Geology of Pavlof Volcano and Vicinity Alaska

By GEORGE C. KENNEDY *and* HOWARD H. WALDRON

INVESTIGATIONS OF ALASKAN VOLCANOES

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PREFACE

In October 1945 the War Department (now Department of the Army) requested the Geological Survey to undertake a program of volcano investigations in the Aleutian Islands–Alaska Peninsula area. The first field studies, under general direction of G. D. Robinson, were begun as soon as weather permitted in the spring of 1946. The results of the first year's field, laboratory, and library work were assembled hastily as two administrative reports. Part of the data was published in 1950 in Geological Survey Bulletin 974–B, Volcanic activity in the Aleutian arc, by Robert R. Coats. The remainder of the data have been revised for publication in Bulletin 1028.

The geologic and geophysical investigations covered by this report were reconnaissance. The factual information presented is believed to be accurate, but many of the tentative interpretations and conclusions will be modified as the investigations continue and knowledge grows.

The investigations of 1946 were supported almost entirely by the Military Intelligence Division of the Office, Chief of Engineers, U. S. Army. The Geological Survey is indebted to the Office, Chief of Engineers for its early recognition of the value of geologic studies in the Aleutian region, which made this report possible, and for its continuing support.

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INVESTIGATIONS OF ALASKAN VOLCANOES

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By George C. Kennedy and Howard H. Waldron

ABSTRACT

An area of about 400 square miles near the end of the Alaska Peninsula and extending along the Pacific coast from Pavlof Bay to Cold Bay, was mapped geologically during the summer of 1946. The oldest rocks, consisting of arkose, are overlain by a thick sequence of fragmental volcanic deposits, principally tuff in the southwestern part of the area and agglomerate in the northeastern part. Diorite stocks cut the tuff and locally have altered it. Copper and gold occur in altered tuff beds adjacent to the diorite stocks. Some basalt plugs and andesite sills also cut the volcanic rocks. Both the bedded and the intrusive rocks are believed to be of Tertiary age. The igneous activity that produced these rocks was followed by a long period of erosion. Near the close of Tertiary time, volcanism was renewed. A series of basalt flows issued from vents along or near a great curving rift of northeast trend, and filled topographic depressions in the old erosion surface. Later, six large strato-volcanoes, accompanied by small cinder cones and associated lava flows, were built up along the rift. Pavlof, largest of these volcanoes, has been active frequently during historic time, its activity ranging from violent eruption of ash and lava to the quiet discharge of ash-laden steam.

INTRODUCTION

The smoke-plumed peak of Pavlof Volcano, 8,900 feet above sea level, forms an imposing landmark near the end of the Alaska Peninsula. The proximity of this active volcano and its satellites to Fort Randall, an Army base at Cold Bay, led to a geologic investigation of the area during the summer of 1946.

The investigation was undertaken during the period May 31 through September 1 by a party that was directed by George C. Kennedy, geologist, and included Howard H. Waldron, geologist, Russell C. McGregor, recorder, and Charles O. Haynes and Leroy T. Isaacson, camp assistants. The results of the work are presented in preliminary form in this report.

The volcanoes of the Pavlof area were probably first seen by white men shortly after the Bering Expedition of 1741, but their first mention is by Kotzebue, reporting on his search for a Northwest Passage in 1815–18 (Grewingk, 1850). Very little geologic investigation has been done in the area in the past, although the prominence and activity of Pavlof Volcano has been noted by many persons. The earliest geologic investigations of record are those by Constantin Grewingk (1850) in 1848. T. A. Jaggar [1] visited the area in 1927 while making a reconnaissance investigation of the Alaska Peninsula and the Aleutian Islands. He returned to the area during the summer of 1928 under the auspices of the National Geographic Society (Jaggar, 1929). Scientific results of his visits have not been published. C. P. McKinley (1929), who accompanied Jaggar in 1928, prepared a topographic map of the area extending from Port Moller on the east to Lenard Harbor on the west. S. R. Capps (1934) briefly examined some coastal parts of the area in 1932. B. R. Hubbard (1935) visited the area in 1934.

Acknowledgment is due Capt. John Weyant, commanding officer of Fort Randall, Capt. E. R. Hoover, ordnance officer of Fort Randall, the staff of the Pacific American Fisheries, Inc., at King Cove, Mr. Alex Dushkin, and the Rev. D. C. Hotovitsky for their cooperation and assistance.

GEOGRAPHY

LOCATION, SETTLEMENT, AND ACCESSIBILITY

The area mapped geologically during 1946, called the Pavlof area in this report, includes about 400 square miles near the tip of the Alaska Peninsula. It covers a strip as much as 15 miles wide along the Pacific Ocean and extends from Pavlof Bay on the east to within a few miles of Cold Bay on the west. Pavlof Volcano, which lies within the area, is about 35 air-line miles northeast of the Army airbase at Fort Randall, about 215 air-line miles northeast of Dutch Harbor, and about 390 air-line miles southwest of Kodiak (fig. 1).

Belkofski, a native village about 22 miles southwest of Pavlof Volcano, and King Cove, about 30 miles southwest of the volcano, are the only communities in the area. Supplies can be obtained at King Cove, the site of a large cannery, a post office, a school, and a general store. A short-wave radio station is operated by the cannery during the summer. Passenger-and-freight steamers deliver supplies to King Cove on their way to and from Bristol Bay and points north.

The Pavlof area is readily accessible only by boat. Good anchorages are found at Ivan Island near Chinaman Lagoon in Pavlof Bay, at Volcano Bay (locally known as Bear Bay), at Belkofski Bay, at King Cove, and at Lenard Harbor in Cold Bay. Many lagoons are accessible by small boats at high tide but are dry or nearly dry at low tide. There are no roads or man-made trails. Trappers' huts scattered throughout the area afford emergency lodging and protection from storms.

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[1] Jaggar, T. A., Scientific exploration of the Aleutian Islands: U. S. Geol. Survey unpublished report.

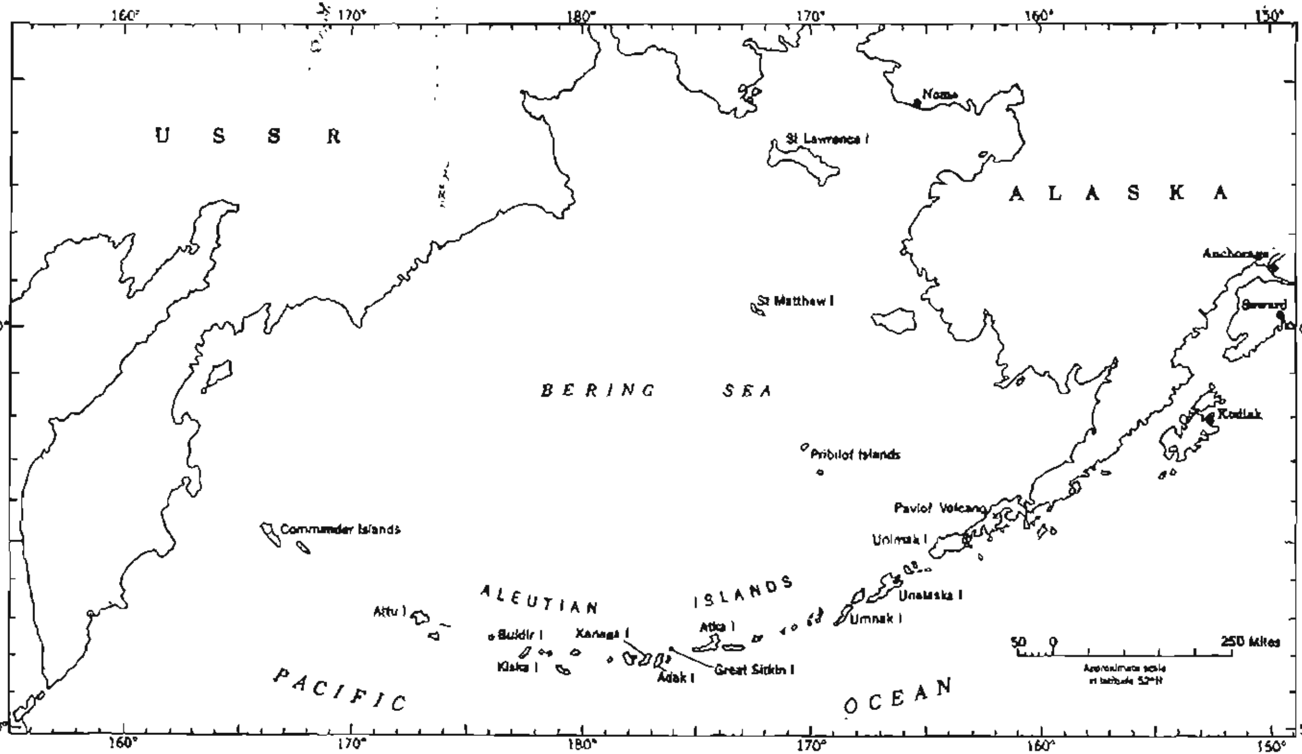


FIGURE 1.—Map of the Alaska Peninsula and Aleutian Islands.

TOPOGRAPHY

The Alaska Peninsula comprises three major physiographic divisions: a narrow lowland facing the Pacific Ocean; a broad, swampy lowland facing the Bering Sea; and the rugged Aleutian Range between. The Pavlof area embraces large segments of the Pacific Ocean lowland and of the Aleutian Range and a small inland segment of the Bering Sea lowland.

Between Cold Bay, at the western end of the area, and Volcano Bay the mountains rise abruptly from the ocean. Steep-walled fiordlike bays indent the rugged coastline, and only a few broad flat valleys breach the cliffs and steep slopes. At the foot of the cliffs are narrow boulder beaches and a few sea stacks. Bay deltas and midbay and bayhead bars are common in the narrow bays and coves. Reefs and offshore rocks, abundantly fringed with kelp, flank most of the headlands.

Northeastward from Volcano Bay is a narrow constructional plain that has been built up by coalescing alluvial fans and sheet floods; it broadens both northward and eastward from Volcano Bay and merges into the Bering Sea lowland at the head of Pavlof Bay. The rather smooth surface of the plain is interrupted by scattered, low, rolling hills. The plain is bordered on the southeast by narrow, steep beaches of black volcanic sand. Barrier beaches enclose large lagoons at the mouths of most of the lowland streams. Much of the seaward part of the lowland is a maze of streams, swamps, marshes, and stagnant lakes. Grass, tundra vegetation, and in some places clumps of alders and willows cover most of the higher landward part. Extensive areas are nearly barren ash and cinder wasteland.

The mountains of the Pavlof area, although a part of the Aleutian Range, constitute an isolated block separated from the main range by lowlands near Pavlof Bay and Cold Bay.

The Bering Sea lowland is similar to the constructional plain of the Pacific Ocean lowland in most respects, but as so little of it is included in the area mapped, no discussion of it is made in this report.

DRAINAGE AND WATER SUPPLY

Several large and numerous small unnamed streams empty into the Pacific Ocean within the mapped area. No measurements of stream flow have been made, but it is certain that the annual winter snows and the perennial snowfields insure an abundant water supply during most of the year. Streamflow decreases greatly during the winter, and some streams cease to flow for a few weeks or months. Melting snow during spring and early summer thaws provides a great volume of water; however, many of the swollen streams carry such great quantities of suspended matter that the water is not usable unless filtered or allowed to settle. During late August and September the water of some streams is undrinkable because of pollution by decaying dead salmon. Only on the surface of recent lava flows and in parts of the country deeply covered by ash is surface water lacking or scarce.

GLACIERS

Glaciers cover much of the upper slopes of the larger volcanoes and occupy the heads of many of the upland valleys. Most of Little Pavlof Volcano, Double Crater Volcano, and that part of Pavlof Volcano above an altitude of about 1,600 feet are covered by a glacier that has an area of more than 50 square miles (pl. 1). Tongues of this glacier that trend both north and east around Pavlof Sister extend to an altitude of 1,000 feet. The flanks of Pavlof Sister, however, are free of ice at altitudes at which nearby Pavlof is covered by glacier. Much volcanic ash is mixed with the glacial ice, and summer melting, added to recent ash falls, leaves a thin, dark ash cover over most of this glacier (pl. 2).

Small glaciers occupy the northeast and southwest slopes of Mount Hague and fill the large crater at its summit. The glacier of the northeast slope of Mount Hague coalesces with the extension of the large glacier of Pavlof, Little Pavlof, and Double Crater Volcanoes. A small glacier, a few square miles in area, trends northward from the summit of Mount Emmons, and a somewhat larger glacier occupies much of the upland south of "Emmons Lake." [2]

Glaciers occupy parts of the highland area of the Aghileen Pinnacles, west of the mapped area, and extend from the summit of Mount Dutton. The boundaries of these glaciers have not been traced. Many small cliff and headwall glaciers occur throughout the upland.

For the most part the glaciers appear to be relatively static. The presence of widespread undissected morainal deposits in areas now free of permanent ice, and the existence of U-shaped valleys and other such typical glacial features throughout the area indicate that glaciation in the recent past was considerably more widespread.

GEOLOGY

The oldest exposed rocks in the Pavlof area are believed to be of Tertiary age. They consist of arkose, and occur in beds overlain by a thick sequence of tuffs and agglomerates. Broad, flat folds characterize their structure. The bedded rocks are intruded by quartz diorite stocks, basalt plugs and necks, andesite sills, and numerous basaltic dikes. The Quaternary rocks of the area comprise basalt

[2] Place names in quotation marks are not shown on standard maps but are used for convenience in this report.

lava flows along a northeastward-trending rift; a chain of large stratovolcanoes, made up of interbedded lava flows and pyroclastic material, which have been built up over the rift; numerous satellitic cinder cones and associated lava flows; and minor glacial, alluvial, and beach deposits. A discussion of the rocks of the Pavlof area and their relationships follows. Insofar as is feasible they are treated in chronological order. The geology of Pavlof Volcano and vicinity is shown on plate 3.

ROCKS OF TERITARY AGE

ARKOSE

The oldest rocks in the Pavlof area are nonfossiliferous beds of green arkose, which crop out in cliffs at Indian Head and in the northwest corner of Belkofski Bay. A thickness of 200 feet of these beds is exposed in the crest of a broad anticline with maximum dips of 2°–3°. Lenses of pebble conglomerate 1–2 feet thick are interbedded with the arkose. The areal extent of the arkose is too small to give any clue as to its source. It is tentatively assigned a Tertiary age because of conformable relations with the overlying locally fossiliferous tuff beds.

BELKOFSKI TUFF

Conformably overlying the arkose is a thick series of well-bedded tuff. These tuff beds crop out principally around Belkofski Bay and on Belkofski Point; therefore, they are designated Belkofski tuff in this report. They crop out also from Dushkin Lagoon, east of Volcano Bay, to King Cove.

The beds are classed as volcanic sandstones and volcanic conglomerates. They are largely composed of fine- to coarse-grained lithic tuff colored in shades of green, purple, and gray. Where the tuff has been reworked by water, the original angular fragments are subrounded to rounded. The tuff is made up chiefly of a microcrystalline aggregate of feldspar microlites and chlorite, but crystals and angular fragments of oligoclase feldspar are included. The beds have been intensely silicified and sericitized in the vicinity of the diorite stocks that intrude them on Belkofski Point and at the head of Volcano Bay. The total thickness of the Belkofski tuff is difficult to ascertain, but it exceeds 3,000 feet.

Numerous plant fossils, principally silicified and carbonized trunks of trees and impressions of conifer needles, are present in the lower parts of the Belkofski tuff. They belong chiefly to an unidentified species of fir. Their age is not yet determined, but it is probably Tertiary. No conifers grow on the Alaska Peninsula, and it is not likely that any have grown there since the early Pleistocene. Silicified and

SLIGHTLY DISSECTED CONE OF PAVLOF SISTER.

Crevassed glacier on lower slopes of Pavlof Volcano (left foreground) is covered by ash. Photograph by U. S. Army Air Force, 1942.

LITTLE PAVLOF VOLCANO.

The slopes are largely ice covered. An active tongue of ice can be seen between Little Pavlof and Pavlof Volcano (on the right). Photograph by U. S. Army Air Force, 1942.

carbonized plant remains, occurring in beds 1–5 centimeters thick, also are present in the formation.

The age of the Belkofski tuff is believed to be Tertiary, partly on the evidence of the fossil fir trees, and partly by analogy with nearby areas. The "lower" beds of Palache's (1904) Stepovak series, exposed in the vicinity of Chichagof Peak, about 85 miles northeast of Belkofski Bay, are described as pyroclastic deposits of early Eocene age. They appear to occur locally, however, and probably are not comparable to the later pyroclastic deposits occurring throughout the Peninsula and assigned a post-Eocene age by W. W. Atwood (1911), G. C. Martin and F. J. Katz (1912), W. R. Smith and A. A. Baker (1924), and R. S. Knappen (1929). Available evidence indicates, therefore, a post-Eocene, pre-Pleistocene age for the Belkofski tuff, and the rocks are tentatively assigned a late Tertiary age.

AGGLOMERATE OF CATHEDRAL VALLEY

A thick sequence of agglomerate beds and subordinate tuff beds and lava flows crops out north of the chain of volcanoes that occupies the central part of the mapped area, and is well exposed in Cathedral Valley. The rocks are predominantly basalt and basaltic andesite. The beds dip north toward the Bering Sea at angles of a few degrees. They are probably comparable in age to the Belkofski tuff, but direct evidence is lacking.

INTRUSIVE ROCKS

The beds of Belkofski tuff are cut by stocks of quartz diorite, by basaltic plugs and necks, by thick sills of andesite, and by smaller sills and dikes of basalt and andesite.

Four stocks, each several square miles in area, occur at the head of Volcano Bay, on Belkofski Point, near the head of Belkofski Bay, and at the head of King Cove, respectively. The stocks are made up of coarsely crystalline quartz diorite that contains about 20 percent quartz, 60 percent andesine felspar, and 20 percent amphibole, biotite, and magnetite. In general this rock has been little altered, but the adjacent tuff beds have locally been sericitized and silicified for distances as great as 1 mile from the stocks. The tuff was also considerably bleached during the period of alteration, thus its original composition is difficult to determine. Bleaching and alteration are particularly conspicuous in the tuff on Belkofski Point. Many contacts between tuff and quartz diorite are gradational because of the intense alteration. Between Bear Bay and Moss Cape, numerous sills extend from the main quartz diorite body into the altered tuff and further obscure the marginal relationships.

The mineralization associated with the emplacement of the diorite stocks is principally pyritization, but extensive, though weak, copper mineralization was noted in the tuffs immediately south of the intrusive mass northwest of the head of Belkofski Bay. Local prospectors have reported finding colors of gold in the altered tuffs of Belkofski Point and near the head of Volcano Bay. Thorough prospecting of these localities is believed warranted.

In addition to the four quartz diorite bodies, several small masses of coarsely crystalline quartz-rich rocks are present about 3 miles north of the head of Volcano Bay. They have been mapped with the quartz diorite, although one of the smaller of these bodies may be granitic in composition.

Several large plugs of fine-grained dark olivine basalt cut the Belkofski tuff north of Belkofski Bay and east of Volcano Bay. At the margins of the plugs the tuff beds have been locally tilted and deformed. These plugs are believed to be the necks of ancient volcanoes that have been eroded away, and are believed to be somewhat younger than the quartz diorite intrusive masses.

One large sill of andesite, probably of the same age as the basaltic plugs, occurs several miles north of Volcano Bay. Numerous sills and dikes of andesite and basalt, too small to map, cut the tuff beds. Most of the dikes are less than 15 feet thick, but a few are as much as 50 feet thick; they can be traced for only short distances.

ROCKS OF QUATERNARY AGE

OLDER LAVA FLOWS

Three extensive lava units fill old canyons and gullies carved in the Belkofski tuff and diorite stocks within the Pavlof area. These lava units—the Arch Point basalt, the Dushkin basalt, and an even older group of basalt flows exposed principally near Black Point—occur on the Pacific side of the Aleutian Range between sea level and an altitude of 4,000 feet, but have been mapped only in the lowlands. They are older than the cinder cones and their associated lava flows (p. 13) that are scattered throughout the central part of the mapped area, and are probably older than Pavlof Volcano and the other large strato-volcanoes (pp. 10–13). The oldest of these flows may be of very late Tertiary age, but most of them are probably Pleistocene, and the lavas as a whole are therefore tentatively assigned a Quaternary age.

Arch Point basalt.—Thick lava flows, designated the Arch Point basalt, are well exposed on Arch Point south of Dushkin Lagoon. They are also exposed a few miles north of the head of Volcano Bay and both north and south of "Emmons Lake;" small exposures may be found at the head of Belkofski Bay. The Arch Point basalt is overlain by, and is therefore older than, the nearby flows of Dushkin basalt (see pp. 9–10). Columnar jointing in the Arch Point basalt is distinctive: hexagonal columns averaging 4–6 inches in diameter are arranged in fanlike patterns; some of the columns on the wings of a few fans are horizontal and resemble stacked cordwood. The rock is dark and contains 1–5 percent conspicuous glistening black hypersthene phenocrysts 2–4 millimeters long; about 15 percent plagioclase phenocrysts 1–3 millimeters long, ranging in composition from that of labradorite to that of bytownite; and sparse crystals of olivine and augite. The sources of the flows are not exposed.

Dushkin basalt.—The most widespread of the older lavas is the Dushkin basalt, well displayed on the north margin of Dushkin Lagoon. The flows occur south of the tip of the long southwestern arm of the glacier extending from Little Pavlof and crop out sporadically over a distance of 20 miles southwestward to Mount Dutton. Locally, a single flow more than 200 feet thick makes up this unit; elsewhere, the unit comprises many superimposed flows, each a few tens of feet thick. In places, such as in the cliffs south of "Emmons Lake," the aggregated flows are several thousand feet thick.

The individual flows of Dushkin basalt are similar to each other. The rock is dark, unaltered, and locally rich in inclusions of dense earlier basalt. A streaked appearance, particularly conspicuous on somewhat weathered surfaces, and not unlike the banding recorded for some Yellowstone Park and Katmai lavas (Fenner, 1923), suggests that in places inclusions of a more siliceous rock have been remelted and dragged out as the lavas were extruded. Coarse columnar jointing is conspicuous in some of the thicker flows. As in the Arch Point basalt, the jointing is not invariably at right angles to the plane of the flow. Some columns are arranged in fanlike patterns, and many appear to lie parallel to the plane of the flow.

The Dushkin basalt characteristically contains 25–35 percent of strongly zoned labradorite phenocrysts, which range in length from 0.5–3 millimeters. About 5 percent each of hypersthene and augite are present as small phenocrysts, 0.5 millimeter across. Hypersthene typically is surrounded by a very narrow zone of fine-grained clinopyroxene. The groundmass is made up of magnetite grains and of plagioclase and clinopyroxene microlites set in a matrix of brown glass.

The widespread distribution and the range in altitude of the flows of Dushkin basalt indicate that they did not all necessarily come from the same vent. It seems likely that they issued from a series of vents or were extruded as fissure flows from the main northeast-trending rift (now marked by the chain of strato-volcanoes and cinder cones) that extends from Pavlof Sister to Mount Emmons. Whatever the exact source, the lava poured out on the Arch Point basalt and partly filled topographic depressions in a pre-Dushkin erosion surface developed on the Belkofski tuff. South of "Emmons Lake" these lavas may have accumulated to sufficient depth to spill over the hills of Belkofski tuff toward the Pacific Ocean. The greatest volume of

Dushkin basalt appears to have been poured out in the vicinity of Mount Emmons.

A major problem, as yet unsolved, associated with both the Arch Point basalt and the Dushkin basalt, is the origin of the crescentic depression, partly filled by "Emmons Lake," bordering the western half of Mount Emmons. It is not a normal feature of glacial erosion, particularly because of its crescentic shape and asymmetric transverse section—the slopes of the outer confining wall of the trough are steep, and the slopes from the bottom of the trough toward Mount Emmons are gentle. The explanation may be that the area surrounding Mount Emmons and Mount Hague—including the depression—is a sunken block or part of a caldera formed when the lavas of the Dushkin basalt were being erupted. These flows would then have poured on the newly lowered surface, building up the foundations of Mount Emmons and Mount Hague as nested cones. Much geologic and topographic evidence contradicts this hypothesis, however, and further work must be done before the true relations can be determined. The original topographic features involving the Dushkin basalt have been profoundly modified by erosion.

Basalt of Black Point.—A group of lava flows, thought to be the oldest of the Quaternary lavas, form a large dome-like hill near Black Point. They also crop out at tidewater in Long John Lagoon, and 20 miles away along the beach in Chinaman Lagoon. An elliptical depression, largely filled with alluvium, at the top of the hill near Black Point suggests the presence of an ancient crater; it may mark the vent from which flows of basalt issued and spread north and south. The lava flows that make up the hill dip away from the summit at angles of about 2°–10°.

The basalt of Black Point is dark reddish brown, dense, and even-textured. It is composed of abundant very small phenocrysts—70 percent labradorite feldspar, 8–10 percent olivine, and 2 percent hypersthene—in a fine-grained groundmass which makes up about 20 percent of the rock. The basalt appears to contain more magnesium and calcium and less silica than most flows of the area. The flows at Black Point contain a much higher percentage of phenocrysts than do the other flows studied.

VOLCANOES AND ASSOCIATED LAVA FLOWS

Six large strato-volcanoes lie along an arc about 12 miles long and constitute the central zone of the mapped area. These volcanoes—Pavlof Sister, Pavlof, Little Pavlof, Double Crater, Mount Hague, and Mount Emmons—appear to be built over a major rift of northeast trend. With the possible exception of Little Pavlof, these volcanoes have been active within historic time, as indicated by well-defined summit craters, lava flows and ash falls that show little sign of erosion, and undissected satellitic cinder cones. The age of the strato-volcanoes cannot be precisely established. Most of the material making up the volcanoes probably accumulated by sporadic eruptions throughout Quaternary time; the uppermost parts are of Recent age. The lowermost parts may be of late Tertiary age.

Wherever possible the lava flows and pyroclastic beds associated with the strato-volcanoes have been individually mapped (pl. 3). The lava flows and pyroclastic beds of each central vent are lithologically and structurally similar, and therefore the products of each volcano are discussed as a unit.

Pavlof Sister.—Pavlof Sister is the northeasternmost volcano in this area. Its uniform slopes of about 33° rise to an altitude of more than 7,000 feet. The slopes of the volcano are covered with cinders and ash, much of which was probably showered on the cone from eruptions of nearby Pavlof Volcano. At the summit is a small crater a few hundred feet in diameter and a few tens of feet deep. Two recent lava flows, one on the north side and the other on the southeast side of the volcano, are largely buried under accumulations of ash and detritus. The upper parts of the flows are buried by ash; it could not be determined whether these lavas spilled from the crater at the top of the volcano or emerged from vents on the flanks of the cone. Gullies, each a few tens of feet deep, are carved on the slopes of the mountain, but they are not deep enough to reveal the structure of the volcano. A few small outcrops at the top of the mountain, in which flows of lava alternate with beds made up of ash, lapilli, bombs, and angular fragments of crater-wall rocks, provide a clue to the internal structure. The diversity of rocks in the exposures and the steepness of the slopes of the cone indicate that this is a strato-volcano made up of intermingled lava flows and pyroclastic deposits.

Pavlof Volcano.—Pavlof Volcano rises to an altitude of 8,900 feet and is one of the highest peaks of the Aleutian Range. Ice that mantles the volcano almost to its summit limits the amount of information that can be obtained regarding the bedrock geology.

A small crater occupies the northeast side of the volcano near its summit (pl. 4). During the summer of 1946, puffs—mostly of steam—emerged from the vent at infrequent intervals. For periods of several days the crater appeared to be inactive. Occasionally a relatively steady emission of steam was observed, and several times dark, ash-laden puffs emerged from the vent. Only a small amount of the ash was carried beyond the limits of the crater.

Pavlof is made strikingly asymmetrical by a long ridge that extends southwestward from the vent. The asymmetric shape of the volcano suggests that the vent has been migrating northeastward. Such migration is common in other volcanic regions, but the reason for it is as yet undetermined.

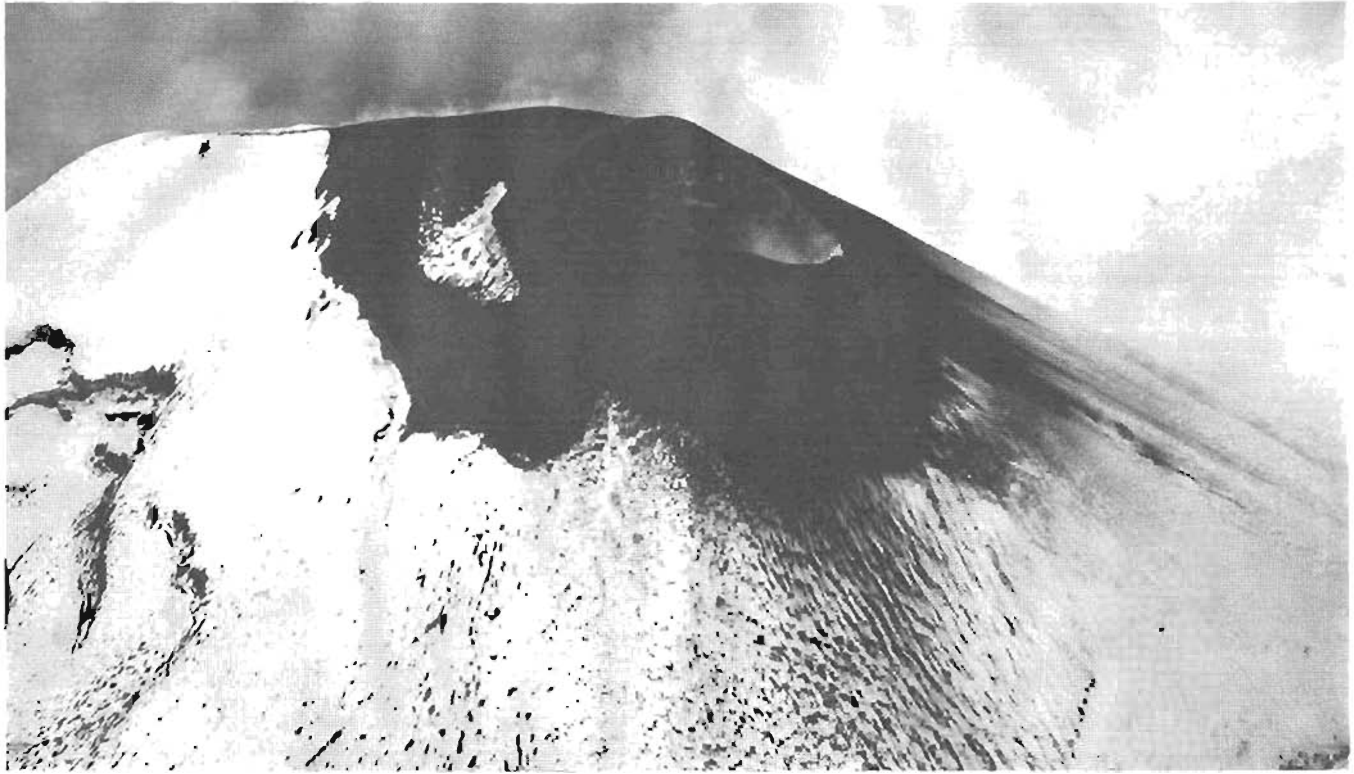
Three narrow lava flows extend seaward from beneath the ice on the eastern and southeastern slopes of the volcano. They are of such recent date that their topographic expression and original blocky surfaces are almost unmodified by erosion. Parts of these lava flows are heavily blanketed by glacial moraine and recent ash falls. Two of the lava streams probably flowed from the cinder cones that project above the ice headward from the exposed parts of the flows.

South of the crest of Pavlof Volcano, headward glacial erosion has carved vertical cliffs, revealing the internal structure of the cone. Layers of ash, lapilli, bombs, and blocks alternate with lava flows and dip at angles of about 30° away from the summit.

Little Pavlof.—Little Pavlof Volcano appears to have been long inactive; most of it has been carried away by glaciers. In vertical exposures southwest of the cone along "Glacier Ridge," interbedded agglomerates and lavas dip away from the core of the volcano at angles of 15°–35°. It appears likely that the period of principal growth of Little Pavlof overlapped that of Pavlof, and the older products of the two volcanoes are interbedded between the two cones.

Double Crater.—Double Crater Volcano is a low hill that projects only a few hundred feet above a surrounding icefield. Two large, partly coalescing craters, each almost 1,000 feet across, occupy the upper part of the volcano. The more southerly of these craters contains a small, permanent icefield and is rimmed by brick-red interbedded agglomerates and lavas. The other crater contains a small lake and is largely filled with alluvium. The flows that extend from this volcano are buried under the surrounding icefield.

Mount Hague.—Mount Hague is perhaps the most spectacular of the volcanoes in the Pavlof area. It is a twin-peaked volcano, the eastern peak rising to an altitude of 4,600 feet above the surrounding icefields and topped by a large, elliptical, glacier-filled crater almost 800 feet deep and two-thirds of a mile in longest dimension. The slopes of Mount Hague are blanketed partly by ice and partly by very recent cinder beds and lava flows. The volcano is a stratified cone made up of alternating lava flows and beds of agglomerate, which apparently have been built upon a foundation of Dushkin basalt. Many recent flows appear to have poured from vents on the flanks of the volcano, particularly on the northwest flank. The large basalt flow (pl. 3, flow 5), which covers much of the lowlands north of Dushkin and Long John Lagoons, may have had its source on Mount Hague's southeast flank, now buried by ice. Because of its fresh, blocky surface and lack of dissection, this flow is believed to be at most only a few hundred years old. The flow is believed to have moved southwestward until it reached the heads of two narrow southeast-trending valleys carved in the older Dushkin and Arch Point basalts. The lava followed these valleys until it flowed out on the



SMALL CRATER ON THE NORTHEASTERN SIDE OF THE SUMMIT OF PAVLOF VOLCANO.

Photograph by U. S. Army Air Force, 1942.

low plain at the valley mouths. Here the two streams spread radially and coalesced. Much of this lava has been capped by a younger and more extensive flow from cone *G* (p. 14).

That volcanic activity has not altogether ceased at Mount Hague is evidenced by the large and spectacular fumaroles on its western flank, described on page 15.

Mount Emmons.—Mount Emmons is the southwesternmost of the large volcanoes in the area. Its cone, like those of the other volcanoes, is made up of interbedded lava flows and layers of agglomerate. It is apparently superimposed upon a platform of Dushkin basalt. The origin of the lower slopes of Mount Emmons has already been discussed in connection with the origin of the flows forming the Dushkin basalt (pp. 9–10). Icefields cover much of the north slopes of Mount Emmons, and satellitic cinder cones and their associated flows are scattered on the flanks of the volcano.

CINDER CONES AND ASSOCIATED LAVA FLOWS

Eleven cinder cones of Recent age occur in the Pavlof area. They are given alphabetic designations in this report. Compared with the large strato-volcanoes, the cinder cones are small, have a maximum height of only a few hundred feet, and are for the most part made up of ash, lapilli, bombs, and blocks, but include subordinate interbedded lavas. Each cinder cone is believed to be the product of a relatively brief cycle of eruption, for nearly all are built around vents from which only one or two lava flows have poured.

Most of the cinder cones are along the main rift on which the large strato-volcanoes are built, and on the flanks of the volcanoes. Some of the cones, however, are distant from the main rift.

Cone *A*, located on the major rift, is a symmetrical cone west of the summit of Mount Emmons. Below it is a small flow that poured from its crater down the side of Mount Emmons into the crescentic "Emmons Lake."

Four cinder cones, each with one or two flows, appear along the main rift between Mount Emmons and Mount Hague. Three of these cones—*B*, *C*, and *E*—are somewhat dissected and are accompanied by flows of small extent. The fourth, cone *G*, which is very fresh-looking, is accompanied by a flow that covers an area of about 10 square miles and extends to the lowlands north of Volcano Bay. The flow forked: one tongue of lava moved southwestward along a canyon carved in the Dushkin basalt and poured into "Emmons Lake," and the other, a larger tongue, moved southward toward Dushkin Lagoon, blocking the stream draining "Emmons Lake" and creating a second, smaller lake. This flow is probably the youngest in the area. It is a typical aa, or blocky flow, having a very irregularly furrowed and blocky surface. Very little ash has been deposited on its lower parts, and vegetation is just beginning to grow. The black top of the flow contrasts markedly with the green of the adjacent plains.

Two cinder cones, *D* and *F*, lie about 1 mile north of the main rift. *D* is a fresh-looking, breached cone from which a moderately extensive flow spilled north, damming a stream and creating a small lake along its western border. *F* is a highly dissected cone of which only two remnants remain. Much of its associated lava flow is deeply buried in ash and glacial outwash from Mount Hague.

Two coalescing symmetrical cones with deep summit craters, cones *H* and *I*, lie about 2 miles south of Mount Hague. The southwest tongue of the glacier from Little Pavlof abuts against them on the east and has piled considerable morainal debris on their flanks. The recent flow from cone *G* partly encircles them on the west. Consequently, any flows associated with these cones are covered.

Cones *J* and *K* project above the ice on the west slopes of Pavlof Volcano. The lava flows that emerge from beneath the ice front down slope from the cones probably belong to them.

The lava flows associated with the strato-volcanoes and the cinder cones consist of somewhat vesicular, gray-to-black basalt containing 20–30 percent phenocrysts. Most of the phenocrysts occur as laths of labradorite feldspar that are from 1–3 millimeters long; 1–5 percent of the phenocrysts are of olivine; 2–10 percent, of hypersthene; and about 5 percent, of augite. Narrow reaction rims of augite surround the hypersthene. Microlites of feldspar and clinopyroxene, and a little brown glass, make up the groundmass.

UNCONSOLIDATED DEPOSITS

Much of the surface of the Pavlof area is thinly covered by Recent ash and by unconsolidated glacial, alluvial, and beach deposits. Only where these unconsolidated deposits are of significant thickness and extent are they shown on the geologic map (pl. 3).

Deposits of volcanic silt, sand, and gravel are widely distributed on the floors of stream valleys, on beaches, and on small marine and stream terraces.

Extensive moraines, only slighted dissected, fringe the lower slopes of the volcanoes. In the vicinity of Black and Bluff Points, thick deposits of recent glacial material occur at altitudes as low as 200 feet. Some of the boulders in the moraines are as much as 20 feet across. Striated and faceted boulders are common. In addition to volcanic rock detritus, the moraines contain a few fragments of coarsely crystalline igneous rock whose source is unknown.

STRUCTURE

The general structure of the Aleutian Range in the Pavlof area appears to be that of a broad, flat anticline, trending northeast.

Gently folded beds having average dips of 5°–10° prevail throughout most of the area. Steeper dips were observed only in the vicinity of intruded plugs and high on the flanks and near the summits of the strato-volcanoes, each of which has superimposed its individual structure on the underlying major anticline.

The large volcanoes seem to be along a major curving rift, but the rift itself is buried and its characteristics are unknown.

Steeply dipping faults of small displacement are common in the Belkofski tuff, but are too small to be shown on the geologic map. Two larger faults have been mapped south of "Emmons Lake", but their relationships are not clear.

FUMAROLES AND HOT SPRINGS

One area of fumaroles and one hot spring were discovered in the Pavlof area. Local residents report the existence of other hot springs beyond the mapped area on the side of the Aleutian Range facing the Bering Sea.

Six large fumaroles and many small ones occupy a steep gully on the southwest side of Mount Hague. They occur at altitudes ranging from 3,200 feet to 3,800 feet. In the summer of 1946, sulfur dioxide and steam were rising in clouds from the major vents, accompanied by a noise like that of a locomotive escape valve, which could be heard a quarter of a mile away. The presence of the fumaroles could be detected by their pungent odor at a distance of several miles downwind.

Extensive deposits of native sulfur occur within the gully, and cones of pure sulfur, 3 to 4 feet high, have been built around each of the vents. Because of the great volume of sulfur fumes, it is impossible, without special equipment, to approach closer than a few hundred feet to the cones. Large blocks of sulfur have tumbled down the gully onto the glacier below. A distinct reddish cast appears on the inside of the sulfur cones and deceptively suggests that they are heated to incandescence by the escaping fumes. This cannot be true, however, owing to the low melting point of sulfur; the red color probably results from the deposition of a sulfur mineral, such as realgar. No blocks of sulfur containing this reddish material were collected.

A hot spring near the northwest corner of "Emmons Lake" comprises two streams that emerge within a few feet of each other and flow into the lake. The temperature of the water was estimated to be 140°F. An 8-inch pipe would probably be required to carry the combined flow of the streams. No incrustations were seen on pebbles within or near the spring, and the water was sweet and odorless. Vegetation for several hundred feet away from the streams was much more luxuriant than elsewhere around the lake.

HISTORIC ACTIVITY OF PAVLOF VOLCANO

The activity of Pavlof Volcano has been often noted in the past, but few specific facts and details have been recorded. Some of the observations that follow are extremely indefinite and may apply to Pavlof Sister.

Grewingk (1850) reports that the volcano was active from 1762–86 and in 1790, and that it was smoking in 1838.

Doroshin (1870) reports the eruption of flames, ash, and rocks in August 1844. In August 1846 he reports another eruption in which lava flowed out on the east slope, fire appeared from the top of the peak, and ash was carried as far as Unga Island, about 55 miles east of Pavlof. The north side of the peak was smoking in August 1852.

An ash eruption is recorded for March 1866 (Coats, 1950).

Becker (1898) states from information compiled by W. H. Dall that in 1880 the volcano showed a "red glare" and that in 1892 it was smoking.

Jaggar (1929) reports that an island trapper said Pavlof was smoking vigorously from 1906–11 and that in 1911 "fire" poured down the mountain and alarming rumbles continued for several months; boulders were thrown into the air and the mountain was said to have cracked open toward the north. The United States Commissioner at Unga gave Jaggar black sand that fell at Unga from Pavlof during an eruption that occurred July 6, 1914.

Other eruptions of Pavlof that were followed by dust falls, and a severe earthquake at King Cove, occurred in October 1917.

"Flames" that reached a height of 2,000 feet above the volcano lighted the village of Belkofski the evening of December 24, 1922, and "flames" were again reported in the winter of 1923.

A strong explosion followed by steam and ash eruptions occurred on January 17, 1924. Crew members of the steamer *Starr* reported that Pavlof was unusually active in December 1929.

Rev. D. Hotovitsky (Hawaiian Volcano Observatory, 1931) reported that Pavlof was smoking all of the summer of 1931. The volcano was in active eruption about May 20, 1931, and at times a glow was seen at the crater; the ash fall was noticeable.

Major explosive eruptions occurred in 1936 and early in 1942; during the intervening period the emission of ash-laden steam was almost continuous. Reports by Army and Navy fliers indicate almost continuous discharge of smoke from the crater since 1942. Activity was probably less during the summer of 1946 than at any time during the preceding 4 years.

GEOLOGIC HISTORY

The geologic history of the Pavlof area is one of recurrent and long-continued volcanism characterized by periods of particularly violent activity followed by periods of relative quiescence during which erosion by streams and glaciers greatly modified the topography.

The first recorded event is the accumulation of a series of arkose beds in the southern part of the area, presumably in early Tertiary time. Sedimentary processes were interrupted by extensive and violent volcanism, during which the beds of Belkofski tuff accumulated to depths of several thousand feet. Locally the tuffs were reworked by streams, and volcanic sands and gravels were deposited in lowland areas. During about the same time interval, violent explosive eruptions produced the agglomerates of Cathedral Valley. Fir forests in the area were blanketed by the hot ash and were destroyed. Bodies of molten rock, possibly the same ones that caused the explosive volcanic activity, were intruded into the thick accumulations of fragmental material where they solidified as diorite stocks. Later, basalt was intruded into fragmental rocks, probably reaching the surface to form volcanoes; andesite sills also were intruded. The volcanic activity was accompanied by gentle warping and, locally, by more intense deformation of the arkose beds and fragmental deposits.

A long interval of erosion followed, during which deep canyons were carved in the tuff and agglomerate beds and in the intrusive rocks.

The period of erosion probably lasted until about the close of Tertiary time, when volcanic activity recurred, principally along a northeast-trending rift. Lava from the rift filled topographic depressions in the underlying rocks and flowed down valleys. Rather persistent central vents developed along the rift, over which strato-volcanoes were built by the quiet outflow of lava alternating with the explosive eruption of ash and coarse fragmental material. Cinder cones and their associated flows were built up around short-lived vents.

Ash from the volcanoes, reworked by sheet floods and streams, has accumulated in lowland areas, and glaciers moving down the sides of the higher volcanoes have built large moraines of volcanic debris along their margins.

Major explosive eruptions are to be expected from Pavlof Volcano and possibly from some of the other volcanoes at intervals in the future; ash may be expected to be carried by the wind for many miles. Eruptions of lava from the flanks of the volcanoes and at new localities along the main locus of volcanic activity will probably occur also.

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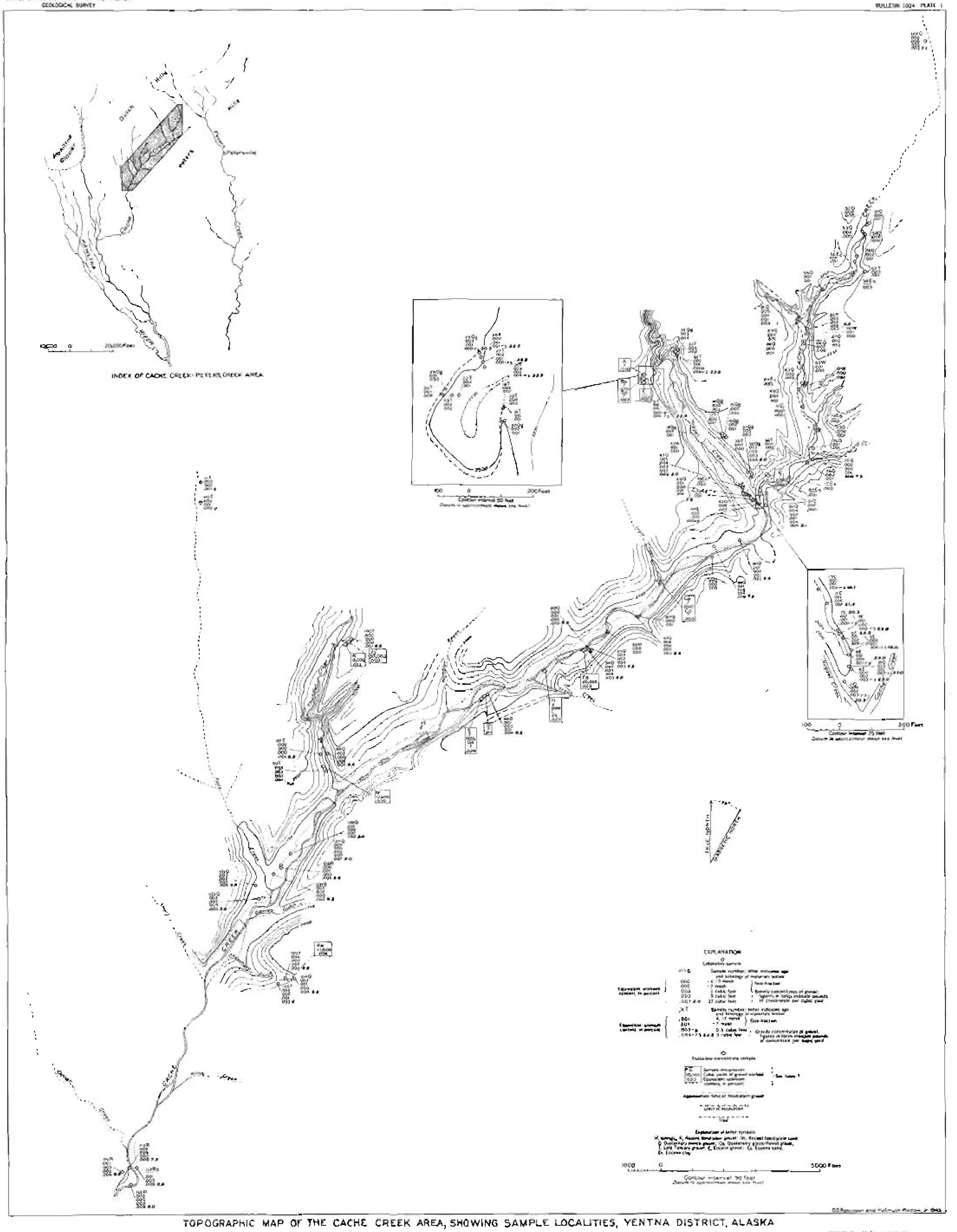
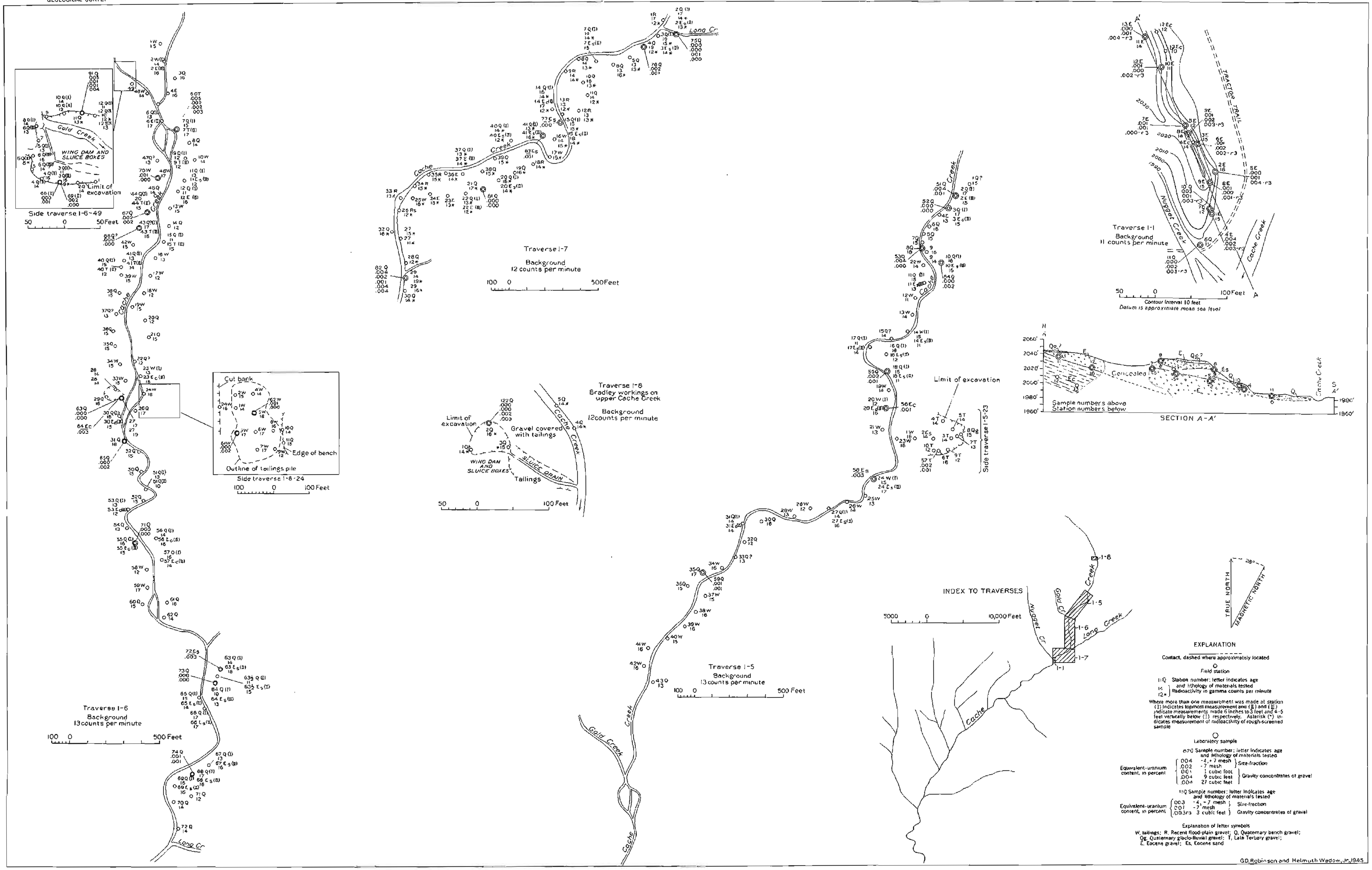
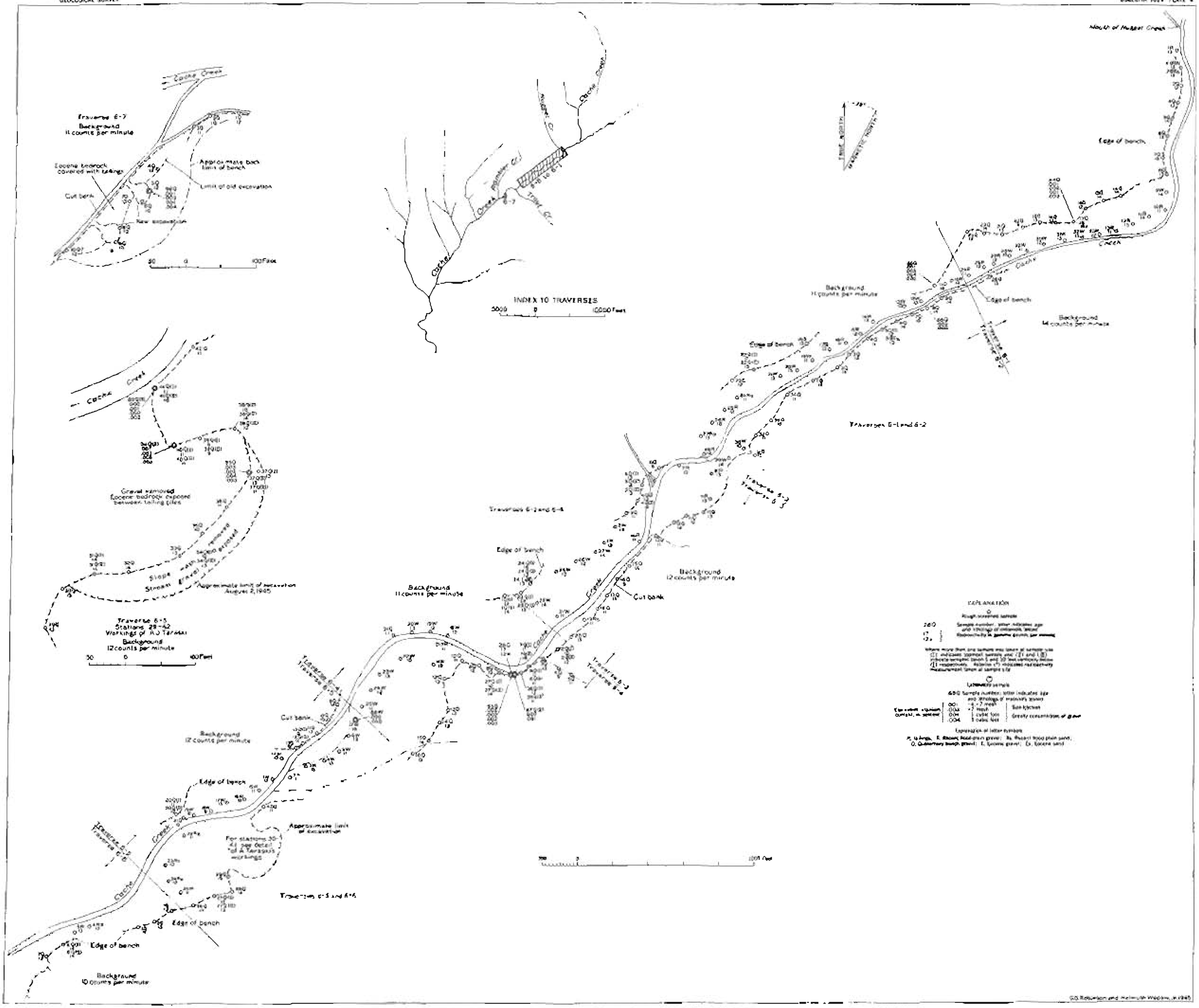


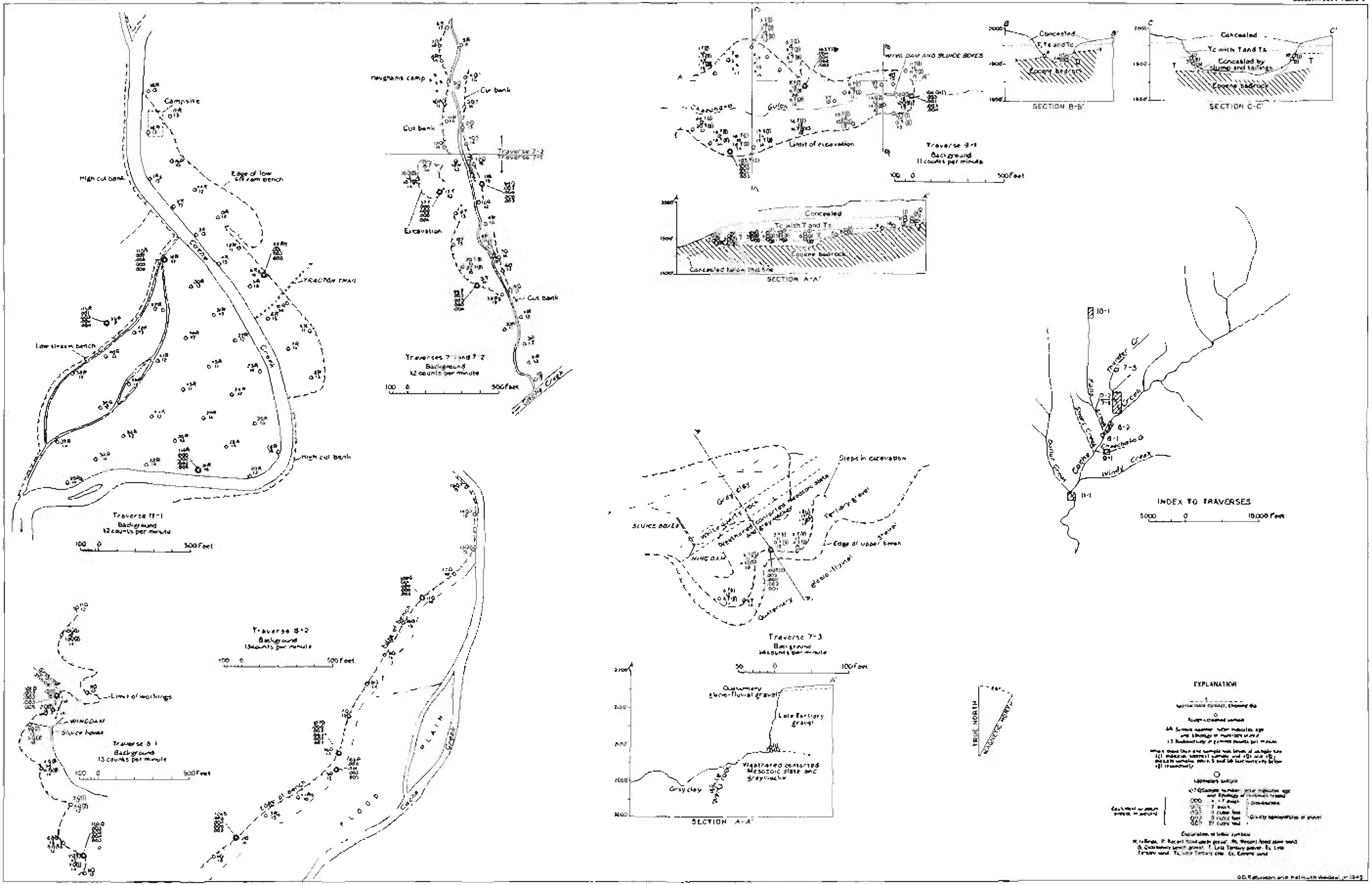
TOPOGRAPHIC MAP OF THE CACHE CREEK AREA, SHOWING SAMPLE LOCALITIES, YENTNA DISTRICT, ALASKA



TRAVERSES ON CACHE CREEK UPSTREAM FROM NUGGET CREEK, YENTNA DISTRICT, ALASKA



TRAVERSES ON CACHE CREEK BETWEEN RAMBLER CREEK AND NUGGET CREEK, YENTNA DISTRICT, ALASKA



TRAVERSES ON THUNDER CREEK AND PART OF CACHE CREEK, YENTNA DISTRICT, ALASKA