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REVISED GEOLOGIC MAP OF THE COLD BAY AND FALSE PASS QUADRANGLES, ALASKA PENINSULA

Frosty Volcano near Cold Bay, Alaska

Quaternary geology by
Frederic H. Wilson[1], Florence R. Weber[2], and Tina M. Dochat[3]

and bedrock geology by
Frederic H. Wilson, Thomas P. Miller[1], and Robert L. Detterman[4]

OPEN-FILE REPORT 97-866

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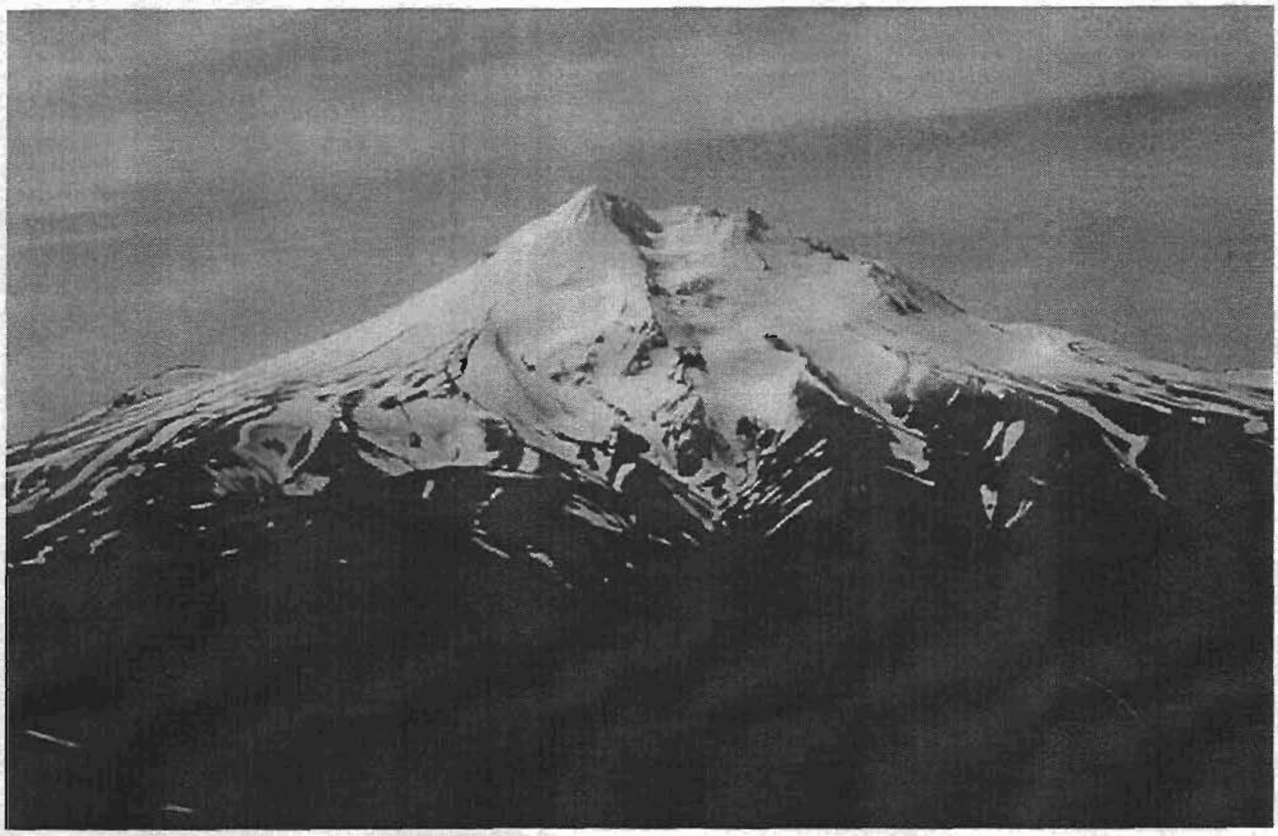

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INTRODUCTION

This map is a revision of the 1992 Open-File Report (Wilson and others, 1992) of the Cold Bay and False Pass 1:250,000-scale quadrangles on the Alaska Peninsula. It is a compilation based in part on the mapping conducted as part of the Alaska Mineral Resource Assessment Program (AMRAP) and the Geothermal Energy Program. Field studies by the authors began as early as 1973 in the quadrangles, but systematic mapping was not begun until 1988. Systematic mapping remains to be completed for much of the southwest part of the map area and in the vicinity of southeastern Cold Bay. Previous geologic mapping in the region, which constituted an invaluable data base for our studies, was conducted by Kennedy and Waldron (1955), Waldron (1961), Burk (1965), McLean and others (1978), and DuBois and others (1989). Revision on this version of the map is largely to the mapping of Quaternary units and is mostly based on aerial photograph interpretation and correlation with similar units in quadrangles to the north and east. New age control and chemical analyses allow us to revise the age of Chert and volcanic rock sequence (unit KJcv) in the Sanak Islands to Late Cretaceous or Jurassic(?) from Cretaceous or Jurassic(?). In addition, a significant correction has been made to the description of the Naknek Formation in this map area. Previously, it was described as consisting of the Northeast Creek Sandstone Member; in fact, the exposed rocks consist of the Indecision Creek Sandstone and Snug Harbor Siltstone Members.

Most of the new field mapping for this map was done by helicopter-supported foot-traverses and with helicopter spot landings. Coverage of areas between surface observations was made using helicopter overflights and interpretation of vertical aerial photography and Landsat imagery. Field investigations were conducted from bases at Cold Bay (1990, 1995, 1996), King Cove (1988), and False Pass (1991, 1992). In addition, some field work in 1984 was also conducted using the U.S. Geological Survey Research Vessel *Don J. Miller II* in the vicinity of Belkofski Bay. Airphoto interpretation of the Quaternary units was done in 1994, 1995, and 1996.

Quaternary glacial units

A Quaternary glacial stratigraphy was originally defined for the Cold Bay vicinity by Funk (1973). Later, Detterman (1986) slightly refined this stratigraphy and incorporated it into an Alaska Peninsula stratigraphy, showing correlations with Quaternary units the length of the Peninsula. Recent work at the northern end of the Alaska Peninsula (Riehle and Detterman, 1993; Mann and Peteet, 1994; Stilwell and Kaufman, 1996) has questioned the assignment of some deposits to particular glacial events on the northern Alaska Peninsula; nonetheless, the general stratigraphy seems to hold up rather well. Using largely aerial photograph interpretation and inference we have attempted to apply this regional stratigraphy to the geology of the Cold Bay and False Pass region. Ground "truth" that would allow detailed description and assignment of units is limited. It is clear that a universal application of the general stratigraphic framework established for the Alaska Peninsula can be locally unworkable due to local climatic, topographic, and volcanic conditions. These local conditions, particularly volcanic activity, may have resulted in non-synchronous glacial advances. In addition, tectonic instability resulted in the incomplete preservation of deposits of some episodes (Winslow and Johnson, 1989). In spite of these factors, we believe that this map represents a reasonable approximation of the geology of the region.

Our mapping and radiocarbon dating (table 1), in conjunction with the efforts of Funk

(1973) show a history of multiple Holocene (neoglacial) glacial advances in the vicinity of Frosty Peak volcano. In addition, in many other areas of the map we have mapped undated deposits of presumed neoglacial age; in some cases more than one moraine to a valley has been mapped. These deposits typically do not extend far (1 km or less) from local cirques, except in the vicinity of Frosty Peak. At Frosty Peak, in Russell Creek valley, dated (table 1, sample TDS-96-09A) neoglacial deposits extend as much as 5 km down valley from the cirque head. We cannot explain the unusually great distance that this particular neoglacial glacier extended. However, we presume that it must bear some relation to the newly recognized history of multiple Holocene eruptive events at Frosty Peak volcano.

On the Alaska Peninsula, the youngest Pleistocene (late Wisconsin?) glacial deposits are assigned to the Brooks Lake glaciation. Divided by Detterman (1986) into the deposits of four stades, the Russell Creek drift of Funk (1973) was considered equivalent to the Iliuk stade, the youngest of the sequence. Work in the Katmai region (Pinney and Beget, 1991; Pinney, 1993) suggests the existence of a fifth stade, named the Ukak stade (mapped as part of the Iliuk stade by Riehle and Detterman, 1993). In the Cold Bay region, we do not have sufficient evidence to determine whether deposits of the Ukak stade exist or to distinguish between the Iliuk and Ukak stades. In the vicinity of Cold Bay, we were able only with large uncertainty to resolve the Cold Bay Formation of Funk (1973) into the deposits of the Kvichak, Iliamna, and Newhalen(?) stades of the Brooks Lake glaciation. However, with distance from Cold Bay, for example in the Cathedral River valley, distinctive units were more apparent. Even so, in the Joshua Green River valley, the three authors of this revised map do not agree on the correlation of the glacial deposits. Weber and Wilson interpret the mapped deposits as largely, but not entirely, alpine glacial advances that correlate with the Iliamna and Kvichak stades of the Brooks Lake glaciation. Dochat interprets these deposits as early to middle Wisconsin alpine advances predating the Brooks Lake stades. In her interpretation, these alpine glaciers had retreated due to loss of source as sea level fell and the Bering Sea floor emerged and as the shelf glaciers built and advanced (Dochat, 1997).

Ground moraine of presumed Brooks Lake age is present in many areas of the map area; in general, it has not been shown separately on the map, except on the peninsula between Morzhovoi Bay and False Pass.

Deposits of the Mak Hill glaciation of early Wisconsin(?) age were correlated with the Morzhovoi Bay Formation of Funk (1973) by Detterman (1986). Funk found this unit exposed in a sea cliff exposure along the Bering Sea coast at the head of Morzhovoi Bay and at the base of sea cliff exposures at several locations in the vicinity of Cold Bay (Funk, 1976). Funk interpreted the deposits in the Cold Bay region to be glaciomarine deposits that had not been subaerially exposed on the basis of the minor oxidation, lack of weathering profiles, and the presence of an upper stratified member.

We are unable to illustrate the location of the deposits at the head of Morzhovoi Bay because the unit is overlain vertically by the Kvichak moraine. We examined the sea cliff exposures here and remain uncertain of their nature and correlation. The exposures are moderately indurated by a fine-grained cement, locally bedded, and includes large, random, rounded to subangular boulders, unlike anything these authors have seen or read about elsewhere on the Alaska Peninsula. It is possible that this is a marine deposit laid down in the ocean in front of and later overrun by, the advancing Kvichak glacier. No fossils were noted but little time for a search was available. This is a very remote, isolated, and fortuitous occurrence to attribute to an older glacial episode, such as the Mak Hill.

Only in the area north of the Aghileen Pinnacles did Funk (1973) map any deposits showing surface expression of this unit, and it is not apparent he actually visited this area. We do recognize deposits of probable Mak Hill and older age in the northeast corner of the Cold Bay 1:250,000-scale quadrangle.

We infer from the presence of subdued land forms suggestive of morainal deposits that

Table 1. Radiocarbon dates from the Cold Bay and False Pass 1:250,000-scale quadrangles

[Sample numbers begining with TDS collected by T.M Dochat (see Dochat, 1997 for further details). Locations for samples from Funk (1973) estimated using modern 1:63,360-scale maps. Samples GX-2789 and GX-2790 locations are corrected here because of a 1 degree error in longitude in the source (Funk, 1973). Funk (1973) samples reported in years BP, not corrected for $^{13}C/^{12}C$ ratio and based on a half-life of 5570 yrs, referenced to 1950 A.D. Calibrated ages calculated using calibration program of Stuiver and Reimer (1993)]

Sample number	Age (yrs BP)	Calibrated age(s) (yrs BP)	Error, 2σ (^{14}C yrs)	$^{13}C/^{12}C$	Location (Lat. and long.)	Description and comments
TDS-96-02D (Beta-96824)	9,130	10,040	140	-27.6	55° 16' 22" N 162° 36' 19" W	Material not reported, Kinzarof Lagoon, maximum age for so-called "Funk" ash, thought to be derived from Fisher Caldera (T.P. Miller, pers. commun., 1997).
TDS-96-02E (Beta-96825)	7,910	8,650	160	-25.2	55° 16' 22" N 162° 36' 19" W	Material not reported, Kinzarof Lagoon, minimum age for so-called "Funk" ash, thought to be derived from Fisher Caldera (T.P. Miller, pers. commun., 1997).
TDS-96-05 (Beta-96826)	3,850	4,240	140	-28.2	55° 0' 17" N 162° 54' 15" W	Peat, base of section, Little John Lagoon, minimum age for alpine moraine.
TDS-96-09A (Beta-96827)	1,170	1,060	120	-23.9	55° 6' 6" N 162° 44' 22" W	Russell Creek, paleosol underlying youngest preserved alpine moraine, maximum age for moraine.
TDS-96-13C (Beta-96828)	3,600	3,890	140	-27.9	55° 12' 44" N 162° 43' 2" W	Peat, near top of Cold Bay bluff section.
TDS-96-13G (Beta-96830)	9,630	10,890; 10,730	140	-25.6	55° 12' 44" N 162° 43' 2" W	Thick peat deposit, Cold Bay bluff, infilling intramorainal pond, minimum age for active ice core.
TDS-96-13E (Beta-96829)	11,590	13,520	200	-28.7	55° 12' 44" N 162° 43' 2" W	Leaf litter on diamicton, Cold Bay bluff, minimum age for deglaciation (Newhalen glaciation?).
TDS-96-15C (Beta-96831)	6,070	6,900	340	-27.9	55° 9' 43" N 162° 43' 27" W	Peat, Russell Creek, between ash deposits overlying Cold Bay (Iliamna) moraine
TDS-96-15C (Beta-96831)	6,070	6,900	340	-27.9	55° 9' 43" N 162° 43' 27" W	Peat, Russell Creek, between ash deposits overlying Cold Bay (Iliamna) moraine

Table 1. Radiocarbon dates from the Cold Bay and False Pass 1:250,000-scale quadrangles (continued)

Sample number	Age (yrs BP)	Calibrated age(s) (yrs BP)	Error, 2σ (^{14}C yrs)	$^{13}C/^{12}C$	Location (Lat. and long.)	Description and comments
TDS-96-15C (Beta-96831)	6,070	6,900	340	-27.9	55° 9' 43" N 162° 43' 27" W	Peat, Russell Creek, between ash deposits overlying Cold Bay (Iliamna) moraine
TDS-96-22G (Beta-96832)	4,780	5,570; 5,520; 5,490	160	-28.1	55° 15' 42" N 162° 48' 13" W	Base of organic mat, Blue Bill Lake basin, maximum age for higher lake level, core sample.
TDS-96-23LT (Beta-96833)	1,790	1,710	140	-28.3	55° 10' 6" N 162° 5' 59" W	Base of organic mat, Russell Creek basin, core sample
GX-2788 .	6,700	7530	330		55° 3'45" N 162° 56 55" W	Peat overlying Russell Creek drift (Funk, 1973)
GX-2745	8,075	8980	450		55° 15' 35" N 162° 47' 30" W	Humic A-horizon from buried soil profile on Cold Bay unit, 30 cm below ash seqeunce, minimum for Iliamna stade (Funk, 1973)
GX-2790	8,425	9440	350		55° 14' N 162° 31' W	Peat above ash overlying Cold Bay drift of Funk (1973)
GX-2744	9,660	10910	615		55° 12' 30"N 162° 42' 40" W	Peat below ash horizon overlying Cold Bay unit of Funk (1973). Minimum for Newhalen
GX-2789	10,625	12560	500		55° 14' N 162° 31' W	Peat below ash overlying Cold Bay unit of Funk (1973). Minimum for Newhalen

deposits as old as the Johnston Hill drift of Detterman (1986) may be located in the extreme northeastern part of the Cold Bay quadrangle. However, the absence of any ground truth in that area makes this correlation tenuous at best.

Late Quaternary history of the Cold Bay region

Recent geologic mapping of a portion of the southern end of the Alaska Peninsula allows us to reconstruct the sequence of glacial and volcanic events during part of the Pleistocene and Holocene in that area. We have chosen to divide the discussion of that history into sections because, although there are similarities across the areas, each region has a distinct character. From northeast to southwest the regions include: 1) the area between Pavlof Bay and Cold Bay, which includes Emmons Caldera and Mt. Dutton and we discuss as the Emmons buttress region; 2) the area between Cold and Morzhovoi Bays, discussed as the Morzhovoi Volcano buttress region; 3) the area between Morzhovoi and Ikatan Bay, informally called "Cape Topolak"; and 4) the Ikatan Peninsula and Unimak Island region. Each of these discussions describe a possible scenario for the region. As has been mentioned previously, radiometric age control and detailed mapping is generally not available; therefore these scenarios are hypotheses for which we encourage the further testing.

Quaternary glacial - volcanic interactions

In the Cold Bay--False Pass map area, the interactions of glaciers and active volcanoes have had a strong influence on the type and morphology of Quaternary deposits that have been mapped. Elsewhere on the Alaska Peninsula (for example, Detterman and others, 1981; Detterman, 1986), Quaternary glacial and volcanic deposits can be mapped and interpreted almost independently. In our map area; however, the active volcanos of Unimak Island, Frosty Peak, Morzhovoi Volcano, Mount Dutton, and the Emmons Caldera--Pavlof Volcanoes have exerted control on the glaciers of the region. On Unimak Island, deposits of presumed Brooks Lake age indicate that Shishaldin volcano in the adjacent Unimak 1:250,000-scale quadrangle may be a largely Holocene feature. During our examination of airphotos covering Unimak Island, we identified no glacial deposits of Brooks Lake age derived from Shishaldin Volcano.

At many localities in the Cold Bay vicinity, a distinctive volcanic ash deposit has been mapped (see Funk, 1973). Later workers referred to this as the "Funk" ash and used it in correlations throughout the area. According to T.P. Miller (personal commun., 1997), this ash is derived from the eruption at 9,100 yr BP of Fisher Caldera on Unimak Island west of the map area (Miller, 1990). The presence of the Funk ash overlying many of the glacial sequences in the region provides one of the strongest means we have of controlling ages of these sequences.

Emmons buttress region

A group of high mountains centered around present-day Mt. Emmons, Mt. Dutton, and the Aghileen Pinnacles at one time formed an island and acted as a buttress around which massive glaciers flowing from the continental shelf to the south were deflected. The end moraines of several of these vast ice bodies were deposited to form the heads of Pavlof Bay, Cold Bay, and other bays, connecting several islands to form the present continuity of the Alaska Peninsula. In addition to the Emmons buttress, ancestral Morzhovoi Volcano and the range of mountains between the west side of present-day Morzhovoi Bay and False Pass also served as buttresses to deflect ice flow from the shelf glaciers.

The Emmons buttress includes the oldest bedrock in the map area. Sandstone of the Indecision Creek Sandstone and Snug Harbor Siltstone Members of the Naknek Formation of Late Jurassic age crop out in the vicinity of Black Hill. The Amoco Production Company Cathedral River #1 exploratory well (Detterman, 1990), drilled to 14,301 ft (4,360 m) in 1973-74 on the Cathedral River, started in the Snug Harbor Siltstone Member of the Naknek Formation (see Detterman and others, 1996). It penetrated a thick Mesozoic section, including most of the Naknek Formation, the Shelikof, Kialagvik, and Talkeetna Formations, and bottomed in the Kamishak Formation(?) of Late Triassic age.

Although the Emmons buttress deflected the shelf glaciers, it was also, at the same time, high enough to support its own mountain glaciers, not only during the period of deposition of as well. Fortunately, the deposits of some these earlier episodes were protected on the northwest (lee) side of the Emmons buttress from scouring by shelf glaciers. Ancestral Morzhovoi Volcano also supported a number of mountain glaciers; however, many of the older glacial deposits derived from the volcano may have been covered by the construction of Frosty volcano after these glacial events.

The northwest side of Emmons buttress is relatively inaccessible and little of the glacial story has been studied on the ground, but there are available excellent aerial photos taken by the U.S. Geological Survey during topographic mapping. In addition, the eruptive history of the volcanoes in the buttress group is being studied as a part of the work of the Alaska Volcano Observatory. Largely through study of the 1:40,000-scale black and white and color-IR aerial photographs we are able to suggest the following sequence (from oldest to youngest) of events impacting the Emmons buttress (see table 2).

The oldest evidence of glaciation on the Emmons buttress is bedrock scouring in the vicinity of Black Hill. The bedrock of Black Hill and the surrounding country is composed of sandstone of the Naknek Formation (unit Jn this map; see also Detterman and others, 1996). The morphology of mountains indicate that they have been overridden by glaciers and Detterman's 1983 field notes report his observation of cobbles that he thought are of probable glacial origin at an elevation of about 750 ft (about 225 m). Possibly this is evidence related to the "oldest drift" of Detterman (1986).

The oldest generally visible deposits of mountain (and possibly shelf) glaciation occupy the lowest parts of Cathedral River valley in the Cold Bay quadrangle. The normal irregular topography of these moraines has been so extensively subdued that the distinction between ground and end or lateral moraines and the exact locations of glacial limits cannot be made with reliability. However, we believe from the evidence available that the outermost extent of the deposits is presently under the Bering Sea. These moraines are dark toned and, from limited ground observation in the adjoining Port Moller quadrangle, we believe they are probably covered by a substantial thickness (1 m?) of humus, dark soil, and ash layers. We also believe that these deposits may correlate with the Johnston Hill drift of Detterman (1986) on the basis of their position and morphological character.

The arms of a better-preserved older morainal arc, which we correlate with the Mak Hill glaciation of Detterman (1986), can be seen farther up the slope enclosing the valley of North Creek to the west of Cathedral River. Subdued knob-and-kettle topography is preserved at many places on this arcuate ridge, but very significantly the outward edge of this moraine shows evidence of modification by the wash of water on a strandline (figure 1). Instead of a normal end-morainal humpy push-profile, the leading edge of the moraine has a smooth, gently outward-facing slope. The strandline apparently stood slightly below the crest of the moraine between 75 to 90 m altitude on the present topography (see table 2).

On North Creek, a moraine that may be a lesser second stade of the Mak Hill glaciation was deposited at an elevation above the strandline and so was not affected by high sea level.

In the northeast part of the Cold Bay quadrangle, on the north side of Black Hill (made up mostly of Jurassic sedimentary bedrock of the Naknek Formation, unit Jn), there is a moraine having similar modified knob-and-kettle characteristics as the oldest of the Mak Hill moraines described above. This feature appears to emerge from a ridge overlain by one of the Pavlof Bay head moraines of Wisconsin age and descends off the hill toward the ocean after crossing a narrow coastal plain. At the foot of the hill, the humpy morainal topography apparently disintegrated into an amorphous mass below the elevation of 75 to 90 m, reconfirming the sea level determined on the North Creek Mak Hill moraine.

The significance of the 75- to 90-m stand of the sea in terms of Quaternary worldwide levels is problematical as the Alaska Peninsula has a history of isostatic and tectonic instability in part in response to rebound after the melting of the continental shelf glaciers and as a response to tectonic adjustments related to the Aleutian Trench. In Weber's experience in the adjacent Port Moller 1:250,000-scale quadrangle and Wilson's there and elsewhere on the Alaska Peninsula, there is evidence, particularly marine terrace levels and uplifted sea caves, which shows the peninsula is currently rising but at a greater rate on the Pacific Ocean side than on the Bering Sea side. Undoubtedly, the high sea-level stands documented there flooded the lower levels of the Johnston Hill and Mak Hill glacial deposits on lower Cathedral River. This inundation brings up the question of whether the Johnston Hill glaciation represents a separate glacial event or is just an earlier stade of the Mak Hill event because the shapes of all moraines seem to disintegrate under ocean water. Despite the isostatic vagaries of the Alaska Peninsula, we infer from the high stand of the sea that there was a significant period of warming postdating the Johnston Hill and Mak Hill glaciations, more like an interglacial period than an interstadial period.

The Mak Hill moraine is also dark toned and probably has soil/ash cover similar to the Johnston Hill deposits.

The next event seen on aerial photographs (figure 1) is an unusual, relatively light-toned series of ridges on the slopes north of the Joshua Green River. These ridges seem to drape across the slopes, extending downhill toward the Bering Sea. Informally termed "the snake" (unit Qvg), they form a continuous band as they wind across the upper part of North Creek and smaller drainages. They seem to conform to valley configuration and form "V" shapes at their lowest extents in the drainage valleys. In one small drainage, the ridges actually seem to trend down into a pre-existing gully. On the basis of brief ground observation and their character on the aerial photos, we believe these ridges probably represent a mixed volcano-glacial event related to the caldera-forming eruption of ancestral Mt. Emmons. Ground examination showed that this deposit is composed primarily of large angular volcanic rocks and minimal fine sediment. Because of the lack of fine material, we are reluctant to call this deposit a lahar or volcanic mudflow. We have considered the possibility that this deposit may be the result of a jökulhlaup (Björnsson, 1975), however, descriptions of jökulhlaups emphasize the large proportion of water (80 percent or more). The character of the "snake" and deposits downslope do not indicate the passage of large volumes of fluid. Jònsson (1982) describes a series of "volcanoglacial debris flows" from Katla volcano in Iceland and in gross aspect these could be similar to the "snake", however, the deposits of these are characterized by a large proportion (60-70 percent) of material, largely pumice, having a grain-size between 0.5 and 4 mm. A later paper on the same deposits (Tòmasson, 1996) is indicative of the controversy over these Icelandic deposits by suggesting that no, these were truly the deposits of a water-dominant (greater than 80 percent) jökulhlaup and not a volcanoglacial debris flow. As the Katla eruption that produced these deposits in 1918 was actually observed and such fundamental controversy exists, this suggests that it will be difficult to resolve the nature of the "snake." We believe that it represents some type of volcanoglacial debris flow, realizing that these are not well defined or described.

A tremendous debris flow deposit covers the higher northwestern slopes of the Emmons buttress (unit Qdf, in part). This deposit contains poorly sorted volcanic material ranging from large meter-sized angular blocks to mud that blankets older deposits. Deposits of the debris flow are present as much as 20 km northwest of Mt. Emmons. We believe that this debris flow, or lahar, because of its wide distribution, was associated with a major volcanic eruption. However, we have no data to indicate that it was hot or contained juvenile material. If these deposits were associated with a large eruption, that eruption may have been one of the Emmons caldera-forming eruptions. Tentative dating of the earliest of these eruptions, by correlation with the Old Crow tephra, indicates an age about 140 ka (T.P. Miller, personal commun., 1996). Emmons may have potentially been the source of the Old Crow tephra, well known as a stratigraphic marker in much of southwestern and Interior Alaska and the Yukon (Hamilton and Brigham-Grette, 1992).

The following event was another major glaciation. Mountain glaciers enlarged the upper valleys of the Joshua Green River, North Creek, and Cathedral River into Yosemite-like canyons that cut through the volcanic debris-flow and lahar deposits. Well-defined, classic

Figure 1. Aerial photograph showing the southern portion of "the snake", volcanoglacial debris flow deposits. Photograph is oriented with north diagonal across the picture to the upper left corner. On the left edge of the photograph, moraine of the Mak Hill glaciation are visible, showing the strandline at 75-90 m elevation discussed in the text. The "snake" meanders across the center of the photograph, overlying the moraine in the lower left corner (Note, the appearance of the snake has been enhanced by outlining on the reproduced image). Visible in the lower right corner of the photograph is the volcanic debris flow deposits which overlies the snake. Photograph is number 1112 of Mission 150, flown June 18, 1962 by the U.S. Air Force. Scale as shown here is about 1:80,000.

end moraines having relatively fresh-looking knob-and-kettle topography were deposited in each of these valleys. They are light-toned, probably because soil and vegetation are sparingly developed on the gravelly ridges. Part of the end moraine of this glacial advance on Joshua Green River is currently under Moffit Lagoon. However, there is no evidence to indicate the moraines of this glacial stade, located below 75 to 90 m on land, were ever affected by the early high stand of the sea. Hence, we believe this stage clearly post-dates the 75 to 90 m stand. Weber and Wilson believe that deposits of this glacial event correlate with the Kvichak stade of the Brooks Lake glaciation. On the southern part of the Emmons buttress, we believe that high-level morainal deposits of the shelf glaciers indicate the ice masses of the shelf and mountain areas were continuous. However, Dochat (1997) believes that these deposits, particularly in Joshua Green River valley, represent one of two alpine glaciations that predate the Brooks Lake glaciation. She further postulates that these alpine glaciers retreated due to lack of source precipitation as the Bering Sea floor became emergent.

Another glacial advance or stade followed, leaving similar deposits in each of these valleys but upstream of the Kvichak or older alpine moraines. In Joshua Green valley, moraine of this stade forms a complete end arc cut only by the river close to modern sealevel (figure 2). This moraine provides the key for Weber and Wilson to correlate the mountain glacial sequence. The left arm of the Joshua Green River morainal ridge merges with one of the shelf glacier moraines that delineates the head of Cold Bay. Based on the character of the deposits, both from aerial photos and ground observation, Weber and Wilson believe these moraines are essentially coeval. All three authors accept the correlation of this shelf glacier moraine with the Iliamna stade of the Brooks Lake glaciation. However, Dochat believes that the evidence at the junction of the alpine moraine and shelf moraine indicates that the shelf glacier over-rode an earlier alpine morainal deposit.

In the Cold Bay area, two even younger shelf glaciations, the Newhalen and Iliuk stades of the Brooks Lake are provisionally identified, but, with one exception, the remnants of <u>no</u> younger moraines can be identified in the canyon valleys of the Emmons buttress. The single exception is in the West Fork of Cathedral River, where a deposit we suggest might be a small moraine is located at the head of the canyon and another at its junction with the main valley. The deposit at the junction could represent the Newhalen stade and the one at the head of the valley the Iliuk stade. It is alternately possible that the junction moraine is a lateral moraine of one of the downstream stades or, less likely, a volcanic debris flow. In that case, the moraine at the head of the West Fork of Cathedral River could well be Newhalen in age. Whatever its age, the deposit at the valley junction has been eroded by large quantities of water flooding down the main valley. This should be no surprise because the head of the main valley has lava flows of at least two ages, which might have catastrophically melted any ice or snow accumulated, producing jökulhlaups.

Many parts of the Cold Bay region record evidence of a high stand of the sea about 15 m above present sealevel. Particularly well preserved are shorelines in Joshua Green River valley. Evidence of this high stand can be found as terraces in much of the coastal area, where deposits older than Newhalen stade glacial deposits are affected. Similar terraces are well known northward along the Alaska Peninsula. In the vicinity of Cold Bay, these terraces are present at roughly the same elevation on both the Pacific and Bering Sea coasts; to the north on the Alaska Peninsula, for example in the Chignik and Wide Bay areas, terrace elevations gradually increase from west to east, indicating differential uplift (Detterman, 1986, p. 156). We believe that there are isostatic, eustatic, and tectonic components to this uplift record.

The lack of evidence for late Pleistocene and Holocene glaciation, on the northwest side of the buttress indicates that additional volcanic event(s) may have taken place. In addition to the lava flows on Cathedral Creek, the head of the Middle Fork of Joshua Green River canyon contains a lava flow and a small debris flow. This, plus the fact that a large amount of water has also come down Joshua Green River indicate that the whole area was heated repeatedly in post-Iliamna time. Pavlof Volcano, Pavlof Sister, Little Pavlof, and Mt. Hague on the northeast side of the buttress all developed in post Emmons caldera-forming time and are known to have had many Holocene and historic eruptions; their ash and ash flow deposits are distributed on the northeast side of the buttress. These volcanic deposits could be covering the late Pleistocene and Holocene glacial deposits or more likely in our opinion, the active volcanism has prevented the development of glaciers in this part of the buttress.

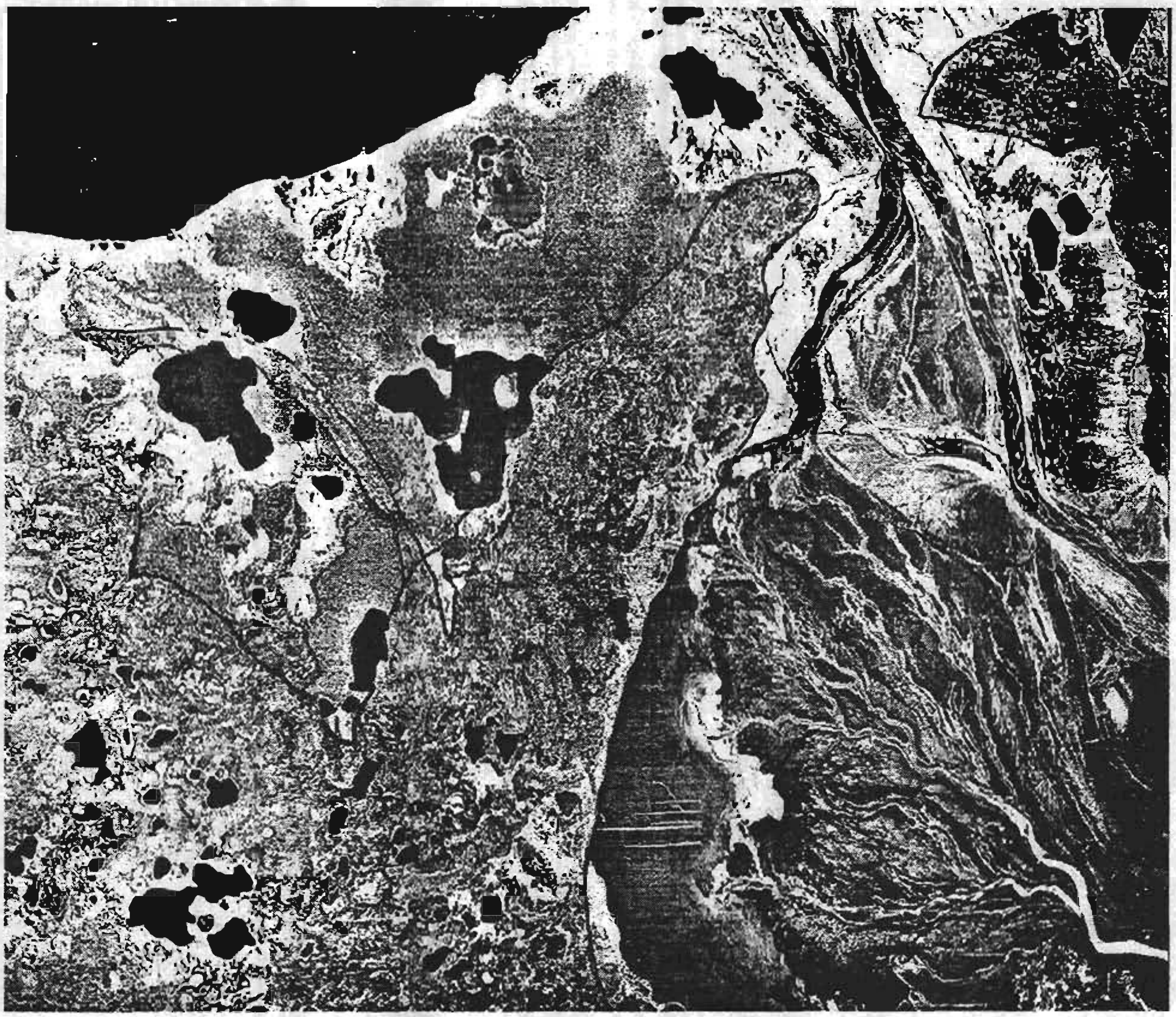

Figure 2. Aerial photograph showing merging of moraines from the Joshua Green River valley and Cold Bay. Smaller morainal ridge in center of photograph is moraine of alpine(?) glacier flowing down Joshua Green River valley. It merges with moraine of the Iliamna stade derived from the shelf and flowing into and through Cold Bay. The form of the moraine of the alpine glacier indicates that the glacier was deflected northward at time of deposition. This image is not as clear as the original photograph which shows no indication that the moraines were any different in age. A thin ridge of moraine is just visible between the lakes in front of the shelf glacier moraine; this ridge appears overrun by the alpine glacier. Upper left corner of photograph is the Bering Sea. Photograph is oriented with north diagonal across the picture, pointing toward the upper left corner (Note, the appearance of the snake has been enhanced by outlining on the reproduced image). Photograph 1193 of Mission 150, flown June 19, 1962 by the U.S. Air Force. Scale as shown here is about 1:80,000.

Table 2. Provisional Quaternary history of the Emmons buttress region [see text for explanation].

Event	Suggested Age
Historic eruptions	
Neoglacial deposits missing (in selected places, or all over?)	
Tephra beds ("Funk [Fisher] ash") in Cold Bay area lying stratigraphically above moraines identified as Newhalen	9 ka
Evidence for eruptive intervals in buttress area	Wisconsin and Holocene
High stand of the sea, roughly 16 m above MSL (Jordan, 1997)	late Wisconsin or early Holocene
Brooks Lake glaciation Iliuk stade missing	late Wisconsin
Brooks Lake glaciation Newhalen stade missing	late Wisconsin
Brooks Lake glaciation Iliamna stade, well developed alpine and shelf glacier moraines on west side of buttress	Wisconsin
Brooks Lake glaciation Kvichak stade, well developed alpine and shelf glacier moraines on west side of buttress	Wisconsin
Major eruption of ancestral Emmons volcano, volcanoglacial debris flow and lahar(?) deposits	about 140 ka
High stand of the sea, shoreline developed on Mak Hill drift (figure 1)	pre-Wisconsin interstadial
Mak Hill glacial episode	pre-Wisconsin
Johnston Hill glacial episode, extremely subdued moraines and outwash	pre-Wisconsin
Oldest glaciation of Detterman (1986), inferred from bedrock scouring and probable glacial erratic cobbles	pre-Wisconsin

Morzhovoi Volcano and Frosty Peak buttress region

Ancestral Morzhovoi volcano was located on the peninsula between Cold Bay and Morzhovoi Bay south of Frosty Peak. Extensive glaciation has removed much of the original volcanic edifice and only remnant flows from the volcano remain. Waldron (1961) recognized the remnant flows represented a large volcanic center, for which he used the name Morzhovoi volcano. In spite of the extensive glaciation of the volcanic center, even neoglacial deposits are uncommon in the immediate vicinity of this volcano. A preliminary K-Ar date of less than 1 Ma for a flow high in the section (Nora Shew and F.H. Wilson, unpub. data) indicates that this volcanic center was active in early to middle Quaternary time (table 3). Waldron (1961) described a history of Morzhovoi Volcano, including caldera formation, and this apparent age is consistent with the timing he suggested. Lacustrine or marine deposits are present in three of the south-facing, glacially carved valleys of the remnant Morzhovoi Volcano behind or landward of beach dune deposits. We believe that water bodies were impounded in these lower valleys by shelf ice during one or more stades of the Brooks Lake glaciation. By inference then, Morzhovoi Volcano must have been glaciated earlier in the Brooks Lake glaciation or before. Small moraines are located in two of the south-facing valleys of Morzhovoi Volcano, one of which also has evidence of flooding. We believe that these moraines are probably correlative with one of the younger Brooks Lake stades and the Russell Creek alpine advances and are not neoglacial moraines. This inference is in part because these moraines extend to much lower elevation than other neoglacial moraines.

Previous workers (Waldron, 1961; Funk, 1973, 1976; and Brophy, 1984) considered Frosty Volcano to have been dormant during Holocene time. Waldron (1961) inferred two episodes of volcanism widely separated in time for Frosty Volcano. The first may have been coeval with some stage of the eruption of Morzbovoi Volcano, either from a parasitic cone or a new vent. Waldron (1961, p. 694) suggested that Frosty Volcano was largely constructed prior to late Wisconsin time because extensive glacial deposits were derived from it and no volcanic products were mapped on top of these glacial deposits. These glacial deposits were later mapped as the Russell Creek drift by Funk (1973, 1976). Based on limited age control (table 1), Funk suggested that the Russell Creek moraines are of latest Wisconsin age. Brophy

Table 3. Provisional Quaternary history of the Morzhovoi Volcano and Frosty Peak buttress region [see text for explanation].

Event	Suggested Age
Neoglacial deposits at Frosty Peak, both north and south craters	1.2 ka
Emplacement of summit cone-building volcanic rocks of south peak	
Eruption of ashflow from Frosty Peak (south crater). Flow ponded behind earlier lava flow (figure 3)	
Development of North Crater and emplacement of volcanic debris flow deposits to west of Frosty volcano	
Eruption of massive lava flow from Frosty Peak; flow may have erupted in an icefield	
Tephra beds ("Funk [Fisher] ash") in Cold Bay area lying stratigraphically above of moraines identified as Newhalen and Russell Creek	9 ka
High stand of the sea, roughly 16 m above MSL (Jordan, 1997)	late Wisconsin or Holocene
Russell Creek alpine glaciation and Brooks Lake glaciation, Iliuk stade. Iliuk stade deposits may form a submerged ridge at mouth of Cold Bay (see map)	late Wisconsin
Brooks Lake glaciation, Newhalen stade glacial deposits found on west shore of Cold Bay	late Wisconsin
Brooks Lake glaciation, Iliamna stade; forms bulk of glacial deposits north of Morzhovoi Bay and Cold Bay	Wisconsin
Brooks Lake glaciation, Kvichak stade; outer rim of glacial deposits north of Morzhovoi Bay and Cold Bay	Wisconsin
Mak Hill(??) glacial episode, glaciomarine(?) deposits north of Morzhovoi Bay	pre-Wisconsin
Eruption of ancestral Morzhovoi volcano	about 1 Ma

Figure 3. Aerial photograph showing the southern flank of Frosty Volcano. North is diagonal across the picture, pointing to the upper left. In the upper center of the photograph, the south peak of Frosty Volcano is visible, composed of the "Volcanic rocks of the summit cone as mapped by Waldron (1961). The rocks fill an older crater, whose rim is visible surrounding the summit cone. In the upper left corner, the thick ponded flow discussed in the text is visible. Just below (southeast) of it are ashflow deposits ponded behind it. The same ashflow came down the linear valley running down the right center of the photograph. In this valley the ashflow continued to the right off the photograph, reaching the coast. Unfortunately, thin cloud cover obscures some of the image as does the poor resolution of the reproduction; however, just visible at the head of the linear valley is neoglacial moraine extending about 1 km from the crater. Photograph 11-5, taken July 26, 1987 for the U.S. Geological Survey.

(1984) largely accepted Waldron's and Funk's mapping of Frosty volcano, essentially reproducing Waldron's map in his report. Detterman (1986) accepted the latest Wisconsin age of Funk (1976) and correlated the Russell Creek drift with the Iliuk stade of the Brooks Lake glaciation, best known from the northern part of the Alaska Peninsula but mapped as far southwest as the adjacent Port Moller quadrangle (Unpublished data, F.R. Weber, R.L. Detterman, and F.H. Wilson, 1988). Our all-too-brief fieldwork in the summer of 1996 allowed us to recognize the products of multiple, presumably Holocene eruptions from Frosty Volcano and necessitates a reinterpretation of the history of Frosty Volcano. Our discovery of extensive Holocene(?) volcanic deposits on the south and west flanks of Frosty volcano (areas previous workers had apparently not reached) further raised doubts in our minds about the accepted history of Frosty volcano.

On the basis of the pattern of Brooks Lake glacial moraines in the vicinity of Frosty Volcano, we believe that Frosty Volcano is largely a latest Wisconsin and Holocene constructive feature. We believe that the Cold Bay moraine of Funk (1973) includes deposits largely of the Kvichak and Iliamna stades and to much less extent the Newhalen stade of the Brooks Lake glaciation as defined by Detterman (1986). These glacial deposits show little or no influence of Frosty Volcano. Yet moraines derived from Frosty Volcano (the Russell Creek drift of Funk, 1973) extend over these older morainal ridges, whereas elsewhere glacial advances younger than the Iliamna and Kvichak stades are much less extensive than the older moraines. As the Iliuk stade of the Brooks Lake glaciation was one of the least extensive (Ukak stade? of Pinney and Beget, 1991, is possibly the youngest and least extensive), we found it disconcerting that Russell Creek drift from Frosty Peak overlaps the Cold Bay moraine: From this relationship we infer that Frosty Volcano was constructed largely after the Iliamna advance but early enough to become an accumulation zone for later glacial episodes. As a result, we have concluded that Frosty Peak (volcano) probably did not exist during most of the Brooks Lake glaciation.

In contrast to Waldron's (1961) interpretation that the caldera-forming eruption of the north caldera of Frosty Volcano was of Pleistocene age, our mapping indicates that the timing of the caldera-forming eruption is latest Pleistocene, most likely between the last Wisconsin glaciation and neoglaciation (table 3). The north crater of Frosty Peak volcano is ice filled and has a glacier draining it to the west. As mentioned earlier, previous mapping (Waldron, 1961; Funk, 1973, 1976; and Brophy, 1984) had shown extensive glacial deposits extending radially from Frosty Volcano. In the valley draining the north crater of Frosty Volcano, these glacial deposits were mapped as extending virtually to the coast of Morzhovoi Bay. In 1996, we found that the valley below the glacier is largely filled by a clast-rich, hydrothermally altered, volcanic debris flow that may extend to as close 1 km to the coast of Morzhovoi Bay. We believe that these deposits are most likely derived from the eruption that produced the north crater of Frosty Volcano. Late Wisconsin glacial deposits are lacking or at least buried by volcanic debris-flow deposits in much of this valley. Due to very limited time in the field, we were unable to determine if the debris-flow deposits from the North Crater overlie drift of Russell Creek (Iliuk) age in the valley or are overlain by drift. From aerial photograph interpretation, we believe that the Russell Creek morainal deposits are located at the distal end of the debris-flow deposits, constraining the age of the eruption to younger than the drift. A radiocarbon date on peat of 6,700 yrs BP (GX2788, table 1) and variously reported as coming from lacustrine deposits (Funk, 1973) or outwash (Funk, 1976) was interpreted as a minimum age associated with these glacial deposits. Unfortunately, Funk (1973) did not describe the section in which he collected his radiocarbon sample, nor did he locate it precisely. We contacted Funk (written commun., 1997) but he was unable to recover notes that would help to resolve these questions. Therefore, it is not possible to determine if the peat deposits he dated overlie the debris-flow deposits or if the debris-flow deposits extend as far as the site of the sample.

Funk's (1973) Frosty drift is derived from the present glacier in the North Crater and he suggests it is of neoglacial age. The neoglacial moraine extends less than 1 km downvalley from the present glacier as shown on the published (compiled from 1987 aerial photography) 1:63,360-scale topographic map; in 1996, the glacier had receded farther upvalley. The age of the Russell Creek drift has been considered latest Pleistocene or earliest Holocene (Detterman, 1986) and if the unit really is present at the distal end of the valley and its age is correct, it may constrain the age of the crater-forming eruption to early Holocene.

The uppermost, southern part of Frosty Volcano (the actual Frosty Peak) is a late Wisconsin(?) and Holocene constructive feature, largely filling a pre-existing crater (figure 3). The unit Waldron (1961) mapped as *Volcanic rocks of the summit cone* largely fills this crater. Largely covered today by perennial snow and ice, these volcanic rocks show no evidence of extensive glaciation, inferring emplacement since glaciation. Off the southwestern flank of the south peak, a thick lava flow, not flowing more than 3 km from its source (figure 3), has been erupted. Its form, which is a lobate ridge extending into an existing glaciated valley, indicates that it may have been erupted into an icefield and ponded, similar to the flows derived from the 1983 eruption of Veniaminof Volcano (Yount and others, 1985). On the opposite valley wall from this flow, a similar, presumably older flow forms a prominent projection and together these flows nearly dam the initially south-draining, glacially carved valley. At some later time, after melting of the ice and, therefore, we believe in Holocene time, an eruption yielding an ashflow came from Frosty Peak (shown as unit Qafd near Frosty Peak on the map, see also figure 3). To the southwest, this ashflow was largely dammed behind the above-mentioned lava flows, forming a thick deposit that has since been dissected by fluvial erosion. In the narrow valley draining Frosty Peak to the southeast, pyroclastic flows from the same eruption also traveled downvalley and spread widely, possibly reaching the west shore of Thinpoint Lake (shown as Thinpoint Lagoon on older maps). Because no distinctive source area for these pyroclastic flows remains apparent, the implication is that the summit cone-building flows of Frosty Peak may have been erupted after this explosive event. We believe that deposits in the uppermost part of this narrow valley are neoglacial moraine, indicating that the eruption did not occur in late Holocene time. However, the relatively fresh character of these ashflows is evidence that they are definitely younger than the debris-flow deposits emanating from the north crater.

"Cape Topolak" region

The area between Morzhovoi and Ikatan Bay is poorly known. Informally called "Cape Topolak" by mining-company geologists working in the area, only recently have topographic maps become available for this region. As a result, the region received less attention in our mapping than it might have otherwise. Clearly glaciated, there is no evidence of late Quaternary volcanic activity, in contrast to the other three described areas. Glacial deposits of this area are difficult to correlate with adjacent areas, in part due to lack of mapping, but also due in part to the lack of distinctive morainal ridges (table 4). We believe that a late-stade glacier of the Brooks Lake glaciation advanced through Ikatan Bay almost to the site of the modern village of False Pass. However, this is not shown on the map due to the fragmentary nature of the deposits. The oldest bedrock of the Cape Topolak region is the Belkofski Formation, which is overlain by rocks of the Tachilni Formation, and both units are overlain by Pliocene and possibly younger volcanic rocks.

Table 4. Provisional Quaternary history of the Cape Topolak region [see text for explanation].

Event	Suggested Age
High stand of the sea, roughly 16 m above MSL (Jordan, 1997)	late Wisconsin or early Holocene
Brooks Lake glaciation, undivided but possibly one of the later stades	Wisconsin, probably late Wisconsin

Ikatan Peninsula and Unimak Island region

Unimak Island appears to contain many of the basic geologic units seen elsewhere in the Cold Bay region. The first of the true Aleutian Islands, it is dominated by late Pleistocene(?) and Holocene volcanic centers. No glacial deposits other than a few neoglacial moraines were observed on the Pacific coast side of the Island or on the Ikatan Peninsula. At low elevation in a few areas, marine terraces are apparent near the Pacific coast, indicating some relative uplift. On the north or Bering Sea side of Unimak Island, extensive glacial deposits are present in the low lands. In the extreme northeast part of the island, these are deposits from shelf glaciers that apparently overrode the Ikatan Peninsula and "Cape Topolak." We believe that the north end of a Kvichak age moraine probably circles Bechevin Bay, outcropping on Unimak Island to the west and merging with the Kvichak moraine of Morzhovoi Bay on the east. Farther west, the glacial deposits were likely derived from the Roundtop and Isanotski Peaks volcanic centers. The most northerly of the glacial deposits we have mapped on Unimak Island we have correlated with the Mak Hill, however, this correlation must be considered extremely speculative. At the extreme western edge of the map area, we were not able recognize any glacial deposits derived from Shishaldin Volcano, which we believe may indicate that it is a largely late Pleistocene and Holocene edifice. Alternatively, the extensive volcanic pyroclastic and debris deposits on the north side of Shishaldin Volcano may overlie glacial deposits that might correlate with the Brooks Lake glaciation.

Deposits of Holocene volcanic eruptions are apparent on Unimak Island in the vicinity of

Table 5. Provisional Quaternary history of the Ikatan Peninsula and Unimak Island region [see text for explanation].

Event	Suggested Age
Development of tombolo connecting former Ikatan Island and Unimak Island, creating Otter Cove	post 1850 AD
Deposition of ash over a wide area in the vicinity of Otter Cove from volcanic eruption of Roundtop and Isanotski Peaks	March 10, 1825
High stand of the sea, roughly 16 m above MSL (Jordan, 1997)	late Wisconsin or early Holocene
Brooks Lake glaciation, Iliuk stade, not recognized	late Wisconsin
Brooks Lake glaciation, Newhalen stade, forms fragmentary morainal arc north of Roundtop	late Wisconsin
Brooks Lake glaciation, Iliamna stade, forms large arcurate moraines north of Roundtop and Isanotski Peaks	Wisconsin
Brooks Lake glaciation, Kvichak stade, glacial deposits north of Roundtop and Isanotski Peaks	Wisconsin
Mak Hill glacial episode, moraines along northeast coast of Unimak Island	pre-Wisconsin

each of the three volcanoes that are wholly or partly in the map area. Large expanses of non-vegetated volcanic ash cover valley floors west of Otter Cove on the southeast part of the Island. These deposits are extensive enough that we were unable to distinguish their source other than that it must have been in the vicinity of Roundtop and Isanotski Peaks. Veniaminof (1840, p. 18) reports a volcanic eruption on March 10, 1825 that is probably the source of this ash. He says, "... the northeast range of Unimak exploded in five or more places and over a large area ..." and goes on to say the ash covered the end of the Alaska Peninsula to a depth of several inches. In part, because of the extensive distribution of the deposits and in part, because of Veniaminof's (1840) report, we believe that they may represent eruptions from both the Roundtop and Isanotski Peaks volcanic centers. In contrast to the deposits on their south flanks, recent volcanic debris is not as apparent on the north flanks of these volcanoes, where older glacial deposits of Brooks Lake age are preserved. On the main part of Unimak Island, the bedrock consists of volcanic rocks we largely associate with the present volcanoes. The Ikatan Peninsula is underlain by older bedrock consisting of the Belkofski Formation and highly altered volcanic, volcaniclastic, and hypabyssal intrusive rocks of late Tertiary and early Quaternary(?) age.

Russian maps dating from the mid-1800's show a passage between Ikatan Bay and Otter Cove (or see Veniaminof, 1840, p. 107). During field work in 1990 in the area of False Pass, Chuck Martinson, a local resident, reported speaking in the 1950's with False Pass village elders, who remembered paddling through this passage during their youth. The two parts of the island were connected by the present tombolo sometime in the late 1800's or early in the 1900's. The suggestion has been made that this change could have been the result of a volcanic eruption. However, there is little confirming information. What this clearly shows, however, is the extremely dynamic character of the landscape.

ACKNOWLEDGEMENTS

Robert L. (Buck) Detterman's death as the 1992 version of this map was being compiled left a profound void. His knowledge of and insight into Alaska Peninsula geology was of tremendous value. His friendship, guidance, and contributions to Alaska Peninsula geology will be long remembered.

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DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS AND SEDIMENTARY ROCKS

QUATERNARY

Qs **Surficial deposits, undivided (Holocene and Pleistocene)**--Typically unconsolidated, poorly to well-sorted, poorly to moderately well-stratified sand, gravel, and silt. Ranges from coarse, subangular to rounded rock fragments to fine sand and silt; locally includes considerable pumice near Emmons Lake volcanic center. Unit locally incorporates fluvial, colluvial, glacial outwash, lacustrine, beach, estuarine, swamp, and eolian deposits. Large areas are covered by organic-rich silt. Unit includes abundant volcanic ash and volcanic debris in vicinity of Joshua Green River and in vicinity of most volcanoes, particularly those on Unimak Island and those that compose the Emmons Lake eruptive center. Eolian deposits, where included, form dunes of sand and pumice 10 to 20 m high. In Cathedral Valley and in the hills surrounding Black Hill, unit includes subdued glacial deposits (drift and outwash) of possible Johnston Hill age of Detterman (1986). Locally divided into:

Qa **Alluvium (Holocene and Pleistocene)**--Typically unconsolidated, poorly to well-sorted, poorly to moderately well-stratified sand, gravel, and silt. Ranges from coarse, subangular to rounded rock fragments to fine sand and silt; locally includes considerable pumice near Emmons Lake volcanic center

Qaf **Alluvial fan deposits (Holocene and Pleistocene)**--Deposits are poorly sorted rock fragments ranging in size from coarse, meter-sized, subangular fragments to fine sand and silt. Fans have a typically well-developed cone-shaped or coalescing cone-shaped morphology. Only larger fan deposits are mapped separately

Qc **Colluvium (Holocene and Pleistocene)**--Unconsolidated, poorly to well-sorted, poorly stratified gravel, sand, and silt. Ranges from coarse, subangular to rounded rock fragments to fine sand and silt. Forms valley fill and is in part composed of remnant ground moraine

Qls **Landslide and slump deposits (Holocene and Pleistocene)**--Deposits have poorly to well-developed lobate morphology and consist of poorly sorted rock fragments ranging in size from large, coarse, subangular fragments to fine sand and silt. Only larger landslide and slump deposits are mapped separately

Ql **Lacustrine deposits (Holocene and Pleistocene)**--Mapped by aerial photograph interpretation and not observed on the ground, expected to be largely composed of fine-grained sand, silt, and clay size particles and variable amounts of organic material

Qb **Marine beach deposits (Holocene and Pleistocene)**--Moderately well-stratified and sorted sand and gravel on beaches. Also includes well-sorted gravel-rich barrier-bar deposits at the head of Cold Bay that most likely are associated with the Newhalen stade glacial deposits (unit Qbln)

Qes **Estuarine deposits (Holocene and Pleistocene)**--Mud and silt in estuaries

Qmt **Marine terrace deposits (Holocene and Pleistocene)**--Stratified and moderately well-sorted sand and gravel. Forms nearly level plains, locally ending at prominent wave-cut scarps. Typically consists of other units that have been reworked

Qd **Dune deposits (Holocene and Pleistocene)**--Largely sand and pumice forming dunes 10 to 20 m high. A 35-sq.-km area north of Shishaldin volcano on the coast of Unimak Island is interpreted as reworked pyroclastic deposits derived from an unknown source. On aerial photographs, a distinctive pattern of rough, closely spaced, semi-linear ridges stands out on the low-relief surface. The form of these deposits is strongly suggestive of linear dunes, reflecting either northwesterly or southeasterly directed winds. Alluvial (unit Qa) deposits appear to partially overlie these deposits along their margin

Qm **Moraine and other glacial deposits (Holocene and Pleistocene)**--Poorly sorted, non-stratified, rock fragments ranging in size from coarse, meter-sized, subrounded to rounded fragments to fine sand and silt. Mainly forms end, lateral, and ground moraines but, locally includes moderately well-sorted and stratified ice-contact and outwash deposits. Deposits younger than unit Qbli1 (Iliamna stade) incorporate a large component of volcanic material and their distribution reflects interaction with active volcanism. Morphologically distinctive drift units are indicated by dashed and dotted internal contacts shown in units. North of Frosty Peak, includes apparent esker deposits. Locally divided into [descriptions largely derived from Funk (1973), Detterman and others (1981), and Detterman (1986)]:

Qnd **Drift, neoglaciation, undivided (Holocene)**--Includes both unsorted, non-stratified angular debris in cirques and in valleys in front of modern and recently melted glaciers and till of other Holocene moraines. Youngest neoglacial drift forms arcuate lobes of unstable and nonvegetated rubble. Earliest neoglacial drift forms vegetated teardrop- and arcuate-shaped moraines. Includes Frosty drift of Funk (1973). Locally indicates multiple neoglacial advances. One particularly extensive advance in the valley of Russell Creek has been dated at no more than 1060 ^{14}C cal yr BP (table 1, sample TDS-96-09A). For most deposits mapped as neoglacial, age control is lacking. Although it is possible that deposits of Holocene age earlier than neoglacial are present, we have no evidence to indicate that this is the case

Qno **Outwash deposits, neoglaciation (Holocene)**--Moderately well-sorted and stratified sandy gravel and pumice in front of modern glaciers and associated unvegetated Holocene end moraines; may be covered by volcanic ash and debris, otherwise little modified

Qrc2 **Russell Creek glaciation II (Pleistocene?)**--Glacial deposits, including till, on the eastern, northern and western flanks of modern Frosty Peak Volcano. Composition ranges from subangular to subrounded clasts, including boulders up to 2 m in diameter in matrix of sand and silt. Till consists of locally derived clasts. Boulders are frequent on moraine crests. Possibly age equivalent to the Brooks Lake Iliuk stade (unit Qblik) shelf glacier advance. Deposits in individual valleys on Frosty Peak Volcano are difficult to correlate; the number of apparent advances varies from valley to valley, and the lack of definitive age control makes direct correlation uncertain at best. Hence, distinction between Russell Creek advances is tentative

Qrc1 **Russell Creek glaciation I (Pleistocene?)**--Glacial deposits, including till on the eastern, northern and western flanks of modern Frosty Peak volcano. Composition ranges from subangular to subrounded clasts, including boulders up to 2 m in diameter in matrix of sand and silt. Till consists of locally derived clasts. Boulders are frequent on moraine crests. Overlies Iliamna moraine of shelf glacier advances and is here correlated with the Brooks Lake Newhalen stade (unit Qbln) shelf glacier advance. These are the most extensive of the Russell Creek glacial deposits. Correlation of the glacial deposits around Frosty Peak is difficult and there is some suggestion that the deposits included in this unit on the north side of Frosty Peak may be older than those on its eastern flank

Qblu **Drift, undivided, Brooks Lake glaciation (Pleistocene)**--Largely till and stratified ice-contact deposits forming well- to poorly preserved and discontinuous moraines. May include a wide range of glacial deposits although moraines constitute the most prominent form and deposits. Locally subdivided into:

Qblik **Drift, Iliuk Stade, Brooks Lake glaciation (Pleistocene)**--Largely till and minor stratified ice-contact deposits forming poorly preserved and discontinuous moraines in some valleys of the map area and remnant deposits along the shores of Cold Bay. Where originally defined, this unit was deposited by alpine glaciers that generally did not extend past the mountain front (Detterman, 1986). However, in map area and to the northeast in the adjacent Port Moller 1:250,000-scale quadrangle, these deposits were in part derived from shelf glaciers. Equivalent to the Russell Creek drift of Funk (1973) according to Detterman (1986); shown here as units Qrc1 and Qrc2. A submerged ridge at the mouth of Cold Bay may consist of deposits of this advance, derived from offshore

Qbln **Drift, Newhalen Stade, Brooks Lake glaciation (Pleistocene)**--Largely till and minor stratified ice-contact deposits forming irregularly preserved and discontinuous moraines in some valleys of the map area and remnant deposits along the shores of Cold Bay. Funk's (1973) measured section of the Cold Bay Formation is in this unit. Where originally defined farther north on the Alaska Peninsula, this unit was deposited by large alpine glaciers that generally did not extend past the mountain front (Detterman, 1986). However, in the southern part of the Cold Bay and False Pass 1:250,000-scale quadrangles and the adjacent Port Moller quadrangle, deposits we correlate with the Newhalen stade indicate that a large offshore ice-mass persisted until late in the Pleistocene. Lithologic and geomorphic evidence indicate that the large Newhalen morainal deposits of the Cold Bay region were deposited at or near sea level and probably were tidewater (or glacial lake-ending) glaciers. At the head of Cold Bay, well-sorted gravel-rich barrier-bar deposits (shown as unit Qb on this map), well-stratified sandy facies, and varved clay sections dominate the exposures of the mapped Newhalen drift

Qblil **Drift, Iliamna Stade, Brooks Lake glaciation (Pleistocene)**--Large generally discontinuous, arcuate moraines showing well-developed form, although knob-and-kettle topography is somewhat altered. Forms inner part of large morainal ridge bounding Morzhovoi Bay and the deposits surrounding Mount Simeon. Formed mainly of till and lesser stratified ice-contact deposits. Weathering of clasts in these deposits is minor, largely confined to the partial disintegration of sedimentary clasts (Detterman, 1986). Data and interpretation from elsewhere on the Alaska Peninsula and in the Kodiak Islands (Mann and Peteet, 1994; Stilwell and Kaufman, 1996) indicates these deposits are late Wisconsin in age. Our interpretation of this indicates these deposits have an age of roughly 24,000 yrs BP or more and Weber and Wilson believe these deposits may be early Wisconsin in age. In the Joshua Green River valley, deposits shown on this map as this unit are mapped by Dochat (1997) as the Ptarmigan Ridge (unit Qpt) alpine advance and are thought by her to be older than the Kvichak stade

Qblk **Drift, Kvichak Stade, Brooks Lake glaciation (Pleistocene)**--Large arcuate end moraines that form the outer part of the morainal ridges that bound Morzhovoi and Cold Bays. Other morainal deposits to the northeast and southwest correlate with these deposits. Formed mainly of till and stratified ice-contact deposits. Forms a large part of the Cold Bay Formation of Funk (1973) as mapped; however, measured section as described by Funk (1973) is in unit Qbln of this map. Weathering of clasts in these deposits is minor, largely confined to the partial disintegration of sedimentary clasts (Detterman, 1986), similar to the Iliamna Stade drift. Data from elsewhere (Mann and Peteet, 1994; Stilwell and Kaufman, 1996) on the Alaska Peninsula indicate this is the oldest of the late Wisconsin age deposits, having an age that is probably somewhat more than 24,000 yrs BP. However, Weber and Wilson infer an early Wisconsin age for these deposits. For the Morzhovoi and Cold Bay moraines, no specific source is known, erratic clasts include "metamorphic" rocks and petrified wood, which Funk (1973) considered "indigenous" to the Shumagin Islands, an unlikely source for these moraines. However, some granitic erratic clasts in the Kvichak drift could well have been derived from the Sanak Islands. In the vicinity of Belkofski Bay and Emmons Caldera, deposits shown as unit Qblk are known to include volcanic debris from the eruption of ancestral Mt. Emmons; the assignment of the deposits in this area to this unit is somewhat tenuous and the exact nature of the relationship between the volcanic debris and glacial deposits is unknown (T.P. Miller, personal commun., 1996). In the Joshua Green River valley, deposits shown on this map as this unit are mapped by Dochat (1997) as the Bear Ridge (unit Qbr) alpine advance and are thought to be older than the Kvichak stade

Qblo **Outwash deposits, Brooks Lake glaciation (Pleistocene)**--Poorly to moderately well-sorted and stratified sand, silt, and gravel forming flat to gently sloping plains in front of end moraines of the Brooks Lake glaciation. Corresponds in part to middle member of Cold Bay Formation of Funk (1973). This unit should develop in front of the deposits of each of the Brooks Lake glaciation advances. Stratigraphically overlying a portion of this unit in the Cold Bay area is a thin unit, up to 2 m thick, consisting of numerous volcanic ash layers, individually as much as 50 cm thick. Funk (1973) used a key stratigraphic sequence of four distinct ash layers that are part of this thin unit, the so-called "Funk" ash, exposed throughout much of his map area for late Quaternary correlations. Radiocarbon dates indicate that this sequence of ashes is between 7,900 and 10,000 radiocarbon years old and according to T.P. Miller (USGS, personal commun., 1997), this ash is the Fisher ash, dated at 9,100 yr BP

Qmhd **Drift, Mak Hill glaciation (Pleistocene)**--Probably conceptually equivalent to Morzhovoi Bay Formation of Funk (1973). In most of the map area, surface exposures are unknown. However, north of Aghileen Pinnacles, subdued morainal deposits are assigned to this unit. These morainal deposits were derived from glaciers flowing off the mountains that constituted the volcanic center that became the present-day Emmons caldera and possibly from a large glacier tongue that flowed northward through Cold and presumably Morzhovoi Bays. Farther north on the Alaska Peninsula, Mak Hill deposits still show distinct lateral and end moraines having crests rounded and subdued by mass wasting (Detterman, 1986). In the map area, Funk's (1973) Morzhovoi Bay unit consists of two units. Lower unit is 10 to 12 m of well-compacted, dark grayish-brown till containing numerous angular boulders having minor oxidation rinds. Weber and Wilson are uncertain that this unit should be correlated with Mak Hill morainal deposits and as mentioned in the text, believe it may be more properly associated with a Kvichak stade advance. Elsewhere, Detterman (1986) described deposits having a weathered zone extending as much as 1 m from the top of the unit and clasts having weathering rinds 1-2 mm thick in the Mak Hill. Upper unit of Funk (1973) consists of stratified sand and gravel or silt and clay conformably overlying till. Contact between two units is irregular or undulating. Although common in younger units, tephra deposits were not described in this unit by Funk (1973). Funk interpreted these deposits as largely submarine in the Cold and Morzhovoi Bay areas; to north of Aghileen Pinnacles, some deposits look sub-areal and are morphologically subdued in part by volcanic ash deposits that blanket area. These characteristics may account for the more subdued appearance of this unit between the map area and elsewhere on the Alaska Peninsula. Very limited age data, none in the map area, indicate an age greater than 40,000 yrs. BP. Funk (1973, 1976) reported exposures of his Morzhovoi Bay Formation at several localities along Cold Bay; we were unable to confirm these Cold Bay localities. However, deposits similar to his description of the upper unit were found along the north coast of Cold Bay and were mapped by us as part of the Newhalen stade (Qbln) drift

Qmho Outwash and related deposits, Mak Hill glaciation (Pleistocene)--Consists in part of upper unit of Morzhovoi Bay Formation of Funk (1973). Moderately well-sorted, stratified, and consolidated sand and gravel or silt and clay deposits in flat to gently sloping plains in front of Mak Hill end moraines. Locally considerably modified by erosion. Locally includes various lacustrine, marine ice-contact, and ice-push deposits. Although common in younger units, tephra deposits were not described for this unit by Funk (1973). However, descriptions of the unit elsewhere on the Alaska Peninsula prominently mention that it locally contains as much as 3 m of silt having numerous volcanic-ash and pumice layers (Detterman, 1986)

Qjh Deposits of the Johnston Hill glaciation--Presumed not present on the basis of mapping by Funk (1973) and by Detterman's (1986) compilation, our air-photo interpretation suggests deposits of this age may be present in the extreme northeast portion of the map area. On the northeast side of Cathedral Valley, surficial deposits along the flank of Black Hill may consist of subdued glacial deposits (largely drift and outwash) of possible Johnston Hill age of Detterman (1986). Original topography is subdued although kettles are locally present absent. Erosion has largely removed all but the grossest depositional forms. A number of drainages through the Black Hill area show alluvial deposits and erosional forms that we think indicate they were outwash channels during the Johnston Hill glaciation. Although not observed on the ground during this project; outside of the map area, Johnston Hill drift shows orange-red staining or oxidation extending a short distance into the unit from its upper surface. Weak cement binds the clasts in this zone, elsewhere erratics have weathering rims 2-3 mm thick and some erratics of sedimentary rocks are disintegrating (Detterman, 1986). Outwash of the Johnston Hill glaciation consists of fine-grained sand and silt also having an orange-red oxidized zone extending a short distance below its upper surface. Varved and therefore, clearly water-lain deposits are present locally. Locally includes a loess mantle up to a few meters thick overlying drift deposits (Detterman, 1986) Other parts of Cathedral Valley we believe are floored by highly modified ground moraine of the Johnston Hill glaciation, show on this map as part of unit Qs. Modification has been through innundation by the sea, local deposition of outwash from the Mak Hill and subsequent glaciations over the ground moraine, and coverage by volcanic air-fall deposits. Although a strandline is visible at an elevation of approximately 75 to 90 m on the Bering Sea coast-facing mountains and hills north and south of Cathedral Valley, we have not been able to trace this strandline into Cathedral Valley

Qsb **Scoured bedrock**--Areas of bedrock showing evidence of glaciation and locally covered by thin colluvium, air-fall volcanic ash, and other surficial deposits. Primarily recognized and mapped in the vicinity of Black Hill (northeastern part of map area) where, we believe the glaciation is ancient relative to glacial units such as the Johnston Hill and Mak Hill drift. In the vicinity of Black Hill, Detterman (written commun., 1983) reported that he saw cobbles that were probably glacial erratics that may be related to this glaciation. These erratics were found at 750 feet elevation, and therefore well above the mapped extent of the Mak Hill and Johnston Hill deposits

TERTIARY

Tvs **Volcanic sedimentary rocks and agglomerate (Pliocene?)**--Unit is of variable thickness and consists of volcanogenic, nonmarine sedimentary rocks and interlayered agglomerate, flows and sills. Included in this unit in the area northwest of the Emmons Lake eruptive center are rocks mapped as the Agglomerate of Cathedral Valley by Kennedy and Waldron (1955), a thick sequence of agglomerate beds and subordinate tuff beds and lava flows that is well exposed in Cathedral Valley. According to Kennedy and Waldron (1955), the rocks are predominantly basalt and basaltic andesite and dip north toward the Bering Sea. Kennedy and Waldron (1955) suggested that these rocks are probably comparable in age to the Belkofski Tuff (later renamed the Belkofski Formation); we suggest here a better lithologic and stratigraphic correlation is with the Milky River Formation (Detterman and others, 1996)

Tta **Tachilni Formation (late Miocene)**--Named by Waldron (1961) for roughly 100 meters of marine sedimentary rocks at Morzhovoi Bay. Formation is composed of gray to brown, poorly consolidated, cross-bedded, subgraywacke sandstone commonly interbedded with volcanic-pebble conglomerate and siltstone (Detterman and others, 1996). Sandstone is composed of 30-35 percent angular quartz, 30 percent volcanic rock fragments, 10-15 percent feldspar, and 5 percent pyroxene and amphibole in a clay matrix. McLean (1979b) reported a thickness of about 460 m for the Tachilni and designated a reference section, 130 m thick at South Walrus Peak; the reference section as measured is incomplete as the basal part was not examined. In determining thickness of the entire unit, Detterman and others (1996) suggested structural complications and poor exposure preclude measurement of a complete section. A considerable part of the unit as mapped by McLean and others (1978) is included on this map in the Belkofski Formation. The Tachilni Formation is richly fossiliferous, including 36 genera of bivalves and 11 genera of gastropods (Detterman and others, 1996). Marincovich (1983) showed that these fossils closely correlate with the Wishkahan Stage of the late Miocene, resulting in a late Miocene age assignment for the unit in contrast to the late Miocene and early Pliocene age reported by McLean (1979a, b). The Tachilni is unconformably overlain by late Tertiary and Quaternary volcanic and volcaniclastic rocks. The contact of the Tachilni and the Morzhovoi Volcanics is generally structurally conformable, although locally unconformable where volcanic flows fill former stream valleys cut into the Tachilni. A lower contact exposed on the coast between Morzhovoi Bay and False Pass is conformable with the underlying Belkofski Formation

Tu **Unga Formation (middle Miocene to late Oligocene)**--Originally named the Unga Conglomerate by Dall (1882, 1896) for exposures west of Zachary Bay on Unga Island (Port Moller B-2 and B-3 1:63,360-scale quadrangles); later redefined a number times and finally made the Unga Formation (Detterman and others, 1996). Section on Unga Island is 275-m-thick and consists of volcanic rocks (lahar deposits, debris-flow deposits, and tuff), sandstone, conglomerate, and carbonaceous shale and coal (restricted to lower part). Sandstone and conglomerate are composed of poorly sorted, and typically loosely consolidated volcanic debris. Unit was formerly restricted to Unga Island, the Pavlof Islands, and along Pacific coast of Alaska Peninsula adjacent to Unga Island, however rocks on the west side of Deer Island, which consist of green to brown mudstone, volcanic breccia and lahar deposits, and carbonaceous shale, are here referred to the Unga Formation. Nowhere are the contacts between the Unga and other units of this map exposed

Tbe **Belkofski Formation (middle Miocene? to late Oligocene?)**--Originally named the Belkofski Tuff by Kennedy and Waldron (1955), later renamed the Belkofski Formation by Burk (1965; McLean, 1979a). McLean (1979a, b) gave a generalized description of a section about 1,830 m thick along northwest shore of Belkofski Bay, where it consists of gray or greenish-gray to gray-brown, tuffaceous, volcaniclastic sandstone, siltstone, and conglomerate containing interbeds of tuff and volcanic breccia. On the Pavlof Islands (Port Moller 1:250,000-scale quadrangle) and on the peninsula between Morzhovoi Bay and False Pass and Unimak Island, rocks of this unit are dominantly red, pink, and purple and are very well indurated. This unit is conformably overlain by the Tachilni Formation and, on the basis of lithologic similarity and apparent stratigraphic position, is likely correlative with the Unga Formation (unit Tu; Detterman and others, 1996). Lower contact of the Belkofski Formation is nowhere exposed. Potassium-argon age determination of a clast from volcanic agglomerate overlying Belkofski Formation on Dolgoi Island (Port Moller 1:250,000-scale quadrangle) is 11.79±0.41 Ma (Wilson and others, 1994)

Ts **Stepovak Formation (early Oligocene and late Eocene)**--Originally called the Stepovak Series by Palache (1904) for rocks exposed on east side of Chichagof Bay, later renamed the Stepovak Formation by Burk (1965; see also, Detterman and others, 1996); and divided into two informal members by Detterman and others (1996). Lower member is a deep-water turbidite deposit composed of dark-brown laminated siltstone and shale and interbedded sandstone that commonly shows graded bedding and rip-up clasts. Upper member, which is rich in unaltered volcanic debris, was deposited in a shallow-water shelf environment. Megafauna distributed throughout the upper member are characteristic of water depths no greater than 30 to 50 m (Louie Marincovich, Jr., written commun., 1983-86). In the map area, rocks exposed in the vicinity of Indian Head on Belkofski Bay, in part originally mapped as the arkose unit of Kennedy and Waldron (1955, unit Ta), are herein assigned to the Stepovak Formation, presumably the upper member. They consist of dusky yellow-green to green, very fine- to coarse-grained, angular to subrounded, volcaniclastic sandstone containing minor interbeds of dark-gray to olive-gray siltstone. Some sandstone layers are mottled green and white, indicating that they are laumontitic and tuffaceous. Unit is faintly bedded, having low-angle tabular crossbeds. Locally, it contains considerable pebble conglomerate and dark olive-gray siltstone containing plant debris; the siltstone is locally intensely bioturbated. Assignment of the rocks at Indian Head to the Stepovak Formation considerably extends the known geographical range of the unit

CRETACEOUS

Ks **Shumagin Formation (Late Cretaceous; Maestrichtian)**--Named and defined by Burk (1965; see also, Moore, 1974a) for typical exposures at Falmouth Harbor on Nagai Island (Port Moller 1:250,000-scale quadrangle), which was later designated as type area of unit by Moore (1974a). In map area, unit is present only in the Sanak Islands. The Shumagin Formation consists of interbedded sandstone, siltstone, mudstone, and shale at least 3,000 m thick (Burk, 1965). Sandstone is dominantly medium-light-gray to medium-dark-gray, very fine- to medium-grained, highly indurated lithic graywacke (Moore, 1974a, b). Sandstone beds range in thickness from 2 cm to 20 m, are graded, and contain abundant shale and siltstone chips (Moore, 1974a, b; Detterman and others, 1996). Thin (less than 10 cm) grayish-black mudstone layers are interbedded with sandstone; however, in some areas mudstone forms the dominant lithology. Thin-bedded siltstone, mudstone, and sandstone sequences are rhythmically bedded and have sharp upper and lower contacts indicative of turbidity current deposition in deep-sea-fan and abyssal-plain environments. Only contact of the Shumagin with a younger unit is observed where the early Tertiary Sanak Island batholith has intruded (Kienle and Turner, 1976; Detterman and others, 1996). At this contact, the Shumagin has been metamorphosed. The Shumagin depositionally overlies a structurally conformable chert and volcanic rock sequence (KJcv). Fossils are uncommon in the Shumagin, but existing collections indicate an early Maestrichtian age for the formation (J.W. Miller, written commun., 1983-88; oral commun., 1991)

CRETACEOUS and/or JURASSIC

KJcv **Chert and volcanic sequence (Late Cretaceous and/or Jurassic?)**--Unit was originally described by Moore (1974b) for rocks on the northeast coast of Long and Clifford Islands in the Sanak Islands. Moore's (1974b) description of these rocks is as follows: "Reddish-brown, light-gray, and grayish-green bedded chert; dark-greenish-gray pillow lavas and tuffs, thin (5-10 cm) medium-gray, medium- to fine-grained sandstone interbedded with dark-gray mudstone." The maximum exposed thickness reported by Moore (1974b) is 250 m; however as no base of the unit is exposed, the total thickness of the unit is unknown. Clasts of chert, presumably derived from this unit, are found in the depositionally overlying massive sandstone of the Shumagin Formation (Ks), hence the assignment by Moore (1974b) of a Jurassic or Early Cretaceous age for these rocks because no fossil or radiometric age control existed. However, recently collected samples of the chert from Long Island yielded fossils of Late Cretaceous, probably Campanian or Maestrichtian age (C.D. Blome, USGS, written commun., 1994). Chemical analysis of the altered pillow lava yielded greater than 60 percent SiO_2 and greater than 2.6 percent K_2O, indicating a calc-alkaline andesite composition. No other locality on the Alaska Peninsula or adjacent islands has similar lithologies, except for parts of the Early Cretaceous Uyak Formation (Moore, 1969; Fisher, 1979) on Kodiak Island, with which Moore (1974b) made a lithologic correlation

JURASSIC

Jn **Naknek Formation, undivided (Late Jurassic; Oxfordian)**--Originally named Naknek Series by Spurr (1900, p. 169-171, 179, 181) for exposures at Naknek Lake at the northeast end of the Alaska Peninsula. Detterman and others (1996; Detterman and Hartsock, 1966; Martin and Katz, 1912) have subdivided unit into five members. Megafossils, particularly the pelecypod *Buchia* (Detterman and Reed, 1980, p. B-38; J.W. Miller, written commun., 1982-88), are common and the fauna, which also includes ammonites, indicates an age range of Oxfordian to late Tithonian (Late Jurassic). The exposures in the vicinity of Black Hill are the southernmost exposure of the Naknek Formation. Strike of the bedding is N50°E and measured dip ranges between 3° and 10° SE. At the highest elevations, the Indecision Creek Member is exposed. At lower elevations and stratigraphically lower are rocks of the Snug Harbor Siltstone. The rocks are typically greenish-yellow, thin- to medium-bedded, fine- to medium-grained sandstone containing abundant fossils, including *Buchia piochii*, *Pleuromya*, and possibly *Buchia okensis* (J.W. Miller, written commun., 1983). At lower elevations, the rocks are thin-bedded silty sandstone and minor siltstone containing abundant *Buchia rugosa* and *Buchia mosquensis* (J.W. Miller, written communication, 1983). Along the Bristol Bay coast, the rocks are thick-bedded, medium-grained, feldspathic to arkosic sandstone containing abundant irregularly shaped mudballs and abundant *Buchia concentrica* (J.W. Miller, written communication, 1983). On the nearby Cathedral River, Amoco Production Company drilled an exploratory well in 1973-1974 (Detterman, 1990). Spudded in the Snug Harbor Siltstone Member, it continued through the Northeast Creek Sandstone Member, and then following an unconformity continued into the Middle Jurassic Shelikof Formation, before finally bottoming in Triassic rocks (Detterman, 1990). "Depositionally the Naknek at this locality represents a regressive, transgressive, regressive sequence. The exposed section of Indecision Creek Sandstone was deposited about middle shelf during a minor regression. This followed a transgression during the time the Snug Harbor Siltstone Member was deposited in a deeper outer shelf environment. The underlying Northeast Creek Sandstone represents a major regression and was deposited in a near shore to subaerial environment" (Detterman, 1990, p. 7). The Naknek is unconformably overlain by Quaternary deposits in the map area; no lower contact is exposed, except as described above in the Cathedral River drill hole. Elsewhere on the Alaska Peninsula, the Naknek is conformable with the overlying Staniukovich Formation and, as here, unconformably overlies the Middle Jurassic Shelikof Formation (see Detterman and others, 1996). The Alaska-Aleutian Range batholith (Reed and Lanphere, 1969, 1972, 1973) was the main source of sedimentary debris for the Naknek Formation

VOLCANIC ROCKS

QUATERNARY

Qv **Volcanic rocks, undivided (Holocene and Pleistocene)**--Andesite, dacite, and leucobasalt lava flows, volcanic breccia, lahar deposits, and debris-flow deposits. Lava flows and clasts in other volcanic deposits of unit are porphyritic, typically glassy, gray to black, and commonly vesicular. Andesite is the overwhelmingly dominant composition and probably constitutes 60 percent or more of rocks. Unit typically forms volcanic edifices; it also forms isolated outcrops that cap ridges, providing a good example of topography reversal caused by erosion. Individual flows are locally as thick as 30 m and are laterally continuous over large areas. Morphologically distinct flows separated on the map by internal long and short dash contacts. Unit also includes basalt, basaltic andesite, and dacite parasitic cinder and spatter cones. Cones are commonly 30 to 300 m high, are steep sided, and have small crater at top. Locally divided into:

Hv **Volcanic rocks (Holocene)**--Mainly andesite, dacite, and leucobasalt lava flows, volcanic breccia, lahar deposits, and debris-flow deposits. Unit also includes basalt, basaltic andesite, and dacite parasitic cinder and spatter cones. Lava flows and clasts in the other deposits are typically gray to black, porphyritic, and commonly vesicular. Clasts are highly scoriaceous to vitrophyric; range in size from cinder-size fragments to bombs 1 m long. Andesite is the principal composition and probably constitutes 60 percent or more of the unit. Individual flows are locally as thick as 30 m and laterally continuous over large areas. Unit typically forms volcanic edifices. Also present as isolated outcrops, which cap or form ridges, providing a good example of topography reversal due to erosion. Includes unit Qfvs of Waldron (1961), summit cone rocks of Frosty volcano

Qfp **Frosty Peak Volcanics (Holocene and late? Pleistocene)**--Light-gray, porphyritic, augite andesite or hypersthene-augite andesite and minor hornblende andesite forming Frosty volcano (Waldron, 1961). Consists of flows and pyroclastic rocks in individual units no more than 30 m thick and typically less than 12 m. Local unconformities are present where shallow valleys were eroded into the underlying agglomeratic rocks and later filled by flows. Two coalescing summit craters are present on Frosty volcano; however, mapping has not been sufficiently detailed to determine if there is significant age difference between the craters. The southernmost of the craters is nearly filled with later volcanic rocks that form the summit cone of Frosty Peak (unit Qfvs of Waldron, 1961, p. 694), mapped herein as unit Hv. Individual flows are difficult to distinguish and map. No detailed mapping of the volcano has been conducted since Waldron (1961)

Qpd **Pyroclastic and debris-flow deposits, undivided (Holocene and late? Pleistocene)**--Dacite and rhyolite ash-flow tuff, debris-flow, block-and-ash-flow deposits, explosion debris including volcanic avalanche deposits, and air-fall deposits in the vicinity of Pavlof Volcano (Emmons Lake center), Mount Dutton, Roundtop Mountain, Isanotski Peaks, and Frosty Peak. According to Miller and Smith (1987, p. 174), pyroclastic deposits "typically are composed of pumice and scoria bombs .... and subordinate lithic fragments in a matrix of fine to coarse ash, pumice, and lithic material." Miller and Smith (1987) also reported that composition ranges from basaltic andesite to rhyolite, although most are dacite. Map unit is interbedded with, and overlies Quaternary glacial debris. Unit records multiple, late Pleistocene and Holocene eruptions. Where known, individual pyroclastic flow deposits are shown by internal contacts. Locally divided into:

Qav **Volcanic avalanche deposits (Holocene?)**--Deposits consist of widely strewn, large angular blocks of volcanic rock on slopes surrounding Frosty Peak. Similar deposits are present in the vicinities of Emmons Caldera and Mt. Dutton; however, they are not separately mapped (see unit Qpd)

Qafd **Ash-flow and ash-fall deposits (Holocene and late Pleistocene)**--Block-and-ash-flow and air-fall deposits in the vicinity of Pavlof Volcano (Emmons Lake center), Mount Dutton, Roundtop Mountain, Isanotski Peaks, and Frosty Peak. Composition ranges from basaltic andesite to rhyolite, although most are dacite (Miller and Smith, 1987). Map unit is interbedded with and overlies, Quaternary glacial debris. Unit records multiple late Pleistocene and Holocene eruptions

Qdf Volcanic debris-flow deposits (Holocene and late Pleistocene?)--Andesite to rhyolite debris-flow deposits in the vicinity of Emmons Caldera, Mount Dutton, and Frosty Peak. Map unit is interbedded with, and overlies Quaternary glacial debris. Unit records multiple late Pleistocene and Holocene eruptions

Qvg Volcanoglacial debris flow deposit (Pleistocene)--West of the Aghileen Pinnacles, snake-like deposit of volcanic debris superimposed on existing topography. Consists of unsorted angular volcanic rock fragments showing in gross aspect a morphology suggestive of fluid flow in waves down slope. Feature apparently derived from highlands in the vicinity of Aghileen Pinnacles, now eroded away

Qcs Cinder and spatter cone deposits (Holocene?)--Steep-sided parasitic cones having small crater at summit. Located on Unimak Island in the vicinity of Shishaldin Volcano

QUATERNARY and/or TERTIARY

QTv Volcanic rocks (Quaternary and Pliocene?)--Andesite and basalt lava flows, agglomerate, lahar deposits, sills, and plugs. These primarily extrusive rocks typically cap ridges. A potassium-argon age from south of Kelp Point is 2.94±0.15 Ma (Nora Shew, written commun., 1991, age report no. 261). A second potassium-argon age from west of Kenmore Head was 1.28±0.04 Ma on a columnar-jointed andesite flow (Nora Shew, written commun., 1993, age report no. 269). Includes the basalt flows of Mount Simeon of Waldron (1961)

QTm Morzhovoi Volcanics (early Quaternary?, Pliocene, and late Miocene?)--Named by Waldron (1961) for a sequence of lava flows, interbedded pyroclastic rocks, and minor volcanic sedimentary rocks that overlies the Tachilni and Belkofski Formations. Unit comprises "the eroded remnants of an ancient large composite cone, ... called Morzhovoi volcano, in the area south of Frosty Peak" (Waldron, 1961, p. 688). Waldron (1961, p. 688) designated a type locality along the Pacific coast south and east of Reynolds Head (sec. 5, T. 59S., R. 90W., Cold Bay A-3 1:63,360-scale quadrangle). At the type locality, the unit consists of poorly consolidated dark sandy shale, sandstone, and fine- to coarse-grained conglomerate composed of subrounded to rounded fragments of volcanic debris. These rocks are conformably overlain by interbedded lava flows, coarse agglomerates, and volcanic breccias of light- to pinkish-gray porphyritic basalt. Total thickness of the unit is at least 900 m. Olivine, which is not common in Alaska Peninsula volcanic rocks in general, is present in small amounts in nearly all examined rocks of the Morzhovoi Volcanics (Waldron, 1961). The age of the Morzhovoi Volcanics is not well controlled. Waldron (1961) inferred an age of no older than latest Tertiary nor younger than middle Pleistocene. Detterman and others (1996) reported that "The upper part of the Tachilni Formation contains several ash beds that were possibly derived from the Morzhovoi volcano." From this, they inferred an earlier age limit of late Miocene for the Morzhovoi Volcanics. Unit is correlative with parts of unit QTv elsewhere in the map area

QTdv Volcanic breccia proximal to Dora Peak (Quaternary?, Pliocene?, and late Miocene?)--Felsic volcanic breccia, agglomerate, lithic and crystal-lithic tuff, and minor lava flows on Ikatan Peninsula. Unit includes massive volcanic breccia more than 100-m-thick as well as thick intervals of agglomerate and tuff. Composition is more siliceous than other volcanic rock units. Unit is hornfelsed, showing development of epidote, and cut by locally numerous quartz veins where near granodiorite pluton of the Ikatan Peninsula (unit Tiu)

TERTIARY

Tvu **Volcanic rocks, undivided (Tertiary)**--Andesite, dacite, and basalt lava flows, tuffs, lahar deposits, volcanic breccia, and hypabyssal intrusions, all locally hydrothermally altered or hornfelsed. No potassium-argon ages are available and there is little stratigraphic control for these rocks. Outcrop and erosional patterns are similar to other Tertiary volcanic rocks

Tv **Volcanic rocks (late Miocene)**--Andesite and basalt flows, sills, and plugs. Extrusive rocks of unit typically cap ridges and consist of massive lava flows, agglomerate, and lahar deposits; unit also includes minor small intrusive bodies. Minor propylitic alteration is characteristic of these rocks. Includes the volcanic rocks of Thinpoint Lagoon of Waldron (1961). A potassium-argon age from the volcanic rocks at Thinpoint Lagoon is 5.23±0.66 Ma; another from Fox Island is 8.89±0.12 Ma (Nora Shew, written commun., 1991, age reports no. 265 and 245)

INTRUSIVE ROCKS

QUATERNARY

Qi **Intrusive rocks (Holocene and Pleistocene)**--Hypabyssal dacite plugs and domes at Quaternary volcanic centers, particularly Frosty Peak, Walrus Peak, and Roundtop

Qvd **Dacitic to rhyolitic domes**--Hypabyssal domes emplaced in the vicinity of Mt. Dutton and other volcanic centers. Typically felsic rocks, dacite to rhyolite

TERTIARY

Ti **Intrusive rocks (Pliocene and late Miocene)**--Medium- to coarse-grained, equigranular, granodiorite to quartz diorite plutons and stocks containing hornblende, biotite, and pyroxene as mafic minerals and typically surrounded by well-developed hornfels zones and sporadic hydrothermal alteration in country rocks. Intrusive bodies are generally located along Pacific coast and include the large pluton on the east side of Belkofski Bay (Moss Cape pluton) and at King Cove. A potassium-argon age on the Moss Cape pluton is 3.21±0.14 Ma (Wilson and others, 1994)

Tiu **Intrusive rocks, undivided (Tertiary)**--Small dikes, sills and stocks of andesite, quartz diorite, or diorite, typically hypabyssal and containing phenocrysts of pyroxene or hornblende in a fine-grained groundmass. No reliable potassium-argon ages are available for these rocks; unit may include rocks of other Tertiary intrusive rock units

Tg **Granodiorite (Paleocene)**--Medium-grained biotite granodiorite pluton of Sanak Island having hypidiomorphic granular texture and locally containing potassium feldspar phenocrysts as long as 1 cm. Potassium-argon ages reported by Moore (1974b) and Kienle and Turner (1976) range from 62.0±3.3 to 61.4±1.8 Ma when recalculated using currently accepted constants (Steiger and Jager, 1977). A rubidium-strontium mineral isochron is 62.7 Ma and a whole-rock isochron is 49.5 Ma (Hill and others, 1981).

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U.S. Department of the Interior
U.S. Geological Survey

REVISED GEOLOGIC MAP OF THE COLD BAY AND FALSE PASS QUADRANGLES, ALASKA PENINSULA

Frosty Volcano near Cold Bay, Alaska

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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