CHAPTER 7

THE ESPENBERG MAARS: A RECORD OF EXPLOSIVE VOLCANIC ACTIVITY IN THE DEVIL MOUNTAIN-CAPE ESPENBERG AREA, SEWARD PENINSULA, ALASKA

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Abstract

The Devil Mountain-Cape Espenberg area of the Bering Land Bridge Preserve includes a volcanic field which lies at the northern limit of basaltic volcanism in Beringia. Ten recognized vents lie within a wedge of thick Cenozoic sediment bounded by the Kobuk Fault and one of its splays.

The Devil Mountain-Cape Espenberg volcanic field consists of five small shield volcanoes and five maars. The shield volcanoes appear to be older than the maars and may predate the formation of permafrost in the region. The maars are of middle and late Pleistocene and Holocene age and are probably the product of phreatomagmatic eruptions that resulted when rising basaltic magma encountered ground water in Cenozoic sediments beneath a cap of permafrost.

The age of the younger maar eruptions is estimated on the basis of radiocarbon-dated samples associated with airfall tephra, tephra-rich alluvium, and a tephra-rich ice-rampart complex at North Killeak Lake. Tephra beds in several ancient thaw-lake deposits were also dated, but these may consist of tephra redeposited long after the original tephra fall. Relative ages of the older maars are based upon the degree of degradation and destruction of associated arcuate tuff ridges. North and South Devil Mountain Lakes formed by maar eruptions about 7,100 and 17,000 years ago, respectively. South Killeak Lake was apparently formed by a maar eruption more than 42,000 but less than 125,000 years ago. The North Killeak Lake maar is probably more than 125,000 years old and the Whitefish Lake maar seems to be older, still.

Each maar eruption deposited a mantle of tephra over an area of 1,000 square kilometers or more. The dated tephra layers can be used to estimate the age of loess deposition and dune activity in the Devil Mountain-Cape Espenberg area. Fossil plant assemblages preserved beneath tephra deposits preserves a record of Beringian vegetation at various moments in the past.

Introduction

The Bering Land Bridge Preserve is notable for the large areas of Cenozoic volcanism that it includes. Volcanism is responsible for much of the landscape in which a hunting and foraging economy was carried on for many thousands of years and in which reindeer herding has been carried on during the present century. The two most recent volcanic eruptions (those that formed the North Devil Mountain Lake maar near Cape Espenberg and the Lost Jim flow near Imuruk Lake) took place within the last 10,000 years and thus very likely had human witnesses.

The numerous cinder cones and extensive basaltic lava flows near Imuruk Lake area are the best known of the volcanic phenomna within the Bering Land Bridge preserve (Hopkins, 1959, 1963; Hopkins et al. 1971; Swanson et al. 1981) and had the best documented impact upon the local people [1]. More remote and

[1] A volcanic eruption graphically described in the oral history of the Inupiat-speaking Kaweruk people of central Seward Peninsula (Oquilluk, 1971, p. 22-23) seems surely to record the eruption of the vast and voluminous Lost Jim flow, south of Imuruk Lake, and the spectacular phreatomagmatic steam explosions that would have resulted when the flow entered Imuruk Lake (Hopkins, 1959, 1963). This event is also evidently recorded by basaltic tephra interbedded in peat on the northeast shore of Salix Bay, Imuruk Lake. Twiggy peat, probably slightly contaminated by modern roots, collected two centimeters below the tephra layer yielded a radiocarbon age of 1,655 +/- 220 years BP (I-8293) (Table 1). (This and all other radiocarbon dates given in this report are uncalibrated; that is, they have not been corrected for temporal variations in the radiocarbon content of atmospheric CO^2).

Not previously described in any formal publication is the small field of young basaltic volcanism that lies within the Devil Mountain-Cape Espenberg area, an area bounded by the Nugnugaluktuk River[2] on the south, the Cowpack River on the west, the coast of the Chukchi Sea on the north, and Kotzebue Sound on the east (Figure 7-1).

The youngest and most spectacular volcanic features in the Devil Mountain-Cape Espenberg area consist of a group of five maars (shallow, broad, low-rimmed explosion craters formed by eruptions rich in steam). Tephra (volcanic ash) ejected from the maars is a conspicuous component of late Quaternary deposits throughout the Devil Mountain-Cape Espenberg area. Organic deposits above and below tephra deposits provide the means of dating at least some of the maar eruptions. Conversely, the tephras, once dated and characterized, can provide a useful time grid by reference to which other late Quaternary deposits in the Devil Mountain-Cape Espenberg area can be dated. The individual tephra layers have not yet been characterized as to grain size, mineralogy, and major and trace element geochemistry, but the 14 radiocarbon-dated samples reported here provide a basis for dating some of the eruptions.

2 U.S.Geological Survey maps render the spelling of this stream as Nugnugaluktuk River, but local residents corrected my pronounciation and told me that the name is more closely approximated by "Nuglungnugtuk" (Harry Kigrook, oral and written communication 8/21/49).

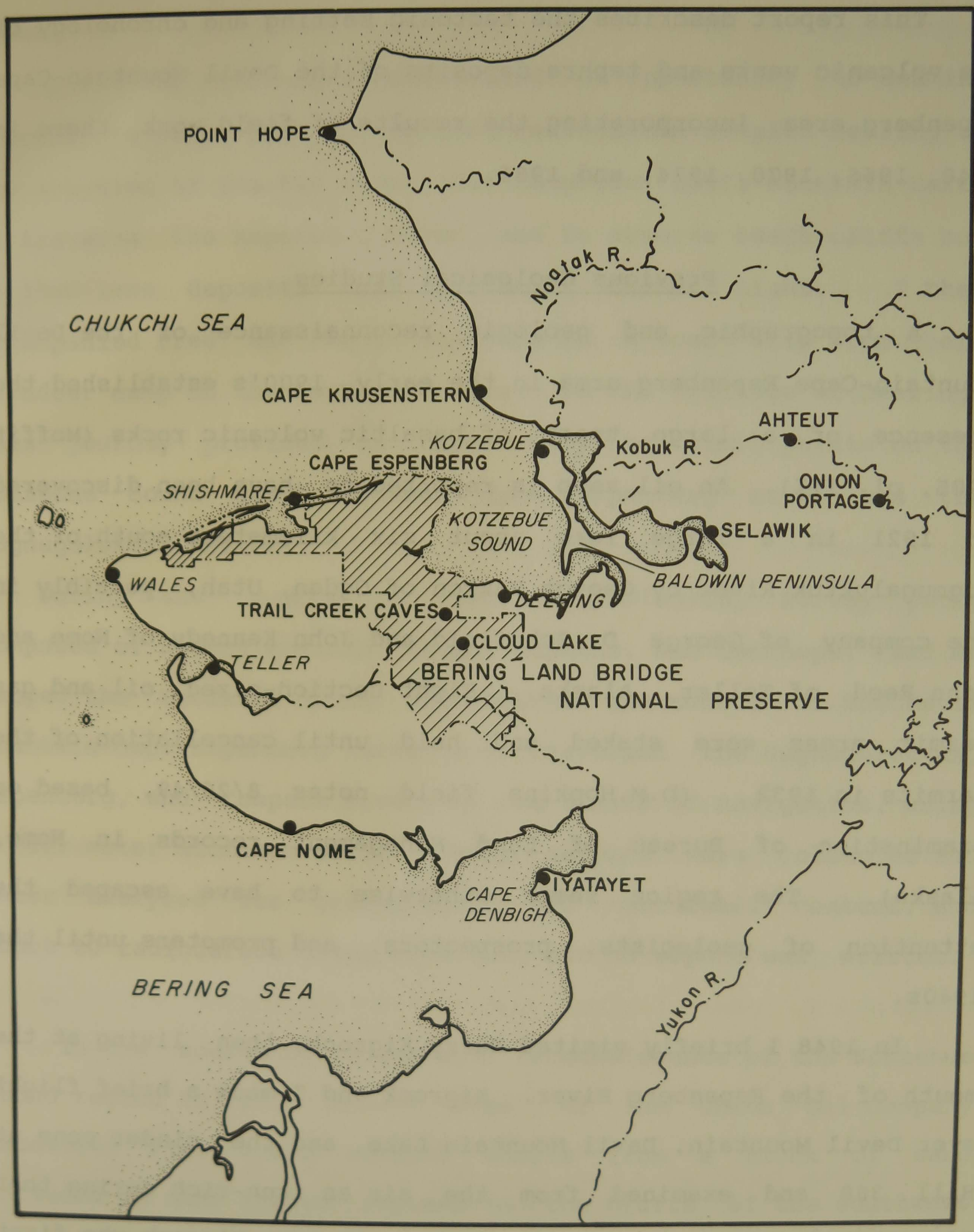


FIGURE I: Bering Land Bridge National Preserve showing localities mentioned in text.

This report describes the tectonic setting and chronology of the volcanic vents and tephra deposits of the Devil Mountain-Cape Espenberg area, incorporating the results of field work there in 1948, 1966, 1970, 1974, and 1986.

Previous Geological Studies

A topographic and geologic reconnaissance of the Devil Mountain-Cape Espenberg area in the early 1900's established the presence of a large tract of basaltic volcanic rocks (Moffit 1905, pl. III). An oil seep is reported to have been discovered in 1921 in a large lake about six kilometers south of the Nugnugaluktuk River by George Paxton of Ogden, Utah, possibly in the company of George D. Schofield and John Kennedy of Nome and John Reed of Teller, Alaska. Eight section-sized oil and gas permit areas were staked and held until cancellation of the permits in 1932 (D.M.Hopkins field notes 8/26/49, based on examination of Bureau of Land Management records in Nome, Alaska). The region seems otherwise to have escaped the attention of geologists, prospectors, and promoters until the 1940s.

In 1948 I briefly visited Harry Kigrook, then living at the mouth of the Espenberg River. Kigrook and I made a brief flight over Devil Mountain, Devil Mountain Lake, and the cinder cone at Hill 368 and examined from the air an iron-rich spring that Kigrook had taken for an oil seep. It was Kigrook who first informed me about the oil claims north of the Nugnugaluktuk

River.

A two-day visit in 1966 provided an opportunity to examine volcanic ejecta and to collect radiocarbon samples bearing on the eruption of the two maars that comprise Devil Mountain Lake, to traverse the Espenberg River, and to observe beach cliffs cut in thaw-lake deposits near Northwest Corner Light. I then accompanied Fred and Fanny Goodhope on a boat trip from their reindeer camp on the Espenberg River to the village of Deering. This journey provided an opportunity to visit points on the Kotzebue Sound coast between Cape Espenberg River and the Nugnugaluktuk estuary.

During the summer of 1970, a Geological Survey party composed of Robert Rowland, Chindi Hopkins, Ned Goodhope, and me mapped the Kotzebue Sound and Chukchi Sea coasts of the Devil Mountain-Cape Espenberg area and traversed the Nugnugaluktuk, Espenberg, and Cowpack Rivers to the limits of navigation, using a four-meter aluminum skiff. Many samples were collected and later analyzed for granulometry and macrofossil content, and about 20 radiocarbon dates were run, but no report was written.

In the course of a geologic reconnaissance of the Kotzebue Sound region in 1973, Robert Rose, of the Union Oil Company recovered Pleistocene mollusk shells from a block of sand included in maar ejecta exposed in the bluffs of the southwest shore of north Devil Mountain (R.J.Merryman, Union Oil Co., written communication 10/1/76). The shells were placed in the

collections of the U.S. Geological Survey in Menlo Park, California. The Devil Mountain-Cape Espenberg area has since been visited by several petroleum company geologists.

In June, 1974, a party funded by the National Park Service and composed of Daniel Livingstone, Paul Colinvaux, and me spent about a week in the Devil Mountain-Cape Espenberg area in order to assess the possibility of recovering long pollen cores from the Espenberg maars. Efforts to sound the lakes were inhibited by a persisting partial ice cover. Nevertheless, the Devil Mountain Lakes were revisited, and the Killeak Lakes and Whitefish Lake were visited for the first time [3]. Several new radiocarbon samples were collected, and a lake sediment core was recovered from Whitefish Lake. Results of the 1974 field study are summarized by Hopkins and others (n.d). Radiocarbon age determinations of about 10,000 years BP were obtained from two segments of the lower half of the five-meter Whitefish Lake core, but a date reversal and the presence of uniform pollen spectra at all levels (Shackleton 1979) casts doubt on the reliability of the radiocarbon dates. Another National Park Service team visited the area in 1976, producing an unpublished report on the origin, geologic setting, and petrography of the Espenberg maars (Forbes 1978).

[3] In the Inupiat dialect of the Cape Espenberg region "Kill'ee'k" means "East Lakes" (plural). The singular would be "Killik". Devil Mountain Lake is "Kitakhleek,", meaning "Double Lakes". Whitefish Lake is "Navaruk", meaning Big Lake (Mrs. Bessie Cross, written communication 9/26/74).

In the winter of 1974-1975, a stratigraphic test well was drilled to a total depth of 2,570 meters near the mouth of "Kiliwooligoruk"[4] Creek by the Standard Oil Company of California (American Stratigraphic Company, 1977). Tolson (1986) incorporates data from the Standard Oil Company's Cape Espenberg No. 1 in his review of the subsurface geology of the Kotzebue sedimentary basin based mainly on seismic profiles and gravity data.

Regional Setting

The Devil Mountain-Cape Espenberg area is a segment of the northern coastal plain of the Seward Peninsula. The Arctic Circle passes through the northernmost part of the beach ridge complex that comprises Cape Espenberg. The vegetation consists of treeless low-arctic tundra. The area lies about 100 kilometers west of the present western limit of spruce and about 150 kilometers beyond the western limit of tree birch. Alder shrubs reach their northwestern limit on the Seward Peninsula at Devil Mountain Lake.

[4]"Kiliwooligoruk" ("Old Wound") Creek is a local name for the stream that drains North Killeak Lake (Fred Goodhope, oral communication 7/27/66).

Tectonic Setting

The Devil Mountain-Cape Espenberg area lies at the southern edge of the Kotzebue Basin, a subsiding tectonic basin that has been receiving sediment from adjoining uplands for more than 40 million years. The Kobuk Fault, a major structural feature of northwestern Alaska, extends approximately west-southwestward across the southern part of the area (Figure 7-2; Tolson 1986). A splay (branch) of the Kobuk Fault extends westward across the area from a point near the mouth of Kungealarook Creek. Neither fault has obvious surface expression, but in the subsurface the two faults delineate a wedge of thick Cenozoic sediments that is adjoined by thinner Cenozoic sediment to the north and south. A fault that displaces late Pleistocene beach sediments on the southern part of the Baldwin Peninsula and swarms of lineaments seen on air photos of northern Baldwin Peninsula (D.M.Hopkins, unpublished data 1961-1964) attest to continuing movement on faults extending through the Kotzebue Basin as does evidence discussed later for Holocene tilting of the basin of North Killeak Lake.

The older Cenozoic sedimentary rocks beneath the Devil Mountain-Cape Espenberg area include a variety of silicic volcanic rocks, lignite, and cemented or well-compacted sandstone, siltstone and mudstone. These older deposits are not exposed at the surface, but their presence is confirmed by exotic blocks incorporated in volcanic ejecta associated with

EXPLANATION

5 0 5 10

SCALE IN KILOMETERS

Qb — Beach sand and gravel

Qe — Estuarine mud

Qa — Alluvium

HOLOCENE

Qt — Tephra of maars

PLEISTOCENE

Qv — Basaltic lava flows of shield volcanoes

PLEISTOCENE AND PLIOCENE

Pelukian shoreline, dashed where approximately located. Cannot be recognized west of Kitik River.

F — Kobuk fault and its splay (approximately located).

Exploratory well

Reported oil seep

x3 — Locality discussed in text

Distal tephra locality not discussed in text

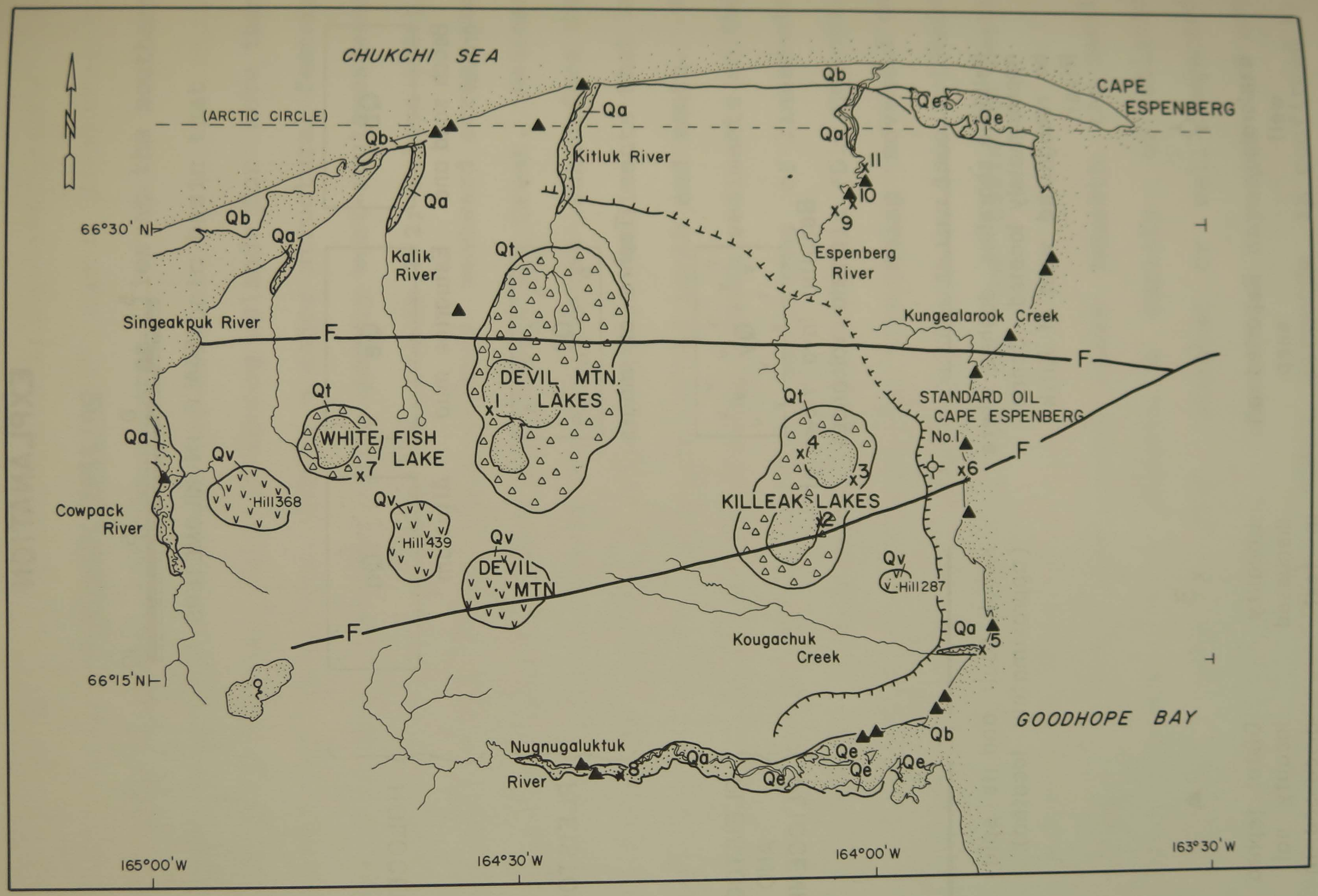


FIGURE 2. Tectonic features and surficial geology of Devil Mountain - Cape Espenberg area. Kobuk fault after Tolson, 1986a. Areas not labelled otherwise are mantled by dune sand and windblown silt of Pleistocene age and thaw lakes of Pleistocene and Holocene age.

some of the Espenberg maars.

It is worth nothing that the Devil Mountain-Cape Espenberg area lies at the northern limit of late Cenozoic volcanism in Alaska.

Quarternary Geology

Low hills extending from Goodhope Bay to the Cowpack River are underlain by volcanic deposits which form the highest part of Devil Mountain-Cape Espenberg area (Figure 7-2). Most of the remainder of the area comprises an ancient coastal plain, underlain at shallow depth by Pliocene and Pleistocene marine deposits. The presence of marine mollusk shells and many small, well-rounded quartz beach pebbles in volcanic ejecta indicate that marine deposits extend beneath the Devil Mountain Lakes. A lowland, three to 10 kilometers wide, along the Chukchi and Kotzebue Sound coasts, is underlain by lagoonal, beach, and nearshore mud and sand deposited during the Pelukian (last interglacial) transgression; these deposits are exposed along the Espenberg River and along the north shore of the Nugnugaluktuk River estuary. The volcanic and Pleistocene marine deposits are mantled by and generally concealed beneath a complex of late Quaternary dune sand, wind-blown silt, and thaw lake deposits. Lowland areas are covered by peat generally less than two meters thick. Stream channels and flood plains are underlain by alluvium, and alluvium is also present beneath dune sand in some river-bank exposures along the Nugnugaluktuk and Cowpack Rivers.

A discontinuous fringe of barrier bar and accretionary

beach ridge complexes extends along the Chukchi Sea coast. The ancient settlements of Kividluk and Singyuk are located on a barrier bar complex that separates Shishmaref Inlet from the Chukchi Sea (Jordan, Chapter 8). Farther east, an accretionary beach-ridge complex 32 kilometers long and as much as two kilometers wide extends eastward from a point near bench mark Kitluk to Cape Espenberg (Mason, Chapter 9). Smaller accretionary beach ridge complexes are found at the north entrance to the Nugnugaluktuk estuary and at several other points along the Kotzebue Sound coast.

The lowest-lying parts of the Cape Espenberg-Devil Mountain area are underlain by estuarine mud deposited behind beach and barrier bars and in estuaries and bays. Mud carried in suspension past Cape Espenberg forms a series of low-lying islands extending from Cape Espenberg to a point about four kilometers north of the mouth of Kougachuk Creek.

Volcanic Geology

A swarm of volcanic vents forms a belt about 32 kilometers long and 12 kilometers wide, extending from the coast of Goodhope Bay northwestward toward the shores of Shishmaref Lagoon (Figure 7-2). Devil Mountain is a small shield volcano (convex lava flow complex that may or may not be capped by a cinder cone). Hills 287, 439, and 368 are probably also small shield volcanoes, but they are heavily vegetated and seem to be deeply mantled with aeolian silt or sand; overflights failed to reveal exposed

volcanic rocks. Whitefish Lake, North and South Devil Mountain Lakes, and North and South Killeak Lakes are maars, and the relatively smooth uplands that surround them are at least partly and probably entirely underlain by thick deposits of tephra. All of the volcanic rocks in the Devil Mountain-Cape Espenberg area examined thus far consist of olivine basalt (Forbes 1978).

The crest of Devil Mountain consists of a swarm of cinder cones that probably delineate a west-northwest-trending eruptive fissure and several short basaltic lava flows. Sand wedges or deeply thawed ice wedges divide the bare slopes of the cinder cones into complexes of large hummocks but the forms of the cones are otherwise well preserved. One lava flow appears from the air to retain the typical form of a pahoehoe flow but appears to have been pervasively shattered by frost-cracking. Elsewhere on the Seward Peninsula, similar frost-shattered basaltic lava flows have yielded K/Ar dates (listed in Kaufmann and Hopkins 1985) ranging from 0.8 to 3.0 million years; but preservation of original craters on the Devil Mountain cinder cones suggest an age at the younger end of this range, based on comparisons with highly degraded cones elsewhere on the Seward Peninsula and on the Pribilof Islands whose ages can be inferred from K/Ar dates on associated basaltic lava flows (Swanson et al. 1981; Cox et al. 1966). The presence of a complete vegetation cover suggests that Hills 368, 439, and 287 are all older than Devil Mountain. All appear to record relatively quiet eruptions that produced considerable volumes of basaltic lava but little

tephra, more than half a million years ago.

The five large maars lie to the north of the shield volcanoes. Each maar was created during a violently explosive eruption; lakes now occupy the resulting craters. A maar origin has also been suggested for certain small round, deeply indented lakes scattered across the maar belt (Forbes 1978), I think it more likely, however, that these represent unusually deeply indented thermokarst lakes (thaw lakes) formed in areas where perennially frozen silt and sand rich in ground ice was buried beneath a thick mantle of tephra from one or another of the five large maars.

★ Why did some volcanic eruptions produce maars and others the more usual basaltic lava flows and cinder cones? Evidence presented later suggesting that the maars are all of middle and late Pleistocene and Holocene age; the shield volcanoes appear to be older. The Cape Espenberg-Devil Mountain area lies within the zone of continuous permafrost in an area where ice-bonded frozen ground is probably at least 100 meters thick (Péwé 1975). The ejecta from the South Devil Mountain Lake maar include material that must have been frozen at the time of eruption. One might assume, therefore, that the presence of a cap of permafrost confined ground water in saturated Cenozoic sediments and provided the crucial precondition for the formation of the Espenberg maars and that the shield volcanoes formed at a time when there was no permafrost on northern Seward Peninsula.

It is true that maars form when the crust is perforated by

phreatic (steam) or phreato-magmatic eruptions produced at shallow depth by rising magma contacting groundwater at shallow depth (Kienle et al. 1980). Confining pressure, however, tends to inhibit steam explosions (Kokelaar 1986; Lorenz 1986). More likely, the difference in eruptive style reflects a difference in the subsurface geology. The Espenberg maars lie near but north of the surface trace of the apparently northward dipping Kobuk Fault (Tolson 1986) in an area underlain by thick and probably water-soaked Cenozoic sediments; the small shield volcanoes to the south may be located in areas where porous Cenozoic sediments are too thin to provide an adequate ground-water reservoir.

Morphology and Deposits of the Espenberg Maars

The Espenberg maar lakes are circular to oval and exceptionally large, ranging from two to five kilometers across[5]. Lake surfaces lie 60 to 80 meters below surrounding terrain, and depths vary widely. North Devil Mountain Lake consists of a central basin said to be at least 30 meters deep (sounding by John Cross, oral communication 1966) surrounded by a shelf, visible on air photos, on which a sounding of 4.8 meters was obtained during our 1974 visit. A sounding of 22 meters was obtained several hundred meters from the west shore of North

[5] The average diameter of maars is said to be 700 meters (C.A. Wood 1980, quoted in Kienle et al. 1980).

Killeak Lake. Whitefish Lake is only six meters deep at the central point where the 1974 pollen core was taken. Because the deeper lakes are slower to warm, depth differences can be inferred from differences in the extent of the ice cover that persisted during our visit in June, 1974 (Hopkins et al. n.d.). Consistent with its great depth, ice covered about 90 percent of the surface of North Devil Mountain Lake on June 26th, while floating ice covered only about 40 percent of Whitefish Lake on June 25th. Differences in the extent of persisting ice cover in late June, 1974, suggests the depth series: North Devil Mountain Lake>> South Devil Mountain Lake>> South Killeak Lake>> North Killeak Lake>> Whitefish Lake.

Devil Mountain Lakes

The Devil Mountain Lakes are the freshest in appearance and the most tightly dated of the maars; the north lake is the fresher and younger maar. The basin of North Devil Mountain lake has maximum and minimum diameters of 5.1 and 3.3 kilometers. South Devil Mountain Lake is the smallest of the Espenberg maars, having maximum and minimum diameters of 3.4 and 2.2 kilometers. The west end of North Devil Mountain Lake has a belt of sandy beaches about 100 meters wide. Elsewhere, beaches are only a few meters wide. Linear ponds, rows of small ponds, and complexes of concentric, arcuate ridges around the periphery of the lake (Figure 7-3b) may be features produced by base surges during vigorous explosive events (J.Kienle, written

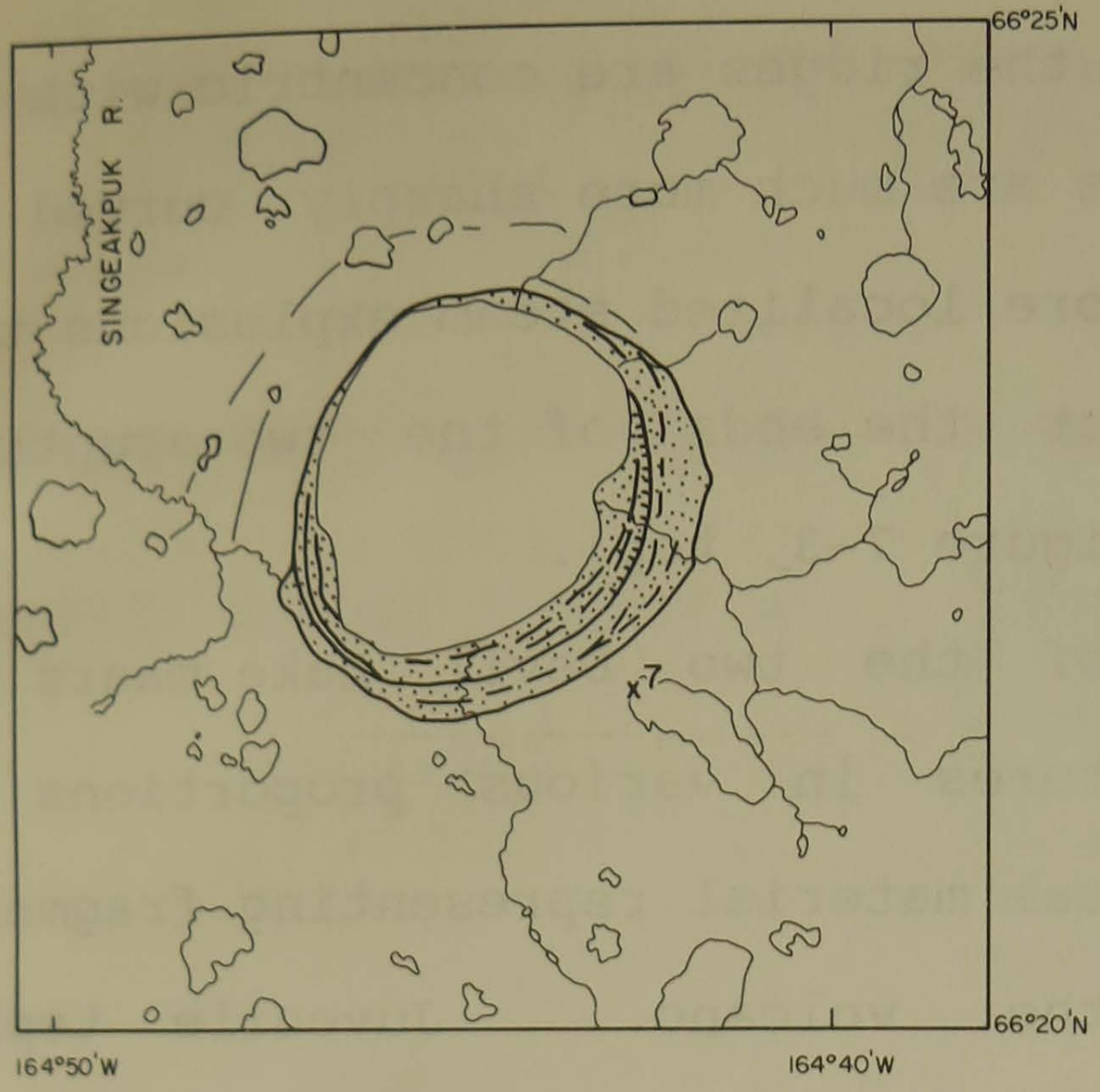


FIGURE 3a: Whitefish Lake.

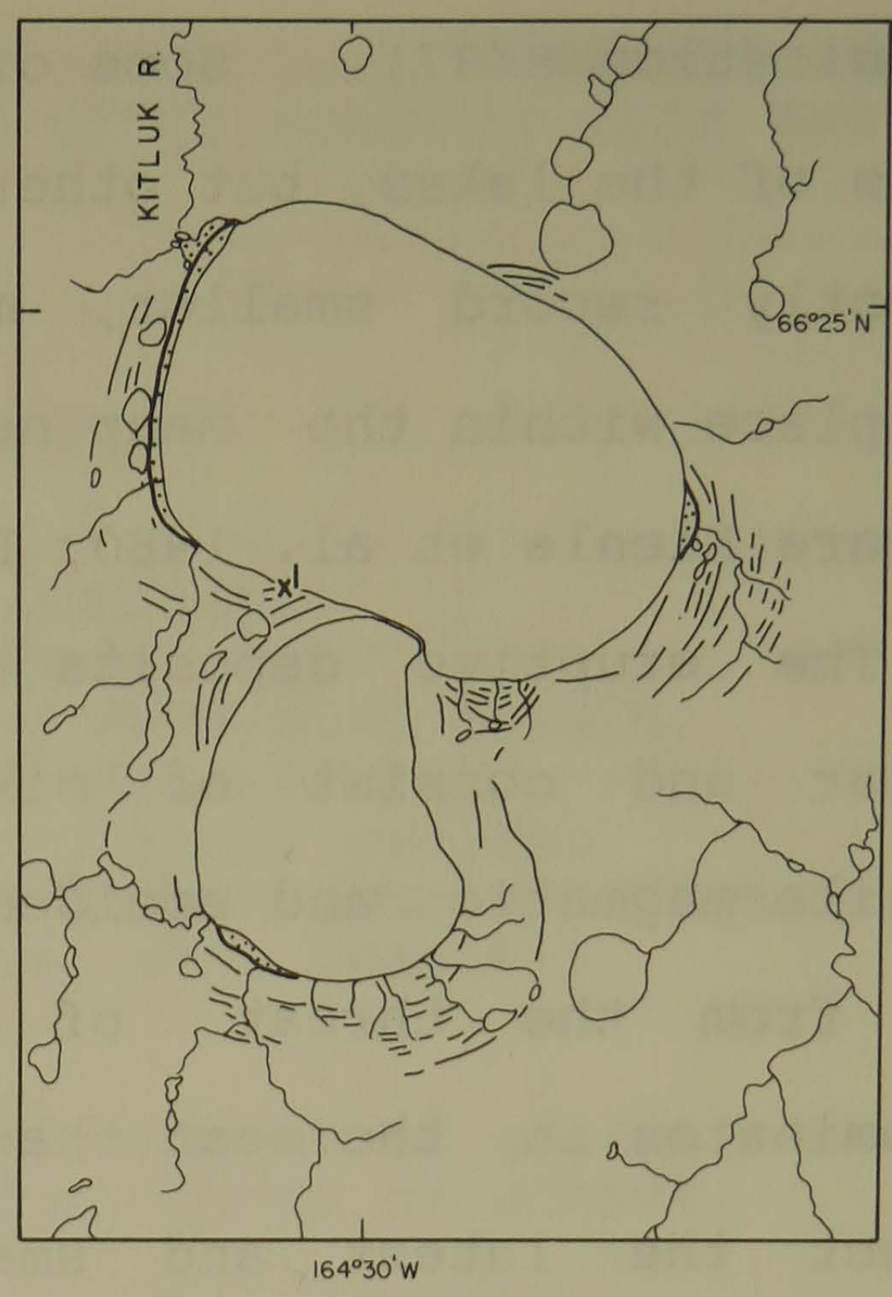
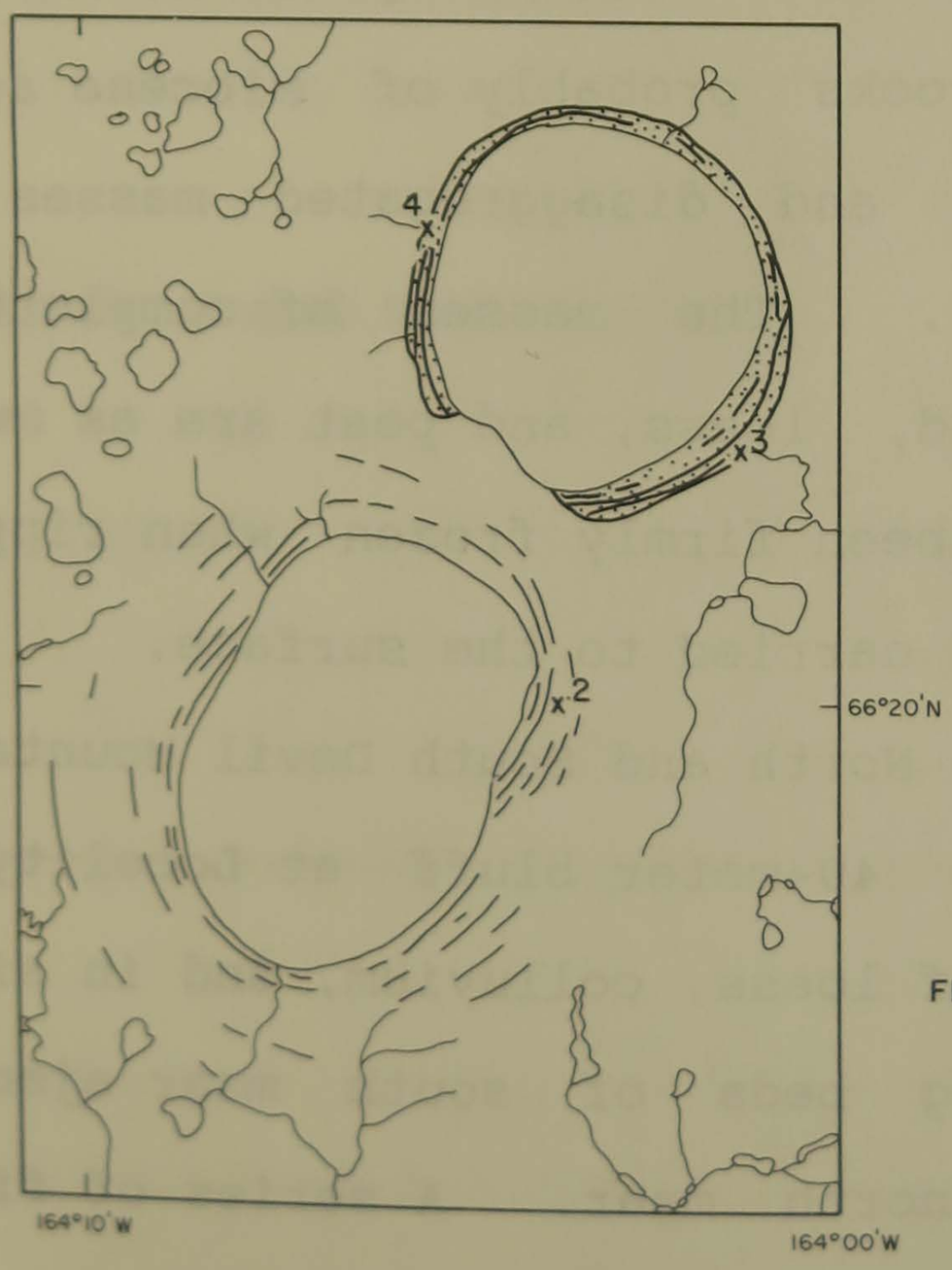


FIGURE 3b: Devil Mountain Lakes.

FIGURE 3c: North and South Killeak Lakes.



SCALE IN KILOMETERS

1 .5 0 1 2

KEY

- LAKE INFILLINGS, MOSTLY ICE-RAMPART COMPLEXES
- OUTLINES MAJOR SWALES BETWEEN ICE-RAMPART RIDGES
- DELINEATES A SCARP, VISIBLE ON AIR PHOTOS, SEPARATING HIGHER RIDGES OUTSIDE FROM LOWER RIDGES INSIDE ON WHITEFISH LAKE ICE-RAMPART COMPLEX
- RIDGE SWALE SYSTEMS
- x3 LOCALITIES MENTIONED IN TEXT

FIGURE 3a-c: Volcanic and post-volcanic features of the Espenberg maar lakes: (a) Whitefish Lake, (b) Devil Mtn. Lakes, (c) Killeak Lakes.

communication 8/87). Some of the ridges are concentric with the shores of the lakes, but others are much more sharply curved and evidently record smaller, more localized steam explosions that took place within the maar near the ends of the two eruptions (compare Kienle et al. 1980; Figure 7-3, top).

The eruptive deposits of the two Devil Lake maars are similar and consist of mixtures in various proportions of juvenile magmatic and accidental material representing fragments torn from the throat of the volcano. Juvenile tephra predominates in the most sharply curved tuff rings that probably reflect the latest and smallest explosions; elsewhere, the ejecta include an estimated 20 to 90 percent of accidental material. The accidental fragments include metamorphic rocks derived from the basement, volcanic rocks of probable Eocene age, unmetamorphosed sedimentary rocks probably of Miocene age, and blocks, rounded "boulders", and disaggregated masses of Quaternary sediments (Table 7-1). The masses of completely unconsolidated pebble gravel, sand, loess, and peat are as much as 0.2 meter across and must have been firmly frozen when ripped from the throat of the volcano and carried to the surface.

Age relationships between the North and South Devil Mountain Lake maars are established in the 40-meter bluff at Locality 1 (Figure 7-2), where 3.0 meters of loess, colluvium, and in situ peat overlie northwestward dipping beds of south maar ejecta and underlie tephra from the north maar. A series of five radiocarbon dates ranging from 11,610+/-350 to 9,350+/-350 BP

TABLE 7-1. CHARACTER OF JUVENILE AND ACCIDENTAL MATERIAL IN THE EJECTA OF NORTH AND SOUTH DEVIL MOUNTAIN LAKE AND SOUTH KILLEAK LAKE.

Probable Subsurface Source	Lithology
Juvenile magmatic material	Fine cinders. Welded scoria. Highly vesicular basalt. Glassy basalt. Frothy basalt pumice. Cored bombs (quartz sandstone coated with basalt).
Paleozoic basement	Angular chunks of quartz. Angular chunks of schist.
Eocene volcanic rocks	Porphyritic rhyolite. Fragments of basalt or andesite with inclusions of white pumice. Cemented quartz sandstone. Lithified siltstone. Compact clay. Ironstone concretions (up to 0.3 m in diameter). Lignite and lustrous coal. Petrified wood.
Pliocene and Pleistocene	Highly rounded quartz pebbles (seen only at Devil Mountain Lakes). Beds of soft sand. Shelly concretionary sandstone. Blocks and rounded "boulders" of completely unconsolidated pebbles gravel, medium sand, loess (wind-blown silt) and peat.

(W-2801 and W-2800) were obtained from organic samples collected in this sequence (Tables 7-2 and 7-3). These relationships show that the North Devil Mountain Lake maar erupted less than 9,300 years BP and that the South Devil Mountain Lake maar erupted more than 11,000 years BP (Figure 7-4).

The presence of abundant remains of dwarf birch in the colluvium that accumulated between eruptions and the general lack of a loess cover on tuff ridges adjoining North Devil Lake maar is consistent with these age assignments. Silt impregnating ejecta from the south lake and the presence of more than a meter of loess-like silt overlying this ejecta at Locality 1 suggest that the South Devil Lake maar eruption may be several thousand years older than the 11,600-year-BP limiting date provided by W-2801. North and South Devil Mountain Lakes are separated by a long, narrow spit concave toward South Devil Mountain Lake, suggesting at first glance that the South Devil Mountain Lake maar transects and is therefore younger than the North Devil Mountain maar. However, the spit was formed by wave action, perhaps amplified by ice shove, long after the lake basins were created by maar eruptions. Surface outline tells us nothing about the relative ages of the two lakes.

South Killeak Lake

The basin of South Killeak Lake has maximum and minimum diameters of 4.3 and 3.0 kilometers. Steep but vegetated slopes rise from the perimeter of the lake. Concentric ridges, swales,

TABLE 7-2. RADIOCARBON DATES MENTIONED IN THE TEXT.

Laboratory Number	Age (ybp)*	Quadrangle, Latitude, Longitude	Location, Hopkins field station	Reference
I-8293	1,655 +/- 220	Bend.C-3 65 38.7'N 163 10.1'W	Salix Bay, Imuruk Lake (74-31)	Kaufmann & Hopkins, 1985
W-3488	4,300 +/- 200	Kotz.B-6 66 21.6'N 164 42.5'W	Cutbank, small lake SW of Whitefish Lake (74-5,74-9)	"
AU-113	7,070 +/- 150	Kotz.B-5 66 16.3'N 164 01.4'W	Cutbank of Kiliwooligoruk Creek (74-28)	"
W-2800	9,350 +/- 350	Kotz.B-6 66 23.6'N 164 31.7'W	Southwest shore, N N.Devil Mt. Lake Lake (66-68,74-15)	"
W-2802	9,410 +/- 350	Kotz.B-6 66 23.6'N 164 31.7'W	"	"
W-3491	9,630 +/- 350	Kotz.B-6 66 23.6'N 164 31.7'W	"	"
W-2803	10,370 +/- 500	Kotz.B-6 66 23.6'N 164 31.7'W	"	"
W-2805	11,550 +/- 350	Kotz.C-5 66 30.7'N 164 01.6'W	Cutbank of Espenberg River (70-19)	"
W-2801	11,610 +/- 500	Kotz.B-6 66 23.6'N 164 31.7'W	Southwest shore, N. Devil Mt. Lake (66-68,74-15)	"
W-2806	14,490 +/- 400	Kotz.C-5 66 31.5'N 164 00.2'W	Cutbank of Espenberg River (70-32)	"
W-2880	16,950 +/- 500	Kotz.C-5 66 30.0'N 164 05.9'W	Cutbank of Espenberg River (70-17)	"

TABLE 7-2. RADIOCARBON DATES MENTIONED IN TEXT (continued)

Laboratory Number	Age (ybp)	Quadrangle, Latitude, Longitude	Location, Hopkins field station	Reference
BETA-18632	16,990 +/- 150	Kotz. A-5 66 11.3'N 164 21.0'W	Cutbank of Nugnugaluktuk River (86-37,86-41)	This report
W-3489	17,630 +/- 800	Kotz. B-6 66 21.6'N 164 42.5'W	Cutbank, small lake SW of Whitefish Lake (74-5, 74-9)	M. Rubin, written comm, 12/26/73
BETA-18549	17,910 +/- 150	Kotz. B-5 66 21.6'N 163 51.5'W	Mouth of Kiliwooligoruk Creek (86-46)	This report
BETA-18547	18,500 +/- 150	Kotz. A-5 66 11.3'N 164 21.0'W	Cutbank of Nugnugaluktuk River River (86-37,86-41)	This report
W-3492	19,600 +/-1000	Kotz.B-6 66 21.6'N 164 42.5'W	Small lake SW of Whitefish Lake (74-5, 74-9)	Kaufmann & Hopkins, 1985
AU-112	19,900 +/- 800	Kotz.B-6 66 21.6'N 164 42.5'W	Cutbank, small lake SW of Whitefish Lake (74-5, 74-9)	Kaufmann & Hopkins, 1985
W-2879	>27,000	Kotz.C-5 66 30.0'N 164 06.9'W	Cutbank of Espenberg River (70-17)	"
W-2884	>31,000	Kotz.C-5 66 31.5'N 164 00.2'W	Cutbank of Espenberg River (70-32)	"
W-2670	>42,000	Kotz.B-4 66 15.9'N 163 49.9'W	Mouth of Kougachuk Creek (70-44)	"

* Radiocarbon dates are uncalibrated: that is, they have not been corrected for temporal variations in the radiocarbon content of atmospheric CO2.

TABLE 7-3. MEASURED SECTION IN BLUFF AT SOUTHWEST SHORE OF NORTH DEVIL MOUNTAIN LAKE (LOCALITY 1, FIGURE 7-2).

Bed Thickness (m)	Sediment Character
	Surface.
< 1.0	Turf, peat, and colluvium.
10.0	Tephra from North Devil Mountain Lake maar.
0.2-0.5	Colluvium: crudely bedded silty gravel containing many twigs of dwarf birch (R.C.Koeppen, Forest Products Lab, written communication 10/8/74). Radiocarbon sample W-2800, 9,350+/-350 years BP, collected in 1/2-cm peaty layer near top.
0.5-0.6	Platey fibrous peat, silt laminae in upper part. Large willow leaves, some twigs. Fills former swale. Radiocarbon sample W-2802, 9,410+/-350 years BP, collected near top; W-3491, 9,630+/-350, collected 5 cm below top.
0.2	Thin and lensy bedded silt and peat.
0.3	Sedge peat.
1.2	Silt (redeposited loess?) containing peaty layers at 0.1, 0.2, and 0.9 m below top. Radiocarbon sample W-2803, 10,370+/-500 years BP, at 0.2 m; W2801, 11,610+/-500 years BP, at 0.9 m.
0.5	Basaltic scoria infiltrated with silt.
7.8	Covered interval.
Lake level	

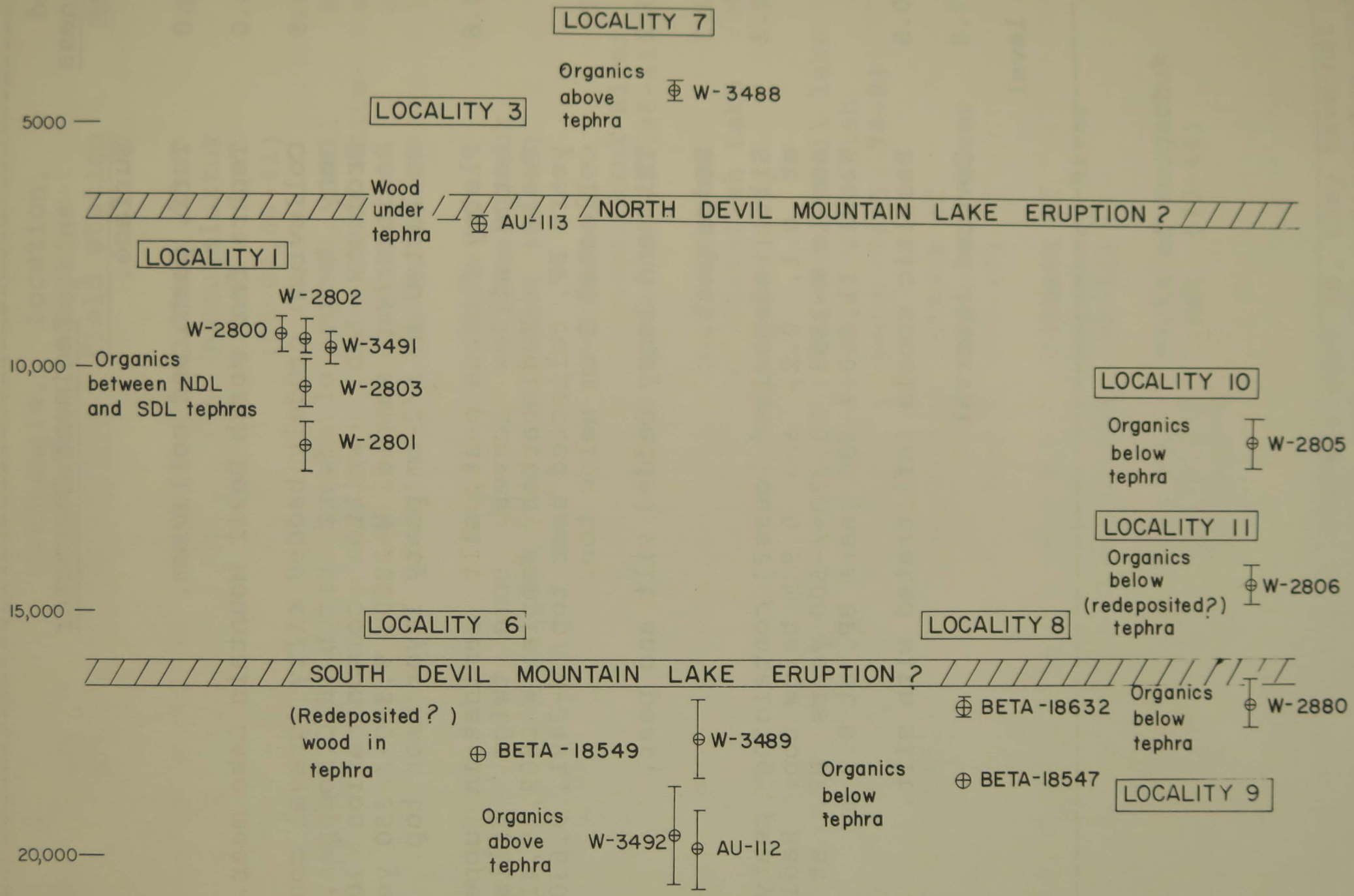


FIGURE 4: Diagrammatic sketch showing radiocarbon dates bearing on age of some of the Espenberg maar eruptions. Locality numbers located on Figure 2.

and gullies in a belt one or two kilometers wide delineate ridges that may represent ancient base-surge deposits. Beaches are narrow and on the west shore consist mostly of boulders. Welded scoria are exposed in a ledge on the east side of the lake; little or no exposed lava or ejecta can be found else where on the basin slopes. However a gully 50 meters deep entering the east shore of the lake (Locality 2, Figures 7-2 and 7-3) exposes ejecta generally similar to ejecta from the Devil Mountain Lake maars. Scattered quartz pebbles are larger and less rounded than the redeposited beach pebbles in the Devil Mountain Lake ejecta.

North Killeak Lake

The original basin of North Killeak Lake is nearly circular and has a diameter of 3.2 kilometers. Two short, faint swales are the only traces of base-surge rings to be seen around the perimeter of the North Killeak Lake maar (Figure 7-3c). The lake shore is separated in most places from relatively gentle basin slopes by a belt of ice-rampart ridges ranging from 120 to more than 500 meters wide. The ice rampart ridges are readily distinguished from concentric rings ascribed to base surges. Concentric rings ascribed to base surges lie entirely outside the original crater walls and are generally much wider and have much more relief than do the ice rampart ridges. Steep slopes along the south shore expose ledges of welded tuff-breccia and compact black, pisolitic accretionary lapilli (clear indications of wet tephra; J.Kienle, written communication 8/87). Loess is

exposed in frost-scars at the crest of the slope.

The ice rampart ridges are mostly composed of coarse, sand-sized brown scoria mixed with small quantities of black, pumiceous basalt pebbles. A scattering of very well rounded quartz pebbles up to one centimeter across is also present. A single pebble of concretionary sandstone containing small marine mollusk shells was found. The material making up the ridges is thus similar to ejecta of the Devil Mountain maars and less similar to ejecta from South Killeak Lake. No loess cover is present, confirming that the ice-rampart ridges are younger than the loess-mantled volcanic deposits exposed at the south rim of the maar.

On June 26, 1974, we watched a large raft of wind-driven candled ice shove gravelly tephra atop the shorefront ridge in front of our camp on the west side of North Killeak Lake. The shorefront ridge there rises an abrupt 1.8 meters from the lake surface. Older ridges are higher, and the oldest stands nine meters above the 1974 lake level. Ridges are spaced 100 to 150 meters, crest to crest. The ice-rampart complex along the southwest shore is wider but lower. The active ridge consists of chunks of peat and rolls of turf standing less than a meter above 1974 lake level; it is backed by a 50-meter belt of marsh at lake level and then by slightly higher gravel ridges rising to about 4.5 meters at the inner edge of the complex. The differences between profiles across the ice-rampart complexes at the west and southeast shores (Figure 7-3) suggests that North

Killeak Lake may have undergone several meters of recent southeastward tilting.

The material comprising the ice-rampart ridges is indeed much younger than the eruption that formed the North Killeak Lake maar, having been deposited in a pre-existing lake beginning shortly after 7,100 years BP. The deposits are dated by small-tree-sized birch wood recovered beneath gravel comprising ice-rampart ridges in the banks of Killiwooligoruk Creek at the point where the stream leaves the lake basin (Locality 4, Figure 7-2 and Table 7-4). The presence in beach-ridge sediments elsewhere of small rounded quartz pebbles and a concretion containing mollusk shells suggests that the ejecta comprising the beaches originated in one of the Devil Mountain Lake maars.

Whitefish Lake

Whitefish Lake, which I have seen only once from a float-plane window, is the shallowest and most subdued of the Espenberg maars. Basin walls are low and deeply dissected (Figure 7-3a). An extensive, integrated drainage enters the lake, incorporating streams as much as six kilometers long. The lake once had maximum and minimum diameters of 4.3 and 3.8 kilometers, but a crescent-shaped ice-rampart plain reaching a maximum width of 900 meters occupies about a quarter of the original basin.

None of the interior slopes are steep enough to expose the ejecta of which the maar walls must be composed. A series of swales to the north and west of the lake and a low bluff

TABLE 7-4. MEASURED SECTION ON KILIWOOLIGORUK CREEK AT EDGE OF NORTH KILLEAK LAKE BASIN (LOCALITY 3, FIGURE 7-2).

Bed Thickness	Sediment Character
	Surface.
4.8 m	Gravelly sand (ice-rampart deposit).
1.0 m	Large wood in frozen mud. Stems of willow and alder (Virginia Page, Stanford Univ., oral comminication 9/23/74; R.C.Koeppen, Forest Products Laboratory, written communication 10/8/74); radiocarbon sample AU-113, 7070+/-150 years BP, from this level.
1.0 m	Beach gravel.
	Stream level

northeast of the lake evidently delineate the faint traces of concentric base-surge rings. The shallow depth of the lake, the extensive ice-rampart complex, and the deep dissection of original walls suggest that Whitefish Lake is by far the oldest of the maars.

Age of the Espenberg Maars

Morphological Evidence

If we assume that the maars were generally similar in initial form, that each originally displayed base-surge rings, that initial wall steepnesses were about equal, and that dissection of the walls has been progressive, then the maars can be divided into age classes on the basis of morphology. It seems clear that the two Devil Mountain Lake maars are youngest; radiocarbon dates and stratigraphy show that the North Lake is the younger of the two. The Killeak Lake maars appear to be considerably older, and morphological differences suggest that North Killeak Lake maar is much the older of the two. Whitefish Lake seems to be still older.

Arrangement of the maars in order of diminishing water depth suggests the same age order. However, the very late age of the ice-rampart ridges that occupy much of the North Killeak Lake basin suggests that infilling of lake basins may have been mainly a function of position and wind direction during later maar eruptions.

The explosive eruptions that produced the maars resulted in

tephra falls that buried the vegetation of the time. In drainage basins near an erupting maar, thick airfall tephra evidently was swiftly stripped from slopes, overloading the trunk streams and causing rapid aggradation. In places, vegetation on flood plain and lower valley slopes was buried by the aggrading streams; in other places, above-ground vegetation was stripped away, but networks of woody roots were buried and preserved. All of these situations provide excellent dating opportunities. In situ peat layers lying some distance stratigraphically below or above an airfall or alluvial tephra layer also provide limiting dates, but these may have been deposited several thousand years earlier or later than the eruption responsible for the tephra fall.

The tephra comprising the ice-rampart complex surrounding North Killeak Lake appears to have been deposited during the nearby eruption that produced the North Devil Mountain Lake maar, and rooted wood buried beneath the oldest part of the complex probably dates the North Devil Mountain lake eruption. A similar dating situation may exist at Whitefish Lake.

Detrital wood and peat in alluvium and lake deposits are untrustworthy dating materials, because buried organic material can be preserved in the arctic and subarctic for tens of thousands of years. These materials are readily redeposited in younger Quaternary sediments (Nelson and Carter in press). Consequently, detrital organics found below, within, or above a tephra may be far older than the material in which they are incorporated, and dating them may lead to quite misleading

conclusions concerning of the age of the eruption that produced the tephra.

Ancient thaw lake deposits in the Cape Espenberg-Devil Mountain area include beds of tephra. Although attempts have been made to date these beds, problems of redeposition discussed below cast grave doubt upon their significance as a basis for dating the maar eruptions.

Tephra in Aeolian Sequences

Radiocarbon dates have been obtained on organic litter associated with tephra falls in exposures on the banks of a lake southeast of Whitefish Lake and on the bank of the Nugnugaluktuk River. These two tephras are of about the same age and most likely reflect the same eruption. Tephra probably of the same age was also seen in at least one other exposure along the upper Nugnugaluktuk River and in exposures on the banks of two thaw lakes near the Kitluk River. The thick tephra in the high and actively caving northwest bank of an active thaw lake one kilometer southeast of Whitefish Lake (Locality 7, Figure 7-2 and Table 7-5) provides the well-dated record of a maar eruption somewhere in the Devil Mountain-Cape Espenberg area. The tephra occurs as sharply defined graded beds that evidently reflect repeated volcanic explosions at the source vent. Two radiocarbon-dated samples collected from a turf layer buried by the tephra yielded radiocarbon ages of 19,900+/-800 (AU-112) and 17,630+/-800 (W-3492) years BP while a very small sample of roots

TABLE 7-5. COMPOSITE SECTION ALONG ABOUT 100 METERS OF NORTHEAST END OF THAW LAKE, ONE KILOMETER SOUTHWEST OF WHITEFISH LAKE (LOCALITY 7, FIGURE 7-2).

Bed Thickness (m)	Sediment Character
	Surface.
0.80	Fibrous peat.
0.15	Peaty, cross-bedded fine aeolian sand.
0.01	Tephra. A few plant stems and peaty streaks at base.
0.10	Loess-like silt, yellow and olive.
0.02	Tephra, banded black and white, lensy 2-mm beds.
0.90	Loess-like silt, brown. A few plant stems and peaty streaks at top, immediately beneath overlying tephra. Radiocarbon sample W-3488, 4,300+/- 200 yrs.BP, from this level ("Unable to avoid some contamination. I got small amounts of <next higher loess> in sample, less than 10%, more than 1%.", Hopkins, field notes 6/25/74).
0.50	Interbedded quartz sand, pumice, and silt, probably product of aeolian redistribution of older sediments. No buried organic layer at base.
1.00	Loess-like silt, dark grey, many roots. Radiocarbon sample W-3492, 19,600+/-1,000 yrs.BP, is based on a very small sample representing a 500-micron sieve concentrate from lower 20 cm of this unit. Sieve concentrate was largely coarse pumice and small concretions.
0.20	Laminated pumice and fine, white quartz sand: aeolian reworking of pumice surface?
1.60-2.00	Bedded tephra, individual beds grade from sandy pumice to silt-sized material.
0.05-0.10	Buried turf, undulating surface with rooted twigs, in places continuous mat of 5-cm grass tufts. Radiocarbon-dated samples W-3489, 17,630+/-800 yrs.BP, and AU-112, 19,900+/-800 ybp, are from this level.
1.40-2.60	Loess, brown, root-bound and oxidized in upper few cm. Contains a buried ice-wedge 1.5 m wide which appears to top at base of overlying tephra.
Lake level	

sieved from loess-like silt 20 to 40 centimeters above the tephra yielded a radiocarbon date of 19,600+/-1,000 years BP. The tephra evidently records an eruption that took place less than 19,000 and perhaps less than 17,000 years BP.

The tephra overlies loess or redeposited loess and thus must be younger than the maar that produced Whitefish Lake, since the exposure lies on the flanks of the Whitefish Lake maar. Overlying the tephra is a 2.7 meter sequence consisting of layers of silt alternating with interbedded pumice, sand-sized tephra, and quartz sand. Radiocarbon sample W-3488, collected within about 0.3 centimeter of the top of this sequence, yielded an age of 4,300+/-200 years BP (W-3488). The sediments above the tephra bed probably consist of aeolian and colluvial sediments, the latter being derived from the slopes of the Whitefish Lake maar.

The same eruption seems to be recorded by a dated tephra exposed on the north bank of the Nugnugaluktuk River at the neck of a cut-off meander about 0.4 kilometer upstream from the mouth of the first right tributary above the Lane River (Locality 8, Figure 7-1 and Table 7-6). The tephra layer is underlain by loess-like silt and overlain by cross-bedded aeolian sand. The tephra is bedded; possibly the bedding represents the products of separate explosions as do the thick beds in the tephra at Locality 7. However, the tephra is underlain in places by a lamina of white quartz sand a few millimeters thick which shows flame structures indicating that the tephra was deposited when

TABLE 7-6. COMPOSITE MEASURED SECTION AT NUGNUGALUKTUK RIVER CUT-OFF SITE (LOCALITY 8, FIGURE 7-2; EXPOSURE WAS EXCAVATED ACROSS A WIDTH OF ABOUT 15 METERS).

Bed Thickness (m)	Sediment Character
	Top: slope (7 degrees) rising to 30 m above river level.
0.50	Loess-like silt.
1.50+	Aeolian fine and medium sand, greyish brown, northward dips of about 15 degrees in upper 0.45 m, thin and horizontally bedded in lower 1.05 m.
0.15-0.30	Black, tephra-rich sand, thin-bedded; locally at base, a 3-5 mm zone of white, more quartz-rich sand, and there, small flame structures involving basal white sand diapirically intrude overlying black sand, suggesting white sand was saturated at time of deposition of the black, tephra-rich sand. Layer is deformed and tilted in parts of the exposure.
0.01-0.30	Discontinuous peat layer; in places, a buried turf composed of grass-like tufts and stems underlain by root-bound silt; where overlain by white sand, however, consists of discontinuous clots or lenses of peat and roots are lacking in underlying silt. Radiocarbon sample Beta # 18632, 16,990+/-150 ybp, from this level.
0.45+	Massive, loess-like silt containing at least one 1-cm clot of peat in upper 30 cm and two dish-shaped peat lenses 5 mm thick and 40 cm long, 30 cm below top. Small, fossil root hairs extend downward from peat layers, which also include small twigs, grass-like fragments, and pellets of microtine rodent dung. Radiocarbon sample Beta # 18547, 18,500+/-150 ybp, from this level.
0.01-0.04	Discontinuous line of peat clots.
0.30	Silt with isolated 1-cm clots of peat.
<0.01	Two dish-shaped peat lenses 5 mm thick and 40 cm long. Small, fossil root hairs extend downward from peat layers, which also include small twigs, tiny grass-like fragments, and microtine dung.
1.9	Covered.
River level	

the sand was wet and that the sand then rose diapirically into the tephra. An underlying thin turf in places is undisturbed but in other places where the sand is present, it is discontinuous and possibly was scoured or eroded during the deposition of the sand. These relationships indicate that the tephra layer may have been slightly redistributed by running water. However, the preservation in places of rooted vegetation beneath the tephra layer suggests that the radiocarbon date of 16,990 +/-150 years BP (Beta #18632; Table 7-6) is a very close limiting date for the tephra fall.

Tephra in Alluvial Sequences

Radiocarbon dates have been obtained for organic materials associated with waterlaid tephra exposed at the mouths of Kougachuk and Kiliwooligoruk Creeks. Buried root complexes, as yet undated, are also exposed beneath waterlaid tephra near the mouth of the Kitluk River. Undated tephra layers a few centimeters thick occur interbedded in alluvium in terraces of the Nugnugaluktuk and Cowpack Rivers. The valley of Singeakpuk Creek which drains Whitefish Lake has not yet been examined.

Definitive evidence for the age of the South Killeak Lake maar eruption is provided by rooted organics collected beneath thick, coarse, waterlaid tephra deposited by a torrential stream. These beds are exposed in bluffs that extend about one kilometer northward from the mouth of Kougachuk Creek (Locality 5, Figure 7-2 and Table 7-7). Near the present mouth of

TABLE 7-7. COMPOSITE MEASURED SECTION OF DISCONTINUOUS EXPOSURES EXTENDING ONE KILOMETER NORTH FROM MOUTH OF KOUGACHUK CREEK (LOCALITY 5, FIGURE 7-2).

Bed Thickness (m)	Sediment Character
	Surface.
0.3-0.60	Peat and turf.
0.0-1.2	Loess-like silt.
2.0-3.2	Sandy, silty and pisolitic tephra, thin bedded to laminated. At some levels displays antidunes and trough cross-bedding, indicating torrenial flow. No detrital wood. Base scoured a few cm into underlying deposits.
0.0-0.5	Buried turf. Radiocarbon-dated sample W-2670, >42,000 years BP, from this level.
0.6+	Sticky, pale greenish-yellow gleyed silt occasional blocks of dark organic silt. Large ice wedges and smaller ice-wedge pseudomorphs lie within this unit.
	Sea level

Kougachuk Creek, the ancient stream that deposited the tephra locally scoured away surface vegetation and excavated into underlying loess immediately before the alluvial tephra was deposited. In other places, the water-laid tephra buried and preserved plant remains representing floodplain meadow vegetation--a moss mat, rooted grass straw, still-green grass stems with fruiting heads, and gnarled, rooted and branched willow shrubs. A few berries and insect remains are also preserved.

An exposure about one kilometer north of Kougachuk Creek seen in 1968 and 1970 records vegetation on the ancient valley slope, also preserved beneath the flood of waterlaid tephra. Beneath the tephra, features resembling cross-sections through the tussock-birch-heath polygons of Hopkins and Sigafoos (1951) were seen. These consisted of dwarf birch (Betula nana) and prostrate willow shrubs of two species in full leaf, rooted in a fossil turf of variable thickness. Beneath the turf lay a 15-centimeter layer of olive silt containing cryoturbated peaty bands, partitioned at regular intervals by vertical zones of fibrous peat. The zone of silt and cryoturbated peat represents an ancient active (seasonally thawed) layer, now perennially frozen, and underlain by the flat top of an enormous buried ice wedge 4.5 meters across. The peat beneath the waterlaid tephra yielded a radiocarbon date of more than 42,000 years BP (W-2670).

The deposits north of the mouth of Kougachuk Creek are

interpreted as representing water-laid tephra that quickly filled the valley of Kougachuk Creek to a depth of five meters or more following a maar eruption very near the drainage basin. The probable source is the South Killeak maar, now drained by Kougachuk Creek. The floodwaters scoured the floodplain in places and buried and preserved vegetation beneath alluvial tephra in others. As the deposit thickened, mesic tussock-birch-heath tundra on the north valley wall nearly five meters above the floodplain was buried. The eruption and flood evidently took place in mid-summer, because willows and dwarf birch were in full leaf, the grass had fruiting heads, and some berries were present.

Seasonal thawing produces an active layer about 75 centimeters thick in contemporary tussock-birch-heath vegetation in the area of the Bering Land Bridge Preserve (Hopkins and Sigafoos 1951). The 55-centimeter thickness of the ancient active layer and the large size of what was then an active ice wedge indicates that the waterlaid tephra at the mouth of Kougachuk Creek was deposited during an interval when summers were shorter than at present. The abundance of birch, however, suggests a vegetation more mesic than the steppe-tundra that existed 12,000 to 25,000 years ago (Ager 1982; Ritchie and Cwynar 1982) during the cold, dry Duvanny Yar interval (Hopkins 1982). Instead, the buried vegetation at Kougachuk Creek suggests an intermediate climatic regime such as that which prevailed between 65,000 to 25,000 years ago during the

Boutellier interval of Hopkins (1982). The waterlaid tephra at the mouth of Kougachuk Creek lies seaward of the probable inner limit of Pelukian (last interglacial) transgression, indicated by a steepening of the topography about four kilometers further inland, and it lies stratigraphically above Pelukian marine sediments exposed in coastal bluffs five kilometers to the south. These relationships indicate that the eruption of the North Killeak Lake maar took place more than 42,000 years ago but more recently than the peak of the last interglacial interval, 125,000 years BP.

An excellent exposure of water-laid tephra, unfortunately of much more dubious geochronological significance, was seen in 1986 at the mouth of Kiliwooligoruk Creek, the stream which drains North Killeak Lake (Locality 6, Figure 7-2). Rapid coastal retreat during the sixteen years since my previous visit had resulted in the exposure of a section (Table 7-8) through a 5.5-meter hillock that is evidently an open-system pingo. Exposed in the pingo is a northward-dipping alluvial sequence more than four meters thick composed of basaltic tephra but containing, surprisingly, a scattering of detrital twigs. On the lower, southern flanks of the dissected pingo, the tephra-rich alluvium disappears, and discontinuous exposures show slightly uplifted Holocene thaw lake sediments consisting of peat and peaty silt. The thaw-lake sediments could be traced into undisturbed low bluffs a few tens of meters further south. Unfortunately, limited exposures and limited time left the relationship between

TABLE 7-8. MEASURED SECTION IN EXPOSURE IN DISSECTED PINGO AT THE MOUTH OF KILIWOOLIGORUK CREEK (LOCALITY 6, FIGURE 7-2).

Bed Thickness (m)	Sediment Character
	Surface.
0.26	Turf and peat, roots of modern vegetation.
0.50	Bedded silt, sandy silt, and peaty silt oxidized to form color B horizon in upper part.
4.20	Fine and coarse basaltic sand containing scattered detrital twigs; thin and slightly wavey bedded. Beds dip five or six degrees northward, parallel to the sloping surface. Interpreted as tephra-rich alluvium uplifted by development of pingo. Beta # 18549, 17,910+/-150 years BP, from detrital twigs from this unit.
0.20	Brown silt.
	Rear of low beach

the alluvium and the Holocene peat uncertain.

Twigs in the water-laid tephra were collected and submitted for radiocarbon dating on the assumption that they would date the eruption of the North Killeak Lake maar. The twigs yielded an age of 17,910+/-150 years BP (Beta #18549). Two alternate interpretations suggest themselves: (1) the alluvial tephra at the mouth of Kiliwooligoruk Creek may be dated by the included wood and may record an eruption of the North Killeak maar about 18,000 years BP; or (2) the alluvial tephra may have been deposited after large quantities of tephra were dumped in North Killeak Lake (and no doubt also in the stream valley) about 7,100 years BP, and the 18,000-year old wood may have been incorporated in the alluvial tephra from older deposits eroded from the valley walls.

There is clear evidence that a maar eruption took place about 18,000 years ago somewhere in the Devil Mountain-Cape Espenberg area. Morphology, however, suggests that the North Killeak Lakes maar is far older than 18,000 years. Although one might postulate that the initial morphology of the North Killeak Lake maar has been obscured by thick tephra ejected during the North Devil Mountain Lake eruption, it seems much more likely that the radiocarbon-dated wood in the alluvial tephra at the mouth of Kiliwooligoruk Creek is redeposited. In view of the lack of a loess cover, the alluvial tephra is probably of Holocene age and of the same age as the oldest ice-rampart deposits in the North Killeak Lake basin.

Tephra in Thaw-lake Deposits

Much of the Devil Mountain-Cape Espenberg area has been occupied by thaw lakes at one time or another during the past 100,000 years. The deposits of ancient thaw lakes are extensively exposed in the coastal bluffs and river valleys of the area. A thaw lake expands by thawing, collapse, and erosion of its banks, producing sediment that is then redeposited in the lake. Gravel, sand, mammal bones, and other coarse debris are deposited in the nearshore zone of strong currents. Uprooted shrubs, chunks of peat, and other coarse organic debris drift down-wind, eventually become waterlogged, and are then incorporated in nearshore sediments of leeward shores. Fossil organic detritus derived from sediments in the banks may also be incorporated in the coarse near-shore sediments. Silt, clay, and fine organic detritrus are carried away in suspension and eventually settle in more central parts of the basin.

Exposed sections through the basin of an ancient thaw lake typically display a basal zone 30 or 40 centimeters thick of sandy sediment, often ripple bedded, and commonly containing large and abundant masses of coarse organic debris. Because it is oldest at the point of origin (usually near the center) and becomes progressively younger as the former margin of the lake basin is approached, the organic-rich, coarse layer may be termed "the basal transgressive layer". The basal transgressive layer is generally overlain by thin-bedded fine sand, mud, organic mud, or fine detrital peat ranging from one to five meters in total

thickness.

Peaty silt and detrital peat predominate in sediments of thaw lakes that existed less than 12,000 years ago, while older thaw-lake deposits in the Cape Espenberg-Devil Mountain region consist mostly of bedded silt and fine sand containing little or no detrital organic material except in the basal transgresive layer.

The older lake deposits evidently date from a time when the entire landscape was aggrading as a consequence of deposition of wind-blown silt and sand blown from the dry floor of Kotzebue Sound and the Chukchi Sea and from the large glacial-outwash streams that crossed the dry sea floor. Ice wedges formed in the accumulating aeolian sediment, but from time to time the cycle was disrupted by development of thaw lakes which destroyed the ice wedges. This complex of aeolian and permafrost processes permitted the repeated development and subsequent filling of thaw-lake basins. Exposures in coastal and river bluffs commonly show as many as three superposed sequences of thaw-lake deposits.

During field studies prior to 1987 and while writing an initial draft of this paper, I assumed that detrital peat underlying and overlying concentrations of tephra in thaw lake deposits would provide close limiting dates for maar eruptions. Dates out of stratigraphic sequence and considerable dispersal in the radiocarbon dates cast doubt on this optimistic assumption, and then Janet Kidd and I observed large quantities

of tephra being reworked into modern thaw lakes from ancient deposits on their banks. We also observed thick beds of redeposited tephra in exposed cross-sections of deposits filling the drained basins of former lakes of Holocene age, in positions where the tephra was clearly redeposited from older airfall tephra deposits interbedded in nearby loess deposits. Thus, at present it seems nearly impossible to distinguish primary from redeposited tephra in thaw-lake deposits. Nevertheless, radiocarbon samples have been collected from exposures of Pleistocene and Holocene lake sediments, partly to elucidate the history of thaw lake development and partly in the unfounded expectation that information bearing on the age of maar eruptions could be obtained. The most intensive dating effort was conducted in the Espenberg River valley in 1970. Steep bluff exposures there display two or three superposed sequences of thaw-lake deposits resting upon Pelukian (last interglacial) beach sand or on aeolian sand that probably represents ancient back-beach dunes of Pelukian age.

Tephra beds appear at various levels in several of these exposures. Organic samples that were expected to limit the age or ages of the tephra beds were obtained in measured sections at Localities 9, 10, and 11 (Figure 7-1).

At Locality 9 (Table 7-9), a tephra layer appears in thaw-lake sediments 4.6 meters above twiggy detrital peat comprising a basal transgressive layer from which a radiocarbon date of 16,950+/-500 years BP (W-2880) was obtained. A second

TABLE 7-9. SECTION IN VALLEY OF ESPENBERG RIVER AT HOPKINS STATION 70-17 (LOCALITY 9, FIGURE 7-2).

Bed Thickness (m)	Sediment Character
	Surface.
0.70	Massive silt.
1.10	Interbedded silt, dark sandy tephra, and "white sandy pumice" (quartz sand?).
0.05	Basaltic tephra underlain by thin "white ash" (quartz sand?).
0.90	Thin-bedded silt, mottled brown.
0.45	Interbedded detrital peat and sand, ripple bedded.
3.05	Thin-bedded fine silt, some sand, a few thin detrital peat laminae; rare fresh-water mollusk shells. Radiocarbon sample W-2879, >27,000 yrs.BP from organics screened from lower 0.75 m of this unit.
0.22	Peaty silt.
0.10	Detrital peat, clots of peat up to 7 cm long: base of thaw-lake sequence. Radiocarbon samples W-2880, 16,950+/- 500 years BP, from this unit.
2.65	Medium and fine sand, cross-bedded, yellow and medium gray with orange mottled areas: interpreted as ancient back-beach dune sand.
0.30	Interbedded olive silt and fine sand, thin-bedded; contains small concretions, rare twigs and marine shell fragments; 1-cm peat lens at top contains stem bases of sedge(?) and some leaves: interpreted as lagoonal marsh deposit of Pelukian age.
0.30	Black, greasy clay with thin sand beds; bits of wood, pumice fragments, rare marine mollusk shell fragments: Pelukian lagoonal mud.
0.15	Medium sand, dark grey, well sorted: Pelukian beach sand.
	River level

radiocarbon date of >27,000 years BP (W-2879) on a very small sample screened from ripple-bedded silt above the basal transgressive layer, evidently consists of redeposited material. The tephra layer at Locality 9 is underlain by a lamina described as "white ash" (Hopkins, field notes 7/12/70) which possibly may be white quartz sand similar to that at the Nugnugaluktuk cut-off site (Locality 7. Figure 7-2).

At Locality 10 (Table 7-10), a one-centimeter tephra layer appears in an undated sequence of thaw-lake sediments older than the basal transgressive layer of a "birch-interval" thaw lake from which a radiocarbon date of 11,550 +/- 350 years BP (W-2805) was obtained.

Finally, at Locality 11 (Table 7-11), redeposited tephra is distributed through about 70 centimeters of lacustrine sediment above a basal transgressive layer from which radiocarbon sample W-2806 (14,490 +/- 400 years BP) was collected. The large thickness of the interval through which the tephra is distributed suggests that it may represent redeposited material derived from an older airfall tephra that had been exposed in the banks of the ancient thaw lake. The basal transgressive layer from which radiocarbon sample W-2806 was collected also contains redeposited material, including tests of marine foraminifera and fragments of marine mollusk shells.

The possibilities of redeposition of both tephra and organic detritus in thaw lakes detract from the utility of thaw-lake sequences for dating maar eruptions. Thus, it is impossible at

TABLE 7-10. SECTION IN VALLEY OF ESPENBERG RIVER AT HOPKINS STATION 70-19 (LOCALITY 10, FIGURE 7-2).

Bed Thickness (m)	Sediment Character
	Surface.
0.30	Turf.
1.20	Peaty lake sediments, twigs up to 1 cm thick, abundant and varied fresh-water mollusks shells ("Birch period" thaw lake deposit). Radiocarbon sample W-2805, 11550 +/-350 years BP, from this level.
1.30	Silt, massive and yellowish in upper 0.3 m fading downward to only slightly oxidized light grey silt at base. Bedding grossly disturbed as result of thaw collapse during deposition of next higher thaw lake sediment sequence.
0.01	Basaltic tephra.
2.00	Silt, thin bedded, slightly oxidized, a few laminae of detrital peat, especially in in upper 0.65 m.
2.55	Silt, thin bedded, and laminae of yellow sand. Basal transgressive layer of late Pleistocene thaw lake deposit.
	Sharp contact.
1.00	Micaceous sandy silt, laminae of peat, strongly oxidized in upper 0.6 m. Bedding grossly disturbed as result of thaw-collapse during development of next higher thaw-lake sediment sequence.
0.21	Interbedded peaty silt and medium sand, clots of pure peat. Cross-bedded in basal 5 cm.
0.005	Fine silty detrital peat (base of oldest thaw-lake deposit).
1.20	Horizontally stratified medium to coarse sand, abundant marine mollusk shells (Pelukian beach sand).
River surface	

TABLE 7-11. SECTION IN VALLEY OF ESPENBERG RIVER AT HOPKINS STATION 70-32 (LOCALITY 11, FIGURE 7-2).

Bed Thickness (m)	Sediment Character
	Surface.
2.70	Covered.
0.70	Silt, olive and rusty brown, laminated; beds of dark tephra; a small twig, a few fresh-water mollusks recovered from this unit.
0.02	Detrital peat, base of a thaw-lake sequence. Radiocarbon sample W-2806, 14,490+/-400 years BP, is organics from this level.
	Sharp contact.
2.30	Silt, olive and rusty brown, thin-bedded, rare lenses of detrital peat, rare twigs, rare fresh-water mollusk shells; bedding disturbed in upper 0.45 m as result of thaw collapse during deposition of next higher thaw-lake sequence.
0.02	Detrital peat, base of a thaw lake sequence. Fresh-water mollusk shells common. A bird bone and a foraminifer test recovered from this unit. Radiocarbon sample W-2884, >31,000 years BP, organics in screen residue from this level.
1.40	Silt, mottled olive and rusty brown, no visible bedding, no organics.
2.30	Covered.
2.35	Interbedded, thin-bedded silt and lesser twiggy detrital peat in upper part grading down to twiggy detrital peat with interbeds of silt and sand and peat, rare small rounded quartz pebbles.
	Sharp contact.
2.10	Fine and medium sand, a few beds of redeposited tephra, a few marine mollusk shells: Pelukian beach deposits.
River level	

present to be certain whether the tephra layers exposed in the tephras exposed in thaw-lake deposits along the Espenberg River are the products of a single eruption more than 11,550 and less than 16,950 years BP or whether instead they represent one, two, or three different eruptions of uncertain age.

Tephra in Marine Deposits

Tephra is a minor constituent of Pelukian interglacial deposits exposed in the Espenberg River valley, in the Nugnugaluktuk River estuary, and in the coastal bluffs for several kilometers to the north of the mouth of the Nugnugaluktuk River estuary. The presence of ubiquitous tephra in these deposits indicates that tephra layers must have been present on the landscape that was eroded by the retreating Pelukian coastal cliff. Normal basaltic eruptions that produce cinder cones and small shield volcanoes such as those in the Devil Mountain-Cape Espenberg area are not very explosive and generally produce little tephra except in the immediate vicinity of the vent. The presence of ubiquitous tephra in the Pelukian beach deposits indicates, however, that tephra was already widely distributed on the landscape of the Devil Mountain-Cape Espenberg area prior to or during the last interglacial epoch. One or two of the Espenberg maars, certainly Whitefish Lake and possibly North Killeak Lake, must be older than the Pelukian transgression, thus older than 125,000 years.

Tephra layers are also present in Kotzebuan deposits on the

Baldwin Peninsula on the east shore of Kotzebue Sound (Figure 7-1). The Kotzebuan transgression is not yet well dated, but geochronological studies in progress by Julie Brigham-Grette and myself indicate that this transgression must have taken place at least 500,000 years ago. The source of the tephra in these deposits is unknown, but the only maars recognized within several hundred kilometers of the Baldwin Peninsula are those in the Devil Mountain-Cape Espenberg area.

Discussion and Recommendation

Because basalt vents of the type found in the Devil Mountain-Cape Espenberg area generally erupt only once, it would be surprising if any of the five known maars were responsible for more than one of the widespread tephra layers. A combination of morphological and geochronological evidence indicates that the most recent eruption in the Devil Mountain-Cape Espenberg region took place at North Devil Mountain Lake at some time between 9,300 and 7,100 years BP (Figure 7-4). The eruption is probably closely dated by the large 7,100-year-old woody stems preserved beneath tephra dumped in North Killeak Lake during an eruption at a neighboring maar.

The South Devil Mountain maar is undoubtedly the next older maar. Assuming that we can disregard radiocarbon dates limiting the ages of possibly redeposited tephra beds in lake sediments, it seems certain that the next earlier maar eruption took place in the Devil Mountain-Cape Espenberg area between about 18,000

and 16,000 years BP and that the South Devil Mountain Lake maar was the source.

The very fresh South Killeak Lake maar, with its numerous well-preserved concentric ridges and swales, is dated as older than 42,000 years BP by the buried peat at the mouth of Kougchuk Creek and as younger than 125,000 years, based on stratigraphic and geomorphic relationships to Pelukian deposits and geomorphic features. Because of its very subdued topography the North Killeak Lake maar appears to be far older. It is probably as old or older than the last interglacial, thus 125,000 years BP or older. Whitefish Lake, certainly the oldest maar, can hardly be younger than the last interglacial interval, 125,000 years BP, and may even be the source of tephra beds which date from at least 500,000 years BP in deposits of the Kotzebuan transgression on the Baldwin Peninsula.

Future field studies will probably add to knowledge of the age of the Espenberg maars. The basin of Whitefish Lake and the valleys of Singeakpuk Creek should be traversed and the Cowpack River should be revisited in hope of finding exposures that will provide more precise information on the age of and environmental conditions during the eruption of the Whitefish Lake maar. A helicopter survey of the valleys of the Kitluk River and Kougachuk and Kiliwooligoruk Creeks may turn up new exposures that will bear on the time and circumstances of the eruptions at the Killeak Lakes and at Devil Mountain Lake. The dissected pingo at the mouth of Kiliwooligoruk Creek should be revisited

as soon as possible in order to reassess the stratigraphic relationships of the deposits exposed there. This excellent exposure, seen in 1986, is most transient. In 1966, when I camped overnight on this pingo with the Goodhope family, it stood well back from the coast. The pingo will be completely destroyed by coastal erosion within a very few years.

Efforts to establish the age of the Espenberg maars have contributed to the dating of ancient aeolian activity in the Devil Mountain-Cape Espenberg region. The 18,000-year-old tephra layers exposed at the thaw lake near Whitefish lake and at the Nugnugaluktuk cut-off site (Localities 7 and 8, Figure 7-2) lie approximately at the boundary between older wind-blown silt and younger dune sand, showing that at least some of the vegetated dunes of the Devil Mountain-Cape Espenberg area were active during the height of the Duvanny Yar cold, dry interval of Hopkins (1982).

Each Espenberg maar eruption produced a tephra fall that blanketed an area of at least 1,000 square kilometers, burying a diversified landscape and a diverse vegetation cover. Although no systematic study has yet been undertaken of the plant fossils in the buried turf layers, differences emerge from even the most casual examination. The vegetation buried beneath tephra-rich alluvium at the mouth of Kougachuk Creek more than 42,000 years BP appears to differ from modern vegetation mainly in its lower stature, an observation that is consistent with the very shallow fossil active layer preserved beneath the buried turf. Buried

turf associated with the 18,000 year-old-tephra appears to consist of tufted short graminoids recording an upland vegetation quite unlike the mesic shrub tundra of the present day. The tufted graminoid matte preserved beneath the 18,000-year-old tephra may be an example of the vegetation responsible for the ubiquitous "herb zone" pollen spectra that dominate Beringian pollen sequences between 14,000 and 25,000 years old (Cwynar 1982; Ager 1982). The 7,100 year old buried tall-shrub thicket at the point where Kiliwooligoruk Creek leaves the North Killeak Lake basin contains the oldest macrofossils of alder known in the Kotzebue Sound area. These observations suggest that a thorough study of the plant remains preserved beneath tephra beds in the Devil Mountain-Cape Espenberg area will be richly rewarding.

Better geochronology and better characterization of individual tephra falls will make them more useful for correlations and for attempts at synoptic reconstruction of the vegetation at times of tephra falls. To refine the geochronology of the maar eruptions, one must focus upon places where rooted vegetation is preserved beneath a tephra fall or tephra-rich alluvium. An effort to characterize individual tephra falls should focus upon the presence or absence and form of phenocrysts and their mineralogy, form and index of refraction of glass shards, and major and trace element geochemistry.

If my age estimates of the ages of the maars are correct, some of the maar lakes should contain exceptionally long records

of lacustrine sedimentation, ranging from more than 42,000 years in South Killeak Lake to perhaps half a million years in Whitefish Lake. Pollen-coring efforts should be preceded by bathymetric and seismic-reflection-profiling surveys. Younger tephra beds, possibly of considerable thickness, and beds of wind-blown sand, are likely to be encountered; innovative pollen coring technologies will be required if these deposits are to be penetrated.

The eruptions that produced the Espenberg maars must have been remarkably large and violent. The exceptionally large dimensions of the craters and the unusually extensive tephra blankets are a testimony to explosions of great force! Another exceptional circumstance is the presence of a nearby stratigraphic test well, which permits an estimate of the depth, age, and stratigraphic sequence of accidental material comprising the ejecta of, at least, some of the maars. Sedimentologic, petrologic, and volcanologic study of the exposed deposits of the Devil Mountain Lake and South Killeak Lake maars can be expected to produce new insights that will contribute to the fundamental understanding of maar eruptions. For example:

1) Does the exceptional size of the maars indicate the presence of exceptionally large ground water reservoirs during the eruptions?

2) Lorenz (1986) postulates that steam explosions originate from progressively greater depths in the source vent as

ground-water is drawn down in the course of eruption. If this is true, then successively younger deposits in a single maar sequence should contain accidental material derived from successively greater depths. Is this true of the eruptive deposits of the Espenberg maars?

3) Did the presence of permafrost somehow play a role in the violence of the Espenberg maar eruptions?

4). What is the nature of the concentric ridges and swales? Although I have suggested that they may be dunes produced by base surges, their dimensions are far greater than base-surge dunes described by Fisher and Schminke (1974, p. 247-255). A careful study of the deposits making up the ridges should contribute to an understanding of their origin.

The extensive basaltic volcanos and lava flows of the Bering Land Bridge Preserve are a significant scientific resource, casting light on volcanic processes and on the tectonic events that surrounded the evolution of the Bering Land Bridge and later of Bering Strait. The Espenberg maars and their associated tephras deserve further study in order to elucidate the processes that produce these spectacular volcanic features. The vegetation covered by the tephra provides a vital record of the former landscape of the Bering Land Bridge Preserve, a record that can greatly enhance our understanding of the paleoecology of Beringia.

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