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Scientific notes and summaries of investigations prepared by members of the Geologic, Water Resources, and Conservation Divisions in the fields of geology, hydrology, and allied sciences

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UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGIC SURVEY

Thomas B. Nolan, *Director*

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FOREWORD

The scientific and economic results of work by the United States Geological Survey during the fiscal year 1961, the 12 months ending June 30, 1961, are summarized in 4 volumes. This volume includes 143 short papers on subjects in the fields of geology, hydrology, and related sciences, prepared by members of the Geologic, Water Resources, and Conservation Divisions of the Survey. Some are announcements of new discoveries or observations on problems of limited scope, which may or may not be described in greater detail subsequently. Others summarize conclusions drawn from more extensive or continuing investigations, which in large part will be described in greater detail in reports to be published at a later date.

Professional Paper 424–A provides a synopsis of the more important new findings resulting from work during the fiscal year. Professional Papers 424–B and 424–C contain additional short papers like those in the present volume.

Thomas B. Nolan

THOMAS B. NOLAN,
Director.

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353. ANALYSES OF GAS AND WATER FROM TWO MINERAL SPRINGS IN THE COPPER RIVER BASIN, ALASKA

By Donald R. Nichols and Lynn A. Yehle, Washington, D.C.

Two gas and mineralized-water springs, previously reported by the authors (1961, p. 1076), were sampled during the summer of 1960. These springs, here termed the Copper Center and Tazlina mineral springs, issue from small mounds and thus may be classed as incipient mud volcanoes. Several other smaller springs, also presumably mineralized, have been seen from the air, but were not visited. All of the springs are in the southeastern Copper River Basin (fig. 353.1), and appear to be associated with mud volcanoes that have been divided into two general groups based on geographic distribution and chemical and physical characteristics. The Drum group (Shrub, Upper Klawasi, and Lower Klawasi mud volcanoes) lies east of the Copper River and has the largest cones, 150 to 310 feet high; its springs are characterized by carbon dioxide gas and warm sodium bicarbonate and sodium chloride waters. The Tolsona group (Nickel Creek, Shepard, Tolsona No. 1, and Tolsona No. 2 mud volcanoes) lies west of the Copper River and has cones 25 to 60 feet high; all but the inactive Shepard mud volcano have springs that discharge methane gas and cool sodium chloride and calcium chloride water.

East of the Copper River, thick glacial, lacustrine, and fluvial deposits mantle andesitic lavas of Tertiary to Recent age. West of the Copper River, marine sedimentary rocks of Cretaceous age, and semiconsolidated sandstone, conglomerate, and a few thin lignitic beds of Tertiary age, are overlain by Pleistocene deposits (Miller and others, 1959, p. 52, pl. 3).

DESCRIPTION OF THE SPRINGS

The Copper Center mineral spring is 2½ miles N. 20° E. of Copper Center (fig. 353.1). It consists of

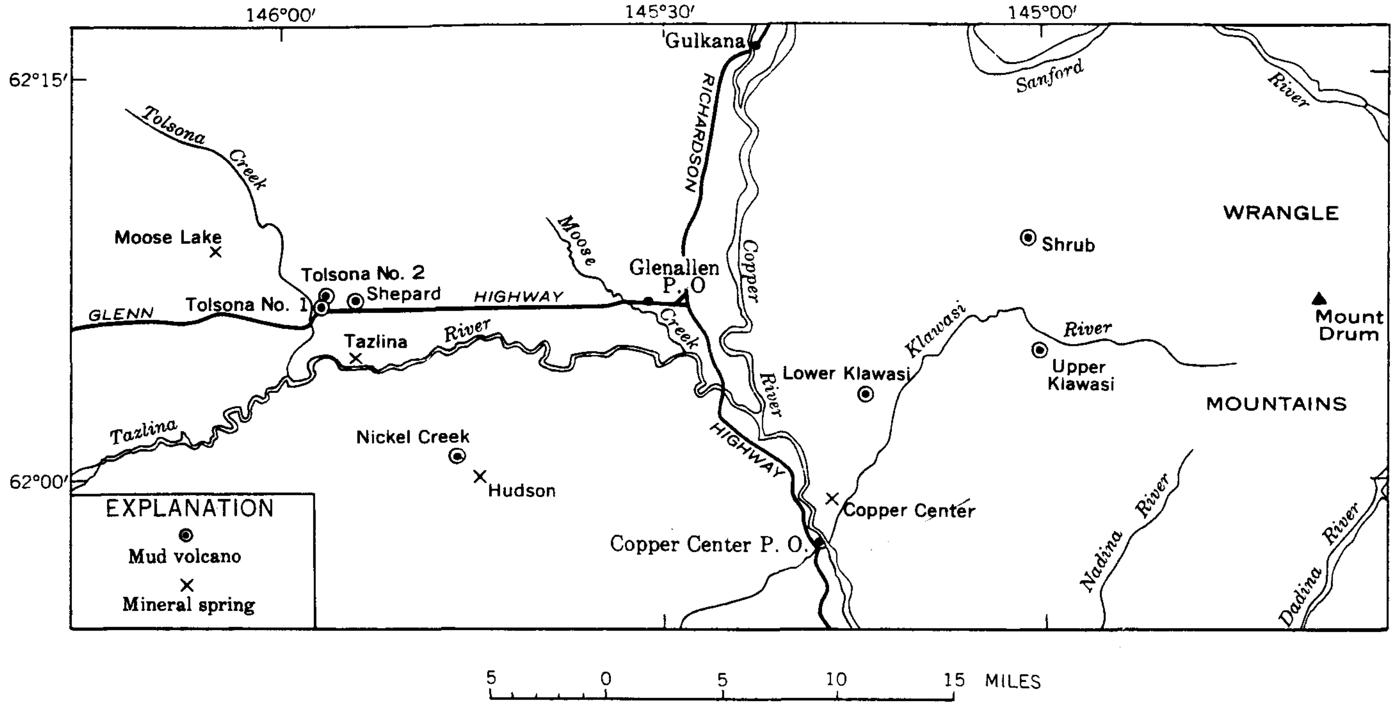

Figure 353.1.—Location of principal mud volcanoes and mineral springs, Copper River Basin, Alaska.

two vents, each 1½ inches wide, and a single pool 5 to 8 feet in diameter and 2 feet deep. The pool and vents lie on the eastern edge of a barren, almost imperceptible mound, the base of which is about 75 feet in diameter and about 1 foot below the nearby ground surface. The mound consists largely of pebbly clayey silt to a depth of at least 3½ feet. The bottom of the pool, however, is covered by medium to coarse sand. Coarse gravel, which lines the drainage channel from the spring, and twigs and sand in the pool are coated by an iridescent bluish-purple precipitate.

When observed, water in the pool was clear green and had a temperature of 63°F, 12° less than the air temperature but 15° to 25° more than ground-water temperature. Water from the pool discharged into a small stream at a rate of about 9 gpm, but sank into the stream bed within 300 yards. Discharge from the vents was insignificant. A dry, grass-covered drainage way, 50 to 500 feed wide, that extends southwestward from the spring to a gully incised in the bluffs of the Copper River suggests that discharge of water from the pools was much greater in the past. Gas bubbled intermittently from several places in the pool and from the two small vents.

The Tazlina mineral spring is in a clearing on a low terrace north of the Tazlina River, about 2½ miles east of Tolsona Creek. In this approximate area, Theodore Chapin, in 1914 (unpublished data), found a "circular area 15 feet across [with] over 50 mud volcanoes * * * [and with] mounds 4 to 5 feet high." The Tazlina spring, which may be the same as Chapin's mud volcanoes, presently consists of 4 pools 3 to 5 feet in diameter on a single grass-covered mound 3 to 4 feet high and 250 feet in diameter. The mound is composed of dark-gray clayey silt and fine sand. Gas bubbled intermittently from 3 of the 5 vents in the largest pool at the mound crest (fig. 353.2), but activity was very sporadic in the other 3 pools on the northeast slope of the mound. The water seeps into grass-covered marshes bordering the pools; the rate of discharge could not be measured. Gray, silt-laden water in the pools had a salty taste and a temperature of 40° F, close to that of the ground water but 35° lower than air temperature at the time measured.

WATER AND GAS ANALYSES

Waters from the Copper Center and Tazlina mineral springs (table 353.1) are similar to waters of the Tolsona group of mud volcanoes (Nichols and Yehle, 1961, table 3); the principal difference is that the average of total dissolved solids of the Tolsona group is much lower than that of the Copper Center mineral spring and much higher than that of the Tazlina mineral spring. Waters from the Tolsona group also have an appreciably higher iron content. Both the spring and mud volcano waters are relatively low in bicarbonate and high in chloride and calcium in contrast to waters of the Drum group.

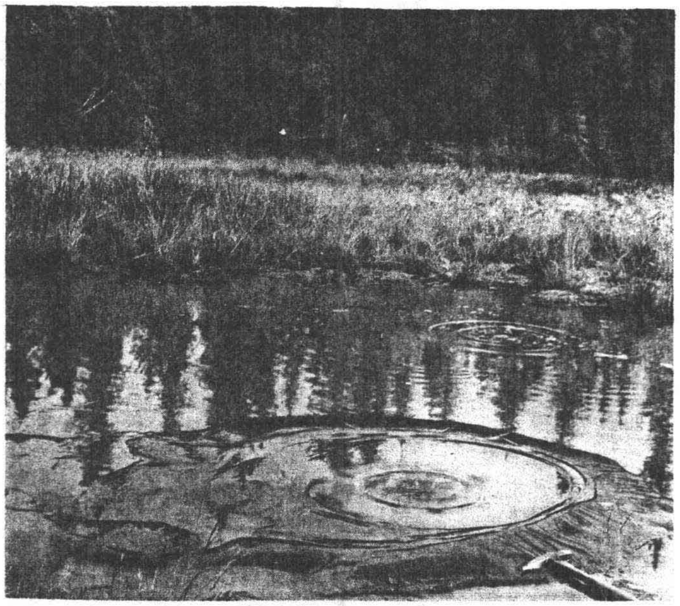

FIGURE 353.2.—Gas bubbling from 2 of 5 vents in pool at crest of Tazlina mineral spring.

TABLE 353.1.—*Analyses of water and ratios of chemical constituents in water from Copper Center and Tazlina mineral springs*

[Analyses by U.S. Geological Survey, Palmer, Alaska.]

	Mineral spring	
	Copper Center (Sample 6129 collected Aug. 7, 1960)	Tazlina (Sample 6131 collected Aug. 8, 1960)
Constituent (ppm):		
SiO_2	24	24
Fe	.0	.03
Ca	3,060	909
Mg	24	48
Na	5,960	1,170
K	55	11
Mn	.04	.25
HCO_3	124	216
SO_4	4.0	3.5
Cl	14,400	3,400
F	1.7	.3
PO_4	.05	------
Total dissolved solids (calculated)	23,600	5,670
Hardness as $CaCO_3$	7,730	2,470
Non-carbonate	7,630	2,290
Specific conductance	36,400	9,800
Density	1.017	------
pH	8.0	7.3
Ratio:		
Ca/Na	.5134	.7769
Mg/Ca	.0078	.0528
K/Na	.0092	.0094
HCO_3/Cl	.0086	.0635
SO_4/Cl	.0003	.0103
F/Cl	.0001	.0009

TABLE 353.2—*Analyses of gas from Copper Center and Tazlina mineral springs, and Tolsona No. 1 mud volcano*

[Mass spectrometer analyses by, and used with permission of, Helium Activity Laboratory, U.S. Bureau of Mines, Amarillo, Tex.; Tr.=trace, less than 0.05 percent]

	Mineral springs		Tolsona No. 1 mud volcano (Sample Y-0.287x, collected Aug. 29, 1960)
	Copper Center (Sample N-0.224d, collected Aug. 7, 1960)	Tazlina (Sample N-0.229, collected Aug. 8, 1960)	
Component (percent):			
Methane	44.6	58.2	63.4
Ethane	.0	.0	Tr.
Propane	.1	.1	.1
n-butane	.0	.0	Tr.
i-butane	.0	.0	Tr.
n-pentane	.0	.0	.0
i-pentane	.0	.0	.0
Cyclo-pentane	Tr.	.0	Tr.
Hexanes plus	Tr.	.0	Tr.
Nitrogen	55.0	40.4	35.9
Oxygen	Tr.	.1	.1
Argon	.1	.2	.1
Helium	Tr.	.1	.1
Hydrogen	.0	.1	.0
Hydrogen sulfide	.0	.0	.0
Carbon dioxide	.1	.9	.2
Total	99.9+	100.1	99.9+
Sulfur odor	------	------	------
Calculated total Btu	454	592	645

Analyses of gas emanating from the Copper Center and Tazlina mineral springs and an analysis of gas from the Tolsona No. 1 mud volcano are presented in table 353.2. These analyses show a high methane and nitrogen content and closely resemble analyses of Tolsona group gases (Nichols and Yehle, 1961, table 2). This contrasts with the predominantly carbon dioxide gas emanating from the Drum group.

The Copper Center and Tazlina mineral springs are included in the Tolsona group of mud volcanoes because of the composition of their water, and especially of their gas. Comparison of the ratios of chemical constituents of the spring water with median ratios of chemical constituents of other waters of different types as reported by White (1960, p. B452) shows no striking similarities, and the source of the water issuing from the springs and mud volcanoes remains uncertain. However, the close similarity of gas from springs and mud volcanoes of the Tolsona group suggests that all have a common source, perhaps from buried Cenozoic marsh or coal deposits, or from porous nonpetroliferous beds of pre-Tertiary (Cretaceous?) age.

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354. THRUST FAULTS IN THE SOUTHERN LISBURNE HILLS, NORTHWEST ALASKA

By Russell H. Campbell, Menlo Park, Calif.

Work done in cooperation with the U.S. Atomic Energy Commission

The structure of the southern Lisburne Hills, Alaska, is dominated by north-trending imbricate thrust faults along which rocks of the Lisburne group of Mississippian age have been thrust eastward over Lisburne and younger strata. The zone of thrust faulting extends from the Chukchi Sea northward to Cape Lisburne where it again passes beneath the waters of the Arctic Ocean (Collier, 1906; Dutro, Sable, and Bowsher, written communication, 1958). The northerly structural trends of the Lisburne Hills are in sharp contrast to the general easterly structural trends of the Brooks Range and Arctic Foothills provinces.

The rocks of the area are exclusively sedimentary, probably all marine, and most are well stratified. They range in age from Devonian(?) (Collier, 1906, p. 16, 17) to Cretaceous and crop out in parallel northeast- to north-trending bands in which the rocks are generally successively younger from west to east (fig. 354.1). No angular unconformities have been observed, but a disconformity probably occurs at the top of the Lisburne group, and disconformities may separate all the younger units.

The overthrust sheets are composed principally of relatively competent limestone and dolomite beds of the Lisburne group, but they locally include infolded segments of older and younger rocks. Silty mudstone of Mississippian age underlies the Lisburne group conformably at a few places, but at most places the contact is a thrust fault, beneath which the less competent mudstone has been plastically deformed. Relatively incompetent mudstone and sandstone of Cretaceous and Cretaceous or Jurassic ages have been intensely crumpled and broken by high-angle faults chiefly along bedding planes and axial planes of folds; they give a gross impression of plastic deformation.

The combined dip slip of the thrust faults is estimated to be a minimum of 5 miles to the east. The photograph (fig. 354.2) illustrates some details of the thrust faulting at a site of particularly good exposure. Beds of the Lisburne group that overlie the Triassic rocks along the Agate Rock thrust belong about 5,000 feet stratigraphically below the top of the Triassic strata. The basal contact of the Lisburne group is exposed in the sheet above the Eebrulikgorruk thrust. Rocks at this horizon belong about 2,000 feet below beds of the Lisburne group that immediately underlie the fault surface.

A regional dip to the east or southeast is indicated by the exposure of progressively younger units from west to east, even though westerly dips are common at surface exposures of the strata. As shown by structure section *A–A′* (fig. 354.1), Mesozoic and Paleozoic strata 25,000 to 30,000 feet thick are present in the eastern part of the area, but have been eroded off the western part. In addition to the stratigraphic evidence, gravity data show a generally gradual decrease in simple Bouguer anomalies from northwest to southeast in the area shown by figure 354.1 (Barnes and Allen, 1961, p. 80–86). All the exposed sedimentary rocks have approximately the same density, so the relatively smooth gravity gradient is interpreted to reflect a gradual eastward thickening of the sedimentary rocks overlying a dense layer that is either relatively smoothly sloping or so deeply buried that its irregularities are not expressed.

The earliest reasonable date for the thrusting in the Lisburne Hills is late Early Cretaceous inasmuch as rocks of that age are involved in the deformation. Some folding of the thrust planes occurred as higher sheets rode over lower ones. Additional relatively

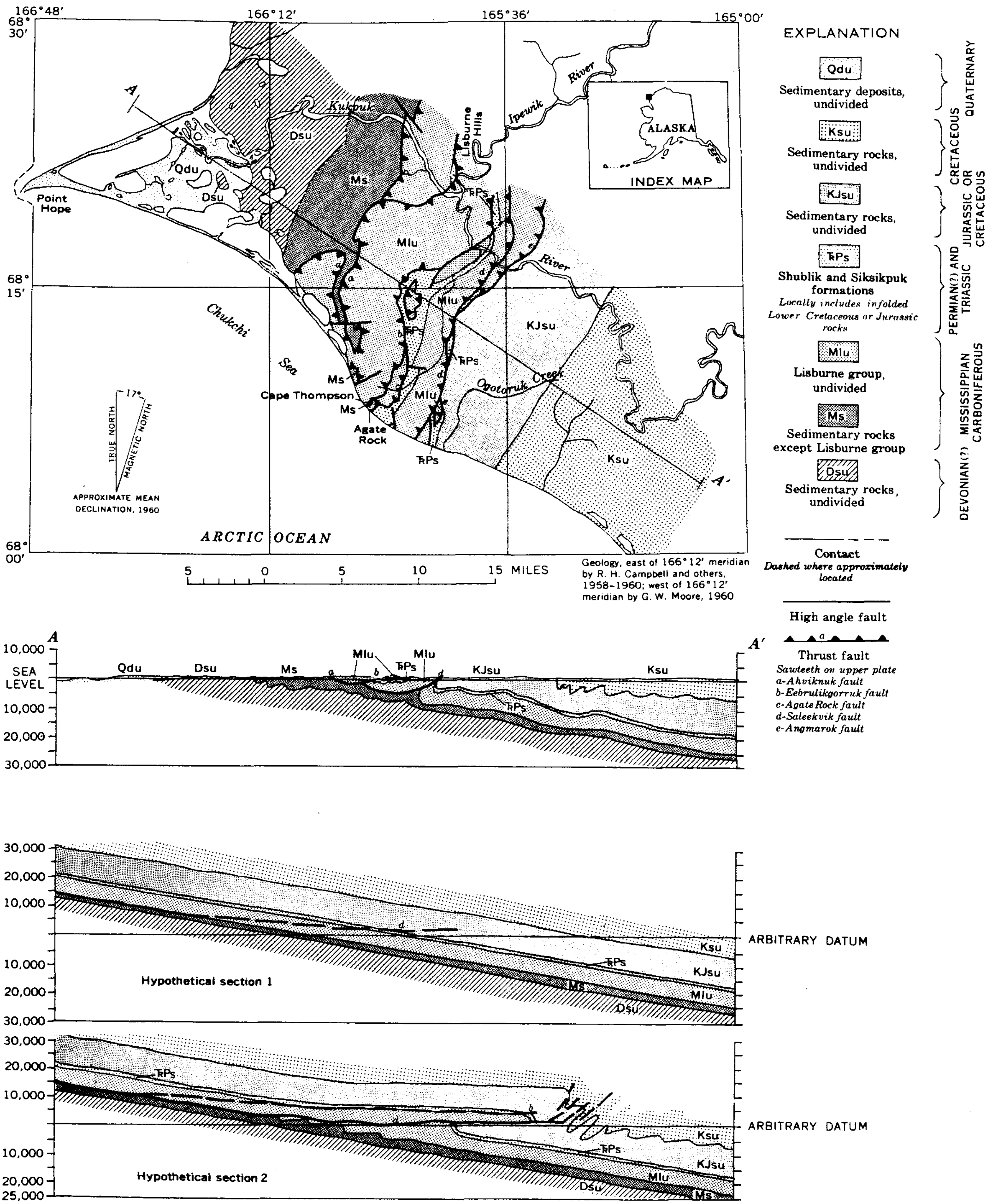

FIGURE 354.1.—Generalized geologic map and sections of the southern Lisburne Hills. Hypothetical sections illustrate suggested development of the thrust faults by gravity gliding.

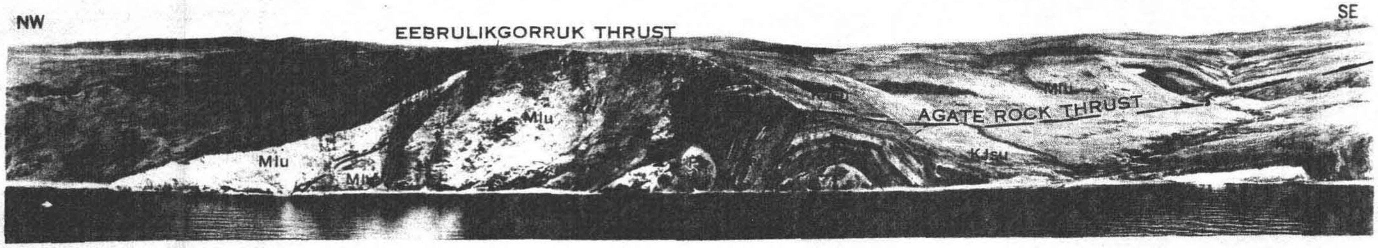

FIGURE 354.2.—Photograph of sea cliffs at Agate Rock showing thrust faults. Ms, Mississippian rocks except Lisburne group; Mlu, Lisburne group of Mississippian age; P, Permian rocks; TR, Triassic rocks; KJsu, Jurassic or Cretaceous rocks. Altitude of cliff top is 625 feet.

gentle folding also probably occurred after the thrusting ceased, and may have been associated with the subsidence of the area around and west of Point Hope. This may account for general westward dips of the thrust planes at their western exposures.

The association of eastward overthrusting with an eastward regional dip suggests that the thrusting took place by gravity gliding as illustrated by the hypothetical sections (fig. 354.1). Thrusting may have been triggered by the same deforming stresses that resulted in upwarp in the vicinity of Point Hope relative to the area to the east and southeast. Relatively competent rocks of the Lisburne group tended to move as coherent sheets, chiefly along numerous weakly bonded bedding planes at and near its base. The mudstone of the underlying unit, particularly if water saturated, could have served as a lubricated, possibly buoyant zone along which the overlying coherent sheets could slide. No low-angle faults have been found in the rocks of Jurassic and Cretaceous age in this area, except small discontinuous ones in locally gently dipping strata. Indeed, it is difficult to visualize how a thrust fault could be maintained as a single flat-lying surface within such incompetent beds. It seems more likely that ahead of the moving sheets of competent limestone these younger rocks were intricately crumpled and the thrust faults split up along bedding planes and axial planes of folds into many faults of small displacement. Frontal piles of such crumpled strata may have prevented further movement on lower thrust planes such as the Angmarok and Saleekvik faults (*e* and *d*, fig. 354.1) so that later movement took place at higher levels, resulting in the imbrication of thrust sheets.

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355. PHYSIOGRAPHIC PROCESSES OF SEDGE MEADOW POOL FORMATION ON LATOUCHE ISLAND, ALASKA

By HANSFORD T. SHACKLETTE, Georgetown, Ky.

Latouche Island is one of the outermost islands of Prince William Sound, lying about 100 miles southwest of the mainland port of Valdez. The climate here is a mild, wet coastal type; the mean annual precipitation is 184 inches, and the average snowfall is about 153 inches. The mean annual temperature is approximately 42° F; the absolute maximum is 82° F, and the absolute minimum is 1° F. The bedrock is predominately hard, compact, dull-gray graywacke and interbedded medium- to dark-gray slate (Stejer, 1956, p. 110–111). Unconsolidated surficial deposits are described by Stejer (p. 111) as follows:

> Unconsolidated deposits of Quaternary age overlie much of the bedrock. Glacial deposits mantle large parts of the valley floor, alluvium occurs in patches along the streams, and talus forms thick blankets along the lower slopes of the high ridge that borders the valley.

The weathered upper layers of the glacial deposits contain sufficient fine silt and clay to form a zone of mineral soil almost impervious to vadose water. The area is thus without effective underground drainage, and most of the heavy rainfall and snow melt water is removed as surface runoff (George O. Gates, oral communication, 1957).

Broad terraces near the seacoast about one-half mile southwest of the village of Latouche are covered for the most part with a sedge meadow plant community (Shacklette, 1961). The principal species of sedges are *Carex Kelloggii* Boott, *C. canescens* L., *C. macrochaeta* C. A. Meyer, *C. sitchensis* Prescott and *C. pauciflora* Lightf., with which are also found cotton grass (*Eriophorum gracile* Koch) and bur-reed (*Sparganium angustifolium* Michx.). Few other plant species are present.

Small pools are conspicuous features of these sedge meadows, which are on the gently sloping terraces. Many of these pools are highly symmetrical, generally rounded to almost circular, as much as 30 feet in diameter, and raised 2 or 3 feet above the general level of the surrounding meadow (fig. 355.1). They have vertical to slightly overhanging banks or rims, formed of the roots and stems of sedges and cotton grass imbedded in reddish-brown peat. Water in the pools is open, clear, and 6 to 10 inches deep. The material on the bottoms of the pools consists of an ooze of unconsolidated dark-brown finely comminuted organic matter that extends downward an undetermined depth but grades into rather firm muck or peat at a depth of about 2 feet. There is no significant growth of mosses in the pools. The rhizomes of the yellow pond lily (*Nuphar polysepalum* Engelm.) are loosely imbedded

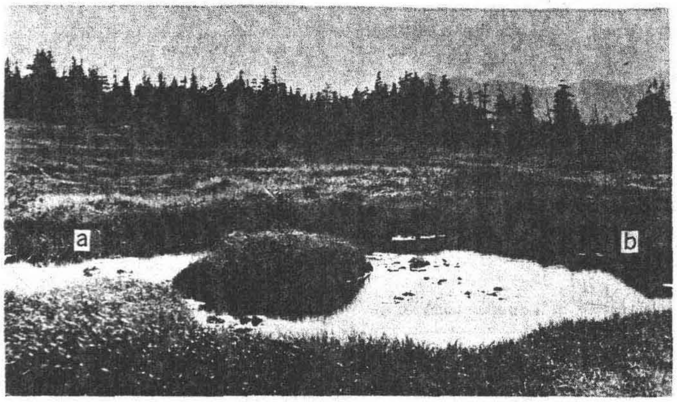
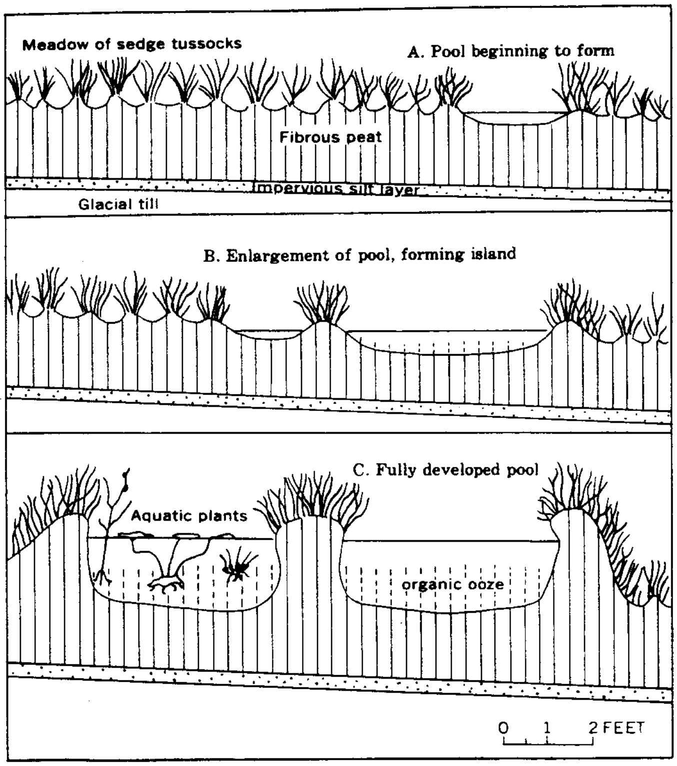


FIGURE 355.1.—Sedge meadow pool, Latouche Island, Alaska. Leaves of yellow pond lily are floating on the surface. The aquatic bur-reed grows in water near the margin (a). Sedges (*Carex* and *Eriophorum* spp.) form a dense, closed sod on the pool rim and island. A break in the rim is beginning to form at the right of the pool (b); this will eventually drain the pool. The terrace ridge in the background bears a scattered growth of mountain hemlock, Sitka spruce, and western hemlock.

in the ooze of the pool bottoms, and scattered clumps of quillwort (*Isoëtes Braunii* Durieu) grow completely submerged in the shallow water. A few plants of bur-reed also grow in the pools as emergent aquatics. These pools have no apparent surface outlets, and the water does not seem to be flowing through them.

The formation of these pools is believed to begin with the damming of a minor surface drainage channel by the growth of one or several sedge tussocks, along with leafy liverworts, principally *Nardia scalaris* (Schrad.) Gray, and a few mosses, principally *Drepanocladus* species, that grow in and around the tussocks. The pool increases in size by an increase in height of the dam through growth of the sedges, and by the thrusting aside of the banks by ice when the water freezes. The outward pressure of the ice tends to form a pressure ridge in the peat at the edge of the pool, creating an elevated rim (fig. 355.2*B*) as the ice of the pool pushes against the still-unfrozen sedge margin. The development of an island in the pool is a fortuitous occurrence and not a constant feature of sedge meadow pools. These islands appear to have originated from the remains of upslope rims that had reached sufficient height to escape flooding and disruptive ice action as the pool increased in size (fig. 355.2*B*, *C*). The disappearance of the sedge tussocks from the flooded areas is believed to be due to the substrata becoming excessively wet for these sedge species to grow well, and to the mechanical disruption of the substrata and the sedge tussocks by ice action. Alter-



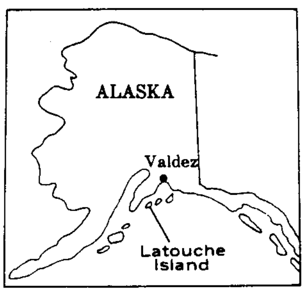


FIGURE 355.2.—Sketches showing evolution of a sedge meadow pool. Non-tussock forming sedges have been omitted. The tussocks are broken up as the pool rim and island form.

nate freezing and thawing of the saturated fibrous peat substrata is probably the principal factor in the formation of the ooze on the pool bottom.

The continued development of sedge meadow pools leads to their eventual destruction. Field observation suggests that when the pools have attained a diameter of 20 to 30 feet a break generally occurs in the downslope rim (fig. 355.1). The pool is thus drained, and the old pool bottom is then colonized by the more hydrophytic species of sedges and cotton grass. The ridged, furrowed, and hummocky microrelief of the sedge meadow is caused by the persistence of the old pool rims, islands, and pool bottoms. Foot travel over this terrain is difficult because of the surface irregularities which are often concealed by the dense sedge growth; numerous pools and soft bottoms of old pools also must be avoided.

Other bodies of water in this vicinity range in size from that of the sedge meadow pools to small lakes (for example, Fish Lake and Lake Putnam, shown on the map of Latouche Island, the Seward A–3, 1:63,360 quadrangle). These pools or lakes lie in slight depressions, have flowing outlets, and do not have elevated margins or rims. It is believed that their origin and history are directly related to the major drainage patterns of the terrain, and that they were not derived from the unique sedge meadow pools described in this report.

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356. REGIONALLY METAMORPHOSED METALLIFEROUS CONTACT-METASOMATIC DEPOSITS NEAR NOME, ALASKA

By C. L. HUMMEL, Bangkok, Thailand

Anomalously large amounts of bismuth, copper, molybdenum, and zinc in sediments from Thompson Creek (a western tributary of the Grand Central River) in the Kigluaik Mountains have been reported previously (Hummel and Chapman, 1960), but when first reported the source of the metals was unknown. These metals are now thought to have been derived from erosion of metamorphosed contact-metasomatic deposits. Four such deposits have been identified near Thompson Creek: two are west of the Thompson Creek drainage and two are on either side of the Grand Central River above the mouth of Thompson Creek (fig. 356.1).

In Thompson Creek, stream sediments containing heavy metals in the light fraction and scheelite in heavy-mineral concentrates are downstream from a wide belt of sulfide-bearing calc-silicate rock formed along the contact of a thick gneissic granite sill (C. L. Sainsbury, oral communication, 1960). Metamorphosed deposits lie along the contact of this same gneissic granite sill at points 4 and 7 miles west of Thompson Creek.

The contact-metasomatic deposit west of the Grand Central River lies along the contact between a body of quartz-plagioclase-biotite gneiss and interbedded marble and biotite schist. The gneiss is believed to be a metamorphosed granodiorite sill. The bedrock relations of the deposit on the east side of the river are unknown.

The contact-metasomatic deposits are difficult to recognize, for they have been recrystallized during the regional metamorphism of the enclosing sedimentary and igneous rocks, which has produced calc-silicates very similar to the contact rock developed near the intrusives. The four deposits shown on figure 356.1 contain scheelite-bearing contact silicates, and the westernmost deposit contains galena and sphalerite associated with scheelite.

The contact-metasomatic deposits associated with regionally metamorphosed intrusive masses represent a type of lode deposit hitherto unrecognized in the Nome area. Similar deposits may be associated with other meta-igneous rocks in the Kigluaik Mountains, and in high-grade metamorphic rocks in the Bendeleben and Darby Mountains on the Seward Peninsula.

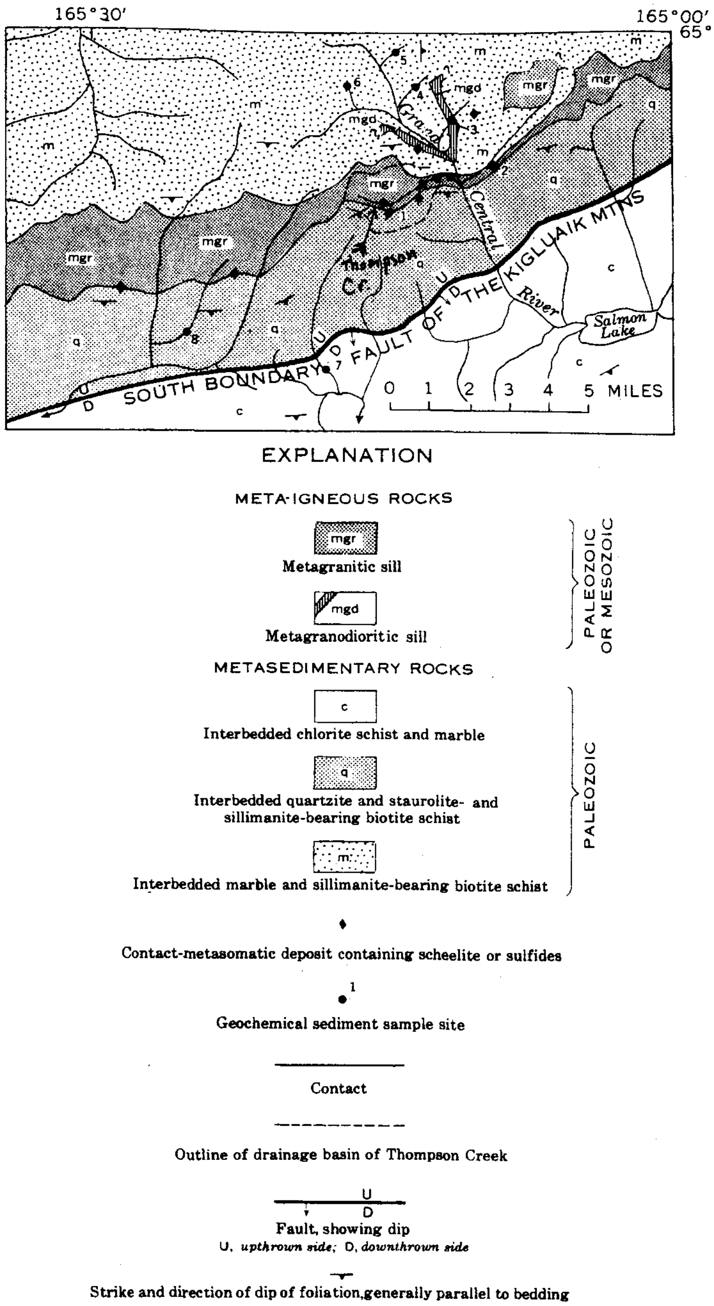

FIGURE 356.1.—Geologic map of part of the Kigluaik Mountains near Nome, Alaska, showing metamorphosed deposits and sediment sample sites.

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Hummel, C. L., and Chapman, R. M., 1960, Geologic and economic significance of some geochemical results obtained from stream sediment samples near Nome, Alaska, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400–B, p. B30–B33.

357. MULTIPLE GLACIATION IN THE HEADWATERS AREA OF THE DELTA RIVER, CENTRAL ALASKA

By Troy L. Péwé, College, Alaska

At least four Quaternary glaciations, each successively less extensive than the former, are recorded on the south side of the central Alaska Range in the headwaters area of the Delta River, an area of broad valleys and low mountains. These mountains, named the Amphitheater Mountains because of small cirque glaciers on the north-facing slopes, have a relief of 2,000 to 3,000 feet (fig. 357.1). A reconnaissance study was made of the entire area, and detailed investigations were made in the vicinity of High Valley.

In the past, glaciers pushed south from the Alaska Range, and some ice was confined to the wide, deep, major river valleys, such as the Maclaren. Much of the ice, however, filtered through gaps and passes in the Amphitheater Mountains and was joined by local glaciers. A small percentage of the ice from the south side of the Alaska Range found egress to the north through the Delta River pass (Péwé and others, 1953, p. 8).

The earliest glacial advance recognized is thought to be early to middle Quaternary age. This advance covered the 6,000-foot peaks of the Amphitheater Mountains and pushed south into the Copper River Basin. No till of this advance is known, but isolated erratics up to 15 feet in diameter occur on top of Paxson Mountain and an unnamed peak in the Amphitheater Moun-

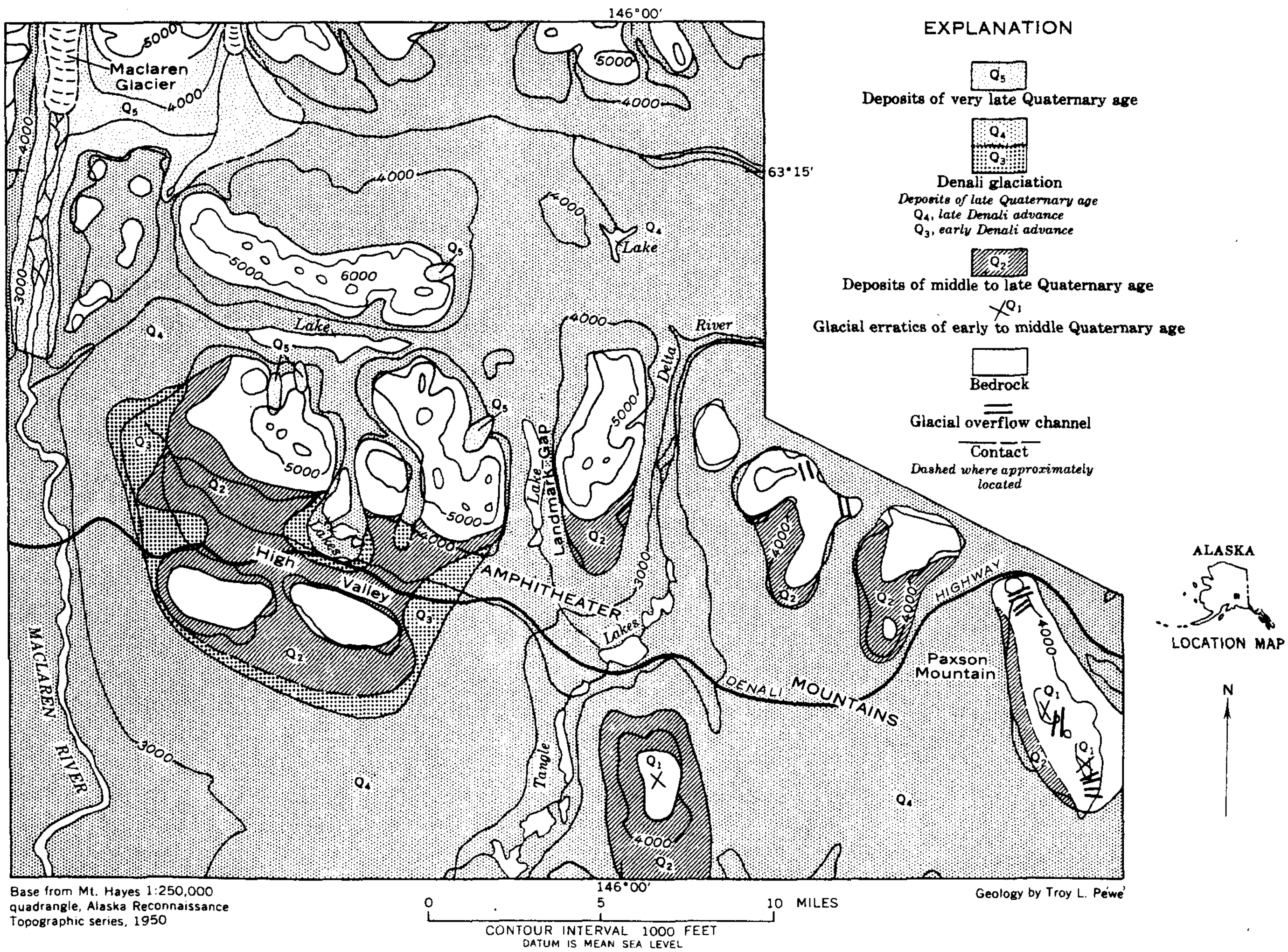

Figure 357.1.—Glacial deposits in the headwaters area of the Delta River, Alaska.

tains (fig. 357.1). A north-trending overflow gorge across the crest of Paxson Mountain was possibly cut during this glaciation. This advance is tentatively correlated with the Darling Creek advance recorded in the lower Delta River area (Péwé, 1952).

The second glacial advance pushed south to the Copper River Basin but did not cover the peaks of the Amphitheater Mountains. Many overflow channels were cut where drainage escaped over low places in ridges which protruded only slightly above the ice surface. These ridges now display high and dry water-cut gashes which are best exhibited just outside the southern border of the mapped area. This advance, thought to be middle to late Quaternary age, left an olive-colored silty till covering the lowlands and flanking the lower slopes of the Amphitheater Mountains. This till is now covered by later Quaternary drift or rubble sheets except above an elevation of 4,000 feet and on the floor of High Valley. No morainal forms of this glaciation are preserved in the area, probably because the drift has been covered by younger drift or rubble sheets. This glacial advance is tentatively correlated with the Delta glaciation of the lower Delta River (Péwé and others, 1953).

The next two glacial advances took place in late Quaternary time and are closely related in extent and age. They are here grouped together and named the Denali glaciation, after the Denali Highway, which traverses the deposits of these advances in the Amphitheater Mountains. The Denali glaciation is correlated with the complex Donnelly glaciation of the lower Delta River (Péwé, 1952).

These two advances did not cover the Amphitheater Mountains, but moved through gaps and were joined by local cirque ice. Ice was thick in major valleys such as the Maclaren River valley on the south side of the range, but was thinner over interfluves. Upon retreat, much of the ice in the headwaters area of the Delta River thinned and stagnated.

Well-preserved moraines, characterized by fresh knob-and-kettle topography, are typical of drift of late Denali age; moraines of early Denali age are more subdued, less effective in deflecting surface drainage, and slightly more extensive (fig. 357.1).

As the ice from the late Denali advance in the area stagnated many ice-contact features formed: eskers, kames and kettles, crevasse fillings, and pitted surfaces. The Tangle Lakes at the headwaters of the Delta River comprise a classic area for such features. They are strikingly fresh and cover an area of several hundred square miles.

Glacier-free lower slopes, especially north-facing slopes, in the Amphitheater Mountains are blanketed by a 3- to 7-foot thick sheet of now inactive rubble that was derived from higher slopes by frost riving during the rigorous climate of the time of the Denali glaciation. Some of the rubble sheets cover older till in High Valley.

During a readvance of the ice in very late Quaternary time (the fourth glaciation) ice streams on the south side of the central Alaska Range did not extend far enough to go through the gaps in the Amphitheater Mountains. Small glaciers in the Amphitheater Mountains deposited arcuate moraines at the mouths of short valleys at altitudes lower than the prominent lateral moraines deposited during the late Denali glaciation.

Cirque glaciers of the Amphitheater Mountains have advanced twice in historic time, each advance leaving two small sharp morainal ridges of angular rubble within a few hundred yards of the present ice fronts. These deposits are about 5,000 feet above sea level and are perhaps correlative with moraines deposited within the last two centuries by glaciers in the Delta River pass (Péwé, 1951, 1957).

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358. RECESSION OF PORTAGE GLACIER, ALASKA

By Ruth A. M. Schmidt, Anchorage, Alaska

Portage Glacier occupies a pass in the Kenai-Chugach Mountains between Cook Inlet and Prince William Sound at the southeastern end of Turnagain Arm, Alaska, in the Chugach National Forest. Because it is close to Anchorage and to the Seward Highway, the U.S. Forest Service has built a road to the area and provided picnic grounds and campsites. Examination of maps and photographs show that the glacier has receded 1.9 miles in 45 years; during this time a proglacial lake called Portage Lake formed behind a terminal moraine.

In 1898 Mendenhall twice crossed the glacier, and stated (Mendenhall, 1900, p. 301)—

* * * the isthmus connecting Kenai Peninsula and the mainland is crossed in a portage of about 12 miles to the head of Turnagain Arm. A glacier covers 4 or 5 miles of this isthmus, and its highest point is 1,000 or 1,100 feet above the sea, with a steep approach from the east. * * * This portage over the glacier is one of the oldest routes in Alaska, since more than a hundred years ago Captain George Vancouver reported that it had been long used by Russian and Indian traders as a means of communication between Cook Inlet and Chugatch Gulf [now Prince William Sound].

The route was used at that time only during the winter and spring months because of crevasses in the glacier during the summer. In 1914 it could still be crossed on a trail, but by 1939 a lake had formed in front of the glacier, and the surface had become too badly crevassed for passage.

Botanical evidence (Viereck, 1960, and oral communications, 1960) indicates that the last major advance of Portage Glacier culminated about 1893. As far as can be determined, the glacier reached about the same position then that it occupied in 1913-1914 when maps of the glacier were made in connection with studies for the Alaskan Engineering Commission. A terminal moraine that is present at this point dams the proglacial Portage Lake. No other terminal moraines have been seen in Portage Valley beyond this one.

Maps based on surveys by the Alaskan Engineering Commission in 1914 and the Alaska Railroad in 1939 (Barnes, 1943, pl. 16), and aerial photographs taken in 1950, 1951, and 1959 provide the following data on the recession of the glacier:

Period:	*Approximate recession of ice front, in feet (fig. 358.1)*
1914 to 1939 (25 years)	3,000
1939 to 1950 (11 years)	5,500
1950 to 1959 (9 years)	1,500
1914 to 1959 (45 years)	10,000

In 1913 elevations above sea level were measured at points *A* and *B* (fig. 358.1) on the northeast side of the surface of the glacier (Giffen and Bagley, 1914). Elevations at these points in 1913 and in two later years are given below:

Date	Elevation (feet)		Remarks
	A	B	
1913	492	934	
1939	----------	734	Surface reported as "at least 200 feet lower" (Barnes, 1943, p. 231).
1950	Lake surface (<150)	550	Estimated from topographic map, Seward D-5.

Barnes (1943, p. 232) reports that in 1939—

Soundings in *** [Portage Lake] *** revealed a maximum depth of 400 feet at the glacier front 2,000 feet southeast of the tip of Turnagain Shoulder, and depths of more than 200 feet at several places within 400 to 600 feet of the south and west shores.

In July 1960 soundings taken by the writer in approximately the same area as the 1939 glacier front gave depths of 250 feet to 260 feet, indicating that sediment about 150 feet thick had been deposited. The depth of the lake increased sharply from the terminal moraine to depths of more than 125 feet within 100 feet of the shore. A maximum depth of 595 feet was measured about 1,000 feet from the glacier front. Because of continual calving, no closer soundings were taken.

Measurements will continue to be made and photographs taken to provide a continuing record. Undoubtedly the recordbreaking high temperatures and low precipitation of the 1960-1961 winter will have a marked effect on the regimen of all the glaciers in Alaska.

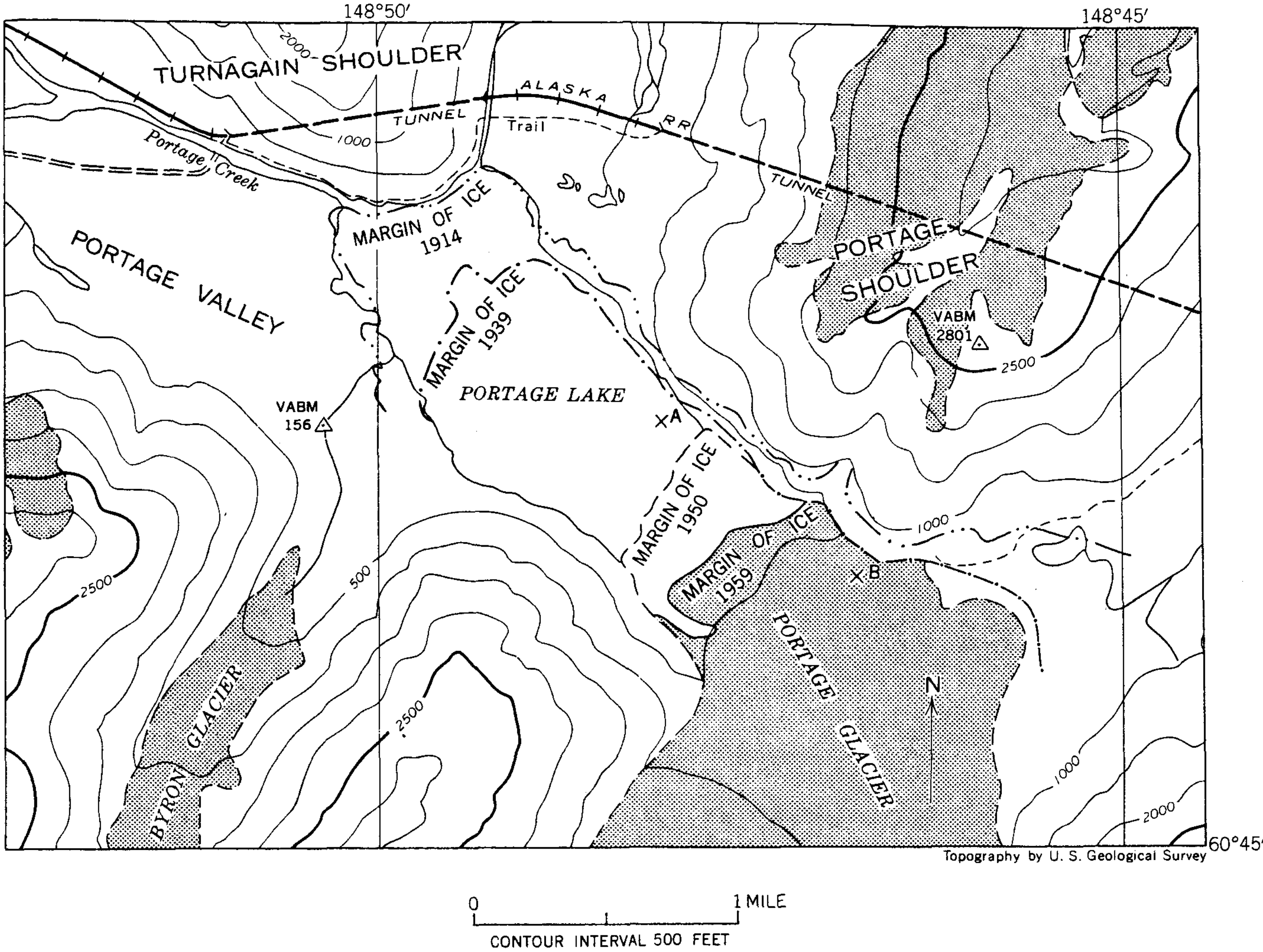

Figure 358.1.—Portage Glacier area, Alaska, showing glacier fronts from 1914 to 1959.

(Points *A* and *B* are described in text.)

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374. EARLY CRETACEOUS (MIDDLE NEOCOMIAN) MICROFOSSILS IN SOUTH-CENTRAL ALASKA

By Harlan R. Bergquist, Washington, D.C.

A small microfauna of middle Neocomian age has been found in rocks associated with the Nelchina limestone in the Talkeetna Mountains, south-central Alaska. This is the second record of Foraminifera of middle Neocomian age in North America—one foraminifer has been described from rocks of Hauterivian age near Coahuila, Mexico (Loeblich and Tappan, 1952).

The microfossils were found in a few samples that were collected by Arthur Grantz and Leo Fay from silty shale beds within and below the Nelchina limestone at five localities along Tyone Creek and along tributaries to Bubb and Billy Creeks (fig. 374.1). The microfauna consists largely of calcareous Foraminifera and a few species of Radiolaria, and in addition 2 species of ostracodes were found in 2 samples. The Foraminifera consist of 17 species of lagenids, 1 rotalid species, and 1 agglutinate species. Some of the Foraminifera appear to be the same as species described from rocks of middle Neocomian (Hauterivian) age of Glanerbrug, Netherlands (ten Dam, 1946, 1948).

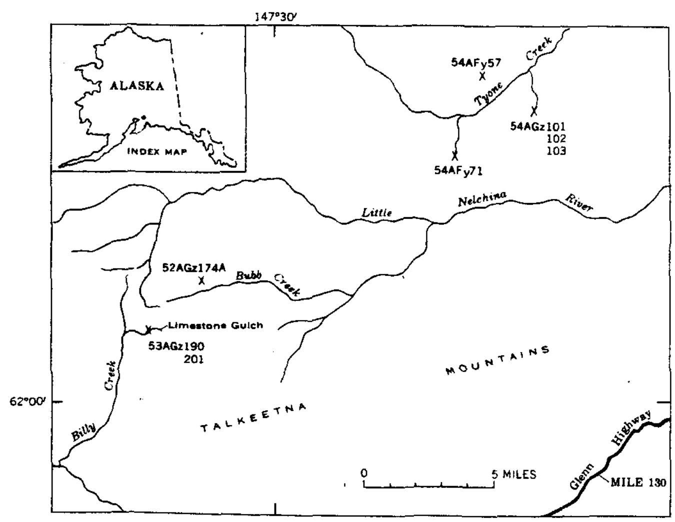

Figure 374.1.—Location of Lower Cretaceous microfossil collections from Nelchina limestone (Neocomian age), south-central Alaska.

Three of the samples were collected from an area south of the Little Nelchina River. Collection 52AGz174A (fig. 374.1) came from silty partings in massive Nelchina limestone on a north tributary of Bubb Creek, 3.38 miles S. 21°30′ E. of the main headwater fork of the Little Nelchina River. The Nelchina limestone there overlies a sandstone unit containing *Buchia crassicollis* (Keyserling) of middle Valanginian age as identified by Ralph Imlay (Grantz, 1953). The sample yielded 6 species of Foraminifera, including 2 that are common to abundant. Two collections (53AGz190 and 53AGz201) were made at Limestone Gulch, a tributary of Billy Creek, about 2¾ miles southwest of the locality on Bubb Creek. Collection 53AGz190 from a siltstone unit immediately below the Nelchina limestone contained 14 species of Foraminifera; 4 were common to abundant. Collection 53AGz201, from a silty parting within the Nelchina limestone, yielded 15 species of Foraminifera, the most found in any of the samples. Six of the species are common to abundant.

Other collections (54AGz101, 102, 103, and 54AFy57 and 71) were made from rocks associated with the Nelchina limestone along tributaries of Tyone Creek, north of the Little Nelchina River (fig. 374.1). Foraminifera from these are similar to those in the other collections, but the samples yielded fewer species; only 2 species were common to abundant in 2 of the collections. Three of the collections (54AGz102 and 103, and 54AFy71) had abundant specimens of Radiolaria.

Because only a few microfossil samples have been obtained from these Early Cretaceous rocks associated with the Nelchina limestone, and additional samples could not be collected readily, only tentative identifications have been made of the fossils as shown in table 374.1. Of the Foraminifera, the following were common or abundant in one or more samples: *Marssonella oxycona* (Reuss), *Lenticulina* cf. *L. münsteri* (Roemer), *Lenticulina* sp., *Robulus* sp. B, *Marginulina* cf. *M. robusta* Reuss, and *Epistomina caracolla* (Roemer). Some of these are the same species that have been found in rocks of middle Neocomian age in Germany, England, and near Glanerbrug, Netherlands. Two species, *Vaginulinopsis* cf. *V. pachynota* ten Dam and *Vaginulinopsis reticulosa* ten Dam,, though of relatively rare occurrence, appear to be the same as forms described from middle Neocomian rocks in the Glanerbrug, Netherlands area (ten Dam, 1946).

TABLE 374.1.—*Distribution of microfossils in samples from Early Cretaceous (Neocomian) strata, south-central Alaska*

[Number of specimens are given if less then 12 were found; C, common (12 to 25 specimens); A, abundant (25 to 50 specimens); V, very abundant (more than 50 specimens found); f, fragment]

Fossil	Collection number						
	52AGz174A	53AGz190	53AGz201	54AGz101	54AGz102	54AGz103	54AFy71
Marssonella oxycona (Reuss)	A	A	A	7	A	C	A
Lenticulina münsteri (Roemer)	8	A	V		A	C	C
sp. (multichambered)	C	C	C	5			
Robulus sp. A (raised sutures)	2	2	4		6		10
sp. B (smooth wall)			C				
Marginulina cf. *M. robusta* Reuss		7	C		1		
sp		2					
Marginulinopsis cf. *M. gracillissima* (Reuss)		1	1				
Nodosaria sp. A (5 costae)		2			3		
sp. B (7 costae)			4				
Dentalina aff. *D. gracilis* d'Orbigny			2				
Rectoglandulina sp	1						
Saracenaria sp		6	2				
Vaginulina sp		2	1				
Vaginulinopsis cf. *V. pachynota* ten Dam	3	7	3				1
reticulosa ten Dam		1	10		1		1
sp			8				
Frondicularia sp. (costate)		f					
Epistomina caracolla (Roemer)		C	C				
Radiolaria:							
Nasselina			P		A	A	A
Spumellina					A	P	A
Ostracoda:							
sp. A, smooth carapace		P					P
sp. B, ornamented carapace		P					

Radiolaria in these samples are nasselline and spumelline forms belonging to the Stichocorythidae, Triacartidae, and Liosphaeridae. Specimens are large, and most have been somewhat distorted by compression. Stichocorythidian forms which may be species of *Dictyomitra?* and *Cyrtocapsa?* are most abundant. Spumelline forms are represented only by Liosphaeridae, which seem to be entirely cenosphaerids and cenodiscids. The Radiolaria in collection 54AGz102 are cenosphaerids and stichocorythidian forms and are preserved as incomplete glauconitic casts. Collection 53AGz201 has a few glauconitic casts of stichocorythidian forms.

Strata of Neocomian age in south-central Alaska have not been extensively sampled for microfossils; it is intended here only to call attention to their presence in these rocks. The Foraminifera are of particular interest as little is known about this group of organisms in the earliest Cretaceous rocks of North America.

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Re-examination of earlier information on the stratigraphic occurrences of the various species of *Tempskya* and consideration of new discoveries indicate that the age of the genus is more restricted than was formerly thought (Read and Brown, 1937), and that in the western part of the United States it is restricted to strata that are Albian in age.

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GEOPHYSICS

383. GRAVITY LOW AT MINTO FLATS, ALASKA

By David F. Barnes, Menlo Park, Calif.

Much of central Alaska consists of broad alluvium-covered topographic basins, which may also be structural basins, containing Cenozoic deposits of considerable thicknesses. One phase of the Geological Survey's petroleum investigations in this area has been the determination of the thickness of these deposits. One of the areas studied is the Middle Tanana basin (Miller, Payne, and Gryc, 1959) that extends for about 100 miles both east and west of Fairbanks. The basin is divided into two embayments by an upland promontory that extends southward to the town of Nenana. Aeromagnetic lines flown south of Fairbanks in 1955 (Zietz and Wahrhaftig, written communication, 1960) cross the center of the eastern and larger embayment, where they show that pre-Cenozoic basement rocks lie within 500 meters of the surface. Recent gravity surveys suggest that a thick section of Cenozoic deposits may be present in the western embayment. The first indication of this sedimentary section was a –40.6 Bouguer gravity anomaly recorded at the village of Minto (Thiel and others, 1958). Recent gravity surveys by the U.S. Geological Survey have defined the form and magnitude of this gravity low (fig. 383.1) that covers all the broad swampy Minto Flats west of Nenana and extends south of them towards the Alaska Range.

Precambrian rocks of the Birch Creek schist (Mertie, 1937) crop out along the eastern edge of the Minto Flats and form the upland promontory that divides the Middle Tanana basin into two parts. The northern and western rim of the flats is formed by hills underlain by strongly folded and faulted Paleozoic and Mesozoic sedimentary rocks (Capps, 1940). The southern part of the Middle Tanana basin slopes upward into the foothills of the Alaska Range, where the Nenana gravel and the coal-bearing formation of Tertiary age crop out (Wahrhaftig, 1958). The structure of these deposits shows that folding and faulting during the middle Tertiary formed local basins in which as much as several thousand feet of sediments have accumulated

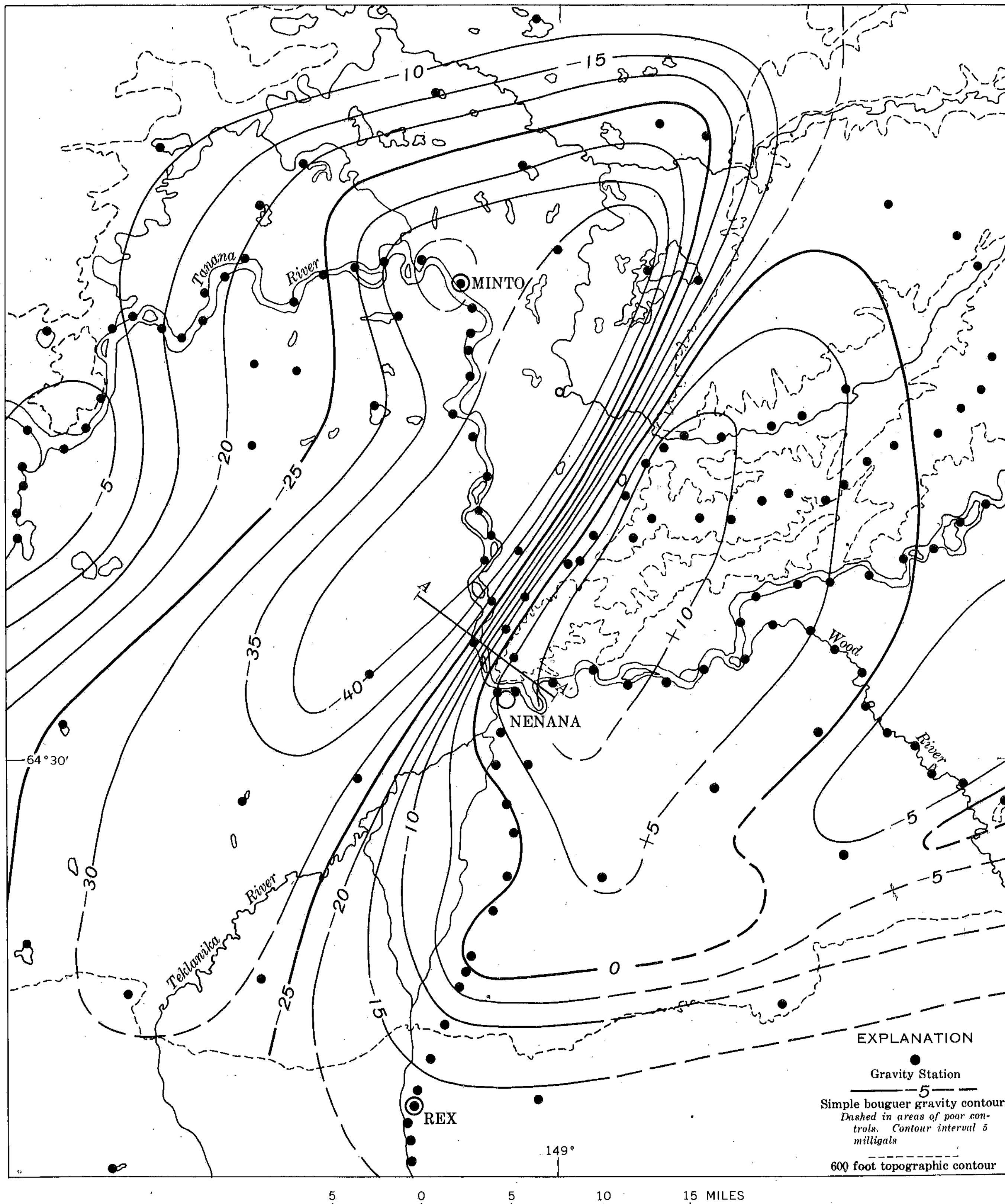

FIGURE 383.1.—Contour map of simple Bouguer gravity anomaly, Minto Flats, Alaska.

(Wahrhaftig, 1950). Physiographic evidence (D. M. Hopkins, oral communication, 1961) strongly suggests that the Minto Flats are actively subsiding, and that sediments are accumulating there at the present time.

Figure 383.1 is a map of the western part of the Middle Tanana basin. The gravity contours show simple Bouguer anomalies computed from observed gravity values at Fairbanks (Thiel and others, 1958) using a rock density of 2.67. The most important features of this map are a broad kidney-shaped low and a steep gradient along its eastern side. The −10 mgal contour defines the outer edge of the low and approximately coincides with the 600-foot altitude contour, which marks the edge of the hills bordering the Minto Flats. Bouguer gravity values associated with all the hills and lowlands adjacent to the flats range from −10 to +12 mgals except on the southern end of the flats where lower gravity values are associated with the Alaska Range. A gravity traverse along the road from Fox to Livengood north of the mapped area crossed contacts between Precambrian, Paleozoic, and Mesozoic rocks but did not reveal any large anomalies. Accordingly, density contrasts within the rocks forming the basement complex are probably not sufficient to explain the anomaly at Minto Flats.

The gravity low associated with the Minto Flats has a magnitude of −35 to −55 mgals in relation to the surrounding areas. The steepness of the gradient west of Nenana indicates that the anomaly has a shallow source; its maximum theoretical depth (Bott and Smith, 1958) is 3 km. As the gradient approximately coincides with a contact at the surface between Quaternary deposits and the denser Birch Creek schist, this contact may be the source of the anomaly. The data do not completely eliminate the possibility, however, that all or part of the anomaly may be caused by another shallow basement contact such as the edge of the possible mafic rock mass postulated by Woollard and others (1960) in the vicinity of Nenana. Nearby outcrops, however, do not show such a mafic rock mass.

The thickness of the sedimentary prism required to cause the Minto Flats anomaly depends on the density contrast between the sediments and the basement rocks, but data for estimating this contrast are scarce. Specific gravities of a dozen hand specimens of Precambrian and Paleozoic basement rocks range from 2.6 to 2.8, but the densities of Cenozoic rocks of the types that may be present beneath the Minto Flats vary widely with age and character. On one extreme, Recent alluvium containing significant amounts of

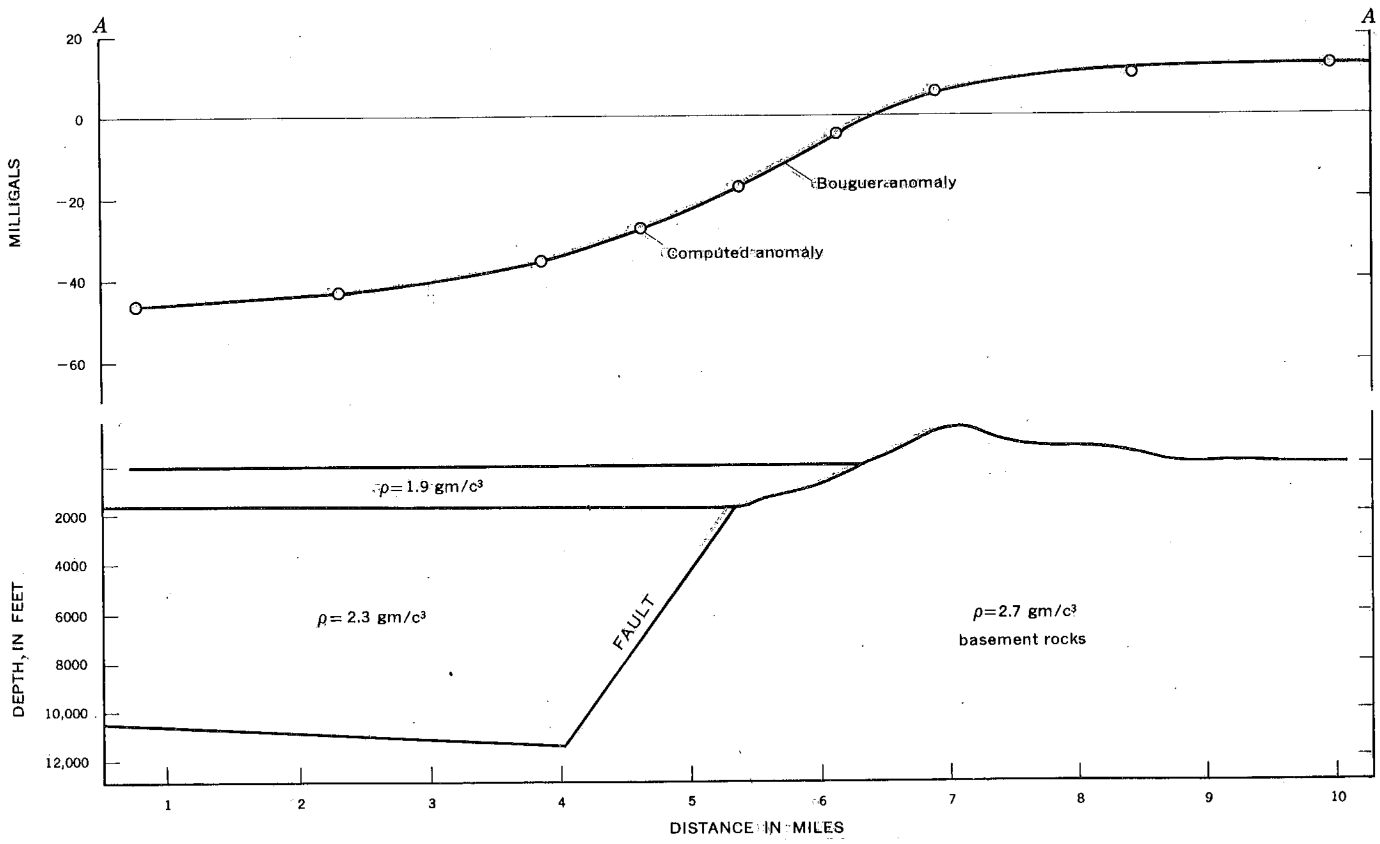

FIGURE 383.2.—Observed and computed gravity on profile *A–A'* north of Nenana and suggested subsurface configuration.

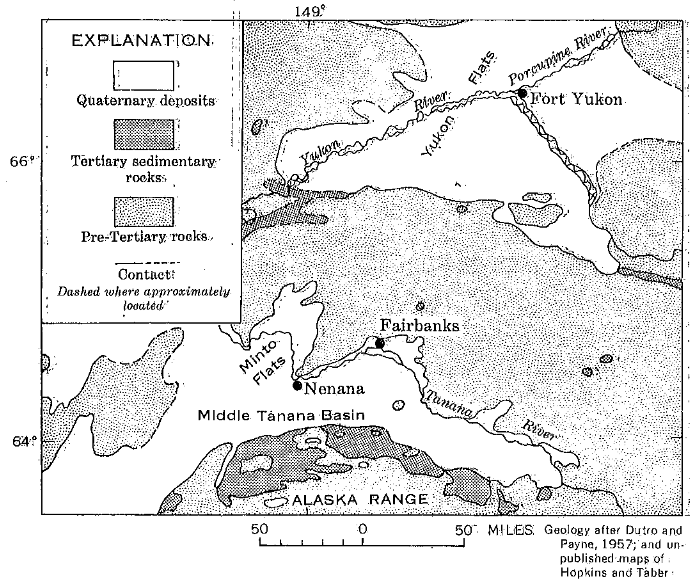

FIGURE 383.3.—Distribution of Tertiary and Quaternary sedimentary rocks in central Alaska.

either ice or organic matter may be lighter than 1.8; and at the other extreme, laboratory measurements of a few hand specimens of water-saturated sandstones of Tertiary age from the Yukon-Tanana area were as high as 2.6. Thus the thickness of the sedimentary section in Minto Flats could range from one to several kilometers. Figure 383.2 shows a plot of the anomaly along profile *A–A′* near Nenana and one of the several basement configurations that could produce such an anomaly. The suggested configuration assumes a layer of low-density alluvium overlying a thicker, intermediate-density section which is separated from the basement rocks by a normal fault. Such a fault would project very close to the oil seep reported near the mouth of the Nenana by Miller and others (1959).

Some conclusions regarding the age of the deeper deposits beneath the Minto Flats may be drawn from the rather large thickness required to explain the gravity anomaly. The maximum thickness of Quaternary alluvium that has been measured in the Tanana Valley is about 250 meters at a seismic station 2 miles south of Fairbanks, measured by the author in 1952. Williams (1960) reports that about 120 meters of alluvium at Fort Yukon are underlain by late Tertiary deposits. Even a 1 km sedimentary section would thus be considerably thicker than nearby deposits of Quaternary alluvium, and even 1 km of subsidence during Quaternary time would represent a rather rapid crustal movement. Accordingly, older Tertiary deposits are probably present in the deeper part of the Minto Flats basin. These Tertiary rocks are probably denser than Quaternary alluvium so the thickness of the section required to cause the anomaly is probably greater than 1 km. The subsidence which created the Minto Flats basin may have begun at about the same time as the subsidence and faulting that created nearby basins in which Tertiary sedimentary rocks are now exposed. Extensive Tertiary deposits (fig. 383.3) are present both north and south of the Minto Flats in the Alaska Range (Wahrhaftig, 1958) and along the Yukon River between the Yukon flats and the Palisades (Eakin, 1913). Coal-bearing rocks are present in the lower parts of both the Alaska Range and Yukon Valley Tertiary sections, and may also be present beneath the Minto Flats. Gravity values at the southern end of the Minto Flats anomaly are lower than in other bordering areas and suggest that the sedimentary prism may have a shallow connection with one of the basins containing Nenana gravel.

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418. GEOLOGIC RESULTS OF NOVEMBER 1960 PROJECT CHARIOT HIGH-EXPLOSIVE CRATERING EXPERIMENT, CAPE THOMPSON, ALASKA

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Work done in cooperation with the U.S. Atomic Energy Commission

In November 1960, a high-explosive cratering experiment was made at the Project Chariot site near Cape Thompson, northwestern Alaska, by the Lawrence Radiation Laboratory, Livermore, Calif., under authorization of the Atomic Energy Commission. The experiment consisted of the detonation of a 256-pound spherical charge of TNT at a depth of 8.7 feet in the Tiglukpuk(?) formation of Jurassic age. At ground zero the Tiglukpuk(?) formation consisted of mudstone in beds having an average thickness of ¼ of an inch and a maximum thickness of about 2 inches. The strike of the beds was fairly constant at N. 55° E.; however, the dip ranged from 80° SE to 70° NW and averaged 85° N.W. As shown on figure 418.1, the mudstone was frozen from the surface to a depth of 1.5 feet (frozen active zone); it was unfrozen from depths of 1.5 to 4.0 feet (thawed active zone); and it was permanently frozen from depths of 4.0 to 9.0 feet (permafrost zone). Annual freezing and thawing had distorted and highly fractured the mudstone in the active zones. Most of the fractures in the frozen active zone were healed by ice, whereas fractures and joint planes in the thawed active zone were uncemented. Mudstone in the thawed zone was more friable than the mudstone in the frozen zones. In the frozen active zone the moisture content was 3.1 percent; in the thawed active zone, it was 3.6 percent; and in the permafrost zone, it ranged from 4.4 to 12.5 percent. Ice lenses and vugs were common in the permafrost zone.

A nearly symmetrical crater 8 feet deep and 26 feet in diameter was produced by the explosion (fig. 418.1). The apparent volume of the crater was 78.5 cubic yards, and the volume of the debris on the lip of the crater was 110 cubic yards (C. Bacigalupi, written communication, 1960), which gives the swell of the debris as 40 percent. Debris was deposited in the crater, in an asymmetrical apron around the crater, and as a fine-grained fallout. Throwout as used in this report consists of material that followed ballistic trajectories to the site of deposition. Fallout consists of material arrested in its ballistic flight by atmospheric drag. The subsequent deposition was controlled by free fall and by atmospheric currents. The fallout did not contain any radioactive debris because a chemical explosive was used. The spatial distribution of debris is shown on figures 418.1 and 418.2. Only minor intermingling of debris of the different zones occurred in the crater.

The average diameter of the area covered by the throwout debris was between 800 and 900 feet (figs. 418.1 and 418.2). The minimum radius of the apron of throwout debris was about 350 feet in a northwest direction, which is the direction of the average dip of the beds. The maximum radius was 550 feet in a southeast direction, opposite the direction of dip.

Three zones of debris were recognized in the apron (fig. 418.2): an inner zone extending from the crater lip to about 45 feet from ground zero; an intermediate zone extending from about 45 to about 250 feet from

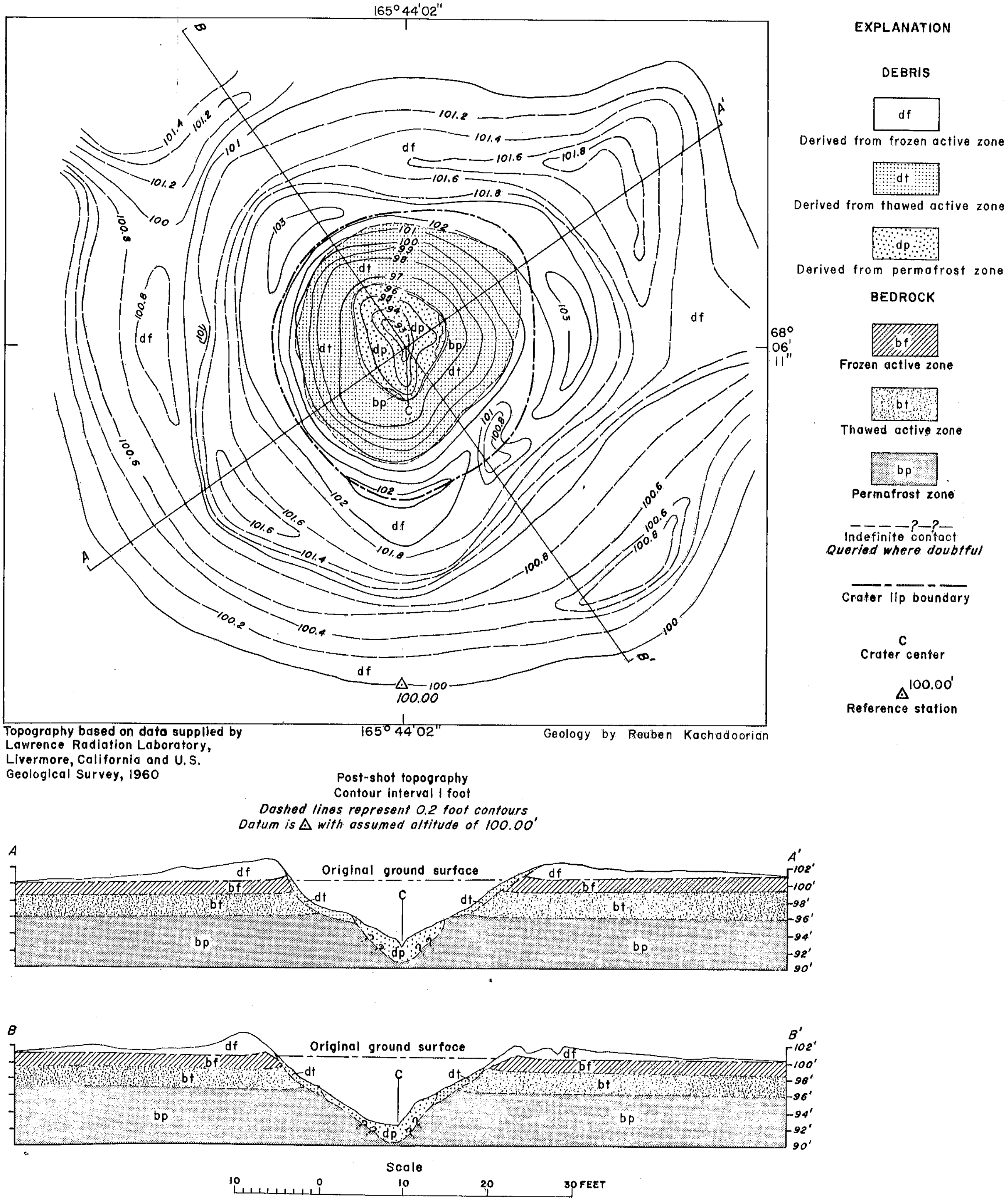

FIGURE 418.1.—Geologic map and sections of November 1960 Project Chariot high-explosive test.

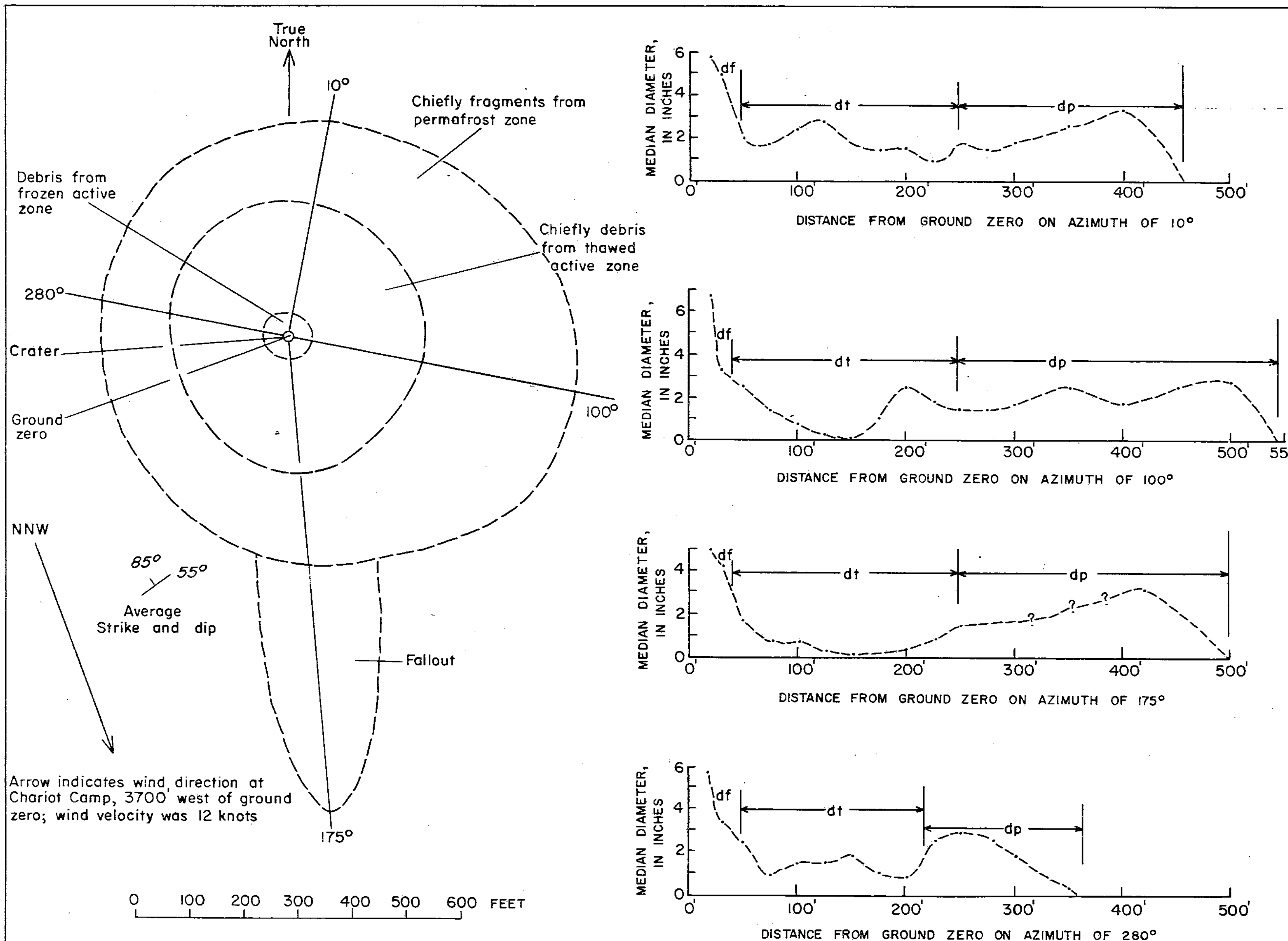

FIGURE 418.2.—Map showing distribution of throwout and fallout debris and graphic depiction of size distribution of throwout debris.

ground zero; and an outer zone extending from about 250 feet from ground zero to the maximum distance of throwout (550 feet).

The rocks in the inner zone were derived from the frozen active zone and consisted of debris that was mostly overturned and had traveled only short distances. The largest boulder noted was in this zone and had the dimensions 5 x 4½ x 1½ feet. The frozen-unfrozen interface, 1.5 feet below the surface, controlled one dimension of the fragments derived from the frozen active zone. No fragment with a minimum dimension larger than 1.5 feet was noted. Although most of the large fragments were overturned and had moved short distances, the top 2 to 3 feet of concrete used to plug the hole in which the explosive was placed landed 335 feet from ground zero on an azimuth of 185°.

Throwout debris in the intermediate zone consisted chiefly of material derived from the thawed active zone. The thickness of debris was much less than that of the debris derived from the frozen active zone, and the median diameter of the fragments was much less than that of fragments obtained from the overlying and underlying frozen rock zones. This was to be expected because the rocks of the thawed active zone were not cemented by ice and were somewhat more friable than the frozen rocks.

Rock fragments in the outer throwout zone were derived chiefly from the more massive mudstone beds of the permafrost zone. The median diameter of the fragments was larger than that of the debris in the intermediate zone, but smaller than that of debris in the inner zone. However, the number of fragments was much lower. Beyond 300 feet from ground zero, only sporadic fragments were noted.

The pattern of deposition of the fine-grained fallout, consisting of nonradioactive particles less than 2,000 microns in diameter as determined by K. H. Larson (written communication, 1961), was controlled by the direction of wind, which at the time of detonation was from the north-northwest (340°) and had a velocity of 12 knots. Fallout debris was seen only south of ground zero (fig. 418.2). The fallout debris was noted as far as 875 feet from ground zero on an azimuth of 175°; the fallout belt was about 215 feet wide, 550 feet from ground zero. The material comprising the fallout consisted chiefly of mudstone from the thinner beds. The zone or zones (frozen active, thawed active, and permafrost) from which the debris was derived is unknown.

The average height of the cloud due to the detonation was about 190 to 200 feet and the width was approximately 175 feet. However, in the center of the cloud a streamer about 30 feet wide rose to a height of approximately 250 feet. This streamer probably marked the trajectory of the concrete plug that landed 335 feet south of ground zero.

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419. ENGINEERING GEOLOGY PROBLEMS IN THE YUKON-KOYUKUK LOWLAND, ALASKA

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Engineering geology problems in the Yukon-Koyukuk lowland, west-central Alaska (fig. 419.1) are concerned mainly with flooding, source of aggregate, and poor foundation conditions caused by seasonally and perennially frozen ground. The lowland is approximately 100 miles long and 40 miles wide, and is bounded by rounded hills 1,000 to 2,000 feet above the flood plains of the major rivers. The area was not glaciated in Pleistocene time but was subject to alternating periods of great deposition and erosion. Unconsolidated deposits of Quaternary age are more than 300 feet thick in places, although locally a few bedrock knobs project above the alluvium.

Two large rivers, the Yukon and Koyukuk, meander across the lowland. The flood plains are covered by a mosaic of tundra and forest interspersed with a complex of sloughs, meander scars, oxbow lakes, swamps, and creeks. For mapping purposes the surficial deposits have been subdivided into 6 map units—2 terrace units, and 4 flood plain units—which may be distinguished largely on the basis of ice and organic content, topographic expression, vegetation, and to some extent lithology. Engineering geology problems differ in degree or kind in the various units.

The two terraces range in height above the flood plains from 30 to 250 feet. They are formed of perennially frozen gray silt and sand with variable amounts of organic matter and include masses of ground ice—vertical and inclined ice dikes or wedges ¼-inch to 3-feet wide and 3 to 15 feet high (Péwé, unpublished

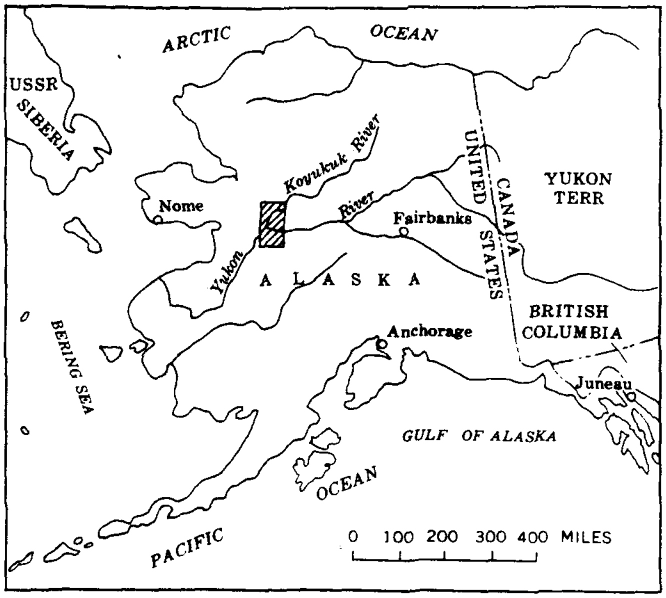

FIGURE 419.1.—Index map of a part of Alaska showing the location of the Yukon-Koyukuk lowland.

data). The terraces, which differ from each other only in relative height, are poorly drained and are covered with a myriad of steepsided thaw lakes, ponds, and swamps. Polygonal ground and braided streams are common. Mosses, sedges, low brush, stunted black spruce, and (rarely) birch grow on these frozen silts. Foundation conditions on both of the terraces are poor. Breaking of the insulating tundra can result in a summer quagmire and the ground will subside because of the thawing of ice masses. The poorly drained fine-grained sediments are also susceptible to intense seasonal frost heaving.

In the northern part of the lowland the terraces are commonly covered by alluvial sand, which in many places forms dunes. The sandy areas are well drained, free of large ground-ice masses and thaw lakes. The dunes are largely inactive and support an open forest of aspen, birch, and spruce. Foundation construction conditions on the ice-free sandy zones are fair although slopes in dry sand are unstable.

The flood-plain map units—"linear," "advanced linear," "coalescent," and "scalloped"—represent four arbitrary phases in the development of the flood plain (fig. 419.2). This area has been cited as a classic example of the development of a flood plain by meandering rivers under subarctic conditions (Péwé, 1947), and the classification of these flood plain units has been extended successfully to the flood plain of the Kuskokwim River (Drury, 1956). The linear phase is the first formed and the scalloped is the last. The four units can be distinguished on the basis of the shape of the lakes, vegetation, and the amount of ice and organic material they contain. The foundation qualities of the units vary largely with the amount of ground ice present. The first phase of development, the linear unit, is made up of gray micaceous silt and sand forming slipoff slopes, islands, and other low areas most recently occupied by rivers. Linear, "point bar" lakes are present and an integrated drainage is lacking. Permafrost is absent or discontinuous; no large ground ice masses are present. Vegetation is made up mostly of grasses, *Equisetum*, alder, willow, and some large cottonwood and spruce trees. This unit is fairly good for foundation purposes but is subject to flooding, river cutting, and icing. The only gravel suitable for aggregate that is present at the surface in the lowland is found sparingly in this unit.

The second flood-plain map unit, marking the advanced linear phase, is lithologically similar to the first. Elongate lakes, partially broken into segments by encroaching vegetation, and discontinuous permafrost (with no large ice masses) are characteristic of this phase. Relatively large birch and spruce with a brushy understory grow on the unit. Although the unit is fairly good for foundation purposes, it is also subject to seasonal flooding.

Broad swampy areas adjacent to the large rivers which are marked by coalescing linear lakes form the third unit or coalescent phase of the flood plain. Large ground-ice masses are present in the organic silt, and melting of these masses results in the partial coalescence of the linear lakes. Mosses, cottongrass tussocks, cranberry, alder, stunted spruce, and birch grow here. The unit is poor for construction as it is very wet and subject to intense frost heaving and to subsidence upon thawing of permafrost. Areas underlain by this unit may be inundated in flood stage.

The last unit of flood plain development is the scalloped phase. Lakes have lost their linear shape, are rounded, and have scalloped edges. Ice wedges and many large masses of ground ice are characteristic of this stage. In general, drainage, ground ice, and vegetation characteristics are similar to those of the adjoining terraces but the unit lies near enough to river level to be flooded occasionally. Because of poor drainage, susceptibility to intense frost heaving, and the presence of large ground-ice masses, the unit is very poor for foundations or construction of any sort.

Precise dating of the units in the area is not yet possible. However, bones of extinct Pleistocene mammals (Mammoth) have been found in deposits of the oldest terrace. A carbon-14 date of 8,140±300 years

FIGURE 419.2.—High-altitude oblique aerial photograph looking south toward the junction of the Yukon and Koyukuk Rivers. The Koyukuk River (dark color) joins the silt-laden Yukon River (light color) at the right. Flood-plain units indicated by number are the (1) linear phase, (2) advanced linear phase, (3) coalescent phase, and (4) scalloped phase. Unit (5) is the high terrace. Photograph by U.S. Army Air Corps, August 24, 1941.

(W–472) (Rubin and Alexander, 1958, p. 1479) was obtained from organic material taken from the scalloped phase of the flood plain. Therefore, the formation of much of the modern flood plain postdates this time; cutting of the terraces took place prior to this date. Eolian reworking of the sand on the terraces has persisted until the present, as indicated by a small area of active dunes north of the Koyukuk River.

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