GEOLOGICAL SURVEY RESEARCH 1967

Chapter D

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Scientific notes and summaries of investigations in geology, hydrology, and related fields

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GEOLOGICAL SURVEY RESEARCH 1967

This collection of 48 short papers is the third published chapter of "Geological Survey Research 1967." The papers report on scientific and economic results of current work by members of the Conservation, Geologic, Topographic, and Water Resources Divisions of the U.S. Geological Survey.

Chapter A, to be published later in the year, will present a summary of significant results of work done during fiscal year 1967, together with lists of investigations in progress, reports published, cooperating agencies, and Geological Survey offices.

"Geological Survey Research 1967" is the eighth volume of the annual series Geological Survey Research. The seven volumes already published are listed below, with their series designations.

Geological Survey Research 1960—Prof. Paper 400
Geological Survey Research 1961—Prof. Paper 424
Geological Survey Research 1962—Prof. Paper 450
Geological Survey Research 1963—Prof. Paper 475
Geological Survey Research 1964—Prof. Paper 501
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STRATIGRAPHIC EVIDENCE FOR THE LATE DEVONIAN AGE OF THE NATION RIVER FORMATION, EAST-CENTRAL ALASKA

By EARL E. BRABB and MICHAEL CHURKIN, JR.,
Menlo Park, Calif.

Abstract.—The stratigraphic position and age of the Nation River Formation have long been controversial problems, primarily because previous workers failed to recognize an unconformity at the base of the overlying Tahkandit Limestone of Permian age at the type locality of these formations near the mouth of the Nation River. In the vicinity of McCann Hill and the Tatonduk River, the Nation River Formation is stratigraphically above shale and chert of the McCann Hill Chert of Early, Middle(?), and Late Devonian age and below similar rocks of Late Devonian to Mississippian age, and thus by superposition is no older than Middle Devonian and no younger than Late Mississippian. Spores collected from the Nation River Formation at 18 localities throughout its type area and elsewhere corroborate the stratigraphic evidence and indicate that the formation is almost certainly Late Devonian.

A recent report by Laudon and others (1966) on the Paleozoic stratigraphy of east-central Alaska has focused attention on the problem of the stratigraphic position and age of the Nation River Formation. The stratigraphic position of this thick sequence of conglomerate, sandstone, and shale, considered since 1930 to be of Pennsylvanian(?) age, is important in reconstructing the tectonic history of eastern Alaska. A Late Devonian age assignment and a revision in the stratigraphic position of this formation were first formally reported briefly by Churkin and Brabb (1965). Subsequently, Laudon and his colleagues offered alternate explanations for its stratigraphic position and its assignment to the Devonian. The purpose here is to document more fully the stratigraphic evidence for the Devonian age of the formation. The palynological evidence for the age of the Nation River Formation has been described by Scott and Doher (1967).

All the basic stratigraphic conclusions of the present report were shown on the preliminary maps of the Charley River (1:250,000) and Eagle D–1 (1:63,360) quadrangles by Brabb (1962) and Brabb and Churkin (1964, 1965) released in open files of the U.S. Geological Survey.

The Nation River Formation crops out in the vicinity of the Yukon River and its tributaries (fig. 1) near the town of Eagle and the Alaska-Yukon Territory boundary. Rocks in this area range in age from late Precambrian to Quaternary, with nearly every geologic system being represented. All the pre-Tertiary rocks have been extensively folded and faulted.

The writers were ably assisted in the field by R. N. Passero and H. J. Roepke, in 1960; J. C. Melik and R. L. Taylor, in 1961; and A. J. Aadland, in 1962.

PREVIOUS WORK

The first map to show the distribution of conglomerate, sandstone, shale, and coal now referred to the Nation River Formation was made by Collier (1903, fig. 2). He thought that these rocks might be Carboniferous or Permian inasmuch as they seemed to lie beneath an unnamed limestone of Permian age, but he also thought that they could be infolded rocks of Eocene age. Collier's stratigraphic interpretation is shown on figure 2, column 1.

Brooks and Kindle (1908, p. 294, 295) named these rocks the Nation River Formation, stating,

> The Nation River series included about 3,700 feet of gray clay shales, with some clay slates interpolated with heavy beds of conglomerate and some sandstone. It is typically exposed along Nation River, where it includes some small seams of bituminous coal. The limits of this formation are well defined. The base is believed to be marked by an unconformity which separates it from the shales and limestone of the Calico Bluff formation. At the top it is limited by the heavy limestone which previously formed the topmost member of the Carboniferous . . .

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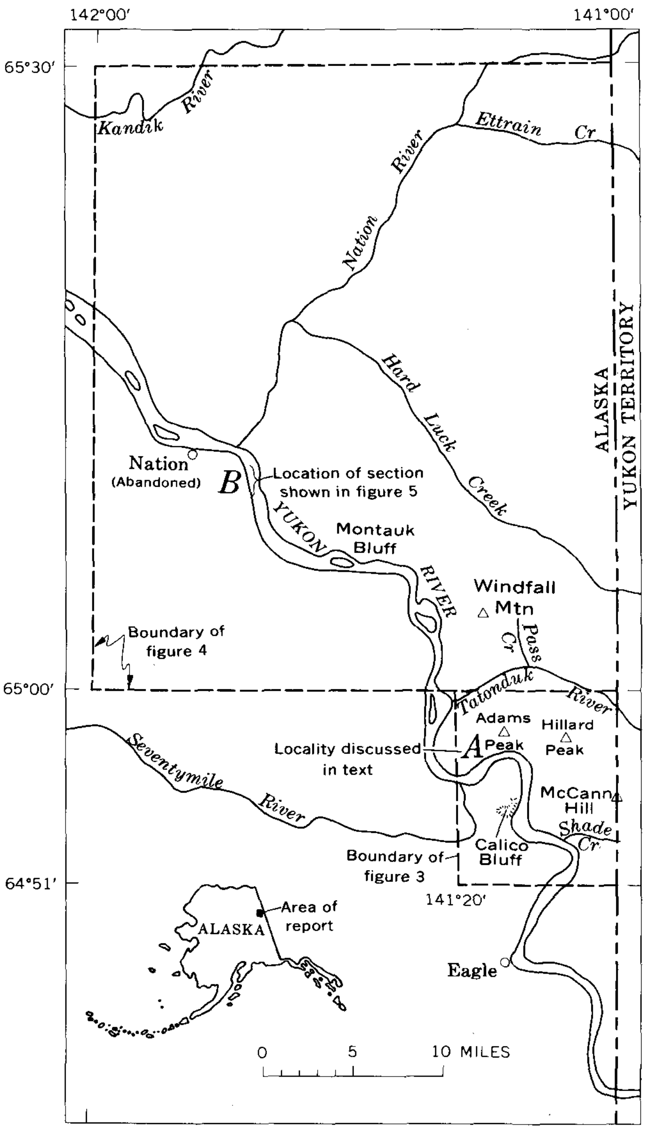

FIGURE 1.—Index map showing location of Nation River area, Alaska.

The stratigraphic succession envisioned by Brooks and Kindle is also shown in figure 2, column 2, but the basal unconformity they observed is near Adams Peak (locality *A*, fig. 1), 20 miles southeast of the Nation River area (locality *B*, fig. 1), and apparently is between the Calico Bluff Formation of Late Mississippian age and unnamed rocks of Late Cretaceous age (Mertie, 1930, p. 146, Kindle collection 11h note).

Cairnes (1914) included in the Nation River Formation the overlying "heavy" limestone mentioned by Brooks and Kindle and extended the age of the Nation River to possibly include Permian, mainly because he worked along the Alaska-Yukon Territory border where the Permian is represented largely by conglomerate and sandstone (fig. 2, column 3). He also included a "peculiar" conglomerate which he thought might represent a till formed during a Permo-Carboniferous glacial period. Subsequent mapping by Mertie (1933, p. 27) and Brabb and Churkin (1964) has shown that this conglomerate is part of the Tindir Group of Precambrian age. Cairnes recognized that still another conglomerate on McCann Hill (fig. 1) might represent the base of the Nation River Formation, but he found no diagnostic fossils to date these beds.

J. B. Mertie's (1930, 1933, 1937) stratigraphic concepts (fig. 2, columns 4 and 5) were based on the first detailed geologic mapping and on a synthesis of earlier work. Mertie designated the Nation River Formation as Pennsylvanian(?) because he believed it graded upwards into the Tahkandit Limestone of Permian age. Fossil plant fragments collected by Mertie and earlier geologists, however, were referred with some uncertainty to the Mississippian or Late Devonian by David White, of the U. S. Geological Survey. Mertie clearly recognized (1937, p. 145) that the age of the Nation River Formation was an unsettled problem.

Nelson (1961) in discussing the Carboniferous and Permian stratigraphy in the adjacent part of the Yukon Territory has shown that the rocks he recognizes as the Calico Bluff and Tahkandit Formations are separated by a limestone and shale unit, not the Nation River Formation.

Churkin and Brabb (1965, p. 182) reported that spores collected throughout the Nation River Formation at several localities, including its type area, are all probably Upper Devonian, according to Richard A. Scott. We also stated that stratigraphic relations show that the formation cannot be younger than the Late Mississippian Calico Bluff Formation.

Laudon and others (1966) questioned this Late Devonian age assignment, stating (p. 1869), "Assignment of a Devonian age to the Nation River Formation introduces complicated and as yet unresolved stratigraphic and structural problems." They, like Mertie, could not see how the Nation River Formation could be overlain by shale and chert of Mississippian age in the vicinity of McCann Hill and Calico Bluff (fig. 1) and by the Tahkandit Limestone of Permian age in the vicinity of the Nation River (fig. 1). They did not consider the possibility of an unconformity at the base of the Tahkandit Limestone, which we believe explains all the stratigraphic and structural relationships observed.

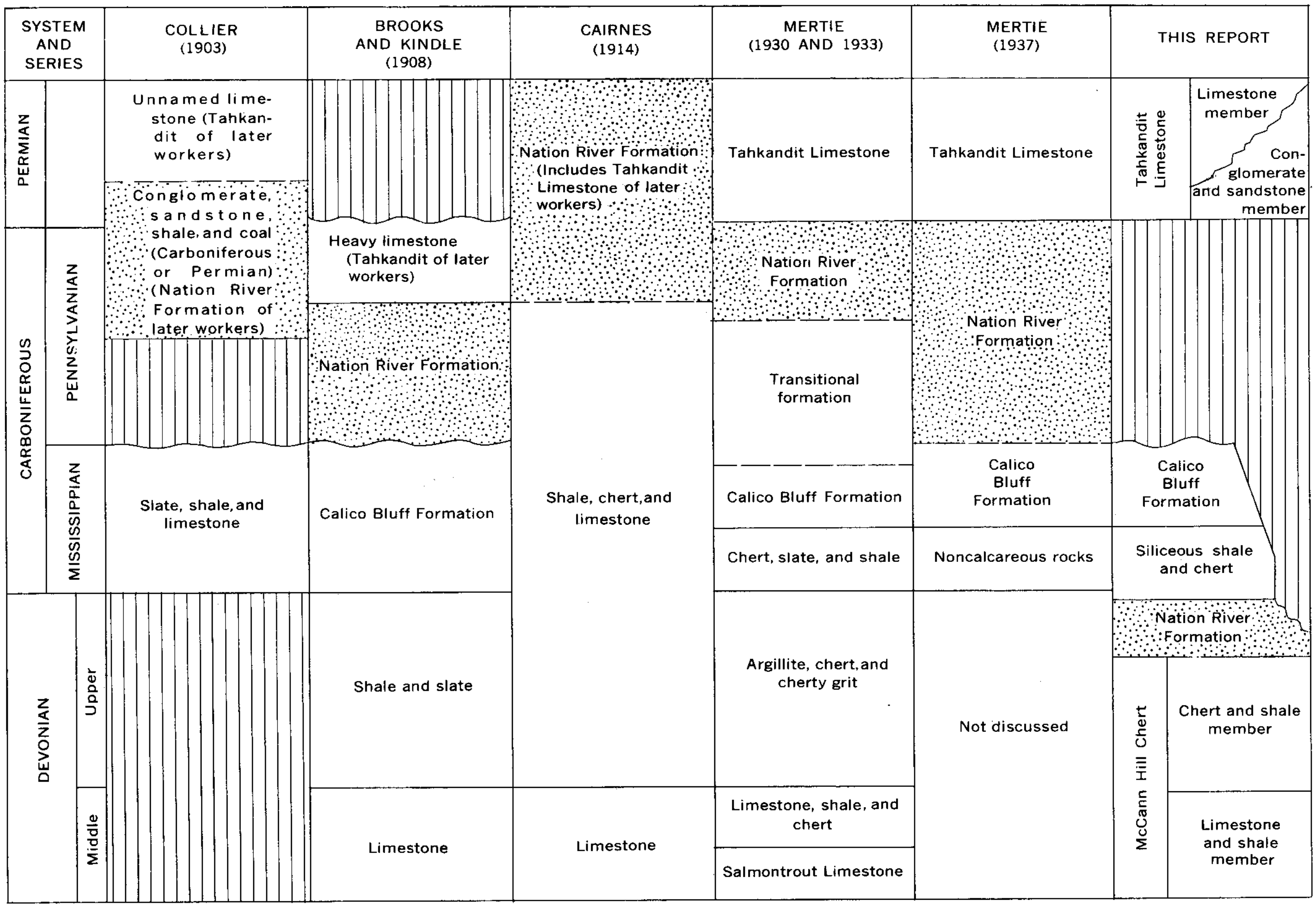

FIGURE 2.—Stratigraphic position and age of the Nation River Formation according to various authors.

Laudon and others (1966, p. 1871) proposed three possible explanations for the problems they presented, as paraphrased in smaller type below:

1. Rocks mapped by Churkin and Brabb (1965) as the Nation River Formation in the Calico Bluff area may be of Devonian age, and a second sequence of clastic rocks, now without a formation name and presumably of Pennsylvanian age, may underlie the Tahkandit Limestone in the Nation River area.

This explanation by Laudon and others is not valid because the second "unnamed" sequence of clastic rocks they refer to is the Nation River Formation at its type locality. If the type Nation River Formation is Pennsylvanian, then the rocks mapped by Churkin and Brabb (1965) as the Nation River Formation in the Calico Bluff area would be probably better assigned to a new formation. The writers of this paper, however, believe that the rocks in both areas are the same age (Late Devonian) and the same formation (Nation River).

2. Post-Mississippian deformation and erosion may have been followed in Pennsylvanian time by unconformable overlap of the Nation River Formation on the Mississippian Calico Bluff Formation near Calico Bluff and on the Devonian McCann Hill Chert near McCann Hill.

This explanation by Laudon and others is not supported by field observations inasmuch as the Nation River Formation has not been found stratigraphically or structurally above the Calico Bluff Formation.

3. The Nation River Formation of Pennsylvanian age may have been moved to its present position on the Devonian McCann Hill chert near McCann Hill by a low-angle thrust sheet from the south.

The writers of the present paper believe, on the other hand, that the Nation River Formation near McCann Hill contains spores of Late Devonian age, and that it probably grades downward into the underlying McCann Hill Chert.

Laudon and others (1966) also expressed considerable doubt that the distinctive chert and shale of the Devonian McCann Hill Chert could be repeated by sedimentary processes during the Mississippian to form the unit that we refer to as an unnamed siliceous shale and chert formation. They infer, therefore, that the McCann Chert and the unnamed siliceous shale and chert are the same formation.

STRATIGRAPHIC RELATIONS

The stratigraphic relations of the Nation River Formation to other formations described here are based on geologic mapping in the Calico Bluff area (fig. 3) and the adjoining Nation River area (fig. 4). Little information regarding the lower and upper contacts of the formation has been previously published.

Calico Bluff area

Mertie (1933, p. 409, pl. 7) mapped an unnamed argillite, chert, and cherty grit formation of Middle Devonian age directly beneath the Nation River Formation near McCann Hill, about 5 miles east of Calico Bluff (fig. 3). He did not recognize this unnamed formation near Adams Peak, 4 miles north of Calico Bluff, or in the Nation River area (fig. 4), where he thought that the Nation River Formation rested unconformably on rocks of Precambrian age. The writers, on the other hand, have mapped this chert and siliceous shale formation, which we named (Churkin and Brabb, 1965, p. 180–182) the McCann Hill Chert, from McCann Hill nearly continuously to Adams Peak and to the Nation River area, 15 miles northwest of McCann Hill (figs. 3 and 4). The McCann Hill Chert and the overlying Nation River Formation are accordant throughout this area, and there is no evidence to suggest that the Nation River Formation rests unconformably on rocks older than the McCann Hill Chert. The rocks in the vicinity of the contact are homoclinal, have moderate dips, and are fairly well exposed.

Near McCann Hill and Hillard Peak (VABM 4065 and formerly called triangulation station Chief) the so-called basal conglomerate of the Nation River Formation mentioned by Cairnes (1914, p. 89) and Mertie (1933, p. 425) is underlain by approximately 450 feet of sandstone that contains several interbeds of siltstone and conglomerate. The sandstone and its interbeds are similar to those of the overlying Nation River Formation and should be included in that unit. The sandstone is underlain in turn by the McCann Hill Chert, which contains a varied shelly fauna of Early and possibly Middle Devonian age near its base (Churkin and Brabb, in press). The contact between the chert and siliceous shale of the McCann Hill Chert and the overlying Nation River Formation is abrupt where it is exposed, but there is no evidence for a stratigraphic break. Instead, the upper part of the McCann Hill Chert contains a few thin interbeds of siltstone, sandstone, and chert conglomerate whose similarity to rocks of the Nation River Formation suggests a gradational relationship.

By contrast, the upper contact of the Nation River Formation in the Calico Bluff area has been generalized through rubble and alluvium-covered slopes in the general vicinity of outcrops where the rocks are tightly folded and (or) steeply dipping. Most evidence suggests, however, that the Nation River Formation is overlain by an unnamed shale and chert formation of Late Devonian and Mississippian age which in turn is overlain by the Calico Bluff Formation of Late Mississippian age. For example, Laudon and others (1966, fig. 2), Mertie (1930, p. 110), and the writers all interpret the dip of Paleozoic rocks southwest of the mouth of the Seventymile River (fig. 3) to be predominantly to the northeast, albeit steep or vertical. If this interpretation is correct, then the sequence is Nation River Formation (oldest) overlain by unnamed chert and shale formation overlain by Calico Bluff Formation (youngest). This area has not been adequately mapped, however, and some of the rocks, such as those near Sinnot Creek may not be correctly identified. Nevertheless, a similar sequence is also indicated by attitudes near the mouth of Shade Creek and in cliffs on the north bank of the Yukon River southwest of Adams Peak.

The area from 1 to 2 miles southwest of Adams Peak (locality *A*, fig. 1) is especially important because it has a homoclinal sequence of rocks ranging in age from Cambrian to Permian, all dipping moderately or steeply to the southwest. Mertie (1933, pl. 7) thought that his unnamed chert, slate, and shale formation of Mississippian age in that area rested directly on limestone of Cambrian age, but we believe (fig. 3 and Churkin and Brabb, 1965, fig. 2) that the Road River Formation, McCann Hill Chert, and Nation River Formation intervene. The formations crop out along wooded slopes around the north rim of an abandoned river channel, and they were overlooked in previous investigations.

Mertie also overlooked the occurrence of about 100 feet of conglomerate and sandstone of Permian age in this sequence. These rocks are overlain unconformably by similar conglomerates and sandstones of Cretaceous age. Fossils from the Permian rocks have been listed by Laudon and others (1966, p. 1873) and compared by them to those of the Tahkandit Limestone. The Permian rocks rest directly and probably unconformably on shale and limestone that has long been mapped as the Calico Bluff Formation (for example, see Mertie, 1933, pl. 7) and from which J. S. Williams

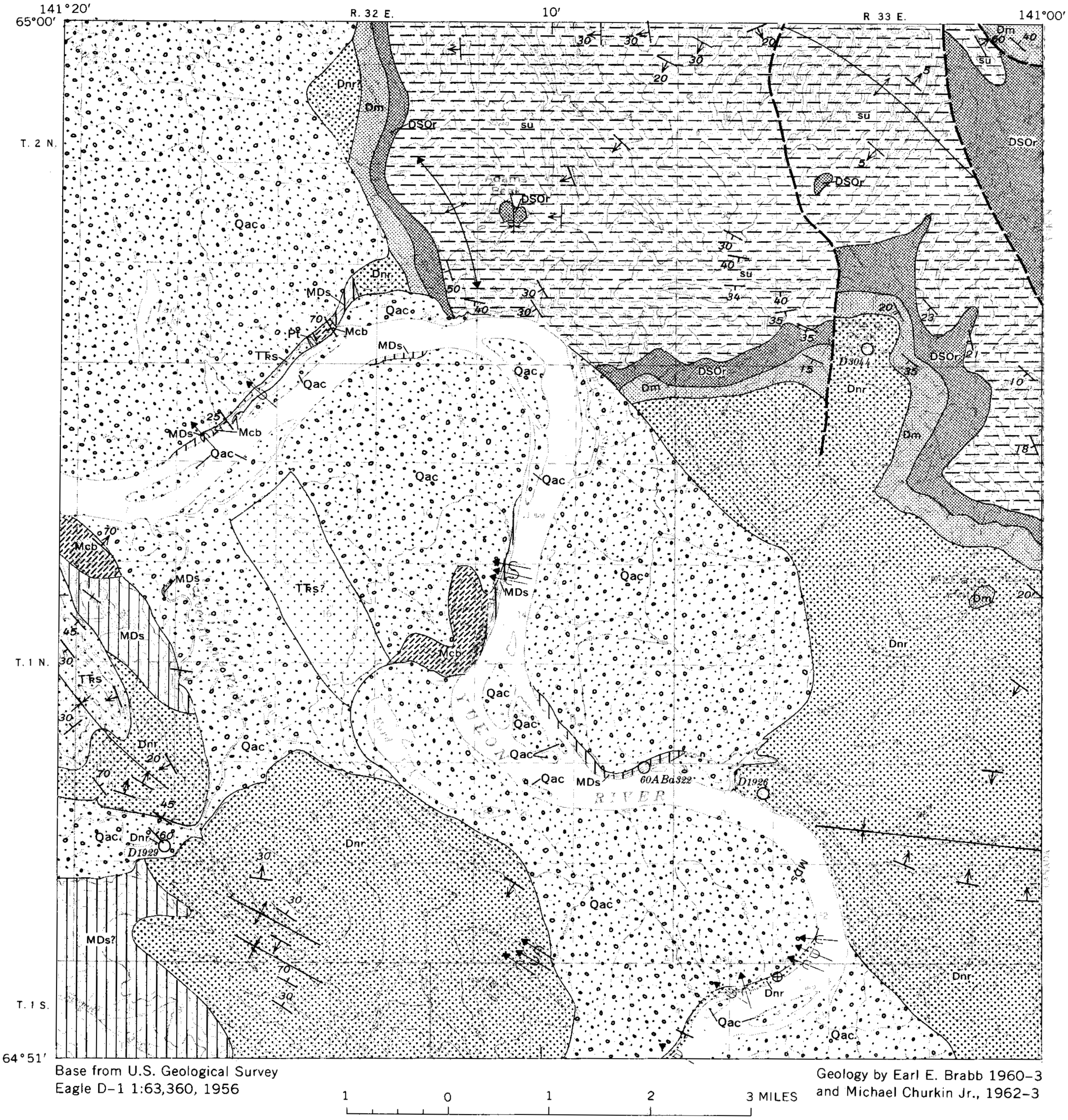

FIGURE 3.—Geologic map of the Calico Bluff area, east-central Alaska. Location of the area is shown in figure 1.

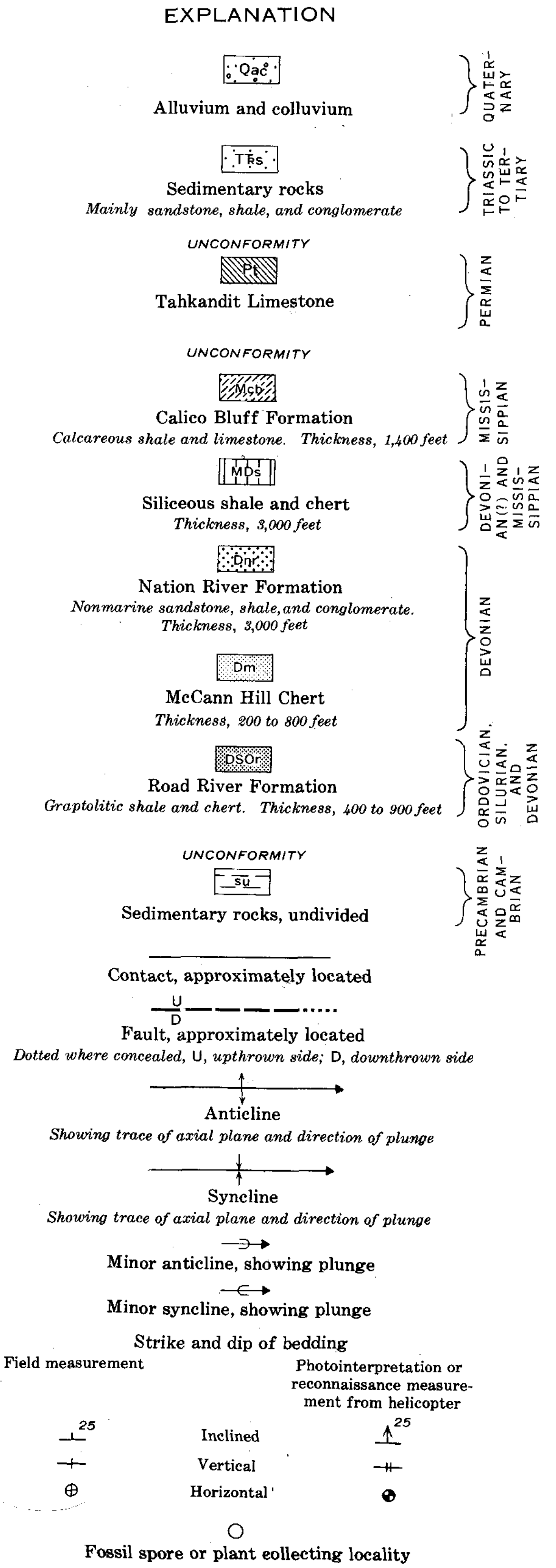

FIGURE 3.

collected the youngest known Mississippian cephalopods in Alaska (Gordon, 1957, p. 13).

Evidence from fossils to support the Devonian age of the Nation River Formation in the Calico Bluff area is meager but consistent. The McCann Hill Chert underlying the Nation River Formation has a fauna of Early and possibly Middle Devonian age near its base (Churkin and Brabb, in press). Fragmentary plant material from the Nation River Formation in the Calico Bluff area (fig. 3) and in the type area (fig. 4) was considered by David White (*in* Mertie, 1930, p. 120) to be Mississippian, and (*in* Mertie, 1933, p. 427) to be Upper Devonian or Lower Mississippian. The following new material was collected in 1960 and 1961 and identified by Richard A. Scott, of the U.S. Geological Survey, whose comments follow the locality descriptions given below (see also fig. 3).

USGS paleobot. loc. D3044 (field No. 61ABa1271). Sandstone of Nation River Formation, about 200 feet above base; lat 64°57.4′ N., long 141°03.0′ W. Collector, Earl E. Brabb, 1961.

"Late Devonian. The spores are badly preserved but are recognizable as the The Nation River assemblage."

USGS paleobot. loc. D1929 (field No. 60ABa723). Nation River Formation, SE¼ sec. 30, T. 1 N., R. 32 E., Seventymile River. Collector, Earl E. Brabb, 1960

"Middle or Late Devonian. This assemblage has been significantly metamorphosed. The remnants include fragments of forms comparable to some of those present at locality 60ABa687, including those spores with bifurcated appendages. There is no evidence of younger forms to suggest reworking of Devonian sediments."

USGS paleobot. loc. D1926 (field No. 60ABa316). Nation River Formation, NW¼ sec. 29, T. 1 N., R. 33 E., lat 64°53.3′ N., long 141°5.3′ W. Collector, Earl E. Brabb, 1960.

"Devonian(?). The spore flora in this sample has been metamorphosed so that most grains are broken and opaque. The possible age assignment is an educated guess based on shapes and fragments of spores."

Fossils from the lower part of the unnamed siliceous shale and chert formation which we believe overlies the Nation River Formation include brachiopods considered by G. H. Girty (*in* Mertie, 1930, p. 94) as possibly Devonian but more probably Mississippian. Fossil wood was collected near the brachiopod locality (see 60ABa322, fig. 3) and identified by Richard A. Scott as follows:

Field No. 60ABa322. Unnamed siliceous shale and chert formation. North bank of Yukon River, lat 64°53.5′ N., long 141°08.3′ W. Collector, Earl E. Brabb, 1960.

"Late Devonian or Early Mississippian. Only one of the 3 specimens of fossil wood could be sectioned because of coalification and degradation. The third specimen is *Callixylon*, a genus of large trees that reproduced by spores but had wood much like the conifers. The genus is widespread in Upper Devonian rocks, occurring in Russia, western and central New York, Oklahoma, Texas. It is also present in the New Albany Shale of Indiana and Kentucky, which is thought to transgress the Devonian-Mississippian boundary. Hence, the age is most probably Late Devonian, but may also be Early Mississippian."

The upper part of the unnamed siliceous shale and chert formation grades upward into the Calico Bluff Formation of Late Mississippian age at its type locality (Mertie, 1930, p. 88).

In summary, stratigraphic relations and fossils indicate: that the Nation River Formation in the Calico Bluff area is Late Devonian; that it is underlain by the McCann Hill Chert of Early, Middle(?), and Late Devonian age, and that it is overlain by an unnamed siliceous shale and chert formation with fossils of Late Devonian or Early Mississippian age near its base. The Calico Bluff Formation of Late Mississippian age is overlain unconformably by sandy beds of the Tahkandit Limestone of Permian age.

Correspondingly, there was a repetition of distinctive siliceous shale and chert deposition during the Devonian and Mississippian. Similar chert and siliceous shale also occur in both the Ordovician and Silurian parts of the Road River Formation (Churkin and Brabb, 1965, fig. 5 and p. 173), and they are thus not restricted to a single formation or a single system.

Nation River area

The Cambrian to Permian sequence exposed southwest of Adams Peak strikes northward and is exposed again along the lower part of the Tatonduk River and its valley slopes between Pass Creek and Windfall Mountain (fig. 1). A partial measured section including limestone of Cambrian and Ordovician age at the base, the Road River Formation and McCann Hill Chert in the middle part, and the Nation River Formation at the top is shown by Churkin and Brabb (1965, fig. 4, column 3). These rocks all dip moderately and uniformly to the west. The Nation River Formation is overlain in succession by the unnamed siliceous shale and chert, the Calico Bluff Formation, and the Tahkandit Limestone. The Tahkandit is preserved at Windfall Mountain as an erosional remnant along the trough of a north-trending syncline. The rocks west of Windfall Mountain dip uniformly and gently to the east except near the mouth of the Tatonduk River where there are minor folds.

No distinctive fossils were found in the McCann Hill Chert immediately underlying the Nation River Formation in the vicinity of the Tatonduk River, but a well-preserved spore assemblage was found in the Nation River Formation at locality D1927 (see fig. 4). Richard A. Scott provided the following information about this assemblage:

USGS paleobot. loc. D1927 (field No. 60ABa451). Nation River Formation; NW¼ sec. 10, T. 2 N., R. 32 E.; lat 65°1.3′ N., long 141°13.2′ W.; north bank Tatonduk River. Collector, Earl E. Brabb, 1960.

"Late or Middle Devonian. This sample contains a well-preserved spore assemblage generally comparable to, but less diverse than that present at locality 60ABa687 (USGS loc. D1928)."

A. E. Waters, Jr., collected plants near Windfall Mountain (fig. 4) from the unnamed siliceous shale and chert which we believe overlies the Nation River Formation. David White (*in* Mertie, 1933, p. 419) commented at length on these plants and indicated that their age is probably Devonian or at latest, Early Mississippian.

The Calico Bluff Formation near Windfall Mountain has long been dated as Late Mississippian (Mertie, 1933, p. 421–422; Gordon, 1957, p. 13) and the Tahkandit Limestone as Permian (Mertie, 1933, p. 431). Mertie (1933, p. 430) explained the absence of conglomeratic beds at the base of the Tahkandit Limestone and the absence of his "Pennsylvanian" Nation River Formation as due to thrust faults, but the lack of conglomerate at the base of the Tahkandit could be a facies change and the absence of the Nation River Formation is easily explained if it is Late Devonian and not Pennsylvanian.

The Nation River Formation exposed along the Tatonduk River (fig. 4) strikes generally northward for about 10 miles and then strikes northwestward and westward along the south flank of a major anticline. Formations stratigraphically beneath the Nation River Formation are last seen in sequence near Montauk Bluff (fig. 1) because to the west they are concealed by younger formations, and on the north flank of the anticline they are extensively faulted.

Corals and other fossils of Early or Middle Devonian age were reported by Churkin and Brabb (1965, table 3) from the McCann Hill Chert directly beneath the Nation River Formation near Montauk Bluff. Several spore assemblages were collected by the writers from the Nation River Formation in the same area (see fig. 4) and identified by Richard A Scott, whose comments follow:

USGS paleobot. loc. D1928 (field No. 60ABa687). Nation River Formation; SE¼NE¼, sec. 10, T. 3 N., R. 31 E.; lat 65°6.3′ N., long 141°24.2′ W.; north bank Yukon River. Collector, Earl E. Brabb, 1960.

"Late or Middle Devonian. This sample contains an abundant, diverse, and excellently preserved assemblage of spores. There are probably more than 25 genera represented, among them, *Leiotriletes, Leiozonotriletes, Hymenozonotriletes, Verrucosisporites, Retusotriletes, Reticulatisporites, Stenozonotriletes*, and *Convolutispora.* Of particular interest is the pres-

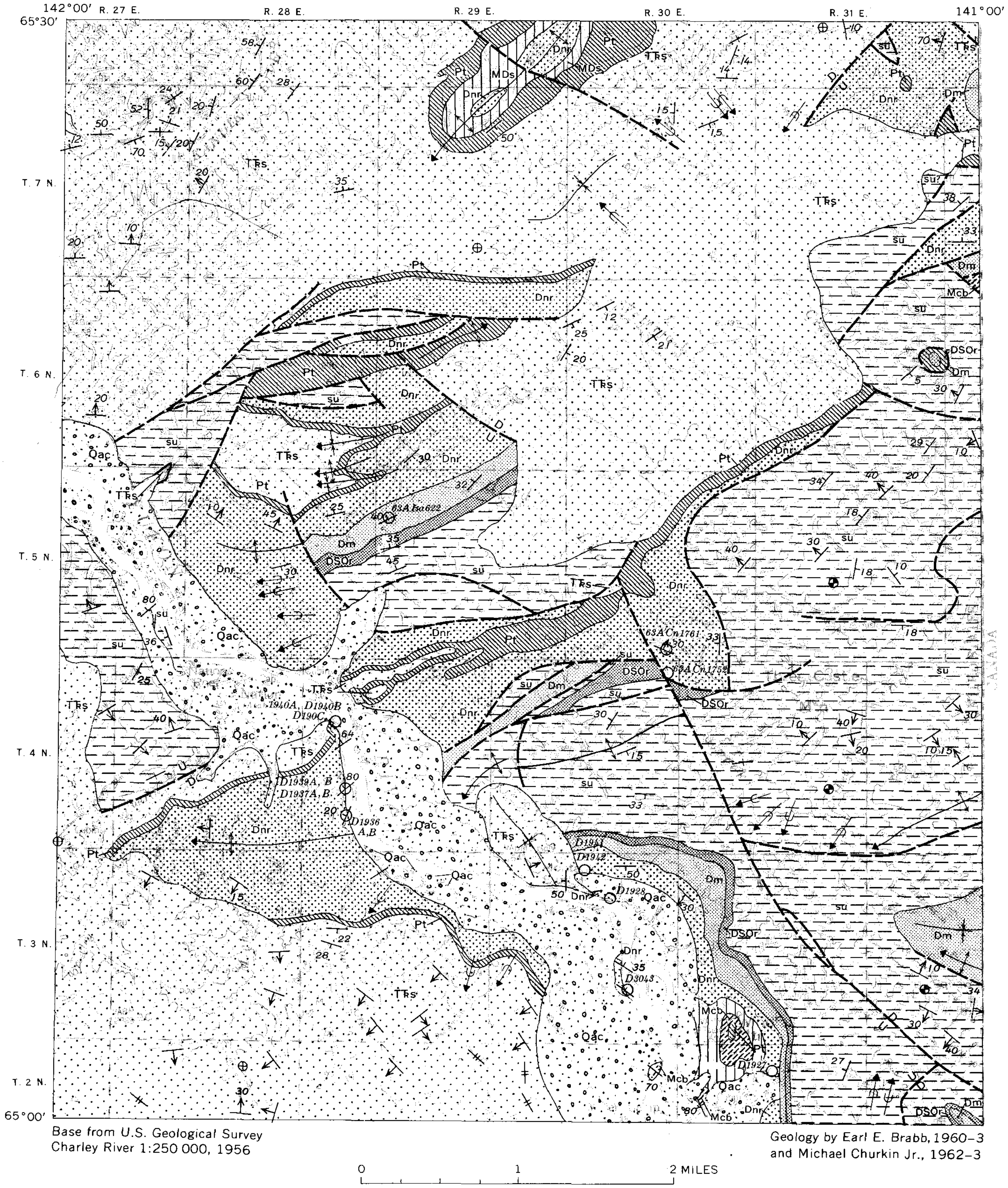

FIGURE 4.—Geologic map of the Nation River area, east-central Alaska. Location of the area is shown in figure 1. Explanation of geologic units and symbols is given in figure 3.

ence of a group of large, trilete spores with bifurcated appendages belonging to the *Archeotriletes-Hystricosporites-Ancyrospora* complex. This group is prominent in Middle and Late Devonian floras from various parts of the world. More detailed study of this assemblage may determine if it is Late or Middle Devonian. My preliminary impression is that it is probably Late Devonian."

USGS paleobot. loc. D3043 (field No. 60ABa981). Olive-gray claystone of Nation River Formation; lat 65°03.8′ N., long 141°23.2′ W., Collector, Earl E. Brabb, 1960.

"Late Devonian. This sample contains essentially the Nation River assemblage."

USGS paleobot. loc. D1941 (field No. 62ACn1023). Nation River Formation. Medium-dark-gray shale bearing plant fragments; NW¼NE¼ sec. 4, T. 3 N., R. 31 E.; lat 65°7.3′ N., long 141°24.6′ W.; west bank of second creek east of Montauk Bluff. Collector, Michael Churkin, Jr., 1962.

"Late or Middle Devonian. This assemblage is poorly preserved. However, the remains of the spores are recognizable as about the same group present in 62AA311A (D1937–A) and most of the other Late Devonian samples (except 62ACn1101, 62ACn1102, and 62ACn1204)."

USGS paleobot. loc. D1942 (field No. 62ACn1031). Nation River Formation. Medium-dark-gray shale stratigraphically below 62ACn1023; Center of SE¼ sec. 33, T. 4 N., R. 31 E.; lat 65°7.7′ N., long 141°26.4′ W. About ½ mile upstream from 62ACn1023. Collector, Michael Churkin, Jr., 1962.

"Devonian(?). A number of spores are present in this sample, but they are badly corroded and broken. Some of the remains suggest Devonian forms, and nothing recognizable is incompatible with this age, but there is no conclusive evidence."

In summary, stratigraphic sequence and fossils indicate that the Nation River Formation in the area from the Tatonduk River to Windfall Mountain and Montauk Bluff is probably Late Devonian; that it is underlain by the McCann Hill Chert, which has fossils of Early or Middle Devonian age; and that it is overlain by an unnamed siliceous shale and chert formation, which has plants of probable Devonian age.

West of Montauk Bluff, the sequence above the Nation River Formation is different and herein lies the problem. The Nation River Formation in the vicinity of the mouth of the Nation River (locality *B*, figs. 1 and 4) is overlain by the Tahkandit Limestone of Permian age, not the unnamed siliceous shale of Devonian and Mississippian age. Nearly all previous investigators have assumed that the Nation River is overlain conformably by the Tahkandit and therefore must be only slightly older, or Pennsylvanian(?). They have then used structure to explain the absence of this "Pennsylvanian(?)" formation in the Calico Bluff area (fig. 3) and near Windfall Mountain (fig. 1). They have overlooked the possibility of an unconformity at the base of the Tahkandit Limestone.

The contact between the Nation River Formation and the Tahkandit Limestone in the type area of these formations can be seen on the southwestern bank of the Yukon River about 1 mile south of the mouth of Nation River (figs. 1, 4, 5). The uppermost shale and siltstone beds of the Nation River Formation, perhaps 100 feet of section, are exposed along the crest of a small anticline, and the older part of the formation is exposed along the river bank farther upstream in the core of a major anticline. The lowest 75 feet of the overlying Tahkandit Limestone consists of sandstone and chert-pebble conglomerate. Unlike the sandstone and conglomerate in the Nation River Formation, these detrital rocks contain abundant productid brachiopods, they have a calcareous matrix, and most of them are glauconitic. Some of the beds are bright green because of abundant glauconite. The contact between the Nation River Formation and the Tahkandit is mostly covered, but the beds on both sides are accordant. In July 1962 the writers dug out the contact and found a 6-inch layer of light-bluish-gray clay separating the top of the Nation River Formation from the basal Tahkandit. This unstratified clay that becomes plastic when wet is interpreted as a residual deposit or paleosol developed by weathering of the Nation River shale prior to Tahkandit sedimentation. In the basal Tahkandit the abundance of glauconite suggests that the contact is disconformable and the associated varicolored chert, sand, and pebbles in the Tahkandit probably represent reworked Nation River conglomerate and sandstone.

The Tahkandit beds shown in figure 5 have furnished a prolific invertebrate fauna (see Mertie, 1930, p. 125-127 for list) which has long been considered Permian, but no fossils had previously been found in the Nation River Formation at this locality. In 1962, several shale samples were collected from which Richard A. Scott eventually extracted the following spore assemblages, arranged with the stratigraphically highest (most northerly localities) first (see figs. 4 and 5):

USGS paleobot. loc. D1940C (field No. 62ACn1204). From 6-inch layer of light-bluish-gray clay separating very top of Nation River Formation from overlying Tahkandit Limestone; NW¼NW¼ sec. 17, T. 4 N., R. 30 E., lat 65°10.6′ N., long 141°41.8′ W. Stratigraphically just above sample 62ACn1012. Collector, Michael Churkin, Jr., 1962.

"Late or Middle Devonian. Excellently preserved assemblage like that in sample 62ACn1011, (D1940A)."

USGS paleobot. loc. D1940B (field No. 62ACn1012). Top of Nation River Formation; from highest stratified shale below Tahkandit Limestone; NW¼NW¼, sec. 17, T. 4 N., R. 30 E., lat 65°10.8′ N., long 141°41.8′ W. West bank of Yukon River. Collector, Michael Churkin, Jr., 1962.

"Late or Middle Devonian. Essentially the same assemblage as in sample 62ACn1011 (D1940A), but slightly less well preserved.

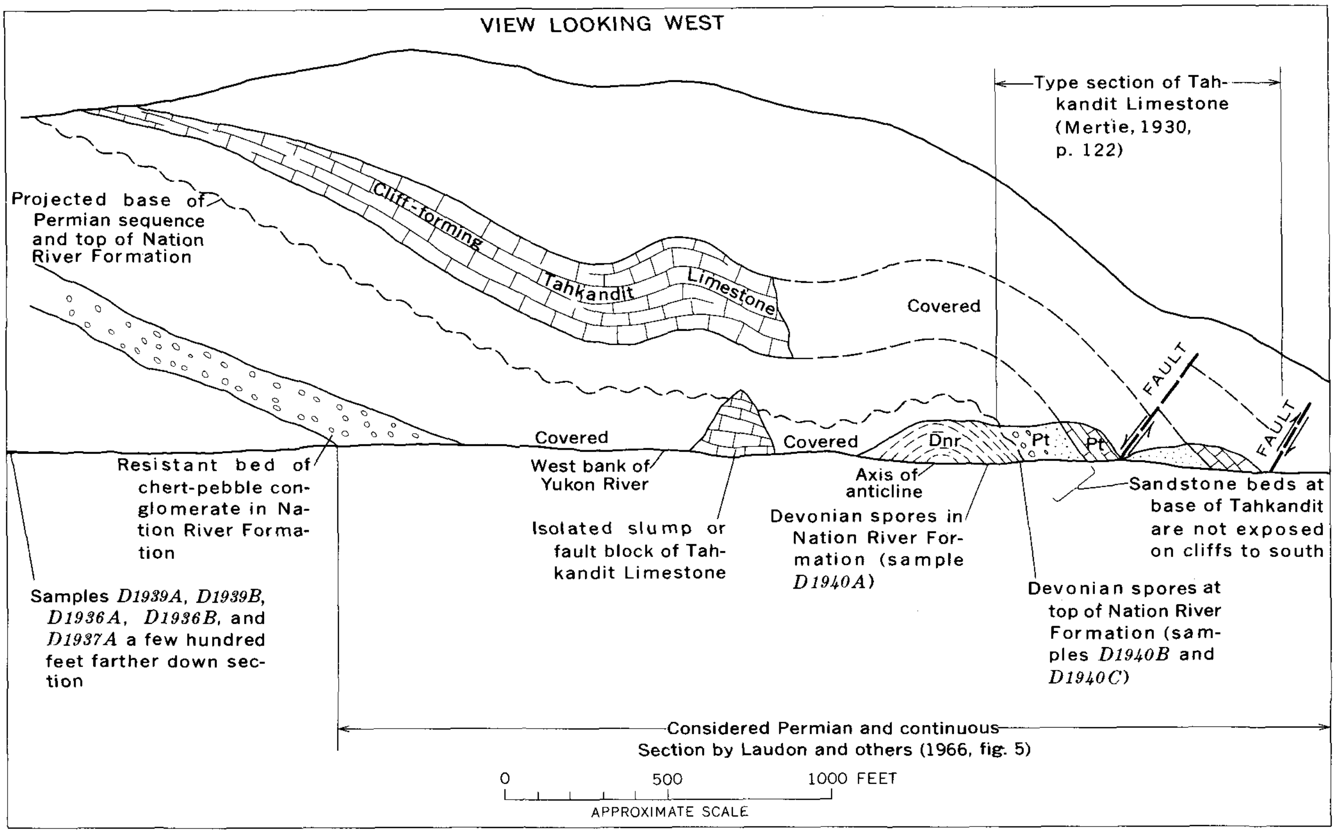

FIGURE 5.—Sketch of geology at type locality of Nation River (Dnr) and Tahkandit (Pt) Formations opposite mouth of Nation River.

USGS paleobot. loc. D1940A (field No. 62ACn1011). Nation River Formation; from shale about 75 feet below contact with Tahkandit Limestone; NW¼NW¼, sec. 17, T. 4 N., R. 30 E., lat 65°10.8′ N., long 141°41.8′ W; West bank of Yukon River. Probably several thousand feet stratigraphically above 62ACn1001. Collector, Michael Churkin, Jr., 1962.

"Late or Middle Devonian. This assemblage has much in common with the Devonian samples listed from the Nation River; however, it contains some new forms and can readily be distinguished from the samples occuring lower in the formation."

USGS paleobot. loc. D1939A (field No. 62ACn1001). Nation River Formation. Olive-gray plant-bearing silty shale thinly interbedded with fine-grained, medium-gray graywacke, NE¼SW¼, sec. 20, T. 4 N., R. 30 E.; lat 65°9.5′ N., long 141°41.3′ W. West bank of Yukon River. Many hundreds of feet stratigraphically higher than 62ACn1002. Collector, Michael Churkin, Jr., 1962.

"Late or Middle Devonian. This assemblage is substantially the same as that in sample 60ABa687."

USGS paleobot. loc. D1939B (field No. 62ACn1002). Nation River Formation. From shale at top of thick conglomerate; SE¼SW¼, sec. 20, T. 4 N., R. 30 E.; lat 65°9.3′ N., long 141°41.3′ W. West bank of Yukon River. Many hundreds of feet stratigraphically higher than 62AA311A. Collector, Michael Churkin, Jr., 1962.

"Late or Middle Devonian. A good assemblage of well-preserved spores essentially similar in composition to 62AA311A. (D1937A)."

USGS paleobot. loc. D1937A (field No. 62AA311A). Nation River Formation. From silty claystone interbedded with chert-pebble conglomerate and graywacke; NE¼NW¼, sec. 29, T. 4 N., R. 30 E.; lat 65°9.0′ N., long 141°41.5′ W. West bank of Yukon River. Several hundred feet stratigraphically above 62AA281. Collector, Arne Aadland, 1962.

"Middle or Late Devonian. A well-preserved and abundant assemblage of spores. All remarks for age and composition under locality 60ABa687 (D1928) apply for this sample."

USGS paleobot. loc. D1937B (field No. 62AA311B). Nation River Formation. NE¼NW¼, sec. 29, T. 4 N., R. 30 E.; lat 65°9.0′ N., long 141°41.5′ W. West bank of Yukon River 15 feet stratigraphically below 62AA311A. Collector, Arne Aadland, 1962.

"Late or Middle Devonian. Basically the same flora as in 62AA311A, (D1937A), but fewer forms recognizable and much poorer preservation."

USGS paleobot. loc. D1936B (field No. 62AA281). Nation River Formation. Interbedded silty shale and graywacke. SE¼SW¼, sec. 29, T. 4 N., R. 30 E,; lat 65°8.3′ N., long 141°41.2′ W. Above west bank of Yukon River and about 150 feet stratigraphically above 62AA251(C). Collector, Arne Aadland, 1962.

"Middle or Late Devonian. This assemblage consists of badly corroded spores. Fragments indicate that the forms present are substantially those of locality 62AA251(C), (D1936A)."

USGS paleobot. loc. D1936A (field No. 62AA251C). Nation River Formation. Silty claystone. SE¼SW¼, sec. 29, T. 4 N.,

R. 30 E.; lat 63°8.3′ N., long 141°41.2′ W. Above west bank of Yukon River. Collector, Arne Aadland, 1962.

"Middle or Late Devonian. A spore assemblage essentially similar to that from locality 60ABa687, (D1928), but less well preserved. The group of spores with bifurcated, anchor-like appendages appears to be lacking; however, this may be a preservation problem because the appendages break off easily. In any case, presence of extremely large, trilete spores approaching the megaspore size range provides independent evidence for Middle or Late as opposed to Early Devonian age. As for locality 60ABa687 (D1928), my feeling is that the age is Late rather than Middle Devonian, but I cannot document this now."

The spores substantiate the physical evidence for an unconformity and indicate that near the mouth of the Nation River, at least, the unnamed siliceous shale and chert formation and the Calico Bluff Formation were removed prior to deposition of the Tahkandit Limestone, if indeed they were ever deposited there in the first place.

If this interpretation is correct, then

(1) There is no unnamed formation beneath the Tahkandit on the south bank of the Yukon River across the mouth of the Nation River, as proposed by Laudon and others (1966, p. 1870). This "unnamed" formation must, by definition, remain the Nation River Formation in this, its type, locality.

(2) There is no need for "unusual structural complications" in the Nation River area, as alleged by Laudon and others (1966, p. 1870).

(3) There is no need for a thrust fault in the Windfall Mountain area, as mentioned by Mertie (1933, p. 430).

(4) There is no need for thrust faults or a post-Mississippian and pre-Pennsylvanian unconformity in the Calico Bluff area, the other alternatives proposed by Laudon and others (1966, p. 1871).

The Nation River Formation is overlain by the Tahkandit Limestone over an area of at least 400 square miles extending from 4 miles southwest of Montauk Bluff (fig. 4) northward to tributaries of the Kandik River about 15 miles north of the mouth of the Nation River, and northeastward to the Alaska-Yukon Territory boundary. The unnamed siliceous shale and chert formation stratigraphically above the Nation River and below the Tahkandit appears also along an anticline in the north-central part of figure 4, suggesting that the 400-square-mile area mentioned above may have been upwarped to form a broad arch during the late Paleozoic.

Three spore samples collected in this 400-square-mile area contribute additional proof that the Nation River Formation is Devonian and is closely related in age to the McCann Hill Chert (see fig. 4 for localities):

Field No. 63ACn1761. Nation River Formation. From medium-gray chert wacke interbedded with light-green to olive-gray micaceous shale containing abundant plant fragments. Center of SE¼, sec. 33, T. 5 N., R. 31 E.; lat 65°12.8′ N., long 141°21.4′ W., High cut bank on east side of Hard Luck Creek. Collector, Michael Churkin, Jr., 1963.

"Late or Middle Devonian. This sample contains less than one-half as many forms as 63ACn1752."

Field No. 63ACn1752. Nation River Formation. From medium-gray micaceous shale thinly interbedded with very fine grained calcareous quartz arenite. SW¼NE¼, sec. 1, T. 4 N., R. 31 E.; lat 65°12.8′ N., long 141°20.7′ W., From high cut bank on east side of Hard Luck Creek. Collector, Michael Churkin, Jr., 1963.

"Late or Middle Devonian. This sample contains an assemblage of Nation River species but preservation is not as good as in the best samples."

Field No. 60ABa622. McCann Hill Chert. Medium-dark-gray fine-grained siltstone. Lat 65°16.3′ N., long 141°38.8′ W.; Collector, Earl E. Brabb, 1960.

"Probably Late Devonian. The broken and highly metamorphosed spores in this sample appear comparable, in so far as their features can be observed, with the assemblage in the Nation River Formation. A variety of trilete forms are present along with the spores with hooked assemblages."

CONCLUSIONS

Recognition that the Nation River Formation is Devonian and not Pennsylvanian makes the geologic history of east-central Alaska more in harmony with that of northern Alaska and the Yukon Territory. The Nation River Formation is similar in lithology to widespread formations of late Devonian age such as the Kanayut Conglomerate in the Brooks Range of Alaska (Brosgé and others, 1962) and the Imperial Formation of the Yukon (Norris and others, 1963), whereas no comparable formations of definite Pennsylvanian age have been recognized in this same area. The Nation River Formation and its lateral equivalents are not associated with a Pennsylvanian orogeny but instead are the record of tectonic instability during the Late Devonian.

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TECTONIC INCLUSIONS FROM A SERPENTINITE, EAST-CENTRAL ALASKA

By ROBERT L. FOSTER, Menlo Park, Calif.

Work done in cooperation with the University of Missouri

Abstract.—Mapping in the western Yukon-Tanana Upland has revealed the presence of northeast-trending alpine-type serpentinite masses with associated tectonic inclusions in the general vicinity of Livengood, Alaska. Serpentinite-associated tectonic inclusions have not been documented previously in Alaska.

A discontinuous belt of ultramafic rocks, identified here as the Livengood trend (fig. 1), extends approximately 120 miles northeastward from near Manley Hot Springs (Tanana A–3 quadrangle) through Livengood to Beaver Creek south of Mount Schwatka (Livengood C-2 quadrangle) in east-central Alaska. The linear bodies making up this belt have known maximum widths of as much as 1 mile and lengths of as much as 10 miles. They conform to the regional grain and extend over larger parts of the western Yukon-Tanana Upland than previously believed by Mertie (1937). Detailed geologic investigations on the ultramafic body near Livengood indicate that the ultramafic rocks have alpine-type serpentinite affinities and are characterized by the occurrence of minor amounts of chrysotile and nickeliferous mineral phases. The serpentinites are in fault and unconformable contact with late Middle Devonian metagraywacke strata, and are associated with chert-carbonate units, altered volcanic rocks, and metadiorite. The Livengood body, moreover, is characterized by the sporadic presence of tectonically transported inclusions of a type previously described from near Cassiar, British Columbia.

Tectonically transported calcium silicate-rich rocks, or rodingites (Bell and others, 1911), associated with serpentinites have been described from many parts of the world and reviewed by Coleman (1966). Some of the tectonic inclusions in the Livengood area are similar in mode of occurrence and petrography to the northernmost noted rodingites or "white rock" bodies described by Gabrielse (1963) from the McDame ultramafic rocks near Cassiar, British Columbia, approximately 750 miles to the southeast (fig. 1).

Most of the Livengood inclusions are tabular, blocky, or irregular in shape; are less than 50 feet in maximum dimension; and consist of olive-green, massive, fine-grained rocks. Light-green coarse-grained poikilitic and subophitic gabbroic rocks, dark-gray amygdaloidal volcanic rocks, light-gray foliated chert and quartzite, and white granular quartzite are less common relict characteristics of the inclusions.

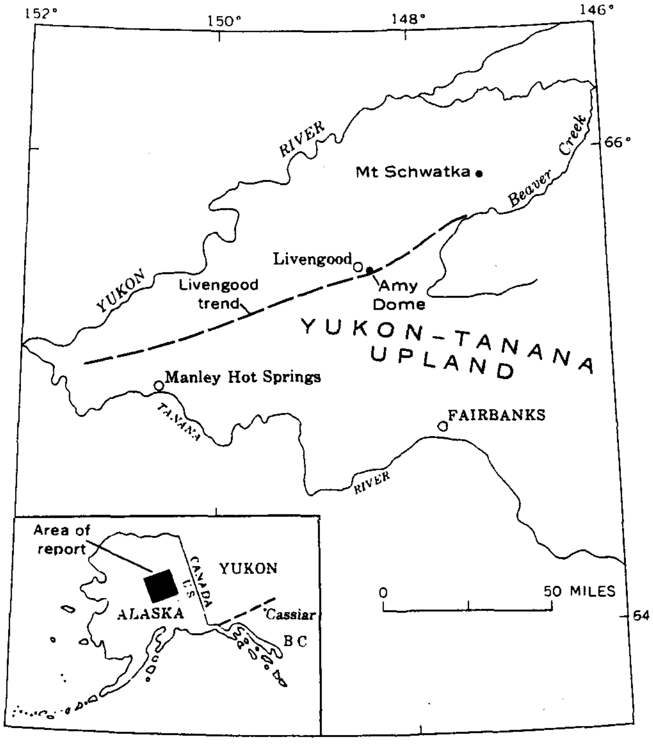

FIGURE 1.—Map of report area, showing trace of Livengood trend.

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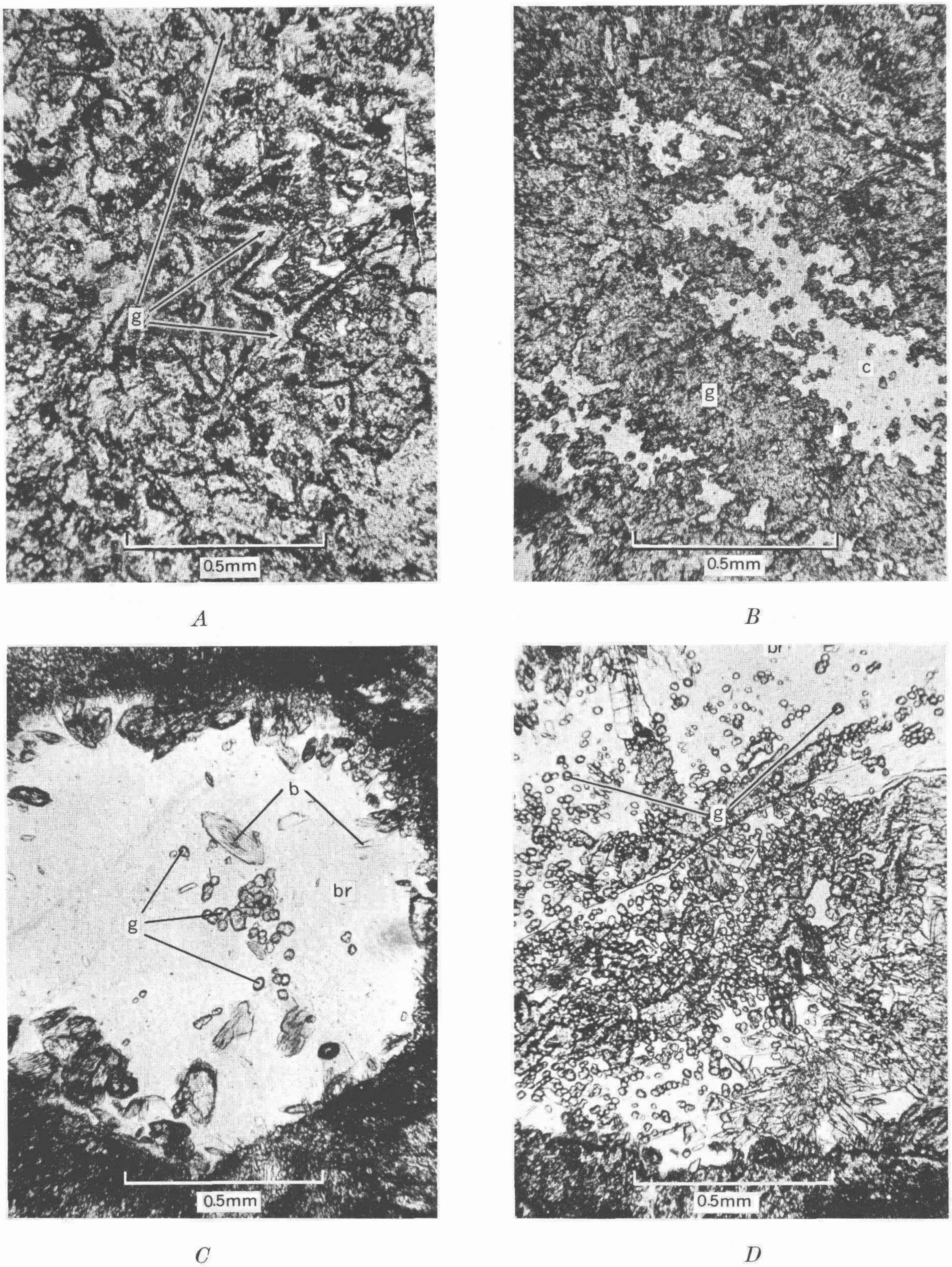

FIGURE 2.—Photomicrographs of tectonic inclusions from a serpentinite in the vicinity of Livengood, Alaska.
A. Garnet (g) pseudomorphous after microlaths of plagioclase. Sample 63AF–99, plane light.
B. Massive garnet (g) in contact with chlorite (c). Sample 64AF–244, plane light.
C. Garnet (g) and unidentified "blades" (b) "floating" in brucite(?) (br) pseudomorphous after olivine. Sample 63AF–108A, plane light.
D. Garnet anhedra (g) "floating" in brucite (br). Sample 63AF–99, plane light.

The fine-grained rocks range from pumpellyite-clinopyroxene-chlorite assemblages to garnet-chlorite-clinopyroxene-vesuvianite assemblages. As much as 50 percent of the volume of the latter is composed of massive garnet, some of which is pseudomorphous after plagioclase laths (fig. 2*A*). X-ray diffraction and optical data indicate that this garnet phase is hydrogrossularite. The coarse-grained rocks range from approximately 70 volume percent garnet that has been partly replaced by chlorite (fig. 2*B*) to (1) mixtures of altered pyroxene anhedra, (2) a pumpellyite-garnet assemblage pseudomorphous after plagioclase, and (3) brucite (pseudomorphous after olivine) surrounded by garnet and an anisotropic brown acicular mineral. The central parts of the brucite pseudomorphs are composed of "floating" garnet anhedra (fig. 2*C*, *D*) and an unidentified colorless mineral with a bladelike habit (fig. 2*C*).

The youngest tectonic inclusions in the serpentinite are semi-randomly oriented blocks derived from dikes that are probably genetically related to a metadiorite stock that makes up part of Amy Dome about 4 miles southeast of Livengood. These inclusions have been metasomatically altered to clinozoisite-epidote-prehnite metadiorite (Foster, 1966).

The Livengood tectonic inclusions (derived from intrusive igneous, volcanic, sedimentary, and metamorphic rocks) were caught up in or intruded into the ultramafic body prior to, or concomitant with final solid emplacement of the mass. The development of rodingite mineral assemblages was genetically associated with the metasomatic metamorphism of the enclosing ultramafic mass during pervasive serpentinization.

Additional detailed geologic investigations of the discontinuous belt of serpentinite masses of the Livengood trend are desirable for a systematic interpretation of the complex structures of the interior of Alaska.

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PROVENANCE OF RECENT GLACIAL ICE IN LOWER GLACIER BAY, SOUTHEASTERN ALASKA

By A. THOMAS OVENSHINE, Menlo Park, Calif.

Abstract.—Erratics of staurolite schist, chaistolite schist, biotite-quartz schist, amphibolite, gabbro, and pyroxenite are common constituents of beach gravels in lower Glacier Bay west of a line near Sturgess Island, Sandy Cove, and Hutchins Bay. These erratics were derived from the Fairweather Range and their present distribution describes the extent of glacial ice from that source, here termed the Russell drainage, in about A.D. 1740. The Muir drainage area may also have contributed ice to lower Glacier Bay but because ice from the Russell system had a much larger extent, it is suggested that discharge from the Russell glacier greatly exceeded discharge from the Muir. Probably the glacial drainage from the Muir area was partly or completely blocked by flow from the Russell glacier; ponding thus produced may have caused development of the extensive icefield observed in the Muir region by early visitors.

A recent glacial advance and retreat of more than 60 miles has been documented by observation (John Vancouver in 1801, quoted in Klotz, 1899, p. 528–530) and geologic studies (Cooper, 1923; Lawrence, 1958) in the Glacier Bay region (fig. 1). The snow that facilitated the advance accumulated in two source areas, here termed the Muir and Russell drainages (fig. 1). A single glacier issued from each source area, and south of Sebree Island these merged to form the large glacier that once filled lower Glacier Bay. For convenience of expression it is necessary to name glaciers that have now melted away or shrunk appreciably. The glacier that filled Muir Inlet was seen by Reid (1896) and termed the Muir Glacier. The Muir Glacier still exists, but is much smaller. The former glacier that earlier filled the northwest arm of Glacier Bay between Russell and Lone Islands was never named but is here termed the Russell Glacier; it issued from the Russell drainage. Observations on the distribution of erratics indicate that most of the lower bay was occupied by ice drawn from the Russell drainage only. This distribution suggests that Russell ice impeded glacial drainage from the Muir area, causing ponding and development of an icefield.

GLACIAL ERRATICS

Shorelines are tightly armored by cobbles and boulders throughout Glacier Bay and the connecting fiords and inlets. The boulders have been derived from nearby deposits of drift (deposited by the post-A.D. 1740 withdrawal of glaciers) and concentrated on the beaches by wave action, although at places in the Beardslee Islands the boulder armor represents incompletely eroded terminal moraines. Inspection of the boulder beaches reveals the presence of rocks derived from the Fairweather Range 20 to 25 miles west of Glacier Bay. The following list characterizes the principal distinctive erratics attributable to a Fairweather source:

Staurolite schist.—Gray to brown fine-grained mica schist; typically contains 2–5 percent 1-millimeter garnet euhedra and 5–15 percent 3–10-mm brown staurolite euhedra; a third or more of the staurolite crystals are twinned.

Chiastolite schist.—Identical to the staurolite schist but with 3–15 percent chiastolite instead of staurolite.

Biotite-quartz schist.—Fine- to medium-grained biotite (⅓) quartz (⅔) rock, commonly friable; particularly distinctive because of a brick-red hematitic weathering crust.

Amphibolite.—Medium to dark gray; typically with strong lineation and foliation; commonly friable.

Pyroxenite.—Yellow green to green 1-mm grained rock, generally massive but rarely with a primary planar structure; boulders are distinguished by a very smoothly abraded surface.

Gabbro.—Rusty weathering brown to black medium- to coarse-grained gabbro; some erratics show primary layering.

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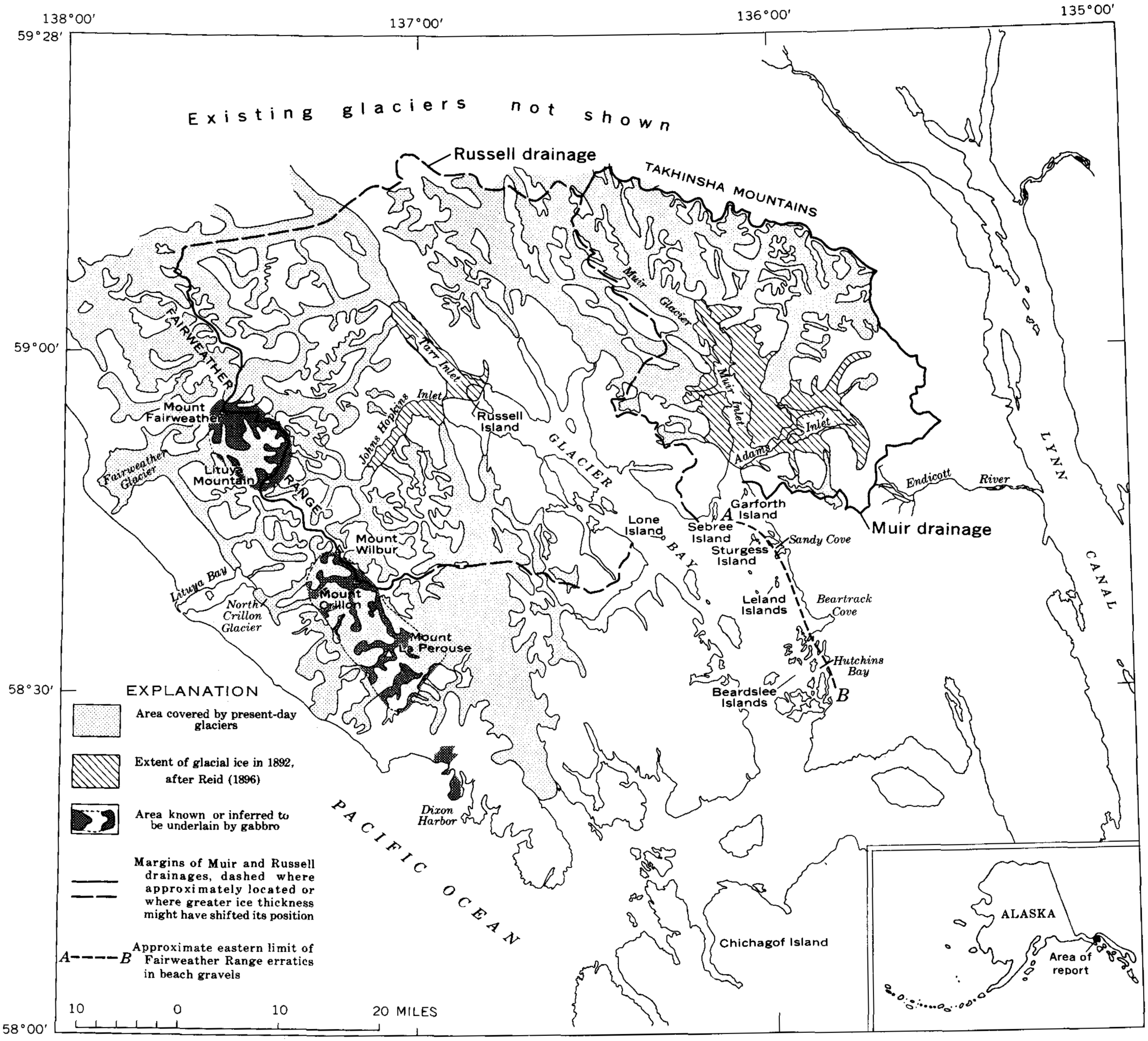

FIGURE 1.—Map of Glacier Bay region, southeastern Alaska.

Two additional types of erratics were recognized as having possible sources in the bedrock of the Johns Hopkins Inlet region:

Greenschist.—Dark- to light-green highly schistose rock; commonly with $\frac{1}{4}$- to 3-inch milky quartz veins.

Quartz monzonite.—Highly leucocratic with minor biotite or hornblende; typically unfoliated or very weakly foliated; occurs in large angular blocks having subconchoidal fracture faces.

Although the greenschist and quartz monzonite erratics compare most closely with similar bedrock in the Johns Hopkins Inlet region, minor amounts of greenschist and unfoliated granitic rock also occur in the vicinity of upper Muir Inlet (D. A. Brew and others, unpub. data).

Erratics of the crystalline rock types described above are conspicuous constituents of beach gravels in Glacier Bay everywhere west of the line *A–B* shown in figure 1. The erratics suite is totally absent along the east side of the bay between Garforth Island and Beartrack Cove. Differences in the composition of beach boulder armor are especially striking in the Sandy Cove area and in the vicinity of Hutchins Bay. In Sandy Cove, the western shores of the peninsula and the large island east of Sturgess Island exhibit abundant crystalline erratics of the types noted, whereas beach gravels on the eastern and inner shores of the cove are composed of limestone, calcareous graywacke and argillite resembling the bedrock exposed nearby. Similarly, in Hutchins Bay, crystalline erratics occur only along the western shores of the bay.

The present distribution of erratics presumably reflects the former distribution of glacial ice at about the time of the maximum recent extent of glaciers in this region (glaciers may have extended to the mouth of Glacier Bay in about A.D. 1740, according to Goldthwait, 1966, p. 8). As shown in the following paragraphs, the ice and the erratics it carried west of the line *A–B* in figure 1 had their source in the Russell drainage, and the ice and erratics east of the line *A–B* came from the Muir drainage (fig. 1).

SOURCES OF THE ERRATICS

Reconnaissance geologic mapping of the Muir Inlet–Takhinsha Mountains region (D. A. Brew and others, unpub. data) reveals no bedrock source for the relatively high grade metamorphic and mafic igneous rocks found as erratics in lower Glacier Bay; these erratics, therefore, were derived from the Russell drainage. Reconnaissance studies of the Fairweather Range suggest sources of the erratics in the region between Mount Wilbur and Mount Fairweather. Three bodies of mafic igneous rock (principally olivine gabbro) are known in the Fairweather Range (Rossman, 1963, p. 11): (1) the Astrolabe-DeLangle stock near Dixon Harbor, (2) the Crillon-LaPerouse stock which includes the mountains of the same names (also known by Kennedy and Walton, 1946, p. 70), and (3) an unnamed gabbro body in the vicinity of Lituya Mountain and Mount Fairweather known only from boulders in the moraine of the Fairweather Glacier. These areas, which are known or inferred to be underlain by the gabbros, are shown in figure 1. Layered gabbro erratics found in lower Glacier Bay could have come either from the northern part of the Crillon-LaPerouse stock or from the gabbro body of unknown extent in the vicinity of Mount Fairweather. No occurrences of pyroxenite in the Fairweather Range are noted by either Kennedy and Walton (1946) or Rossman (1963), but pyroxenite might well be expected in association with the gabbro (Williams and others, 1955, p. 80).

The high-grade metamorphic rocks found as erratics probably were derived from the contact zones of the olivine gabbros. The Crillon-LaPerouse stock intrudes actinolite, staurolite, biotite-quartz, graphite, and hornblende schists as well as amphibolite northeast of the head of Lituya Bay (Kennedy and Walton, 1946, p. 68). Rossman (1963, p. 9) reports that "amphibole and biotite schists * * * compose most of the bedded rock in the area immediately north of the North Crillon Glacier." Rossman notes further that "in areas that have recently been uncovered from beneath snow and ice, the rock [biotite schist] contains andalusite, or, less commonly, staurolite * * * accompanied by small but abundant garnets." The observations of Kennedy and Walton (1946) and Rossman (1963) pertain to the west flank of the Fairweather Range, but it is probable that rocks of similar metamorphic grade occur at many places near the intrusive contact of the gabbro. Probably, therefore, the high-grade metamorphic rocks of the erratics suite were derived from the east flank of the Fairweather Range near the contact zones of either the Crillon-LaPerouse stock or the gabbro body of unknown extent near Mount Fairweather.

DISCUSSION

The present distribution of erratics, because it reflects the former distribution of ice, provides a measure of the relative glacial discharge from each major source area. Thus it is inferred that the recent glacial ice discharge from the Russell system greatly exceeded that of the Muir system. An effect of apparently greater discharge of the Russell system could have been produced if the western half of lower Glacier Bay were much shallower than the eastern half; in fact, however, the western half of lower Glacier Bay is deeper than the eastern half (U.S. Coast and Geodetic Survey, 1942).

That the discharge of ice from the Russell glacier exceeded that from the Muir seems surprising in view of the quantities of ice observed at lower elevations in each drainage by early scientific visitors. John Muir, who visited Glacier Bay in 1879, discovered an icefield of impressive size occupying Muir and Adams Inlets and the adjacent lowlands (Muir, 1893). H. F. Reid's topographic map (1896) shows the east-west dimensions of the icefield as 17 miles, the north-south as 14 miles; the surface lay between 1,000 and 2,000 feet above sea level over most of its extent. Reid's limits of the icefield are reproduced in figure 1. At the same time that Muir Inlet was occupied by an icefield, the valley glaciers of Tarr and Johns Hopkins Inlets had termini about 12 miles in advance of their present positions (fig. 1) (Reid, 1896; Gilbert, 1904). On the basis of maps and observations made near the end of the 19th century, therefore, it is clear that at lower elevations, the Muir drainage contained the larger amount of ice. Similar relations persist today, for valley glaciers of the Muir system are broader (fig. 1), probably deeper, and coalesced to a higher degree than valley glaciers in the Russell system.

Thus from the amounts of ice in each drainage at the end of the 19th century and today, observers might infer that glaciers of the Muir system had played the dominant role in the previous advance into lower Glacier Bay. The distribution of erratics, however, indicates otherwise. The following paragraphs explain these apparently contradictory relationships.

The hypothesis proposed is that ice drainage from the Muir region was partly or completely blocked by the relatively larger amount of ice flowing into lower Glacier Bay from the Russell drainage. Under these conditions three observed effects would be expected: (1) Ice from coalescing valley glaciers would form a large icefield. Reid's (1896) map of this icefield has already been noted (fig. 1). (2) Glaciers would seek other exits. Reid's (1896) map portrays a lobe of the Adams icefield extending southeastward into the valley of the Endicott River (fig. 1). (3) Recession of the Muir Glacier would lag behind that of the Russell glacier after recession had reached the junction of the two ice streams.

According to Lawrence (1958, fig. 6, p. 98), the Muir glacier and ice from the northwest arm of Glacier Bay (Russell glacier of this report) separated by 1860; between 1860 and 1899, the Muir retreated about 5 miles while the ice in the northwest arm of Glacier Bay retreated about 22 miles. Rapid recession of the Muir Glacier began only after 1899 (Field, 1947). These effects, which are consistent with the hypothesis of impeded drainage, are also consistent with a hypothesis of snow nourishment in the Muir drainage greater than in the Russell drainage. But if this were the case, it might normally be expected that glaciers would have advanced into Muir Inlet earlier than the Russell glacier would have advanced southward into the northwest arm of Glacier Bay. Goldthwait (1963, p. 42–43; 1966, p. 7–8), however, using carbon-14 dates, argues that glaciers advanced into Muir Inlet from the north and west at a later date than the time at which ice from the northwest arm of Glacier Bay (Russell glacier of this report) dammed the mouth of Muir Inlet and produced the lakes in which the late Wisconsin lacustrine member of the Van Horn Formation of Haselton (1966) was deposited. Thus, the hypothesis remains tenable that the large accumulation of glacial ice in the Muir area was the result of impeded drainage. Possibly also, the large amount of glacial ice present there today (1967) is chiefly relict, reflecting a former strongly positive accumulation caused by the partly or completely ponded drainage.

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UPPER PLEISTOCENE FEATURES IN THE BERING STRAIT AREA

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Abstract.—New data on upper Pleistocene deposits east of Bering Strait may solve some problems of correlation. Erratics (Skull Creek erratics) of a widespread pre-Wisconsin glaciation are now recognized; the east limit of the early Wisconsin York Glaciation is defined, as is the northwest limit of Wisconsin glaciers from the Kigluaik Mountains. An anomalous glacial pattern is shown for two adjacent ranges (York and Kigluaik Mountains) and existing glacial correlations are refined. The barrier bar along the northwest coast of Seward Peninsula is migrating landward rapidly. Local destruction of marine terraces of Yarmouth(?) and Sangamon age can be explained by glaciation and dune migration.

Continuing fieldwork on the western Seward Peninsula (fig. 1) has given much additional information on the upper Pleistocene features and deposits. The new information gives additional support to conclusions already presented (Sainsbury 1965) and leads to new conclusions that support earlier ideas (Hopkins and others, 1960). This paper contains more evidence supporting the proposed former existence of two glaciations (York and Mint River) of Wisconsin age, names a Recent glaciation (Esch Creek), and names erratics (Skull Creek) of a widespread glaciation of pre-Wisconsin age. It shows that the Pleistocene features may be traced eastward into the Grantley Harbor area, where important placer gold deposits occur. It further points out that the postulated Wisconsin glacial histories of the two main mountain ranges of the western Seward Peninsula (York and Kigluaik) differ substantially, which leads to the conclusion that either the postulated history is in error or that a very anomalous pattern of glaciation existed.

Acknowledgments.—The author is indebted to D. M. Hopkins and D. S. McCulloch for helpful reviews of this paper. During 1966, Hopkins spent three days in the field, during which time the marine deposits at California River were jointly examined, and other upper Pleistocene features and problems were discussed.

GENERAL GEOLOGY OF THE YORK MOUNTAINS

The general geology of the area is particularly favorable to the analyses of glacial advances by tracing erratics and by studying juxtaposition of moraines and marine strandlines. The entire western Seward Peninsula consists of but three main types of sedimentary rocks, and two highly contrasting types of plutonic rocks. The highest hills (York Mountains) from which the ice advanced northward over the lowlands are composed of fossiliferous limestone, whereas the wide lowlands are underlain entirely by slates, dark phyllites, and schistose argillaceous limestone; this situation allows easy recognition of erratic boulders and their source areas.

The highest peak in the York Mountains is Brooks Mountain, a 2,898 foot-high very coarsely porphyritic biotite granite stock about a mile across surrounded by calc-silicate rock and biotite-andalusite hornfels. It is the only such stock in the York Mountains. Because the main ice sheet in Wisconsin time centered on Brooks Mountain and flowed east, north, and south from it, an uninterrupted train of distinctively diverse erratics (porphyritic granite, hornfels, and limestone) marks the course of glaciers outward from the mountains and across the slate areas. Moreover, the area is a sparsely vegetated tundra where most hills higher than a few hundred feet are completely barren. On these hills, glacial erratics (especially of granite and tactite) are easily discerned. In the lowlands north of the mountains, several rivers have many cutbacks that show complete sections; and along the coastline to the south, marine erosion is exposing the old terrace deposits and valley fill and provides excellent exposures of all deposits younger than Sangamon (Pelukian transgression of Hopkins and others, 1960).

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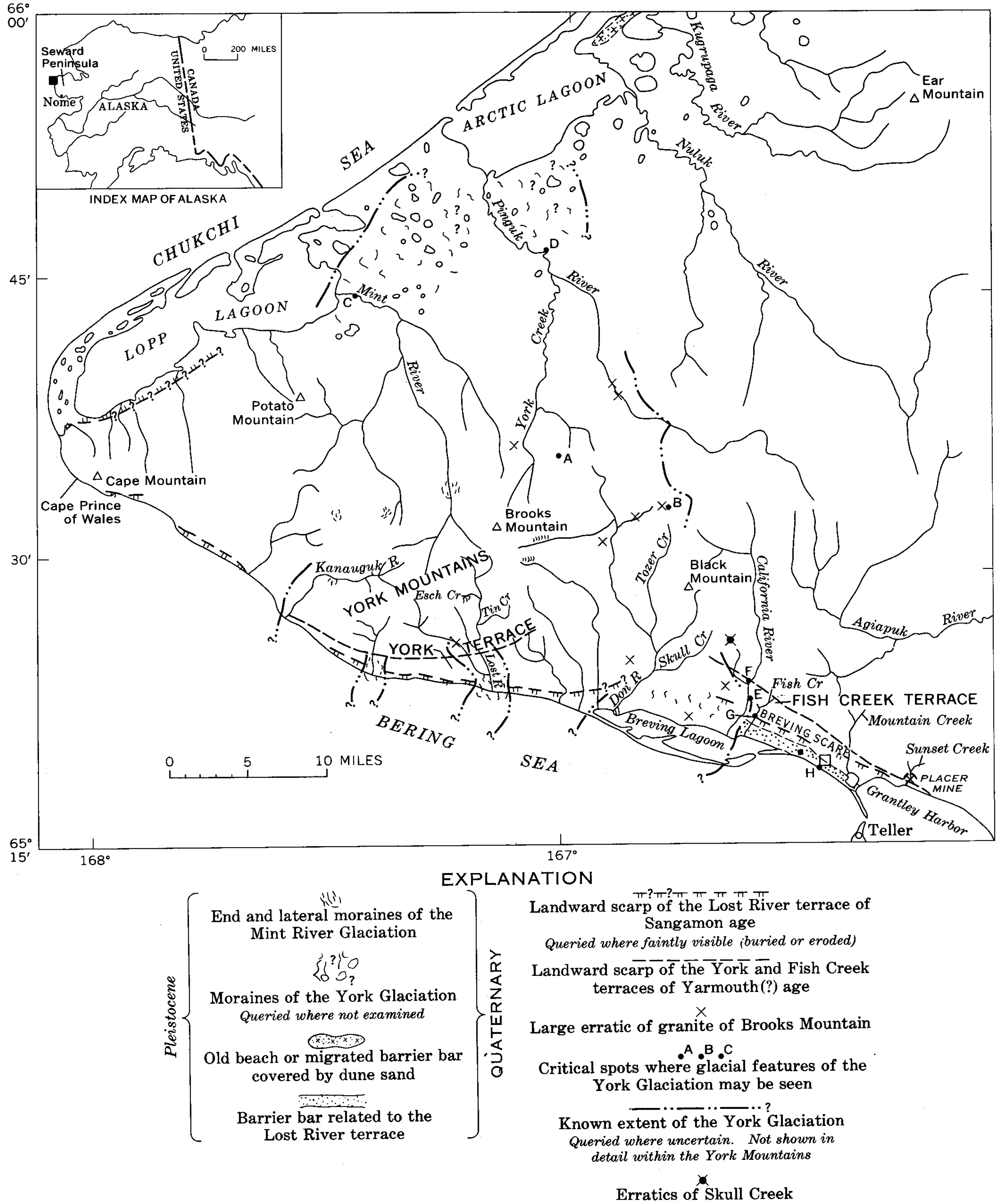

FIGURE 1.—Map of the western Seward Peninsula, Alaska, showing the upper Pleistocene features discussed in this report.

THE MARINE PLATFORM

Interrelations between glaciations and marine transgressions are well displayed in the Bering Strait region, where two distinct and extensive marine terraces are locally covered by glacial deposits. The older terrace of probable Yarmouth age (Sainsbury, 1965a), an elevated marine platform extending unbroken along the south side of the York Mountains for about 20 miles, is notched on its seaward side by the younger Lost River terrace of Sangamon age which extends east and west of the York (fig. 1). The York terrace was uplifted some 400 feet and gently warped after Yarmouth time; the Lost River terrace is undeformed, and its planed rock surface generally stands between 10 and 20 feet above sea level. A remnant of the York terrace is preserved at Cape Mountain on the Bering Sea (fig. 1) at an altitude of about 500 feet, showing that late Pleistocene uplift of several hundred feet extended into the Bering Strait. Hence, it is probable that during most of the Pleistocene prior to the uplift in late Pleistocene time, the Bering Strait was a seaway rather than a land bridge, as has been postulated by many workers.

GLACIATION REPRESENTED BY THE SKULL CREEK ERRATICS

Fieldwork in 1966 resulted in the recognition of erratics on hilltops near but several hundred feet higher than the terminal moraines of the York Glaciation (large dot and cross, fig. 1). The erratics lie in a saddle at an altitude of 770 feet in limestone hills west of the California River and east of Skull Creek (Teller B–4 quadrangle). Terminal moraines and drift of the York Glaciation mantle the lower slopes of the hills on the south side, reaching a maximum altitude of 250 feet. The high-level erratics consist of angular plates of biotite-andalusite hornfels, presumably from the hornfels zone around the biotite granite of Black Mountain, 5 miles northwest (fig. 1). Nowhere do they form a veneer, and hence they are not a mappable unit. Ice that overrode the saddle would have been unconfined ice several hundred feet thicker than the ice that left the lower moraines, and would, therefore, have extended much farther seaward than the ice of the York Glaciation. Significantly, the direction of ice movement was to the southeast, and the ice, therefore, may have been centered over Brooks Mountain, as was ice of the York Glaciation. The earlier glaciation is not named, but the erratics left by it are referred to as the Skull Creek erratics.

The earlier glaciation predates the Lost River terrace of Sangamon age (if not, drift would have buried the scarp and terrace deposits of that age beyond the limits of the York Glaciation, which it did not do). Unless the scattered cobbles which lie upon the York and Fish Creek terraces, and which are best explained as of marine origin, are in reality drift of the early glaciation, the early glaciation may be pre-Yarmouth in age (for example, it did not mantle the Yarmouth age terrace with drift). If the scattered cobbles on the York terrace are Skull Creek erratics, they may be correlative with an ancient (drift of pre-Illinoian? or early multistage Illinoian? age) glaciation in the Kobuk River area some 300 miles northeast (Fernald, 1964, p. K6; McCulloch, 1965). It is probable that rounded topography impressed on the hills between the western end of the York Mountains and Cape Mountain, and which the writer believes is ice-scoured topography, is correlative with this early glaciation. Pending proof of greater age, the Skull Creek erratics are here considered to be of pre-Wisconsin age, possibly Illinoian. No moraines or till of this glaciation are known, and the evidence for its former existence is the ice-rounded topography and the scattered erratics of hornfels at Skull Creek.[1]

GLACIATIONS OF WISCONSIN AGE

In the western Seward Peninsula, Sainsbury (1965b) has recognized and named two glaciations of Wisconsin age, principally on the basis of a study of the central York Mountains. New work proves that the York Glaciation of early Wisconsin age was centered over the York Mountains (fig. 1). Its ice spread north of the mountains for at least 20 miles, where the ice formed a thick piedmont lobe covering at least several hundred square miles and left moraines that obliterated the Lost River terrace at the present shoreline of the Chukchi Sea. Valley glaciers penetrated south of the mountains only along the major valleys, where they left moraine and outwash over the marine terraces.

After retreat of the York Glaciation, and before the maximum advance of the Mint River glaciers, large alluvial fans and talus cones were built outward into the main glaciated valleys. On the south side of the York Mountains, where no glaciers formed during the Mint River Glaciation, valley fills as much as 100 feet deep were deposited locally; these fills were subsequently trenched deeply by streams.

The Mint River Glaciation, of late Wisconsin age,

[1] High-level erratics were found in 1967 on mountaintops 75 miles east of the York Mountains, and indicate that ice from an unknown source (probably an icecap) flowed south from the Chukchi Sea and overrode this part of the Seward Peninsula. The erratics are correlated with the Skull Creek erratics.

was restricted to north- or west-facing valleys in the York Mountains, and both terminal and lateral moraines are well preserved. Ice flowed down main valleys as much as several miles from cirques, but did not coalesce into piedmont lobes. The larger moraines are shown on figure 1.

A third glaciation is here named the Esch Creek Glaciation from the well-defined moraine at the type locality which is in the large cirque in the headwaters of Esch Creek, a tributary of Lost River. It is presumed to be of Recent age because the moraines lie in or near cirques. The moraines consist entirely of limestone; they are practically undissected and are enclosed by modified end moraines (probably Mint River) about 1 mile downstream.

The Esch Creek Glaciation moraines lie on broken bedrock and have only scattered patches of tundra grass on top. The moraine at the type locality is confined to the cirque and extends only about half a mile from the headwall. During the Esch Creek Glaciation, ice was confined entirely to high-level cirques facing north in the central York Mountains. A large cirque on the southwest shoulder of Brooks Mountain that heads against a ridge 1,400 feet high was extensively glaciated during the Mint River Glaciation, but not during the Esch Creek Glaciation, showing that the perennial snowline was higher during the Esch Creek Glaciation. Most cirques that were ice filled during the Esch Creek Glaciation head against ridges exceeding 1,700 feet in altitude.

CRITICAL POINTS OF OBSERVATION OF THE YORK GLACIATION

Because the moraines of the York Glaciation are not easily observed in the lowlands along the northwestern Seward Peninsula, and because the restricted moraines south of the York Mountains give no clue to the former great extent of ice north and west of the mountains, specific localities that disclose critical relations are marked on figure 1 (points A to E) and are briefly discussed here. The absence of large moraines of the York Glaciation in the York Mountains may be explained by the fact that almost all the bedrock north of the ridge line of the mountains was buried by ice, which probably accounts for a small accumulation of morainal material and, consequently, restricted terminal moraines. Moraines are noticeable only at the extreme terminus and along glaciated valleys on the south side of the mountains, where well-defined terminal and ground moraine is preserved and still contains closed depressions and pools that form subdued hummock and kettle topography. Some of the critical points of observation used to establish the age and extent of the York Glaciation are discussed below (fig. 1).

At point A, at an altitude of 1,050 feet on the northwest shoulder of a rounded mountain on the extreme north front of the York Mountains, scoured and grooved limestone is exposed in several places. Near the grooved limestone are widely scattered erratics of tactite and gravels of polished quartz. The limestone has been exposed since the retreat of the ice. The erratics are from Brooks Mountain, some 7 miles to the southwest. Polished quartz pebbles, which extend to an altitude of 1,250 feet on the adjacent hill and are also foreign to the area, are waterworn—presumably in subglacial streams. The exposures prove (1) that ice no longer confined to valleys was almost 1,000 feet thick along the north front of the mountains and (2) that the ice sheet was Wisconsin in age, for it is inconceivable that glacially grooved limestone continuously exposed could have survived from Illinoian time or ice sheets of an earlier time.

At point B, at an altitude of 470 feet in the low rounded divide between the Don River and Tozer Creek, a cutbank exposes numerous large boulders, some faceted, of granite from Brooks Mountain in a till-like matrix. The exposure proves that ice from Brooks Mountain, 12 miles west, moved upvalley along the Don River and its tributaries for several miles, and that it crossed the divide.

At point C (figs. 1, 2), a high cutbank on the south bank of the Mint River, glacial till containing polished and striated cobbles overlain by shingled outwash gravels and loess is exposed at river level (altitude about 20 feet). The exposure is in a large area of low hummocky hills and many lakes where the Lost River terrace has been obliterated. The hummocky topography extends some 15 miles northeast to the Pinguk River, and several miles southwest. Numerous peat bogs and filled lakes are interspersed among the lakes between hummocks, and drainage is poor. Many of the morainal hills are notched by river terraces indicating widespread fluvial action unrelated to the present drainage, probably during retreat of the ice. The exposure proves (1) that ice moved at least 20 miles north from its source area in the York Mountains and formed a large piedmont sheet, and (2) that, on the basis of all existing evidence, the moraine obliterated the Lost River terrace, and hence is Wisconsin in age.

The relations at point D, a high cutbank on the northeast side of the Pinguk River in an area of low

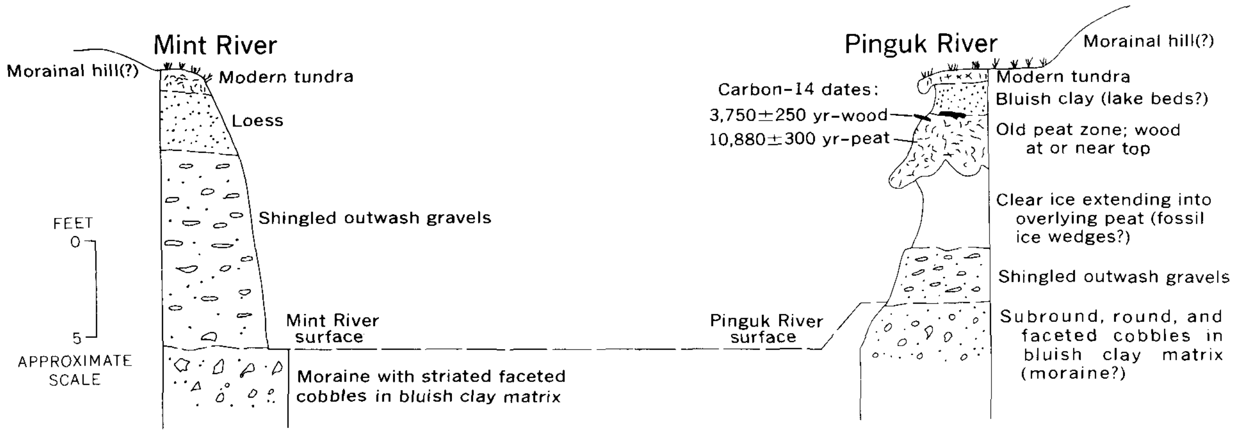

FIGURE 2.—Sections exposed in cutbanks on the Mint (*C*, fig. 1) and Pinguk (*D*, fig. 1) Rivers.

hummocks and lakes, are shown in figure 2. The shingled gravels at the base of the cutbank are similar to those above the till in the cutbank on the Mint River, and are considered to be outwash gravel. The underlying material containing faceted cobbles in a clayey matrix is believed to be moraine. From the air, it can be seen that the cutbank is near the edge of an old flat surface that lies between low hummocky hills, covered by thick tundra, and the Mint River. This surface could be either an old filled lake or a high-level terrace, but is more probably a filled lake.

Wood and peat from the cutbank were dated by the carbon-14 method by Meyer Rubin, U.S. Geological Survey radiocarbon laboratory, to establish the youngest possible age for the outwash gravels (fig. 2). The peat, consisting of grasses and sedges, proved to be 10,880 ± 300 years old, and the wood, 3 feet higher in the section, is 3,750 ± 250 years old (U.S. Geol. Survey Nos. W–1776 and W–1773.) The sequence is interpreted to show (1) the advance of glaciers of the York Glaciation, (2) retreat of the ice and modification of the moraine by fluvial action, or advance of the glaciers of the Mint River Glaciation and deposition of outwash gravel, (3) formation of the peat zone on a bench about 10,000 years ago, (4) increase of water, possibly by blocking of subsurface drainage by permafrost, which created a small lake having a growth of woody shrubs on its banks some 3,750 years ago, and (5) formation of the modern tundra after the lake was filled or was drained by erosion by the Pinguk River.

At point E, a cutbank on the east bank of the California River, angular and faceted cobbles in a blue clay matrix can be recovered by digging with a shovel below river level. The faceted cobbles and the resemblance of the matrix to the clay-matrix till containing striated cobbles on the Mint River, suggest that the material is moraine. This is the most easterly point at which morainal material has been found; significantly, it also marks the eastern margin where the Lost River terrace of Sangamon age has been obliterated. From here eastward to Grantley Harbor, the Pelukian transgression strandline (Lost River terrace) and a corresponding offshore barrier bar are continuously exposed in the present seacliffs (fig. 1.). West of the California River, hummocky topography extends west to the Don River, and moraine is exposed locally in frost boils and along the beach of Breving Lagoon. Observations of the above localities are convincing evidence of the wide extent of ice during the York Glaciation of early Wisconsin age.

DESTRUCTION OF THE YORK TERRACE

The excellent state of preservation of the York terrace along the south front of the York Mountains leads one to seek an explanation for its absence elsewhere. Along the south front of the peninsula, absence of parts of the terrace can be correlated with soft bedrock (slate), for example, in the area west of the Kanauguk River, and between the Don and California Rivers. Its complete absence along the north side of the peninsula cannot be so explained, and leads to the conclusion either that the terrace never existed (unlikely), or that it has been totally destroyed by processes of erosion which did not operate south of the mountains.

Two explanations for the situation above are that (1) a much wider distribution of ice on the north side of the mountains existed during both the early glaciation represented by the Skull Creek erratics and the York Glaciation, and (2) increased erosion was caused by heavier snowfall and later runoff. Without question, the York Glaciation was much more widespread north of the mountains, for ice reached almost to the present shoreline of the Chukchi Sea, some 25 miles north of its source at Brooks Mountain, whereas it penetrated south of the mountains only along low passes or around the west end where coalescing valley glaciers probably formed a piedmont lobe. On the basis of (1) the absence of moraine at most places on the York terrace, and (2) the undissected surface of the terrace, one can conclude that the York terrace south of the mountains was not covered by ice that left the Skull Creek erratics or ice of the York Glaciation. Therefore, the York terrace north of the mountains probably has been eroded principally by glacial scouring during two widespread glaciations.

At present, snowfall north of the mountains seems both to be heavier, and to last longer, than to the south. From several years of personal observation, it can be stated that deep snow persists about a month longer on the north side of the mountains. During this critical period, seasonal frost thaws and the runoff from melting snow removes the soil more effectively than the snowmelt while seasonal frost persists. This process could have contributed in a minor way to erosion of the York terrace north of the mountains.

Incidentally, we should note the possibility that ice from the Chukotsky Peninsula in Siberia may have pushed southeast through the Bering Strait to meet ice flowing north from the York Mountain and forcing an unusually thick accumulation of ice along the northwestern Seward Peninsula. Reliable information on the eastward extent of ice from the Chukotsky Peninsula is lacking. The sampling methods used by marine geologists and oceanographers (Creager and McManus, 1965) have not been capable of recovering glacial till buried by upper Pleistocene and Recent sediments in the Bering Strait regions. For example, a coring device would have to penetrate as much as 30 feet of Recent sediments, several feet of silt, and several feet of outwash gravels (as shown in fig. 2) before entering till recognized as such only by its content of straited and faceted cobbles. Statements have been made denying the existence of glacial deposits in the Bering Strait areas because piston core samplers neither reached bedrock nor recovered glacial material similar to that exposed near the present shoreline. These statements may be wrong, for they are based on nondefinitive data. Moreover, D. M. Hopkins (oral commun., 1967) stated that divers from the Navy Electronics Laboratory observed striated bedrock off Cape Prince of Wales in 1966, a fact which strongly suggests the possibility of glacial scouring in the Bering Strait.

DESTRUCTION OF THE LOST RIVER TERRACE BY GLACIATION

From figure 1, it is seen that proven or probable till exists in the areas where the Lost River terrace disappears as a distinct topographic feature. At several places, this till (or outwash gravel) is exposed where it overlies the marine platform of the terrace. In areas beyond the probable termini of the glaciers of the York Glaciation, the Lost River terrace is preserved, or obscured by other processes presently operative in the area, for example, dune migration.

POSSIBLE DESTRUCTION OF THE LOST RIVER TERRACE BY DUNE MIGRATION

Between the Kugrupaga River (fig. 1) and Shishmaref (fig. 3), on the offshore barrier bar, there is an extensive lowland with numerous low hummocky hills, many of which are elongated parallel to the coastline.

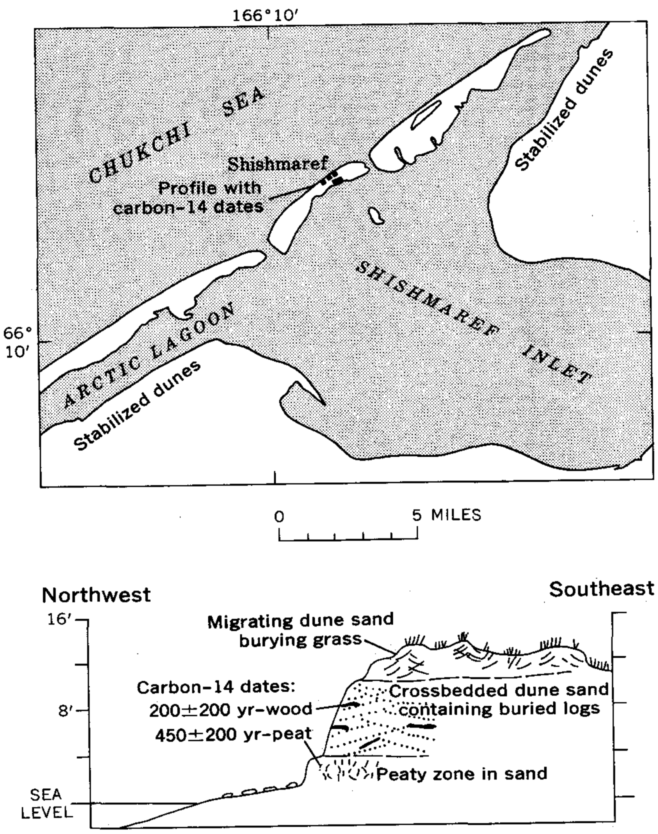

FIGURE 3.—Shishmaref Inlet, and section along modern beach.

Low-level aerial reconnaissance disclosed that most of the trenched hills are composed of stratified sand; some have gravels at the base. These hummocks probably are mostly sand dunes that have been stabilized by tundra, and it is entirely possible that in this area the Lost River terrace was obliterated by migrating sand dunes rather than by glaciation, or alternatively, that moraine is present but covered by dune sand.

Between Shishmaref Inlet (fig. 3) and Arctic Lagoon, an ancient barrier bar composed principally of sand extends along the mainland side of Arctic Lagoon for 12 miles (fig. 1). Because the ancient barrier bar is composed principally of sand, it probably originated by shoreward migration of dune sand on a barrier bar, as is happening to the present barrier bar. This modern bar is about 0.5 mile wide at Shishmaref (fig. 3), and it is migrating landward rapidly. The Eskimos at Shishmaref say that "about 50 feet" disappear from the front of the bar each year (Walter Noyapuk, oral commun., 1965). A cross section of this bar as exposed along the beach southwest of Shishmaref shows logs in dune sand above a peat zone buried beneath cross-bedded dune sand (fig. 3); radiocarbon dating shows the peat to be only 450 ± 200 years old and the logs 200 ± 200 years (U.S. Geol. Survey Nos. W–1778 and W–1771). As the peat and wood represent backslope tundra and beachwood buried by migrating dune sand, it is concluded that the beach is migrating landward at the rate of at least half a mile (the width of the bar) in a few hundred years.

TERRACES EAST OF THE CALIFORNIA RIVER

Two terraces extend east from the California River to Grantley Harbor (fig. 1). The lower terrace can be correlated confidently with the Lost River terrace, but the upper terrace lies well below the York terrace, and has a canyon cut into it that is filled with marine and continental gravels. The higher terrace, which has its landward scarp at an altitude of about 350 feet, as opposed to about 650 feet for the York terrace, is here named the Fish Creek terrace. The lower terrace, here correlated with the Lost River terrace of Sangamon age, is composite, and consists of an outer gravelly barrier bar generally below 80 feet in altitude; it contains numerous fragments of marine shells, and it has an inner scarp, here termed the Breving Scarp, which lies below about 100 feet in altitude. Where exposed along Fish Creek (*G* on fig. 1), the Breving Scarp truncates bedrock. Seaward of the scarp, ground level slopes gently seaward for about a mile, then rises toward the barrier bar. Bedrock is beneath stream level in this area, and is buried by dark, organic-rich muck and silt. The surface expression is that of either an old filled-in lake or a lagoon. Both the scarp and the barrier bar can be traced eastward almost to the modern beach at Grantley Harbor (fig. 1).

The Fish Creek terrace has a bare rock surface sloping up landward at about 100 feet per mile from where it is truncated by the Breving Scarp, and its slope steepens abruptly at about 350 feet altitude. Boulders, angular cobbles, and pebbles of rocks of lithology foreign to the area lie scattered on the terrace surface where bedrock is exposed. At an altitude of about 150 feet in Fish Creek valley, 1.2 miles landward of the Breving Scarp, marine gravels containing large rounded boulders of lava are well exposed, and lie in the streambed below the level of the terrace surface. The marine gravels are not continuous with the marine gravels of the Lost River terrace. The sloping surface of the Fish Creek terrace and the landward slope break can be traced eastward to Mountain Creek (fig. 1), where an abrupt change in bedrock lithology occurs along a fault trending up Mountain Creek. Quartz-mica schists of greenish cast that crop out east of the fault are faulted against the argillaceous limestones to the west. The terrace can be traced east of the fault, but owing to the more rapid weathering of the schist, the hills are lower and more rounded, and the landward scarp is subdued. The terrace ends about a mile east of Sunset Creek where the inner scarp intersects Grantley Harbor. There is no suggestion of the terrace on the south shore of Grantley Harbor.

Owing to the lower altitude of Fish Creek terrace, and the occurrence of marine deposits in a canyon cut into it, the Fish Creek terrace cannot be positively correlated with the York terrace, although additional study probably will prove it to be the same surface but at a lower altitude.

MARINE DEPOSITS IN CANYON OF THE CALIFORNIA RIVER IN FISH CREEK TERRACE

A complex sedimentary fill of a canyon that is cut into the Fish Creek terrace is well exposed on the west bank of the California River where the river issues from the mountains at a point 4 miles from Breving Lagoon. The deposits (fig. 4) consist of wood- and shell-bearing beach deposits which enclose a wedge of conglomerate of continental origin, and which is overlain by thin deposits that contain angular to rounded erratic boulders and cobbles of glacial origin (York

Glaciation). The slopewash conglomerate contains the same lithologies as lithified continental conglomerates that occur on the York terrace to the west (Sainsbury, 1965a). The base of the marine gravels on the California River is below the level of bedrock exposed a few hundred yards downstream, a fact which shows that the gravels were deposited in a canyon trenched below the level of the Fish Creek terrace.

The exposures imply the following sequence of events, oldest first:

1. Cutting of the marine platform represented by the Fish Creek terrace; or, uplift of an older terrace (or eustatic lowering of the sea) and trenching of the terrace by the California River.
2. Rise of sea level and deposition of marine deposits.
3. Temporary lowering of sea level and encroachment of a wedge of nonmarine gravel of local origin.
4. Rise of sea level and final cutting of the seacliff, deposition of the upper marine gravels, and then lowering of sea level.
5. Advance of glaciers of the York Glaciation.
6. Trenching of the valley fill by the modern stream.

The age of the marine deposits in the California River is not certain. No diagnostic fossils were recovered, although a carbon-14 age date on the wood gave the age as greater than 35,000 years (U.S. Geol. Survey No. W–1984). Furthermore, there are not sufficient exposures to prove whether the Fish Creek terrace was originally a continuous surface that was trenched by the California River, or whether a canyon existed prior to cutting of the Fish Creek terrace and was filled by deposition of the marine gravels. The lapping of beach gravels toward the old seacliffs (fig. 4) suggests that the upper gravels were deposited during the final cutting of the terrace. The glacial deposits which overlie the marine deposits prove that the marine gravels are older than the York Glaciation of early Wisconsin age. The fact that the Breving Scarp of probable Sangamon age bevels the Fish Creek terrace suggests a pre-Sangamon age for the gravels. In this report, these marine deposits in the California River are dated only as probably pre-Sangamon. If the Fish Creek terrace is correlative with the York terrace, the deposits may be as old as Yarmouth(?). Whatever their age, the deposits show a two-stage sea-level stand separated by a time interval of unknown, but probably short, length.

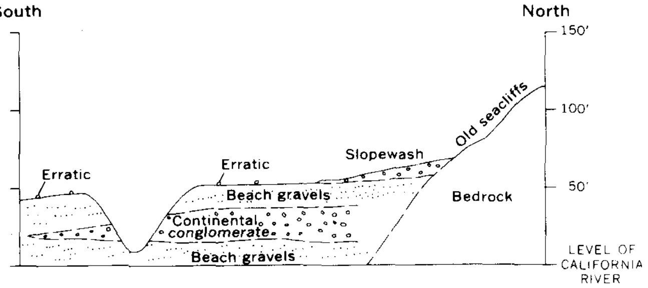

FIGURE 4.—Marine and continental gravels on west side of the California River.

SUNSET CREEK PLACER GOLD DEPOSIT

Near the east end of the Fish Creek terrace on Sunset Creek is a gold placer deposit (fig. 1). It is the most westerly one in a large and important field of gold deposits on the western Seward Peninsula (Brooks and others, 1901). It extends upstream and downstream from the old slope break of the modified seacliffs of the Fish Creek terrace, where deposition occurs because of reduced stream gradient. Greenschists east of the fault along Mountain Creek contain numerous small gold-bearing quartz veinlets, which, on weathering, provide the gold for the placer deposits.

PROBLEMS AND CORRELATIONS

Several problems remain unsolved relative to the late Pleistocene history of the western Seward Peninsula, as summarized below:

1. Age and extent of the glaciation that left the Skull Creek erratics.
2. Age of the marine gravels filling the canyon of the California River, and in upper Fish Creek.
3. Correlation of glacial advances in the York Mountains and the Kigluaik Mountains.

The first can be solved only by considerably more fieldwork in adjacent areas, but the glaciation that left the Skull Creek erratics obviously was widespread. It is perhaps worthwhile to note here that evidence is accumulating in widely separated areas of northwestern Alaska that suggests a very widespread glaciation of pre-Wisconsin age. This glaciation is represented by the unnamed pre-Illinoian glaciation of Fernald (1964, p. K6) in the Kobuk, by the Skull Creek erratics of the writer, and by permissive evidence of glaciation of pre-Sangamon age in the Cape Thompson area (Sainsbury and others, 1965, p. 241–244). Fernald (1964, p. K6) cautiously suggests that his glaciation was "perhaps of ice-cap proportions," Sainsbury and others (1965, p. 244) cautiously suggest that ice from an unknown source may have blocked drainage in lowland areas not formerly considered as glaciated in the Cape Thompson area (although the topography looks ice-scoured to the writer). Also, they suggest that the glaciation that left the Skull Creek erratics must have extended over lowlands far beyond the limits of the York Glaciation which itself was of much greater extent than postulated recently by Péwé and others (1965). It is perhaps time to state not so cautiously that an icecap may have existed over much of northwestern and northern Alaska.[2] Absolute age dates for the shells in the marine deposits in the California River will give additional information on the age of the deposits.

Correlation of glacial advances between the York and Kigluaik Mountains still presents problems, the major one being the single glaciation of Wisconsin age in the Kigluaiks. Elsewhere in northwestern Alaska, two glaciations of Wisconsin age are recognized (Fernald, 1964, p. K12–K16). If there is a single Wisconsin glaciation in the Kigluaik Mountains, then a very anomalous glacial pattern exists between two adjacent ranges on the Seward Peninsula.

The writer and D. M. Hopkins spent a few days in 1966 in an attempt to resolve the question. With the new information presented here, and the benefit of mutual discussion, the following explanations of the problem were considered:

1. Instead of being of Sangamon age, the Lost River terrace is older and the York drift therefore is older.
2. A drift of early Wisconsin age is present but unrecognized in the Kigluaik Mountains.
3. The glaciation of early Wisconsin age did not extend beyond the limits of the Salmon Lake Glaciation, and hence is everywhere covered by Salmon Lake drift.
4. The Salmon Lake drift can be subdivided into drifts of early and late Wisconsin ages.

The facts warrant agreement on several of these points as follows:

1. The Lost River terrace almost certainly is of Sangamon age, and the terminal moraines of the York Glaciation definitely have covered the terrace and are, therefore, younger and hence Wisconsin.

[2] For additional evidence of this icecap, see footnote 1 on p. D205.

TABLE 1.—*Correlation chart for upper Pleistocene features and events in the Seward Peninsula–Bering Strait–Kobuk area, Alaska*

Age		York Mountains (Sainsbury, this paper)	Kigluaik Mountains (Hopkins and other, 1960)	Central Kobuk region and Baldwin Peninsula (Fernald, 1964; McCulloh, 1965)
Recent		Protalus ramparts Esch Creek Glaciation	Mount Osborn Glaciation	Modern glaciers and recessional moraines in Schwatke Mountains Ulaneak Creek Glaciation
Wisconsin	Late Wisconsin	Mint River Glaciation (two distinct pulses) Alluvial fans, stream terraces, and talus cones	Alluvial fans, talus cones, and terraces. Salmon Lake Glaciation (undivided pulses)	Walker Lake Glaciation (2 or 3 pulses)
Wisconsin	Early Wisconsin	York Glaciation	Alluvial fans, talus cones, and terraces. Salmon Lake Glaciation (undivided pulses)	Ambler Glaciation
Sangamon	Pelukian Transgression	Lost River terrace and covering marine deposits	Coastal terrace between Port Clarence and Cape Douglas-Second Beach at Nome	
Pre-Sangamon		Skull Creek erratics	Nome River Glaciation Iron Creek Glaciation	Kobuk Glaciation Earliest glaciation

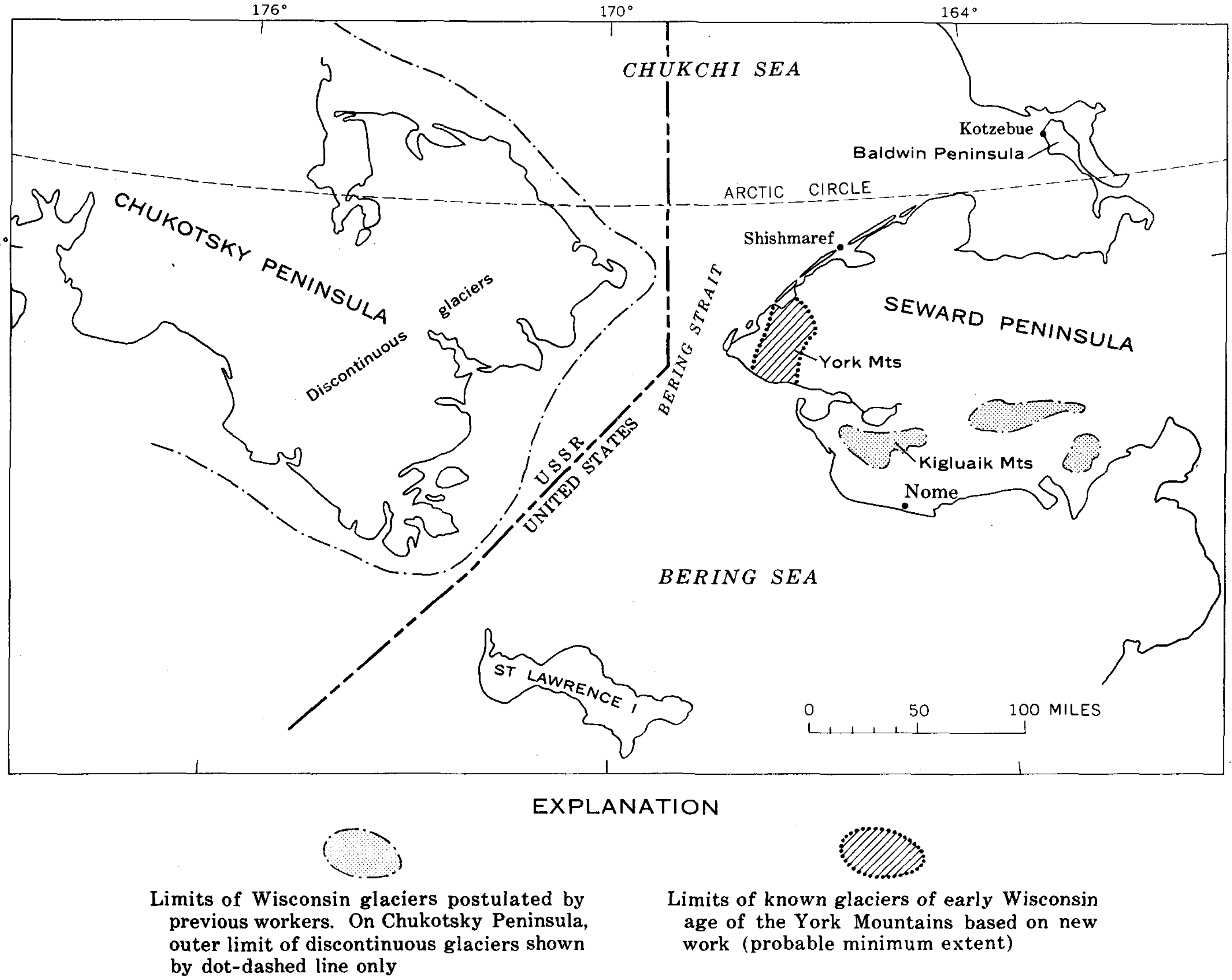

FIGURE 5.—Map of the Bering Strait area, showing the contrast in the postulated extent of glaciations in Wisconsin time on opposite sides of the strait. Source of Russian data: Gerasimov and Baranov (1964, p. 199).

2. Glaciers (Wisconsin) never extended northwest from the Kigluaiks as far as the north shore of Grantley Harbor, as is proved by the preservation of the Lost River terrace (Sangamon). This suggests an anomalous glacial pattern, for the Kigluaiks are, on the average, some 2,000 feet higher than the York Mountains, yet in Wisconsin time ice could not have extended any farther outward than did ice from the York Mountains.
3. The Salmon Lake Glaciation is complex and probably can be subdivided.
4. A till of early Wisconsin age may be present in the Kigluaiks but is not recognizable by current work.

The above four statements largely remove the problem of correlation. Should future work show, however, that ice of Wisconsin age never extended beyond the Salmon Lake moraines, we must find the explanation for the much greater extent of ice from the much lower York Mountains. The only possible factor, climate excepted, that may be significant is late Pleistocene uplift of the Kigluaik Mountains, which are bounded on the north front by a range-front fault showing Recent movement.

On the basis of the information given here, a correlation chart for upper Pleistocene glaciations in the Seward Peninsula-Bering Strait-Kobuk area has been compiled (table 1) using information by Hopkins and others (1960), Fernald (1964), McCulloch (1965), and Sainsbury (this paper), for the three areas. A map showing the correlated extent of glaciers in Wisconsin time on the Alaskan side of the Bering Strait is given in figure 5.

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