Reports

Pleistocene Glaciation on St. George, Pribilof Islands

Abstract. *A small ice cap (covering about 12 square kilometers) and at least two—probably four—cirque glaciers (each covering less than 1 square kilometer) occurred on St. George Island, Pribilof Islands, probably during the Illinoian Glaciation. Snowbanks persisted during a later cold cycle, probably during the Wisconsin Glaciation, with no glaciers existing. We found no evidence of glaciation on other Pribilof islands.*

The Pleistocene history of the Pribilof Islands interests geologists, anthropologists, and biogeographers because the islands lie near the southwestern edge of the continental shelf that extends between Alaska and Siberia, beneath the Bering and Chukchi Seas (Fig. 1). The islands are thus favorably situated to provide a record, as to time and environment, of former land connections between Asia and America. Barth recognized evidence of glaciation in 1948 (*1*); we gave special attention to the glacial record in 1965. The Pribilofs comprise two large islands —St. Paul and St. George—and three islets near St. Paul.

St. Paul consists of cinder cones and lava flows that were erupted during the last 400,000 years (*2*). Marine, aeolian, and colluvial sediments are intercalated with the lava flows, and wind-blown sand covers much of the northern and eastern parts of the island. Rush Hill, 204 m, is the island's highest peak; the altitude of most of the uplands in the center of the island is 60 to 75 m. The surface of the uplands is a primarily volcanic topography that has been smoothed and softened by frost action but has not appreciably eroded. Barth suggested that poorly consolidated, water-laid agglomerate exposed in the lower part of Black Bluffs, a cliff eroded by waves on a small volcanic cone, was "probably dumped by ice" (*3*), but we think this deposit is water-laid volcanic-explosion breccia. St. Paul has never been glaciated.

St. George Island is an undulating highland underlain mostly by volcanic rocks that were erupted between 2.5 and 1.0 million years ago (*2*). Marine sediments underlie the volcanic rocks, and marine and colluvial sediments are intercalated in the volcanic sequence; a basement of serpentinite and aplite is exposed along part of the southeast coast. The form of the island has been profoundly modified by faulting and uplift; the topography is now dominated by a narrow ridge, extending along the western part of the north coast and culminating in High Bluffs (309 m), and by a broad fault-block plateau in the southeast (highest point, Ulakaia Hill, 289 m) (Fig. 2).

This topography, formed originally by volcanic activity and by differential uplift, has been denuded principally by frost action and marine erosion. The volcanic rocks of the Pribilofs are so permeable that most precipitation infiltrates; very little runs off. St. George has only a few perennial streams, and three small stream-carved valleys in the eastern part of the island form a striking break in the otherwise smoothly flowing contours. Frost, however, has been and still is active in softening the original volcanic and tectonic topography. Although permafrost may not occur in the Pribilofs, solifluction and creep resulting from cycles of freezing and thawing are active. Large-scale-patterned ground now overgrown with moss and lichens testifies to even more vigorous frost-denudation in the past. Frost riving—the breaking up of bedrock by cycles of freezing and thawing —appears not to be progressing on a large scale at present, but basaltic lava flows exposed at the surface have everywhere been reduced to loose rubble during past intervals of more severe climate. Hopkins (*4*) shows that past intervals of more active frost riving in western Alaska can be equated with glacial intervals.

Marine erosion is now active, and precipitous sea cliffs have been carved around much of the coast. At least two past intervals of higher sea level are recorded in low-lying areas by sheets of marine gravel that extend to old shorelines at altitudes of 14 to 20 m and 6 to 8 m (Fig. 2).

Although St. George's topography has been formed primarily by volcanism, tectonic activity, frost denudation, and marine erosion, glacial erosion and deposition are evident in at least three and probably five areas. A small ice cap and an adjoining small cirque glacier once occupied about 12 km^2 on the high land north, east, and southeast of Ulakaia Hill; and at least two and probably four cirque glaciers, each covering less than 1 km^2, once occupied the northwestern ridge (Fig. 2). These five areas are all marked by erosional topography in which sequences of subhorizontal lava flows as thick as 50 m have been removed.

Barth noted several exposures of till-like sediments resting on serpentinite along the southeast coast, and he found a polished and striated pavement carved on serpentinite a short distance northeast of Garden Cove (*5*). But Barth failed to recognize ice-scoured topography on the uplands nearby, and he took certain unsorted sediments underlying the basalt sequence southwest of Garden Cove to be of glacial origin (*6*). Therefore he concluded that the glaciation of St. George took place in early Pleistocene time, before most of the volcanic activity (*7*). We have confirmed the existence of glacial striae and of glacial till resting upon serpentinite on the marine terrace northeast of Garden Cove, and we have found much additional evidence of glaciation on the island. However, all the evidence relates to a single glacial episode that took place long after volcanism ended on St. George. The unsorted sediments underlying the volcanic sequence, that Barth interpreted as glacial, locally contain fossil mollusks; we doubt that they are of glacial origin.

Ice-smoothed pavements and roche moutonées, shattered by frost riving but still readily recognizable, abound within 1 or 2 km northwest of Garden Cove. Raised bogs, on rock steps eroded across individual lava flows, evidently occupy ice-scoured basins.

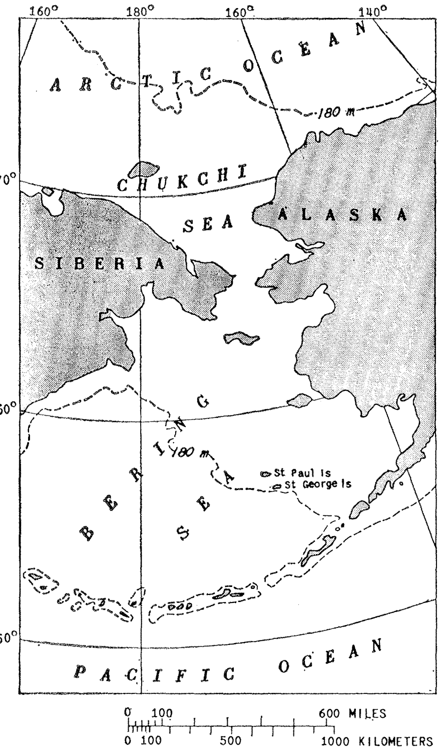

Fig. 1. The Pribilof Islands, St. Paul and St. George. The Bering-Chukchi continental shelf is enclosed by the 180-m contour (dashed line).

We noted no striae on the upland, where none would be expected because striae are rarely preserved on the weathered surfaces of porous basaltic lavas.

End moraines are rare because most of the small glaciers terminated in areas now below sea level. However, a series of subdued but well-defined morainal ridges as high as 10 m marks the northern limit of the glaciers that spilled northward over the Ulakaia fault scarp; the ridges enclose a series of low areas now occupied by raised bogs and small bog lakes. Masses of drift, forming local convexities in the Ulakaia fault scarp below the cirque north of Ulakaia Hill and below the pass followed by the Garden Cove trail, may represent recessional moraines. These deposits and the deposits of glacial till on the Garden Cove marine terrace are easily distinguished from the talus and frost-moved colluvium on St. George because they contain boulders derived from several different lava flows of contrasting lithology. Some serpentinite and basalt boulders on the Garden Cove terrace are striated and many are faceted.

The three anomalous stream-carved ravines on eastern St. George are so placed that they would have carried large quantities of glacial meltwater; we assume that they were carved during the glaciation.

The several cirques on the island are carved into uplands ranging in altitude from 150 to 180 m; the cirque floors lie between 100 and 180 m. The small ice cap near Ulakaia Hill seems to have originated on a wide plateau surface ranging from 150 to 240 m in altitude, but narrower parts of the plateau, as high as 200 m, apparently remained free of glacial ice. We conclude that during the glaciation the snow line lay at about 150 m.

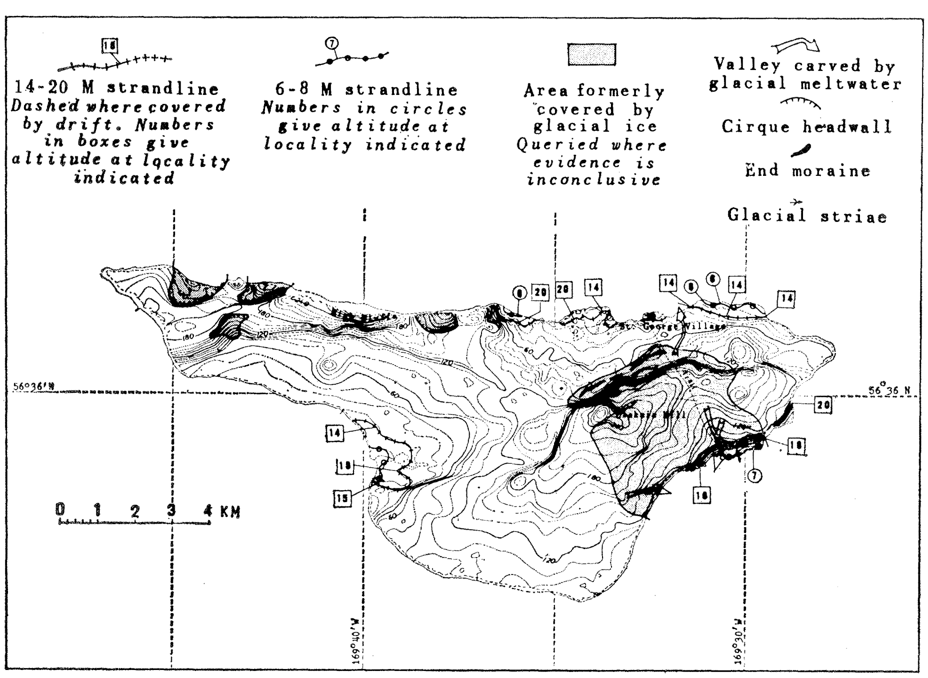

Fig. 2. Glacial features and late-Pleistocene strandline on St. George Island.

Several features suggest that the glacial phenomena are pre-Wisconsin. The subdued topography of the end moraines and the thorough frost-brecciation of roche moutonées and of ice-scoured pavements indicate that the glaciation was followed by a long period of climate more severe than at present. The moraines, cirques, and ice-scoured surfaces are comparable in degree of modification by frost action to glacial features on Seward Peninsula that were formed during the Nome River (Illinoian) Glaciation (*4, 8*).

Stratigraphic relations on the Garden Cove terrace reinforce the suggestion that St. George was glaciated during Illinoian time. The glacial drift there overlies—is younger than—beach gravel extending up to a buried shoreline at an altitude of 18 m, and the drift is incised by—is older than—a strandline at an altitude of about 7 m. Our stratigraphic studies on St. Paul strongly suggest that the 14- to 20-m strandline represents the shoreline during the Kotzebuan transgression, of pre-Illinoian age, and that the 6- to 8-m strandline represents the shoreline during the Pelukian transgression, of Sangamon age (*9*).

The glacial features on St. George Island evidently were formed during the Illinoian Glaciation. The island seems to have lacked glaciers during the Wisconsin Glaciation, although nivation beneath persistent snowbanks appears to have sharpened cirque headwalls and some steep, ice-scoured, rock steps. We conclude that the snowline lay at an altitude of about 150 m on St. George during the Illioian Glaciation and higher than 200 m during the Wisconsin Glaciation.

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Crystal Structure of Umangite, Cu_3Se_2

In the study of the phase relations of the copper-selenium system, single crystals of the composition Cu_3Se_2 have been synthesized. This compound, known as mineral umangite, is the only phase in the Cu-Se system for which the structure has not been elucidated. The structure determination has been carried out with the synthetic material.

A mixture of copper and selenium in the ratio 2.9 to 2.0 was enclosed in an evacuated silica tube and kept at 500°C for 2 days. The product was ground to fine powder, resealed in a new evacuated silica tube, kept first at 500°C for a week and then at 80°C for a month. After the run, the final product was covered with small crystals of Cu_3Se_2. The inner part of the product was, however, found to be an assemblage of crystals of two other phases, $Cu_{1.8}Se$ and CuSe.

The precession and Weissenberg methods were used to study the synthetic Cu_3Se_2 single crystals. The symmetry is tetragonal, with diffraction aspect P-2_1-, giving the possible space groups $P\bar{4}2_1m$ and $P42_12$. The cell dimensions obtained by the x-ray diffraction powder method are: $a = 6.406 \pm 0.002$ Å and $c = 4.279 \pm 0.002$ Å. With a cell content of Cu_6Se_4, the density is calculated as 6.590—in good agreement with the measured values 6.44 to 6.49 for the artificial compound (*1*).

The crystallographic data given by Berry and Thompson (*2*) are as follows: $a = 6.402$ Å and $c = 4.276$ Å, with space group $P4/mmm$. In order to elucidate the conflict between the diffraction aspects of the synthetic and natural materials, single crystals of umangite, Sierra de Umango, Argentina (*3*), were studied. The diffraction aspect of the natural specimens is P-2_1- as in the case of the synthetic crystals.

The intensities were measured visually on the Weissenberg films for the synthetic crystals. They were corrected for Lorentz and polarization factors. No absorption correction was made. Interpretations of the Patterson projections on (001) and (100) gave a structure uniquely based on the space group $P\bar{4}2_1m$. The atomic parameters obtained by the two-dimensional difference Fourier method are as follows: 2 Cu(I) in equipoint a at 0,0,0; 4 Cu(II) in equipoint e at $x, \frac{1}{2} - x, z$, with $x = 0.147$ and $z = 0.750$; 4 Se in e at $x, \frac{1}{2} - x, z$, with $x = 0.275$ and $z = 0.250$. The R-factors are 0.12 and 0.13 for ($hk0$) and ($h0l$), respectively.

The structure is projected on (001) and on (100) in Fig. 1, *A* and *B*, respectively. In this structure, as in typically intermetallic compounds, Cu atoms are as closely bonded with one another as with Se atoms. On the basis of the distribution of these bonds, the structure is considered to consist of sheets extending parallel to (001). All the Cu—Cu bonds are included inside the sheets, and their bond distances of 2.63 or 2.66 Å are slightly longer than the atomic distance found in metal copper 2.56 Å. Each Cu(I) is surrounded by four Se at 2.49 Å and four Cu(II) at 2.63 Å; and each Cu(II) by four Se at 2.43 and 2.37 Å, and by two Cu(I) at 2.63 Å and by one Cu(II) at 2.66 Å. Each Se is surrounded by two Cu(I) at 2.49 Å and by four Cu(II) at 2.43 and 2.37 Å.

Preliminary experiments on the electric properties of this synthetic Cu_3Se_2 indicate that the conductivity decreases with increasing temperature. The mechanism of conduction is, therefore, metallic.

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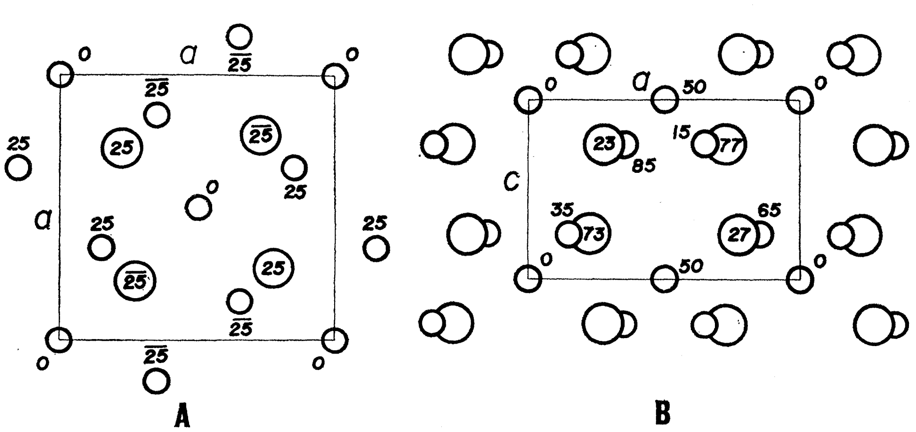

Fig. 1. (*A* and *B*) The structure of Cu_3Se_2 projected on (001) and (100), respectively. Large circles represent Se atoms and small circles Cu atoms. Numbers give z-parameters in *A*, and x-parameters in *B*.

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Infrared Spectra from Fine Particulate Surfaces

Abstract. *Characteristic spectral information can be obtained from a surface composed of fine particles either if the spectrum is observed at sufficiently high signal-to-noise ratio or if the particles are well compacted.*

Recent publications (*1*) concerning spectral reflectance or emittance by particulate surfaces have indicated that the surface tends to appear black when the particle size is small compared with the wavelength. Thus it is generally concluded that little or no characteristic spectral information can be gained by remote sensing of lunar or planetary surfaces if the surfaces are composed of fine particles. We now show both theoretically and experimentally that most of the spectral information is not really lost under these circumstances if one observes the spectrum at sufficiently high signal-to-noise ratio or if the surface is well compacted.

We consider first the case of a semi-infinite medium having a smooth surface and composed of uniformly distributed particles of diameter and spacing much less than a wavelength. Under these conditions the reflection by the medium of a beam of radiation is predominantly a coherent surface effect caused by the discontinuity at the surface of the average values of the optical