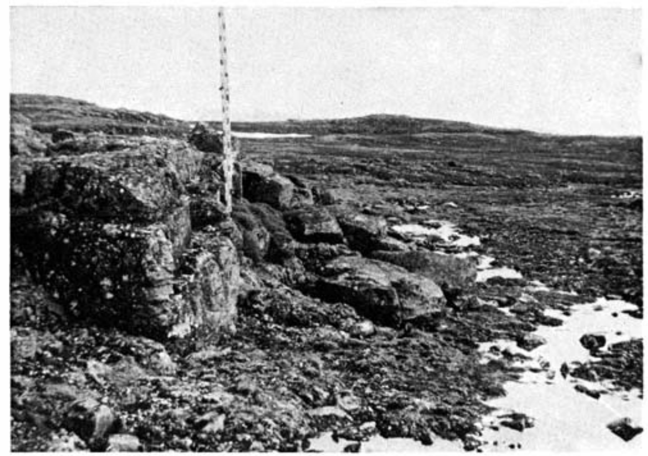
Fig. 7. *Striking, well developed, raised marine beaches consisting of angular chert gravel. Northwest corner of Blomesletta peninsula, Spitsbergen. Svalbard. Center beaches are about 25 m above sea level. Sefströmbreen in background entering Ekmanfjorden.* (Photograph No. 4419 by Troy L. Péwé, July 21, 1979.)

PLATE 2

A

B

C



D

scarps are believed to have formed partly due to the high susceptibility of the vertically jointed dolerite to frost wedging and also wave action.

A detailed topographic map of a part of the peninsula was constructed by plane table and alidade, mapping the distinguishable raised beaches of the area (Pl. 3). The bedrock in this map area is dolerite. Glacial striations as well as vertical joint sets in the dolerite have been recorded to demonstrate their relationship to the beach scarps.

The lowest beach in the detailed study area is a low profile type beach 8.0 m above sea level (Pl. 3). Mollusk fragments composed of their original hard parts in this beach have been dated at 6,070 ± 65 (SI-4307) C-14 years B.P. Low profile beaches in the detailed study area occur up to 15 m in elevation and formed in a reenterent where they were protected from high energy coastal conditions.

Above 15 m elevation, the average slope increases and back scarp beaches, cut into the dolerite bedrock, predominate (Pl. 3). Generally, these beaches become rounded and less distinct as they increase in elevation. This is apparently due to the longer amount of time they were exposed to denudation, primarily by frost action. Dates have been obtained on 21.2 m and 31.3 m beaches (Pl. 3) from samples of *Mya truncata* of 8,920 ± 70 (SI-4306) and 9,780 ± 75 (SI-4308) C-14 years B.P., respectively.

PLATE 2

Wave-cut back scarps in dolerite on raised beaches, northwest Blomesletta peninsula, Spitsbergen, Svalbard. (Se Plate 1 for location and distribution of sites, beaches, and scarps.)

A. Relatively fresh wave-cut scarp behind beach. R. H. Péwé digging marine pebbles and shells from tundra-covered beach deposits. Scarp is fresh and only slightly destroyed by frost action. Elevation 13 m above sea level at east end of beach '5.' Approximate age 7,000 years. (Photograph No. PK22792 by Troy L. Péwé, July 13, 1979.)

B. Wave-cut scarp in dolerite behind raised beach. Note the destruction of the scarp by weathering (mainly frost action) over thousands of years. Snow and liquid water plentiful throughout the summer freeze-thaw season. Elevation 15.3 m. Age of scarp approximately 8,000 years. On west side of map area shown in Plate 1. (Photograph No. PK22879 by Troy L. Péwé, July 19, 1979.)

C. Wave-cut scarp in dolerite behind elevated beach. Note the destruction of the scarp by weathering (mainly frost action). Elevation approximately 15 m. Age of scarp approximately 8,000 years. Digging up the beach gravel and marine fossils base of scarps. (Photograph No. PK22793 by Troy L. Péwé, July 13, 1979.)

D. Essentially destroyed wave-cut scarps and frost-heaved blocks on dolerite surface. West side of map area shown in Plate 1. View south. Elevation approximately 47 m. Age of scarps approximately 10,000 years. (Photograph No. PK22883 by Troy L. Péwé, July 20, 1979.)

Periglacial geology

Preliminary statement

The periglacial zone was first defined by the Polish geologist Walery von Lozinski (1909) to describe the climatic and geomorphic conditions of areas peripheral to the Pleistocene continental ice sheet of Europe. Although the exact conditions are disputed among workers in this field, all would agree that the periglacial environment is characterized by a cold, rigorous climate (Jahn 1961, p. 3). Péwé (1969, p. 2) defines the contemporary periglacial zone as all areas where permafrost and/or intense frost action are present. Both of these criteria apply to the Blomesletta peninsula where various periglacial features such as permafrost, frost heaving of joint blocks, sorted stone circles, mud circles (spot medallions) (Jahn 1975, p. 88), and tundra hummocks exist.

A field excursion in 1910 to Spitsbergen led by De Geer (1910) and Högbom (1914) during the XI International Geologic Congress, was the first international trip organized to study active periglacial features. As a result of this trip, a rapid increase in periglacial research occurred, not only in Svalbard, but throughout the world.

Permafrost

Svalbard is in the continuous zone of permafrost (Fig. 8). Permafrost underlies the entire archipelago of Svalbard with a carapace of frozen ground between 200 and 450 m thick (Liestøl 1976). The permafrost thickness varies locally depending upon the geographic setting; permafrost is less thick in valleys than on mountain tops. Although the exact thickness of permafrost on the Blomesletta peninsula is unknown, data is available from Longyearbyen and Sveagruva to the south. Permafrost is 450 m thick on the Sarkofagen mountain ridge near Longyearbyen and 280 m at Liljevalchfjellet near Sveagruva (Liestøl 1976). The thickness of permafrost in Adventdalen near Longyearbyen has been reported by A. Orheim of SNSK (oral communication 1979) as 100 to 160 m.

Between 12 July and 22 July, 1979, the depth to frozen ground on the bare chert raised beaches of the Blomesletta peninsula increased from 15 cm to 46 cm. The temperature during this period was unseasonably high with Longyearbyen reporting an all-time recording high of 21°C.

Frost heaving of dolerite blocks

On Blomesletta the most prominent frost heave features are the up-thrusted, well-jointed, glacially smoothed dolerite blocks (Fig. 9). When the glaciers which covered Blomesletta 10,000 years ago receded, they left behind a smooth, well-jointed surface of dolerite. As the glacier withdrew and the seas trans-

PLATE 3

Detailed topographic map of raised beaches on northwest Blomesletta peninsula, Svalbard, showing raised beach deposits, glacial striae direction, C-14 sample sites, strike of vertical sets in dolerite, and comparative photograph site. Topography from plane table survey, July 1979 by Richard H. Péwé, Dana E. Rowan, and Troy L. Péwé.

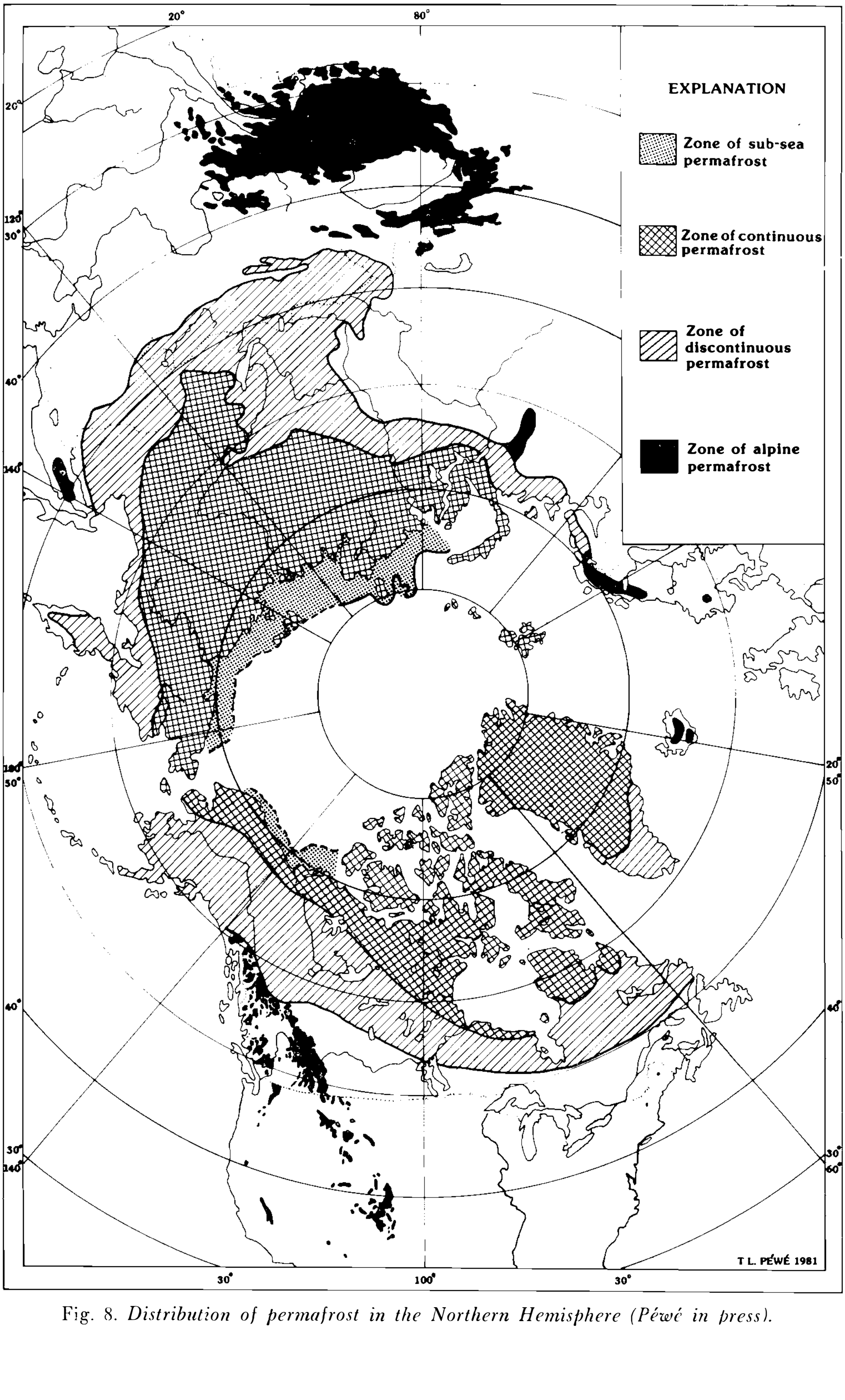


Fig. 8. *Distribution of permafrost in the Northern Hemisphere (Péwé in press).*

Fig. 9. *Frost-heaved blocks of dolerite up to 1.2 m high. Blocks have been heaved above and from a glacially smoothed bedrock surface. Area is 45 m above sea level and has been exposed from the sea and glacial ice for approximately 10,000 years. View west from dolerite sill, northwest Blomesletta peninsula, Spitsbergen, Svalbard. Sefströmbreen entering Ekmansfjorden in background.* (Photograph No. 4398 by Troy L. Péwé, July 13, 1979.)

gressed over the peninsula, silty, clayey till as well as marine silts and clay were deposited into the dolerite joints. As crustal uplift occurred, the sea withdrew and the dolerite surface was exposed to a rigorous cold climate with alternating freezing and thawing. Water, primarily derived from melting snow, percolated into the well-jointed dolerite. The water was restricted in its downward migration by the underlying permafrost and concentrated in the dolerite joints, rich in fines, of the active layer. With these conditions, the well-jointed dolerite was subjected to intense frost heaving. Currently, individual polygonal blocks of dolerite are heaved as much as 1.8 m above the original surface (Pl. 4, B). Frost heaved joint blocks have been reported elsewhere (Högbom 1908; Yardley 1951; Washburn 1969 and 1973, p. 66); however, data are available on the Blomesletta peninsula to suggest a minimum rate of the joint block heave. By assigning sea emersion dates, obtained from the emergent curve (Fig. 6), to specific heaved blocks, average minimum heave rates of the polygonal blocks have been obtained. As observed in Plate 4, A, B, C, the rate of frost heave varies greatly from 0.03 mm/year (Pl. 4, C) to a maximum calculated uplift rate of 0.18 mm/year (Pl. 4, B) assuming frost heaving occurred every year since deglaciation at a constant rate. Frost action is currently occurring on the peninsula as suggested by: (1) lack of lichen cover on surface clasts as well as the lower parts of frost heaved dolerite blocks, (2) lack of vegetation in the sorted mud circles, and (3) the fresh form of the sorted circles. The degree of frost action, however, has undoubtedly varied with changes of climate through time as well as differing ground conditions. Some dolerite blocks are less active than others and the heave rate cited is an average value for individual blocks.

Wave and frost action on back scarps

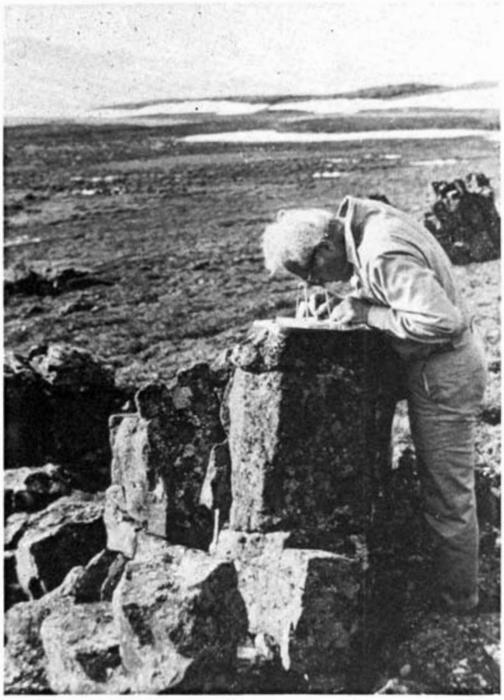
Step-like back scarps occur on the dolerite between sea level and approximately 60 m elevation (Pl. 2, A). They were formed by both frost and wave action as isostatic rebound occurred. Frost action provided the main mechanism needed to split and rive the dolerite (Jahn 1961, p. 22) whereas the wave action transported the debris away from the base of the back scarp. This process can be observed today on the Blomesletta coast (Fig. 10). As the back scarp beaches are raised above sea level by isostatic uplift, only the process of frost action continues to act on the back scarps. Without wave action present to remove the debris from the disintegrating back scarp, this area is soon choked by frost rived debris leaving a gentle rise (Pl. 2, D) where once a sharp step-like scarp existed. The back scarp beaches of Blomesletta occur in various stages of denudation forming step-like benches near sea level and becoming more rounded and worn with an increase in their elevation and therefore age (Pl. 2).

Sorted and unsorted circles

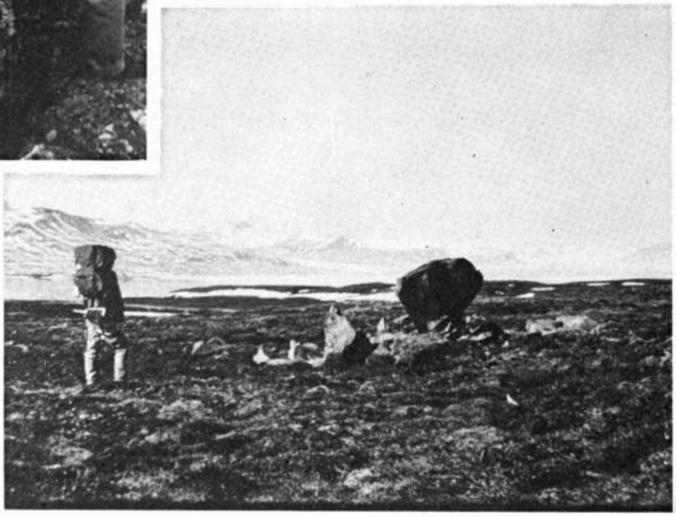
Sorted and unsorted circles are widespread in Svalbard (Dutkiewicz 1967, p. 52; Jahn 1958, p. 230; 1961, p. 5; 1975, p. 131). On the Blomesletta penin-

PLATE 4

Frost-heaved joint blocks of dolerite on previously smoothed and polished glacial surface. Northwest Blomesletta peninsula, Spitsbergen, Svalbard, See Plate 1 and 2 for locations.



A. Joint block heaved about 1.1 m. Elevation 47 m above sea level. Exposed from under ice and marine waters for approximately 10,000 years. Calculated frost heave rate equals 0.11 mm/year. (Photograph No. PK22821 by Troy L. Péwé, July 14, 1979.)



B. Joint block about 1.8 m high. View toward Sefströmbreen. Raised beach elevation 35 m. Exposed from under ice and above marine water about 9,800 years. Calculated frost heave rate equals 0.18 mm/year. (Photograph No. PK22802 by Troy L. Péwé, July 14, 1979.)

C. Joint blocks heaved from 5 to 30 cm. Elevation 36 m above sea level. Exposed from under ice and above marine water about 9,800 years. Calculated frost heave rate for 30 cm block equals 0.03 mm/year. (Photograph No. PK22882 by Troy L. Péwé, July 20, 1979.)

sula they commonly occur on the raised chert beaches between strandlines where moisture collects. The sorted circles are uniform in size containing a flat central silt circle approximately 45 cm in diameter surrounded by a raised ring of loose, angular chert beach gravel 2.0 to 5.0 in diameter and approximately 15 cm above the central circle. Excavation revealed that the silt of the central portion of the circle graded into sand and gravel with depth.

Active unsorted circles are uniform in size approximately 30 cm in diameter and consisting of shell fragments in a matrix of dark green-gray marine clay. The absence of vegetation within the circle suggests the current activity of the circle.

Sorted mud circles

Sorted mud circles occur in the sediment overlying the limestone. The circles, 0.4 cm in diameter, are composed of a gritty, sticky center, surrounded by a ring of highly angular buff limestone clasts 5.0 to 10 cm in diameter. X-ray analysis of the clay fraction from the circles revealed a high montmorillonite content (J. T. Bales, written communication, 1980). The high montmorillonite content gives the clay a high shrink-swell property which may add to the development of the circle. The circles are currently active as indicated by the emergence of fresh rock and shell fragments and the lack of vegetation in the central portion of the circle.

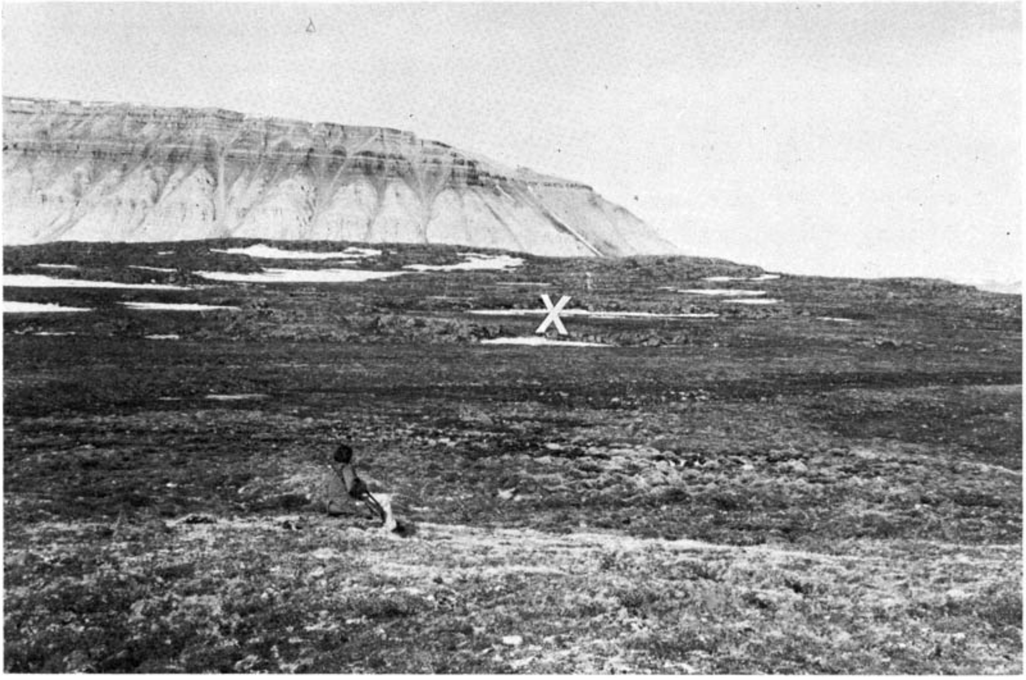
Cryoplanation terraces

Cryoplanation terraces are minor step-like landforms consisting of nearly horizontal bedrock surfaces covered by a thin veneer of rock debris and bounded by ascending or descending bedrock scarps or both (Demek 1969; Reger and Péwé 1976, p. 99). Cryoplanation terrace scarps, which range in height from 1 to 75 m and form slopes between 9 and 32°, occur on high ridges and hill crests. The treads (flat areas) of the cryoplanation terrace vary in slope from 1 to 10° and in area from 3×10^3 to nearly $1 \times 10^6 m^2$ (Reger and Péwé 1976, p. 99—100).

Cryoplanation terraces are formed by a series of processes including nivation, frost action, mass wasting, melt water washing, and piping (Reger 1975, p. 142). The presence of permafrost and snow is a necessary requirement for their formation. The backcutting of scarps is implemented by frost action splitting and riving bedrock at the back walls of nivation hollows. The melting snow of the nivation hollows produces the needed water for frost action. The terrace tread morphology is maintained by the underlying permafrost. Frost-rived material from the back scarps is transported away from the scarp by melt water washing and mass movement. Because of water saturation on the tread due to the presence of shallow permafrost, solifluction and frost creep can transport the products of scarp destruction down tread (Reger 1975, p. 181—182). Reger and Péwé (1976, p. 108) have estimated that cryoplanation terraces form with a mean July temperature between 2 and 6°C which roughly

PLATE 5

View looking west of raised marine beaches cut on dolerite, northwest Blomesletta peninsula, Spitsbergen, Svalbard.

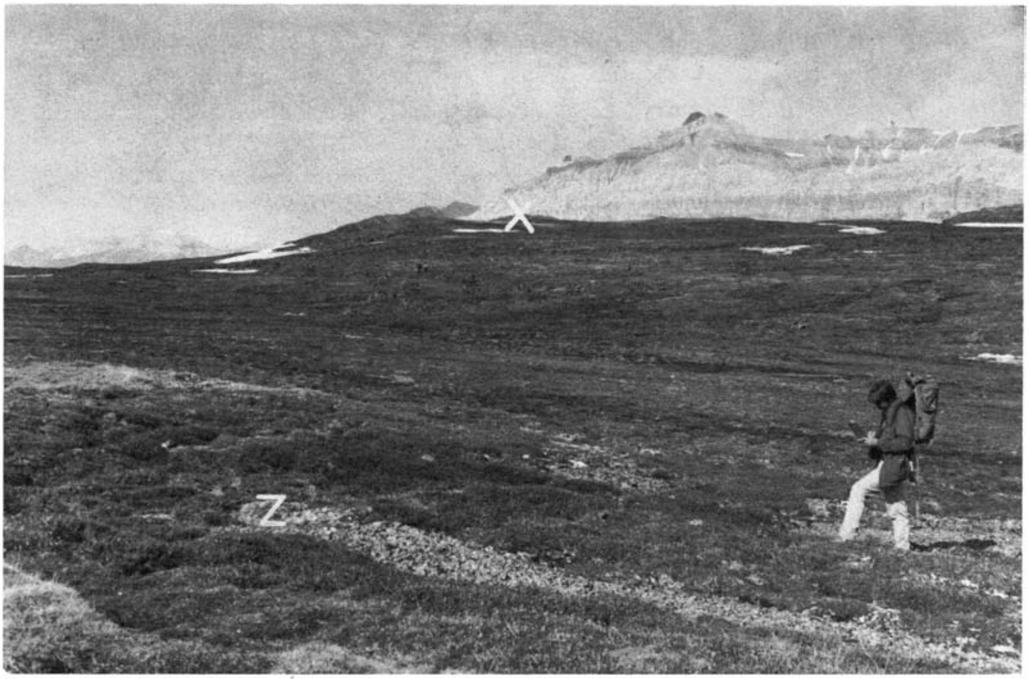


A. Scarps approximately 1—2 m high at the backside of most elevated beaches. X marks the location of station which is 20.5 m above sea level. At an elevation of 31.3 m just outside of the photograph to the right, fossil marine mollusks *(Mya truncata)* on the ancient beach were dated at 9,780 years of age. See Plate 2 for location of photograph and fossil sites. (Photograph No. 4405 by Troy L. Péwé, July 13, 1979.)

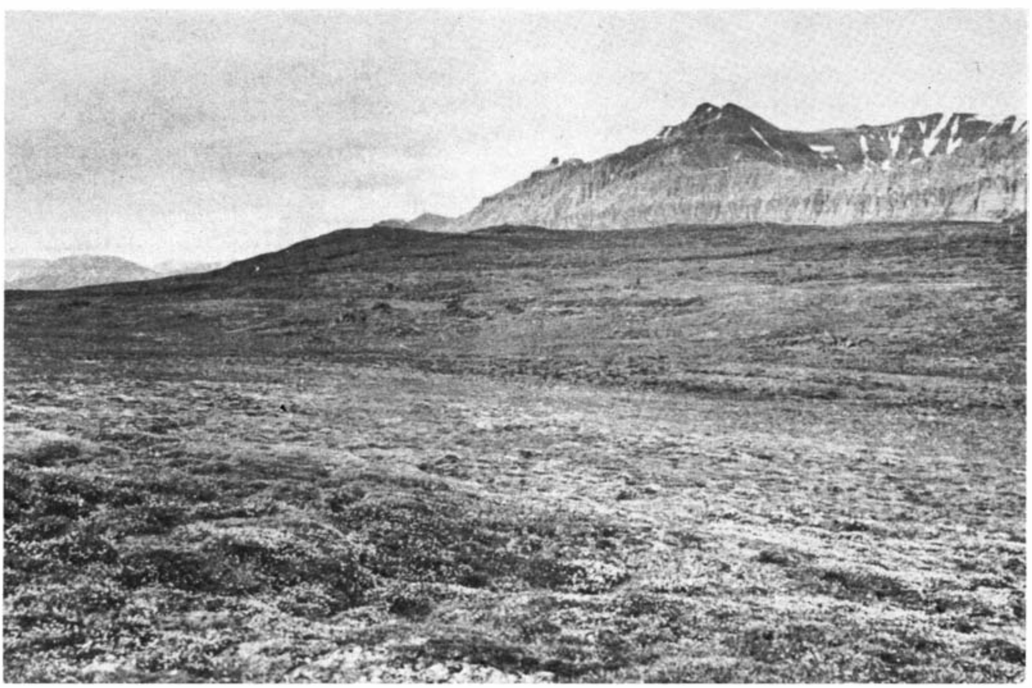
B. Duplicate photograph taken from same location by Professor R.S. Waters in 1958 (Waters 1962, Pl. 6). Professor Waters interpreted these elevated beaches as active cryoplanation terraces.

PLATE 6

Comparative photographs of elevated marine beaches, north end dolerite sill, Blomesletta peninsula, Spitsbergen, Svalbard.



A. The raised beaches reach almost to the high point of the middle ground. High point 'X' is 99.6 m above sea level. Point 'Z' in the foreground is one of the sorted circles of patterned ground where fossil beach mollusks are brought to the surface by frost action. Radiocarbon date of the marine shells at this station indicates age of 9,025 years. Beach is 40.8 m above sea level. Beach pebbles and marine fossils occur on almost all of the elevated beaches. See Plate 1 for location of photograph and fossil site. (Photograph No. 4415 by Troy L. Péwé, July 14, 1979.)



B. Duplicate photograph taken from same location by Professor R. S. Waters in the summer of 1958. Waters described these upper beaches as active cryoplanation terraces (Waters 1962.)

corresponds to a mean annual air temperature of —12°C. Lingering snowbanks at the back scarps of the terraces are needed throughout the summer months to provide the water necessary for nivation and down tread transport of debris.

Blomesletta investigations

In 1962, R. S. Waters reported active cryoplanation terraces on the Blomesletta peninsula (Waters 1962, p. 89—101). Waters described these terraces as having tread widths up to 60 m and near vertical back scarps 1 to 2 m in height occurring on a moderately sloped, quasi-horizontally jointed dolerite (Pls. 5, B; 6, B).

Our investigations indicated that the dolerite, rather than having quasi-horizontal joints, is predominantly composed of vertical joints (Pls. 1, 3). The treads of the terraces are rich in moisture and, therefore, thickly vegetated with moss. Excavation into the tread surface through 5 cm of turf revealed 15 cm of red clay underlaid by well rounded pebbles 2 to 5 cm in diameter composed of limestone, chert and dolerite. Mollusk shells are common in the gravel. Two comparative photographs were taken of Waters' photographs sites showing a series of terraces (Pls. 5, A, B; 6, A, B). A detailed topographic map was made by plane table methods outlining distribution of the terraces (Pl. 3).

We believe that these terraces are not cryoplanation terraces, but raised beach treads and scarps cut by waves. There are four basic reasons for our belief that the terraces on the Blomesletta peninsula are not cryoplanation terraces. First, the climate of the Blomesletta peninsula has been too warm for cryoplanation terrace formation since the land was exposed by glacial retreat. The mean annual air temperature for the area is only as cold as —5.5°C (Fig. 3). This differs widely from the predicted —12°C necessary for terrace formation.

Second, cryoplanation terraces require tens of thousands of years to form. Blomesletta was scoured smooth by a glacier only 10,000 years ago and exposed to freezing temperatures for only 5,000 to 9,000 years as suggested by C-14 dating described above. If the terraces were cryoplanation terraces, one would expect the older and therefore higher terraces to be better developed for they have been forming for a longer time. However, the younger terraces near sea level are the best developed and have been exposed to freezing temperatures for the least amount of time.

Third, the terraces observed on Blomesletta are morphologically and geographically different from cryoplanation terraces. Cryoplantion terraces occur most commonly on higher ridges and hillcrests. The terraces on Blomesletta have been cut into the slopes and are poorly developed on the ridge crests.

At the base of true cryoplanation back scarps, highly angular clasts occur. This material, derived solely from the bedrock, is composed of rock material of the scarp. The terraces observed on Blomesletta, however, have well rounded fragments of mollusk shells, chert, limestone, and dolerite in the back

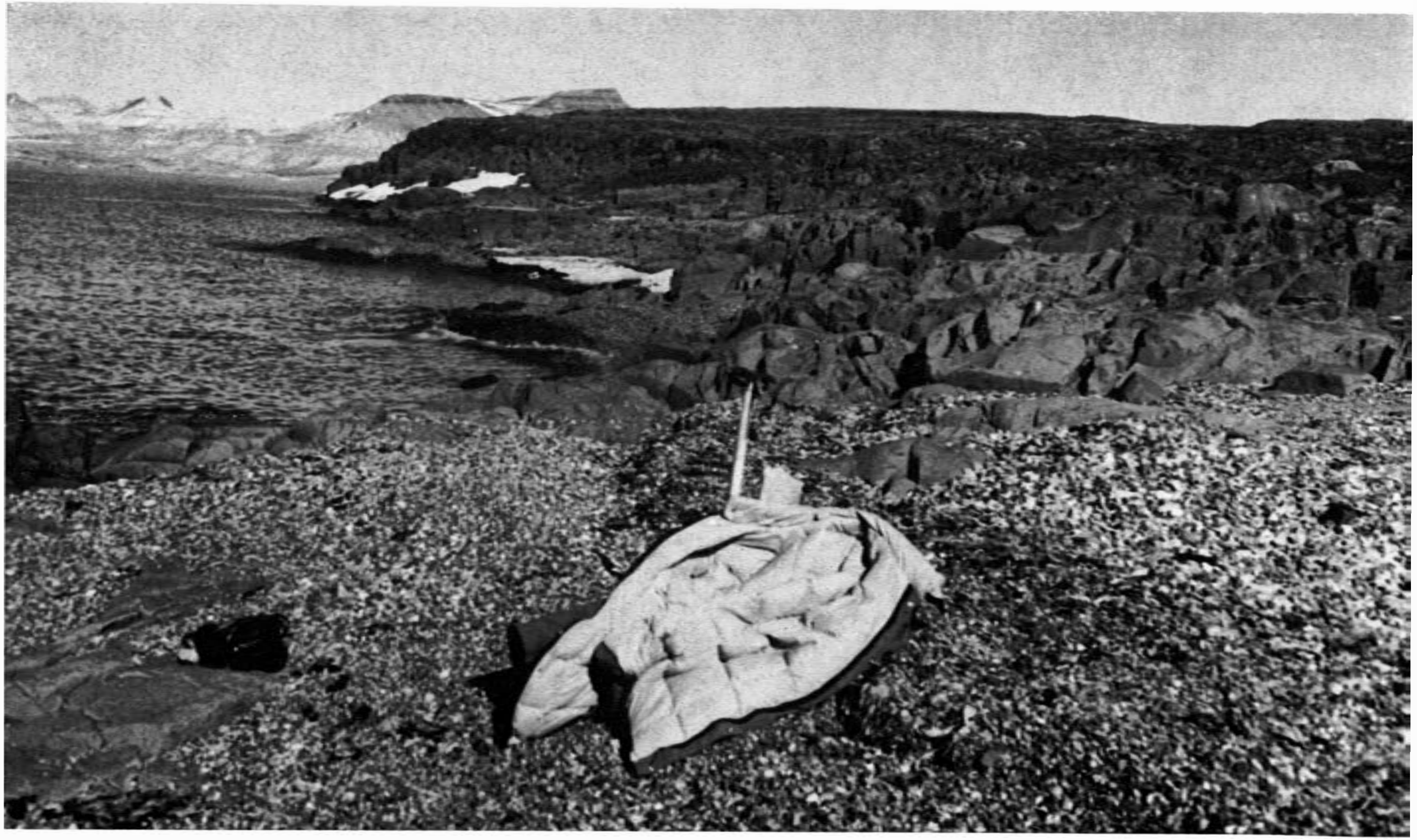


Fig. 10. *Modern beach being formed at sea level with back scarps cut in dolerite sill. Northwest corner, Blomesletta peninsula, Spitsbergen, Svalbard. Angular chert and marine shells on tread. The modern beach and scarp are similar to the raised beaches and scarps in the same area.* (Photograph No. 4420 by Troy L. Péwé, July 21, 1979.)

scarp matrix. Both the shape and lithology of this material suggest that it did not originate from the back scarp, but was transported from a distant source.

Evidence which supports the wave-cut origin of these terraces is as follows: (1) the presence of mollusk shells at the back scarps of the terraces; (2) radiocarbon dates of the terrace elevations which correspond to regional sea level at the time of their formation; (3) the rounded pebbles of differing lithology present on the terrace treads; and (4) the presence of fresh terraces, having the same morphology as the reported cryoplanation terraces, currently being cut in the well-jointed dolerite on the Blomesletta coast.

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