Geology and Ore Deposits of the Central York Mountains, Western Seward Peninsula, Alaska

GEOLOGICAL SURVEY BULLETIN 1287

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By C. L. SAINSBURY

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Description of the geologic structure, stratigraphy, petrology, and ore deposits of an area containing tin deposits and a new type of beryllium deposit

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GEOLOGY AND ORE DEPOSITS OF THE CENTRAL YORK MOUNTAINS, WESTERN SEWARD PENINSULA, ALASKA

By C. L. Sainsbury

ABSTRACT

In the central York Mountains, carbonate rocks of Early, Middle, and Late Ordovician age aggregating at least 8,000 feet in thickness are thrust northward over slate and argillaceous limestone of pre-Ordovician age which were intruded by gabbro in pre-Ordovician time. Normal faults of four distinct systems cut the thrust plates, and, in Late Cretaceous time, stocks of biotite granite, abnormally rich in beryllium, tin, boron and other trace elements pierced the thrust plates. In part following the intrusion of the granites, a strong set of normal faults developed striking N. 60°–85° E. through the central York Mountains, and locally these faults cut the granites. Still later, dikes of granite, rhyolite porphyry, and finally, lamprophyre were injected into some of these faults. Trace elements in the lamprophyres prove that they are mafic rocks, probably derived from the sima, and that they cannot be related genetically to granite.

Shortly after intrusion of the lamprophyre dikes, ore deposits of tin, beryllium, and fluorite were formed from solutions probably derived from deeply buried hot granite where the granite was ruptured by normal faults. Ore shoots were localized beneath thrust faults where the faults are intruded by dikes, and a major ore-bearing structure, the Rapid River fault, is 50 percent mineralized for half its length, or a distance of 8 miles. The tin deposits contain cassiterite and stannite in topaz greisen with abundant sulfides of copper, lead, zinc, and iron, as well as wolframite. The beryllium deposits contain fluorite, chrysoberyl, diaspore, muscovite, and tourmaline, with trace to small amounts of euclase, bertrandite, helvite, phenakite(?), todorokite, and hematite. Beryl occurs sparsely in late veins of quartz and fluorite. Chrysoberyl is the earliest and commonest beryllium mineral, followed by euclase and bertrandite, and then phenakite(?) and beryl. Helvite is restricted near granite to banded skarns which consist of magnetite and fluorite. Throughout the district, a strong zonation is displayed from tin deposits in greisen through transitional veins of sulfide minerals with fluorite and chrysoberyl to fluorite-beryllium deposits and thence to barren veins of silica and fluorite with trace amounts of beryllium. This zonal arrangement of deposits probably will be found elsewhere in the world where greisen tin deposits occur in carbonate rocks.

The ore deposits of tin and beryllium are of considerable economic and strategic value. Although the known tin deposits contain only about 23,000 short tons of tin metal—less than one-half year's supply at the 1965 consumption rate—they represent by far the largest lode reserves of tin in the United States. The known beryllium deposits, though not in production, contain about

4,500 tons of beryllium metal, more than 10 times the beryllium contained in all known domestic pegmatite deposits of substantially lower grade. As the beryllium ores contain more than 50 percent CaF_2 they constitute a large reserve of fluorite, which, together with fluorite ores associated with the tin deposits, totals some 1 million short tons of fluorite. In addition, the known tin deposits contain approximately 62,000 short ton units of WO_3, and important but as yet unassessed amounts of silver, lead, and zinc.

The geochemical cycle of the trace elements beryllium, tin, tungsten, boron, lithium, copper, lead, zinc, and niobium shows that these elements were enriched in the biotite granites and were strongly fractionated among the minerals of the granites. From the granites these rare elements moved outward into contact rocks and ore deposits.

During the supergene cycle, clear geochemical anomalies were formed in stream sediments, soils, and plants near ore deposits, and geochemical prospecting of these anomalies led to the discovery of the beryllium lodes. With the possible exception of zinc and niobium, the rare elements that are associated in the rocks and ores remain associated in the supergene processes. Fixation of zinc in clay soil and tundra plants may account for the relatively small amount of zinc in stream sediments.

Datable Pleistocene events in the York Mountains begin with the Yarmouth Interglaciation when the York Terrace, a wide marine platform, was cut. In Illinoian time, the York Terrace was uplifted almost 400 feet, and during the Sangamon Interglaciation a second marine platform (Lost River Terrace), which is not deformed, was cut. During Wisconsin time the widespread York Glaciation was followed by the more restricted Mint River Glaciation. A pre-Wisconsin glaciation of much greater extent than the York Glaciation has also been recognized. Because uplift of the York terrace extended into the Bering Strait, it is probable that prior to the uplift in Illinoian time the Bering Strait was a seaway and a barrier to land migration rather than a land bridge.

INTRODUCTION

LOCATION

The area of study encompases some 400 square miles near the western tip of the Seward Peninsula, Alaska, in the Teller B–5, B–6, C–5, and C–6 quadrangles. In an attempt to establish a regional picture, other areas were visited, and samples were taken for analyses, especially from granite stocks. The general areas of interest, and the main area mapped, are outlined in figure 1. Within the area of figure 1 are concentrated the only lode and placer deposits of tin that have produced commercially important amounts of this metal in the United States. The tin deposits are associated with biotite granite intrusives that are the extension into Alaska of a long belt of granites, many with associated tin deposits, in eastern Siberia. The belt of known tin deposits, lode and placer, continues eastward through central Alaska.

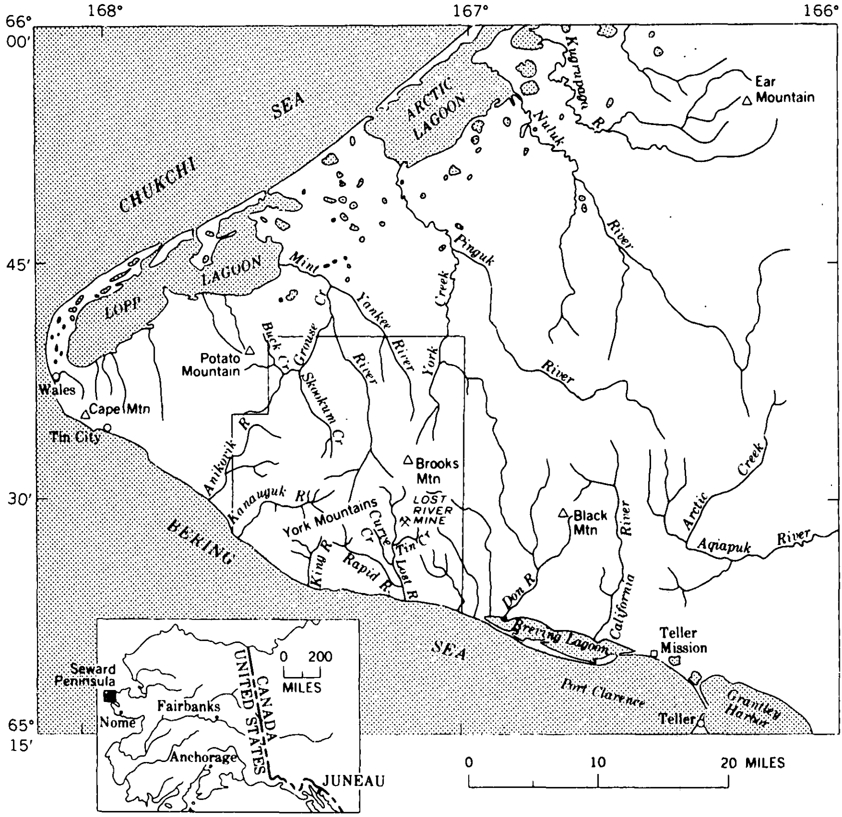

FIGURE 1.—Western Seward Peninsula, Alaska, showing areas discussed in this report.

PURPOSE AND SCOPE OF REPORT

Originally, the stated objectives of this research were (1) to decipher the structure and stratigraphy of the central York Mountains in order to ascertain the geologic setting of the main tin deposits near Lost River; (2) to apply the information gained from step 1, in conjunction with geochemical prospecting, in a search for new ore bodies; (3) to determine the geochemical distribution of certain rare elements, particularly tin, tungsten, beryllium, lithium, fluorine, boron, and niobium, in the rocks, minerals, and ores of the district; and (4) to decipher the geomorphic history of the area, with particular emphasis on the origin and history of the York Terrace (Bench), a wide surface, carved on bedrock, that is a prominent geomorphic feature throughout the mapped area.

Solution of the original objectives of the study required collection of data too voluminous for total inclusion here. In addition, the discovery of attractive new beryllium deposits, with subsequent demand from private industry for information to help plan and direct physical exploration, required earlier publication of much data that otherwise would have been included in this report. (See "Selected References.") The Pleistocene history is being published separately, and is presented here only in abstract. This report is confined to data directly related to the ore deposits, to the stratigraphy and structure of the area, and to geochemical data not presented elsewhere.

METHODS OF STUDY

Geologic mapping was done directly on topographic maps at a scale of 1:40,000. Stations were located using an aneroid barometer and by resection of angles by Brunton compass to prominent topographic features. A base camp was established at the Lost River mine, and field camps were placed and reached by light airplane piloted by the author, by weasel (a tracked vehicle), or by backpacking. Mapping was facilitated by use of kodachrome slides and aerial photographs and by aerial reconnaissance. Stratigraphic sections were measured at critical localities, and more than 50 collections of fossils were used in the correlation and dating of rock units. Many of the fossils, however, are new species, without diagnostic stratigraphic value as yet. Planetable maps of the main beryllium deposits discovered during fieldwork were prepared. Total fieldwork required about 1 month in 1960 and 3 months in each of the years 1961–64.

ACKNOWLEDGMENTS

The work discussed herein, and the results reported, were greatly aided by the cooperation of numerous people and companies. I specifically acknowledge the following: Mr. and Mrs. Clayton Pearson and Mr. and Mrs. Lenhart Grothe, owners of the Lost River mine, for shelter and other favors; Pearce Walsh and his father (who is now deceased), Mike Walsh, of Nome, for numerous favors and heartening support; and Mr. and Mrs. Robert Blodgett and Mary Tweet, of Teller, for off-hours service for groceries and mail and for other hospitalities. For technical information included herein I thank Robert Fulton of Newmont Mining Co., John Conrow and Carl Glavinovich of United States Smelting, Refining and Mining Co., S. G. Sargis of U.S. Steel Corp., and R. V. Berryhill and A. L. Kimball, U.S. Bureau of Mines. Chrysoberyl in the Lost River area was identified for the first time in samples submitted by Berryhill, and this information was given to the writer orally. I also thank the individual claim owners for permission to publish data on their claims and for pleasant companionship in the field, notably Pearce Walsh of Nome, Barbara Winkley of Bondi, Australia, and Fred Pankratz, James F. Brown, John Brezonick, and V. W. Vanderbilt of Fairbanks.

Various phases of the work were discussed with Profs. C. F. Park, Jr., K. B. Krauskopf, Adolf Knopf, R. R. Compton, and Evan Just, of Stanford University, and the report was improved as a result of advice and reviews by them. In the office, helpful advice was extended by my colleagues W. R. Griffitts, D. R. Shawe, D. E. Lee, and W. N. Sharp.

A beryllium detector designed by W. W. Vaughn and built by John Ohm, of the U.S. Geological Survey, proved of great value in analyzing samples in the laboratory and in tracing ore zones in the field. The photomicrographs reflect the skill of E. P. Krier, U.S. Geological Survey.

To W. R. Griffitts I am sincerely grateful for his written advice in 1960 calling attention to the fact that beryllium deposits might be found on the western Seward Peninsula, which proved to be a good prediction.

Field mapping was facilitated by the able assistance of Donald Grybeck, Thomas Smith, James Kelly, and Donald Peters, who were my assistants at various times from 1961 to 1964.

In the laboratory, rocks were studied by examination of thin sections and insoluble residues of carbonate rocks and by chemical and spectrographic analyses. An improved method was developed using the classical method of staining calcite, combined with selective leaching of parts of uncovered thin sections, to reveal delicate structures normally hidden in carbonate rocks (Sainsbury, 1965a). Study of beryllium ores and of the distribution of rare elements in individual minerals was aided by pure mineral separations prepared by standard techniques, supplemented by aluminum chloride leach to remove fluorite. X-ray diffractometer patterns were prepared for the identification of minerals and to check the purity of minerals submitted for analyses. For all minerals positively identified for the first time in the district, principally beryllium minerals, the main X-ray diffractometer peaks are given in table 9. Opaque ore minerals were studied in polished sections, and identifications were confirmed, where necessary, by X-ray techniques.

PREVIOUS WORK

Much of the knowledge of the geology and ore deposits of the central York Mountains is based upon work by Brooks, Richardson, and Collier (1901), Collier (1902), Knopf (1908, 1910), and Steidtmann and

Cathcart (1922). The occurrence and mineralogy of the tin deposits were well described by Knopf, and they are not redescribed here. Instead, the present work on the beryllium-fluorite deposits is integrated with Knopf's earlier work to develop a zonal relation of the tin and beryllium deposits.

I have benefited greatly from all the previous work, and where disagreements are apparent the reader should realize that these disagreements do not reflect upon the earlier work, but that they reveal merely the advance of knowledge of the area which is based solidly upon the earlier work.

SEDIMENTARY ROCKS

Several workers have discussed the stratigraphy of the rocks of the mapped area, beginning with Brooks, Richardson, and Collier (1901), Collier (1902), and Knopf (1908). Kindle (1911) discussed both the stratigraphy and the faunal zones of the Port Clarence Limestone, and Steidtmann and Cathcart (1922) presented a more detailed description of the stratigraphy. In these descriptions, certain general statements were in agreement, but each writer also pointed out uncertainties about the stratigraphic sequence. All early workers believed that the oldest rocks of the York region (slates) are pre-Ordovician in age, and that the limestones of the York Mountains (Port Clarence Limestone) are principally Ordovician in age, but they included some Silurian and Mississippian rocks. On the geologic map of Alaska (Dutro and Payne, 1957), the slate assigned to the pre-Ordovician by all previous workers was erroneously reassigned to the Triassic.

The early uncertainty regarding the stratigraphic succession in the Port Clarence Limestone, with the exception of the confusion in assignment of the slate to the Triassic, is explainable on the grounds that thrust faulting in the York Mountains was not recognized. The geologic map (pl. 1) demonstrates that limestones of different ages are in thrust-fault contact, and that limestone and slate locally are in thrust-fault contact. Hence, although some reference is made here to earlier discussions, the following description of the stratigraphy is based largely upon the writer's work and upon fossil determinations made by R. J. Ross, Jr. (U.S. Geol. Survey), and Dr. Rousseau Flower (New Mexico Inst. Mining and Technology) on collections made by the writer.

In describing the carbonate rocks, the classification scheme of Folk (1959) is used. The textures of the limestones differ, and certain textures are good indicators of depositional environment. Briefly, the limestones here described, in Folk's terms, are as follows:

Micrite.—Very fine grained even-textured limestone with less than 10 percent of terrigenous material; it represents solidified microcrystalline calcite ooze.

Pelletal limestone.—Even-textured limestone composed of rounded or ovoid aggregates of microcrystalline calcite ooze, generally 0.03–0.08 mm in size; the ovoid aggregates are considered to be fecal pellets.

Sparry limestone.—Crystalline limestone with calcite grains exceeding 10 microns in diameter, and generally clear. The sparry calcite probably represents a pore-filling cement, or recrystallized fine-grained carbonate.

Rudite.—Limestone composed of rounded fragments of limestone in a cement of finer grained calcite. If the rounded fragments came from within the basin of deposition, they are called "intraclasts."

These terms are often combined to describe mixed rocks; for instance, an intrasparrudite is a rudite with sparry calcite cement between the clasts. A silty micrite is a micrite with more than 10 percent terrigenous silt. A pelsparrite is a pelletal limestone with some sparry cement. For a full discussion of the origin of limestones, as exemplified by the texture and composition, and of the depositional environment, the reader is referred to Folk (1959).

PRE-ORDOVICIAN ROCKS

SLATE OF THE YORK REGION

Steidtmann and Cathcart (1922, p. 16–17), following earlier workers, described the slate that crops out west of the mapped area and in the north half of the area shown on plate 1 as "dark-colored to glistening black graphitic sediments of exceedingly fine grain without prominent bedding," a description that applies only to the slaty parts of the unit generally near major thrust faults. In the area of plate 1, the slate also contains thick beds of graywacke and carbonaceous phyllitic limestone. The massive graywacke is slightly schistose in places, but in others, beds of graywacke as much as 2 feet thick are found that are not foliated or recrystallized. West of Skookum Creek, graywacke in beds as much as 2 feet thick forms a sequence at least 200 feet thick, and is underlain and overlain by banded siltstone. Simliar beds are seen north of Brooks Mountain, where graywacke is thrust over carbonaceous slate, and although no stratigraphic measurements were made, the graywacke and siltstone form a significant percentage of the slate formation. A piece of graywacke typical of that from the area north of the Kanauguk River (pl. 1) consists of angular to subrounded grains of quartz and feldspar averaging 0.15 mm in diameter in a matrix of clay minerals, calcite, and carbonaceous matter. Most of the feldspar is plagioclase, some of which is clear and some of which shows albite twinning. Of the matrix material, calcite is most abundant and amounts to about 5 percent of the rock. Sporadic grains of white mica impart a crude foliation to the rock, but the poor sorting and stratification on a small scale are notable characteristics of the graywacke.

The upper part of the slate unit grades into the overlying argillaceous limestone through a transitional zone several hundred feet thick which, from base up, consists of black carbonaceous phyllitic siltstone; schistose agrillaceous rock which weathers bone gray; strongly laminated brown-weathering siltstone with lenticular beds of dark-gray to black limestone veined with small white calcite veins; and finally gray slate about 200 feet thick. These units were mapped separately only in the headwaters of Skookum Creek in order to demonstrate the conformable relation with the overlying limestone. The transitional sequence has been recognized throughout the York Mountains where exposures are good.

Considerable discussion has been devoted in earlier publications to the relation of the slate to the overlying limestone. Collier (1902, p. 18) considered the limestone of the York Mountains to be unconformable over the slates; Knopf (1908, p. 12) discussed the problem in detail and concluded that the slate grades upward into the Port Clarence Limestone; Steidtmann and Cathcart (1922, p. 21) concluded that in the York Mountains and at Cape Mountain conformable relations exist, although this supposed conformable sequence of limestone over slate involves limestone of Mississippian age at Cape Mountain and of Early Ordovician age in the York Mountains. This confusion is caused by two factors: (1) lumping of all the limestones of the western Seward Peninsula into one unit, and (2) failure to recognize thrust faults in the areas discussed.

At present, it is definitely established that the "slate of the York region" is gradational upward into a thin-bedded argillaceous and dolomitic limestone. This limestone, however, is pre-Ordovician in age and properly is not considered as part of the Port Clarence Limestone as originally defined. This limestone unit is shown on the geologic map (pl. 1). Near granite, thermal metamorphism has converted argillaceous limestone to calc-silicate rock, destroying original color and making varieties of argillaceous limestone difficult to separate. This is especially true of the limestones surrounding Brooks Mountain on the north and east sides, where argillaceous limestones of different ages are in thrust contact.

ARGILLACEOUS AND DOLOMITIC LIMESTONE

The argillaceous limestone, locally schistose and containing numerous quartz-carbonate veins and veinlets, overlies the slate conformably or with only minor discordance throughout the area of plate 1 although it has not been mapped separately everywhere. Beds of silty claystone averaging about ½–1 inch in thickness are interlayered with beds of fine-grained silty, argillaceous, and dolomitic limestones which on fresh fracture are distinctly light olive gray to medium gray. Minute cubes of pyrite are abundant locally in the limestone, and the weathering of the pyrite gives a distinct orange-red coloration to slopes underlain by the argillaceous limestone. The argillaceous limestone is moderately to intensely deformed into small-scale folds, and locally displays a fracture cleavage which crosses the bedding (fig. 2).

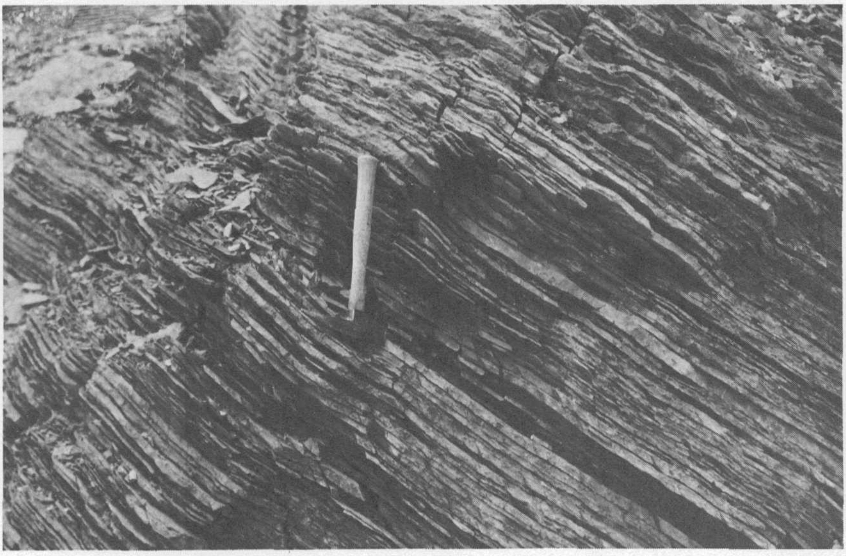

FIGURE 2.—Cleaved thin-bedded argillaceous limestone which overlies the "slate of the York region." Exposure is beneath the thrust fault on the western end of the limestone of the York Mountains, at the head of Clear Creek.

Near faults, the argillaceous limestone is intensely drag folded. It is everywhere cut by veins and veinlets of quartz and carbonate, the ubiquitous presence of which in most places distinguishes it from younger limestones which are lithologically similar.

A typical piece of argillaceous limestone from beneath the thrust fault on the mountain between the headwaters of Lost River and the east headwaters of Mint River (specimen 61–ASn–501) consists of finely banded medium-dark-gray silty micrite which in thin section is seen to consist of about 60 percent micrite and about 40 percent terrigenous material, principally clay minerals, mica, and quartz or chert grains. Except for one mica flake, the terrigenous grains are less than 0.04 mm in diameter. Heavy minerals include a few zircons, fragments of pyroxene, and antigorite(?), the last two suggesting that mafic rocks were being eroded somewhere within the source area that furnished the terrigenous fragments. Pyrite forms a few isolated grains as well as strings of grains, the weathering of which forms an orange-yellow rind on the specimen.

The red-weathering argillaceous limestone is in thrust contact with younger fossiliferous rocks of the overlying limestone in most of the mapped area, and at places as far away as the Don River and Teller Mission, 30 miles east. Because of the crumpling of the beds and the thrust relations with younger rocks, the thickness of the unit cannot be determined, but it must be several hundred feet. No fossils of any type, or structures suggestive of fossils, have been observed in the thin-bedded argillaceous and dolomitic limestone shown on the geologic map.

UNDIFFERENTIATED LIMESTONE AND ARGILLACEOUS AND DOLOMITIC LIMESTONE

Unfossiliferous limestone, which is probably younger than the thin-bedded argillaceous and dolomitic limestone that overlies the slate of the York Region crops out over an area of some 10 square miles between the Mint River and Skookum Creek, and is transitional above it. Fold axes of larger folds in these younger limestones trend almost east, and the larger folds are complicated by numerous and complex minor folds. The rocks contain numerous veins and veinlets of quartz and carbonate.

The stratigraphic succession is shown best at the north end of the hill between Mint River and Skookum Creek on the south-facing slope, which is almost perpendicular to the dip of the beds. The red-weathering argillaceous and dolomitic limestone is overlain by about 500 feet of thin-bedded, platy argillaceous limestone that weathers gray green. The limestone is greenish gray on fresh fractures. Next higher beds, about 200 feet in total thickness, are very thin bedded (½–¼ in.) argillaceous and phyllitic limestone which is greenish gray on both fresh fracture and weathered surface. This sequence is succeeded by about 700 feet of thin-bedded argillaceous limestone containing about 50 percent of clayey layers rhythmically interbedded with medium-gray fine-grained micritic limestone. In the micritic limestone are occasional rounded surfaces suggesting stromatolites. The thin-bedded argillaceous limestone weathers to rounded slopes with a distinct brownish tinge. No fossils were observed in any of the beds below the top of this upper thin-bedded limestone. The thin-bedded argillaceous limestone is transitional through about 150 feet of section into overlying medium- to thin-bedded dolomitic limestone which is brownish gray on fresh fractures and distinctly brownish on weathered surfaces. The dolomitic limestone, at least 750 feet thick, weathers to blocky plates as much as 2 feet in diameter. In the uppermost part of these rocks, weathered plates occasionally display a faint worm-tube cast, or fucoidal mark, which is the first hint of fossils in the section.

From the above descriptions, it is seen that in the area north of the mountains west of Mint River as much as 2,300 feet of unfossiliferous limestone overlies the lowermost thin-bedded argillaceous and dolomitic limestone unit. For the most part these overlying beds are characterized by quartz-carbonate veinlets, moderate to intense drag folding, and total absence of fossils. These characteristics are deemed sufficient to assign the rocks to the pre-Ordovician, although it is possible that the uppermost beds containing fucoidal marks are equivalent to the lower part of the overlying rocks of earliest Early Ordovician age, which are exposed elsewhere.[1]

Very thin bedded argillaceous limestone crops out over an area, approximately half a mile across, around the mouth of Esch Creek, a tributary of Lost River. These rocks (fig. 3) are highly contorted and contain some quartz-carbonate veinlets. Their west boundary is a fault dipping shallowly west, and the east boundary is beneath the alluvium of Lost River. After repeated examination, the writer is unable to assign these rocks definitely, and on the map they are included with the rocks of earliest Early Ordovician age that underlie most of Lost River valley in that area. There is a distinct possibility that these rocks are equivalent to the very thin bedded limestone about 200 feet thick that occurs in the rocks of pre-Ordovician age in the area between Skookum Creek and the Mint River. If so, they are probably a window in an unrecognized thrust fault.

SUMMARY OF PRE-ORDOVICIAN ROCKS

The pre-Ordovician rocks described change gradually from unfossiliferous shale and graywacke through thin-bedded argillaceous and dolomitic limestone into argillaceous limestone and dolomitic limestone with a few worm casts and fucoids in the uppermost part. The

[1] Geologic mapping in 1966 to the east of the area discussed in this report showed that a thick section of limestones and dolomitic limestones overlies the beds classed as undifferentiated limestone and argillaceous limestone in this report. These rocks may include rocks of Cambrian age, and although they are not fossiliferous they are older than the Lower Ordovician rocks discussed in this report.

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FIGURE 3.—Very thin bedded argillaceous limestone of uncertain age exposed around the mouth of Esch Creek, a tributary of Lost River.

oldest of these rocks are intensely folded, moderately metamorphosed to slate or phyllite, veined with quartz-carbonate veins, and intruded by gabbro. The youngest beds are but slightly folded and are unmetamorphosed; they are sparsely fossiliferous in the upper part. The time span represented by them, then, is sufficient for a period of widespread plutonic activity to die out, for the intrusives to be deformed and made schistose, and for the deposition of thousands of feet of argillaceous limestone prior to the appearance of the first fossils. It is entirely possible that this time span covers the Precambrian-Cambrian boundary, the so-called Lipalian Interval, but in the absence of confirmatory proof, such as absolute age dates, the rocks can be assigned only to the pre-Ordovician.

LOWER ORDOVICIAN ROCKS

Limestones of Early Ordovician age compose the bulk of the bedrock in the York Mountains. For the most part these limestones dip northward, and when viewed from the air they give the impression of a homocline broken only by normal faults. Reports by Brooks, Richardson, and Collier (1901, p. 31), by Collier (1902, p. 21), by Knopf (1908, p. 63), and by Kindle (1911) established the age of the limestone as Ordovician, predominantly Early Ordovician, with some Silurian. The stratigraphic succession, however, remained a matter of considerable speculation.

Within the area mapped these Lower Ordovician limestones have been grouped into three map units, the lowermost of which may be transitional downward into the uppermost pre-Ordovician rocks just described, and the uppermost of which spans the boundary between Lower and Middle Ordovician. They are best classified on the basis of their depositional environment.

ARGILLACEOUS LIMESTONE AND LIMESTONE

(shallow-water facies)

A thick sequence of argillaceous limestones with features indicative of a shallow-water environment of deposition is exposed continuously in sea cliffs and in stream valleys from the mouth of Lost River westward to the Kanauguk River. These rocks show a gradational change upward through several thousand feet of section, from thin-bedded fine-grained carbonaceous limestone and dolomitic limestone with a few interbeds up to several feet thick of massive dark limestones and into the predominantly massive rocks of the overlying mapped unit. The lower, thin-bedded rocks have swash marks, ripple marks, cross-bedding, fucoidal marks, and abundant rounded clasts of limestone similar in composition to the surrounding rock (fig. 4). Where the rocks are markedly crossbedded, they consist predominantly of dolomite and terrigenous minerals; elsewhere dolomite is mostly subordinate to calcite. The massive limestones are calcitic, and locally they have a knobby surface strongly suggestive of stromatolites (fig. 5). The stromatolites and crossbedding show that the section is right side up in the seacliffs west of Lost River.

In measured sections at the seacliff west of Lost River valley, and west of the mouth of Koteebue Creek, the limestone was grouped into distinctive types. West of Koteebue Creek, 1,052 feet of beds was measured (table 1). Beds in this measured section fall into 10 distinct

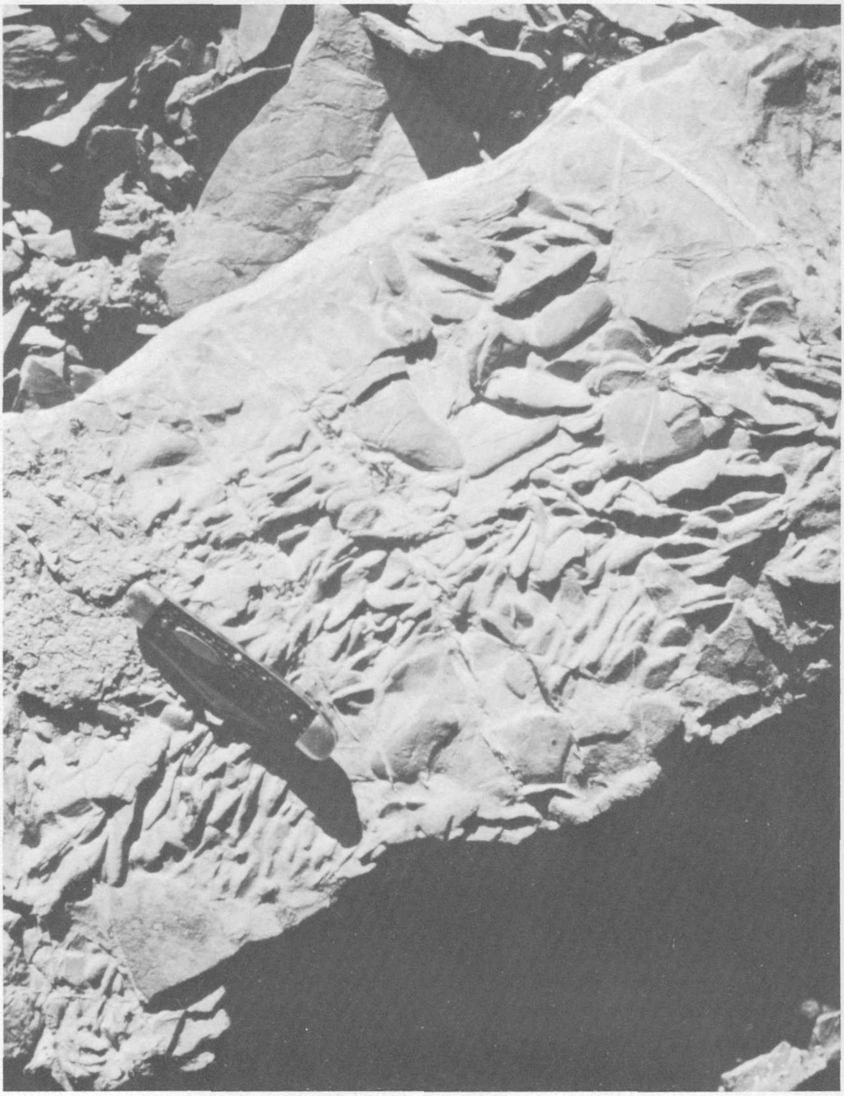


FIGURE 4.—Clastic limestone (rudite, or "intraformational conglomerate") in beds of the shallow-water facies of the Lower Ordovician limestones.

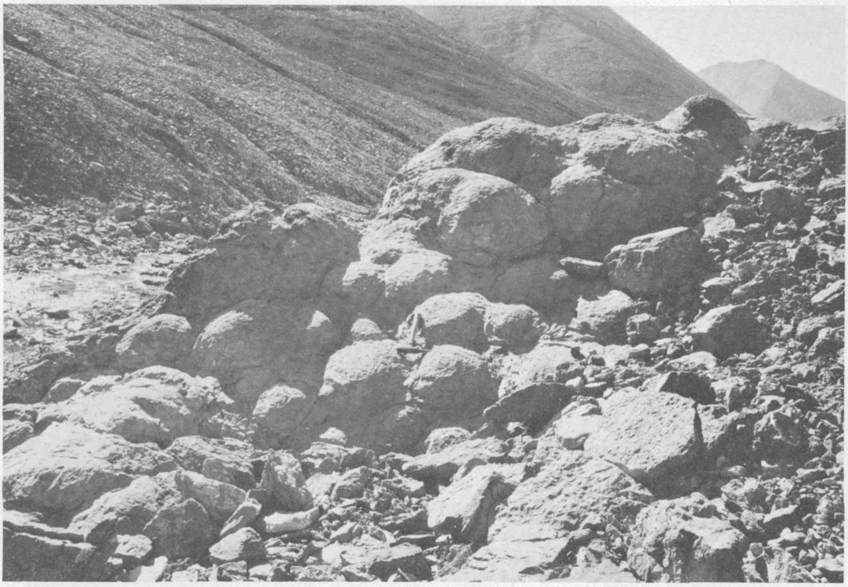


FIGURE 5.—Knobby-surfaced limestone of the shallow-water facies of the Lower Ordovician limestones. Exposure is in the north-flowing stream which enters the south headwaters of the Kanauguk River.

types of lithology which are repeated throughout the section and which are described as follows:

Type 1.—Thin-bedded (1/2–1 in.) medium-gray fine-grained argillaceous limestone tending to lensoid fragments surrounded by clayey and carbonaceous films.

Type 2.—Medium-bedded (4–8 in.) medium-gray sugary-textured limestone.

Type 3.—Crossbedded light-gray sugary-textured dolomitic limestone; beds 4–6 inches thick.

Type 4.—Thin- to medium-bedded (1–6 in.) granular medium-gray to light-brownish-gray limestone with 1/16-inch white calcite specks; weathers medium dark gray.

Type 5.—Medium-gray sugary-textured dolomitic limestone; faintly laminated. Beds 2–10 inches thick; weathers light gray.

Type 6.—Massive medium-gray medium-grained limestone with discontinuous contorted films of clay.

Type 7.—Thin-bedded medium-gray limestone with about 40 percent clay in discontinuous "chips" parallel and perpendicular to bedding; weathers olive gray to olive green.

Type 8.—Thin-bedded (1/2–1 in.) sandy-textured to fine grained medium-light-gray limestone with beds of angular broken limestone and argillaceous beds. Weathers to curved plates showing clasts, cusps; local gray chert.

Type 9.—Very thin bedded (1/8 in. or less) medium-gray to olive-gray argillaceous limestone; weathers limonitic.

Type 471.—Thin-bedded (1/2 in.) medium-gray limestone alternating with thin beds (1/4–1/2 in.) of clay weathers limonitic yellow and forms thick, blocky plates.

TABLE 1.—*Measured section in Lower Ordovician argillaceous limestone and limestone, west of mouth of Koteebue Creek (section* M–M', *pl. 1*)

[Each numbered rock type is described at its lowest stratigraphic position in the measured section. Types of limestone are described in text above. The approximate percentages of each type of limestone are as follows: Type 1, 21; type 3, 11; type 4, 9; type 5, 14; type 6, 13; type 471, 21; type 8, 3; other, 5]

Lithology	Thickness (feet)
Bottom of section.	
Massive medium-gray to light-brownish-gray sparry limestone with knobby surface suggesting stromatoliths (type 6)	5.0
Thin-bedded (½–1 in.) medium-gray fine-grained argillaceous limestone tending to lensoid fragments surrounded by clayey and carbonaceous films (type 1 limestone)	20.0
Crossbedded light-gray sugary-textured dolomitic limestone; beds 4–6 in. thick (type 3 limestone)	23.0
Massive medium-dark-gray crystalline limestone	1.5
Type 1 limestone; beds 1–3 in. thick	15.0
Massive medium-gray limestone	3.0
Type 1 limestone; beds 1–2 in. thick	10.0
Type 3 dolomitic limestone	5.9
Type 1 limestone	4.0
Type 3 dolomitic limestone; few limestone clasts	18.1
Type 1 limestone; beds 1–2 in. thick	14.0
Massive medium-gray limestone with discontinuous thin clayey films	6.0
Type 1 limestone; beds 1–2 in. thick	19.0
Break in line of section.	
Type 1 limestone; local faint crossbedding	12.0
Massive medium-gray fine-grained knobby-surfaced limestone	3.0
Type 3 dolomitic limestone; beds 1–2 in. thick	9.9
Thin-bedded medium-gray to light-olive-gray fine-grained argillaceous limestone	13.0
Type 3 dolomitic limestone medium-gray	17.0
Very thin bedded (1/8 in. or less) medium-gray to olive-gray argillaceous limestone; weathers limonitic (type 9 limestone)	6.0
Type 1 argillaceous limestone	19.8
Massive medium-gray medium-grained limestone with discontinuous chips of clay	3.0
Medium-bedded (4–8 in.) medium-gray fine-grained limestone with thin (1/8–1/4 in.) interbeds of clay	23.0
Thin-bedded (1/2 in.) medium-gray limestone alternating with thin beds (1/4–1/2 in.) of clay, weathers limonitic yellow and forms thick, blocky plates (471 type)	12.0
Thin- to medium-bedded (1–6 in.) granular medium-gray to light-brownish-gray limestone with 1/16 in. white calcite specks; weathers medium dark gray (type 4 limestone)	11.0
Massive medium-gray medium-grained limestone with discontinuous contorted films of clay (type 6 limestone)	10.0

TABLE 1.—*Measured section in Lower Ordovician, argillaceous limestone and limestone, west of mouth of Kotzebue Creek* (*section* M–M', *pl. 1*)—Continued

Lithology	*Thickness (feet)*
Type 1 argillaceous limestone; beds average about 1 in	40.9
Type 1 argillaceous limestone; beds 1–3 in. thick	20.8
Massive medium-gray medium-grained limestone	2.0
Thin-bedded (1/2–1 in.) sandy-textured to fine-grained medium-light-gray limestone with beds of angular broken limestone and argillaceous beds. Weathers to curved plates showing clasts, cusps; local gray chert (type 8 limestone)	14.0
Type 6 limestone beds 1–4 in. thick; faintly laminated in upper 4 ft	10.0
Type 471 limestone; approximately 50 percent clay beds	16.0
Medium-gray medium-bedded argillaceous limestone	6.0
Type 471; typical	55.0
Type 1 limestone	11.0
Type 471; weathers more greenish gray	20.0
Type 6 massive limestone	5.0
Type 1 thin-bedded limestone	15.0
Type 471 limestone	31.2
Type 4 massive limestone	6.0
Type 1 thin-bedded limestone with numerous ripple marks	14.0
Type 6 massive limestone with knobby surface	6.0
Principally type 471 with minor type 1 limestone	27.0
Type 6 massive limestone	10.0
Type 5 dolomitic limestone	12.1
Type 471 limestone; few fucoidal markings	22.0
Medium-bedded (4–8 in.) medium-gray sugary-textured limestone (type 2)	5.0
Medium-gray to medium-light-gray thin-bedded (1–1-1/2 in.) sugary-textured argillacous limestone with beds of tabular broken fragments of limestone similar to enclosing beds (type 2)	18.2
Type 5 dolomitic limestone	4.0
Rudite, showing clasts of limestone to 1-1/2 in.	.5
Thin-bedded (1–1-1/2 in.) dolomitic limestone with about 30 percent clay; weathers to greenish gray curved plates	5.6
Type 471 limestone	38.0
Type 6 massive limestone; disoriented clay partings	6.0
Thin-bedded medium-gray limestone with about 40 percent clay in discontinuous "chips" parallel and perpendicular to bedding; weathers olive gray to olive green (type 7)	4.0
Type 5 limestone	4.0
Thin-bedded (1/2–1 in.) interbedded fine-grained limestone and clay; weathers yellow (type 471)	3.0
Type 4 limestone; argillaceous partings; clayey "chips"	13.0
Medium-gray oolitic limestone	0.5
Type 4 limestone; numerous clayey "chips"	2.0
Medium-bedded type 4 limestone; numerous white specks	41.0
Medium-gray sugary-textured dolomitic limestone; faintly laminated; beds 2–10 in. thick; weathers light gray (type 5)	16.1
Partly covered, but consists of type 6 massive limestone and medium-gray finely laminated dolomitic limestone, weathering light gray	135.0

TABLE 1.—*Measured section in Lower Ordovician argillaceous limestone and limestone, west of mouth of Koteebue Creek (section M–M′, pl. 1)*—Continued

	Thickness (feet)
Type 6 massive limestone	6.0
Type 3 limestone; few ellipsoidal concretions 4 by 1 in.	8.0
Granular medium-gray to light-brownish-gray medium-bedded limestone with white specks; weathers dark gray (type 4)	18.0
Massive medium-gray limestone; shattered (type 6)	25.1
Crossbedded laminated dolomitic sugary-textured limestone; weathers buff; beds 2–12 in. thick (type 3)	47.0
Massive medium-gray medium-grained limestone with discontinuous "chips" of clay (type 6)	24.0
Total measured section	1,052.2

Although the various types recur throughout the section, the crossbedded laminated dolomitic beds are most common and thickest near the base, the massive beds increase gradually upsection, and the thin-bedded regularly alternating limestone and argillaceous limestone (type 471) becomes more abundant and thicker upward. The scarcity of chert in the thicker beds is diagnostic, for in the overlying units chert is noticeable in the massive beds and is associated with a color change to light brownish gray. These criteria can be used to determine roughly what part of the map unit is represented in different fault blocks, but only if sufficient beds are exposed to show changes in the section.

The measured section (table 1) constitutes only a small part of the unit. A constructed cross section, continuing from the measured section, shows that these Lower Ordovician shallow-water-facies beds could be as much as 4,500 feet thick in the area west of the mouth of Koteebue Creek (sections *M′–M″*, *P–P′*, pl. 1).

The lithologic variations seen in thin sections of limestone from the measured section are too numerous to describe completely, but a few typical rocks are described as seen in stained thin sections.

Specimen 61–ASn–36 is a laminated crossbedded dolomitic limestone from the mouth of Koteebue Creek (type 3, table 1) and consists of an impure dolomitic limestone containing approximately 40 percent of terrigenous angular to subround fragments composed of quartz, plagioclase, zircon, leucoxene, mica, and tourmaline. Dolomite forms isolated rhombs and strings of rhombs, whereas calcite forms connecting patches and some formless isolated grains. The terrigenous grains average about 0.06 mm in diameter, and the dolomite rhombs, 0.08 mm. The laminations are caused by a faint increase of terrigenous fragments. The rock is classed as a quartzo-feldspathic limy dolomite or dolomitic limestone.

Specimen 61–ASn–1 is thin-bedded medium-dark-gray argillaceous and carbonaceous faintly laminated ruditic limestone from the beach 2 1/4 miles west of the mouth of Lost River (type 8, table 1). The limestone is fucoidally and ripple marked. It consists of about 80 percent micrite or pelletal calcite, locally recrystallized to sparrite, 15 percent dolomite, and 5 percent terrigenous fragments of plagioclase feldspar, quartz, mica, and clay minerals which surround and cement rounded clasts as much as one-half inch in diameter of micritic or pelletal limestone. The faint laminae are caused by strings of terrigenous angular to subrounded fragments that average about 0.04 mm in diameter. The calcite grains are less than 0.002 mm in size. An insoluble residue contains several grains of pyroxene. The rock is an intrasparrudite composed of rounded fragments of micrite or pelsparrite.

Specimen 61–ASn–26 is rhythmically banded limestone and claystone of the upper part of the shallow-water facies, from the ridgeline at the head of the center fork of Koteebue Creek (type 471, table 1). Clayey bands 1/16–1/4 inch thick are interbedded with light-olive-gray fine-grained limestone averaging about one-half inch in thickness. The limestone consists of uniformly sized micrite less than 0.006 mm in diameter with scattered rounded areas of chert(?) about 0.06 mm in diameter. Claystone layers contain less than 10 percent calcite and are mostly clay- and silt-sized fragments of mica and chert(?)

The main fossils, which occur sparsely in beds of the shallow-water facies, are brachiopods, gastropods, and trilobite fragments. A few beds contain rounded clots, suggestive of oolites, and extremely few beds contain noticeable fossil fragments. All fossils identified to date are either lowermost Canadian in age, or include forms that range upward into the Canadian (Early Ordovician).

The depositional environment of the shallow-water facies is proved by the ripple marks, clastic limestone, and high percentage of terrigenous fragments. The depositional basin bordered a landmass which furnished detrital quartz, feldspar, and such minerals as pyroxene, zircon, and leucoxene (minerals diagnostic of the gabbro of pre-Ordovician age), along with large amounts of clay. This mineral assemblage suggests that the slates of the York region, with their gabbroic intrusives, were being eroded at places on the landmass which furnished the terrigenous fragments.

LIMESTONE AND ARGILLACEOUS LIMESTONE

(quiet-water facies)

Conformably above the limestones of the shallow-water facies is a thick section of thicker bedded limestones with subordinate thin-bedded limestone and argillaceous limestone, all of which was deposited in quiet water. The transition from shallow-water facies is gradual through several hundred feet of section, and the contact in any particular area is picked arbitrarily at the first massive limestone which is more than 30 feet thick. Some of the massive limestones change thickness laterally; therefore the contact as shown on the geologic map probably is not a single continuous horizon. Nevertheless, the contrast between the two units is unmistakable, and they are easily distinguished except where the upper part of the shallow-water facies is faulted against the quiet-water facies. The transition is best shown where exposed on the west wall of the cirque south of the central part of Rapid River.

The basal massive limestones range in color from medium gray to light brownish gray, but are predominantly brownish gray. On fresh fractures they display crystal faces as much as one-sixteenth inch in diameter which give a distinctive crystallinity to the rock. The limestones weather into cliffs having extremely rough, pitted surfaces. Some beds are faintly bedded; others are massive through dozens of feet. The massive limestone is entirely calcitic and characteristically contains scattered nodules and lenses of chert.

Interbedded with the massive limestones are thin- to medium-bedded calcitic limestones, most of which lack the ripple marks, swash marks, and clastic limestone fragments typical of thin-bedded limestones in the shallow-water facies; many are fucoidally marked, however. In some sections hundreds of feet thick, thin-bedded argillaceous limestone may account for almost half the rock, but the massive interbeds tend to retain a brownish tinge and to contain chert nodules, which distinguish them from the thicker beds in the shallow-water facies. In marked contrast to the fossils in massive limestone in the shallow-water facies, which include brachiopods and trilobites, are the sparse but noticeable cephalopod siphuncles in the quiet-water limestones. The crossbedded laminated dolomitic limestone characteristic of the shallow-water facies is completely lacking.

A well-exposed section about 2,500 feet thick, typical of the limestone and argillaceous limestone of the quiet-water facies, was measured in a mountain between the King River and the south drainages of Rapid River (M–M′, pl. 1) and is shown in table 2. The measured beds lie well above the base of the thick-bedded unit, and a constructed section to the base of the unit shows that approximately 4,000 feet of beds underlies the measured beds. Minor faults possibly cause repetition of beds, but no faults are known which could cause a repetition of a substantial amount of the 4,000 feet. The total thickness of rocks in the thick-bedded unit in the area southwest of Rapid River is indicated, therefore, as approximately 6,500 feet.

The main types of limestone, used in the descriptions in table 2, are as follows:

Type A.—Thin-bedded (1/4 in.) fine-grained conchoidally fracturing medium-gray limestone with argillaceous partings.

Type A-2.—Medium-gray conchoidally fracturing blocky-weathering limestone; bedding everywhere discernible but faint (1–4 in.).

Type B.—Massive medium-gray to brownish-gray hackly fracturing sparry limestone; generally contains scattered nodules of gray chert; weathers rough and pitted.

Type C.—Massive medium-gray medium- to coarse-grained hackly fracturing limestone; weathers rough and pitted; scattered small cephalopod siphuncles.

Type D.—Thin-bedded (1–4 in.) medium-gray to light-brownish-gray faintly crystalline limestone; weathers medium light gray; minor argillaceous partings, few fucoids.

Type 471.—Thin-bedded 1/2 in.) medium-light-gray to light-brownish-gray limestone and claystone in alternating beds; weathers to ovoid "buttons;" distinctly reddish on weathered surfaces.

TABLE 2.—*Measured section in Lower Ordovician limestone and argillaceous limestone*

[Each lettered rock type is described at its lowest stratigraphic position in the measured section. Types of limestone are described in text above]

Lithology	*Thickness (feet)*
Bottom of section.	
Type C. Massive medium-gray medium- to coarse-grained hackly-fracturing limestone; weathers rough and pitted; scattered small cephalopod siphuncles	6.0
Type A. Thin-bedded (1–4 in.) fine-grained conchoidally fracturing medium-gray limestone with argillaceous partings	6.6
Type C	4.0
Type A, but thinner bedded (1/2–1 in.); no fucoids	7.0
Type C	10.0
Type A	5.0
Type C	4.5
Type A	6.0
Type B. Massive medium-gray to brownish-gray hackly-fracturing sparry limestone; generally contains scattered nodules of gray chert; weathers rough and pitted	2.0
Type A	5.0
Type B	2.4
Type A, approaching type 471	11.0
Type C	3.0
Type A	4.0
Type C	6.5
Type A	1.2
Type 471. Alternating thin beds (1/2–1 in.) of fine-grained medium-gray conchoidally fracturing limestone and clay; limestone predominates; clay weathers limonitic yellow; argillaceous beds average 30 percent	4.0
Type B	6.0
Type A. Beds average 8 in	4.0

TABLE 2.—*Measured section in Lower Ordovician limestone and argillaceous limestone*—Continued

Lithology	*Thickness (feet)*
Type A. Beds 1–4 in	16.0
Type A, approaching type 471	23.0
Type A	9.0
Type A–2. Medium-gray conchoidally fracturing blocky-weathering limestone; bedding everywhere discernible but faint (1–4 in.)	13.0
Type A, approaching type 471	3.0
Type B	8.0
Type A, approaching type 471	6.0
Type B	10.0
Type A, approaching type 471	8.0
Type B	10.0
Type A–2	9.0
Type B. Bedding locally apparent	13.0
Type A. Local fucoidal marks	34.0
Intrasparrudite; abundant fossil hash	1.4
Type A–2, approaching type 471 locally	22.0
Type B, but bedding locally apparent	29.5
Type A, tending toward type 471	13.0
Type B	6.0
Type A. Local fucoidal marks	46.0
Type C. Local disoriented clay seams	15.0
Type A	30.0
Type B. Black on joint facings; recrystallized cephalopod siphuncles	12.7
Type A, tending toward type 471	10.0
Type C. Tawny chert in strings; weathers blackish	7.0
Type A–2	14.0
Type A, locally becoming type 471 (estimated 20 percent argillaceous partings)	12.0
Type A, locally approaching type A–2	43.0
Type C	3.0
Type D. Thin-bedded (1–4 in.) medium-gray to light-brownish-gray faintly crystalline limestone; weathers medium light gray; minor argillaceous partings; few fucoids	13.4
Type B	8.0
Type A	8.0
Type B	22.0
Type A. Uniform; abundant to moderate fucoids	67.0
Type C. Locally distinct bedding	7.0
Type A, locally approaching type 471 Minor fracturing.	38.0
Type C	7.0
Type A, tending toward type 471	9.0
Type C. Faint bedding in lower 2 ft	10.0
Type A–2	4.0
Intrasparrudite; clasts average 1 in. in diameter; abundant gastropods	1.0
Type A, but tending toward type 471	3.0
Type C. Faint bedding	7.0

TABLE 2.—*Measured section in Lower Ordovician limestone and argillaceous limestone*—Continued

Lithology	*Thickness (feet)*
Type A, but tending toward type 471	8.0
Type C	12.0
Type B. Locally faint bedding; scattered chert nodules	1.0
Type D	5.0
Type A. Beds less than 2 in.; local fine laminations	42.0
Type C. Abundant dark-gray-weathering dark-gray chert	10.0
Type A. Bedding indistinct locally	16.0
Type D	19.0
Type C, but noticeably browner	5.0
Type A	14.5
Type B, but noticeable bedding (4–8 in.)	7.0
Type B. Abundant chert	2.0
Type A	29.0
Snow-covered, probably type A	35.0
Type A. Moderate fucoidal marking	20.0
Type B. Sparse cephalopod siphuncles	5.0
Type A. Few fucoidal markings	15.0
Type B. Faint bedding locally	6.0
Type A	10.0
Type B, but with discontinuous chips of clay	17.0
Type D, but beds 2–8 in. thick	10.0
Covered zone. Broken?; type B?	8.0
Medium-bedded type B (beds average about 1 ft)	12.0
Type C	10.0
Break in line of section.	
Type B. Scattered brachiopods (*Finkelnburgia* sp.)	6.0
Type B, locally A–2 type	53.0
Type B	6.0
Type A, grading to type A–2 at top	21.0
Type B. Few interbeds type A–2; sparse chert	31.0
Types A and A–2 interbedded	28.5
Type B	6.0
Type A	10.0
Type C	4.0
Type B	3.0
Type A. Beds 2–8 in.	44.0
Type A. Very distinct argillaceous partings	17.0
Type A. Few clots dark chert	6.0
Type B	2.4
Type D	11.0
Type C	2.0
Type A	34.0
Type B	14.0
Thin to medium-bedded light-brownish-gray to medium gray limestone	51.0
Type A	7.0
Type A–2	10.0

TABLE 2—*Measured section in Lower Ordovician limestone and argillaceous limestone*—Continued

Lithology	*Thickness (feet)*
Type A	23.0
Type C. Faint bedding	5.0
Type A–2	11.0
Type C	5.0
Type A–2	4.0
Thin-bedded (2–5 in.) medium-gray to light-brownish-gray coarse-grained faintly argillaceous limestone with intrasparrudite beds; noticeable cephalopod siphuncles	5.0
Type B	2.0
Type A–2	1.0
Type C	2.0
Type A–2	45.5
Type B. Noticeable cephalopod siphuncles	5.5
Type A–2	30.0
Medium-gray to light-brownish gray intrasparrudite limestone; sparse cephalopod siphuncles	2.5
Type B. Very coarse grained	4.0
Type A–2. Large clots of gray chert	8.0
Type B	10.0
Type A–2	4.0
Thin-bedded (2–4 in.) light-brownish-gray sparsely oolitic and fossiliferous limestone	3.0
Type B	13.0
Medium-gray conchoidally fracturing blocky-weathering limestone; bedding discernible (1–4 in.) but faint (type A–2)	52.0
Type B. Noticeable cephalopod siphuncles	6.0
Type A, but with bedding less distinct	23.0
Type B	8.0
Type A, but with bedding less distinct	20.0
Type C	2.0
Massive-appearing medium-gray fine-grained limestone with discontinuous argillaceous partings; faint bedding	60.0
Type A	17.4
Type C	5.0
Type A	12.6
Type C	4.7
Type A	2.2
Type C. Fossils include gastropods and cephalopod siphuncles	2.6
Type A	4.4
Type C	2.0
Type A. Locally 4-in. beds of intrasparrudite; some ripple marks	72.0
Type C. Locally coarse-grained; sparse chert nodules	5.5
Type A	31.8
Type C	1.6
Type A	26.3
Type C. Massive	2.2
Type A. Minor argillaceous material	12.8

TABLE 2.—*Measured section in Lower Ordovician limestone and argillaceous limestone*—Continued

Lithology	*Thickness (feet)*
Thin-beded medium-gray fine-grained limestone with about 80 percent argillaceous material	8.5
Type C. Noticeable chert parallel to bedding	4.6
Type A. Beds 1–2 in. thick	20.0
Hype B. Noticeable chert in "strings" parallel to bedding	15.0
Type B. Faint bedding; sparse chert	11.0
Type B. Scattered gray chert nodules as much as 4 in. in diameter	29.0
Type B. Faint bedding; locally laminated	16.0
Type B. Massive limestone	9.0
Medium-gray fine-grained conchoidally fracturing faintly laminated limestone; beds average 1 ft. in thickness	7.5
Broken zone of thin-bedded and massive limestone	6.0
Medium-gray fine-grained faintly laminated limestone	1.0
Type A. Beds 1–4-in. thick	18.5
Type C. Massive; gray	1.6
Thin-bedded (1-2 in.) medium-light-gray to light-brownish-gray limestone and claystone alternating in beds; weathers to ovoid "buttons;" distinctly reddish on weathered surface (type 471) Minor brecciation.	6.0
Type B. Massive	29.0
Type B. Faint bedding	4.0
Type B. Massive	29.0
Type B. Faint bedding	10.0
Type B. Massive	12.0
Type B. Faint bedding	3.5
Type B. Local dark chert resembling silicified corals	14.0
Type B, with very faint bedding	6.7
Type B massive limestone; weathers light gray to light pinkish gray	94.0
Thin-bedded (1–4 in.) medium-gray to light-brownish-gray faintly crystalline limestone; weathers medium light gray; minor argillaceous partings; few fucoids (type D)	8.0
Type B massive limestone	2.8
Type A limestone	3.4
Type B massive limestone; sparse chert; cephalopod siphuncles	9.6
Type A limestone	21.8
Massive medium-gray medium to coarse-grained- hackly-fracturing limestone (type C)	6.0
Type A limestone	17.0
Type B massive limestone	2.8
Type B massive limestone	6.4
Type A limestone (1–4 in. beds)	10.0
Type B massive limestone	6.4
Thin-bedded (1–4 in.) medium-gray limestone with argillaceous partings; argillaceous bands weather yellow orange	25.0
Massive medium-gray to brownish-gray hackly-fracturing sparry limestone; scattered nodules of gray chert (type B)	5.0
Type A limestone	14.0

TABLE 2.—*Measured section in Lower Ordovician limestone and argillaceous limestone*—Continued

Lithology	*Thickness (feet)*
Massive medium-dark-gray conchoidally fracturing limestone with locally sparry cement; weathers light gray type C)	5.0
Thin-bedded (1–4 in.) fine-grained conchoidally fracturing medium-gray limestone with argillaceous partings (type A)	5.0
Total thickness of measured section	2,496.0

NOTE.—The appropriate percentage of each rock type listed above is as follows: type A, 46; type B, 24; type C, 10; type D, 5; type A–2, 15.

Typical specimens of the massive limestone are as follows:

Specimen 61–ASn–27 is medium-light-gray to light-brownish-gray massive limestone (type B) from a thick bed near the base where exposed in the west wall of the cirque south of the central part of Rapid River. It consists of round to subrounded intraclasts averaging about 1 mm in diameter surrounded by clear sparry calcite. The intraclasts are composed of grains or pellets less than 0.002 mm in diameter. Insoluble residues are almost entirely rounded clots of fine-grained silica and of clear quartz. The rock is an intrasparrudite.

Specimen 63–ASn–229B is medium-gray massive limestone (type C) from the ridge at the head of the middle headwaters of the south fork of Cassiterite Creek. It is calcitic limestone composed of a mixture of rounded intraclasts of micrite or pelletal limestone, oolites (both radially and concentrically developed), ostracodes (?), fragments of crinoids(?), and bits of fossil hash encased in clear sparry calcite. Insoluble residue consists of a minute amount of chert, clay minerals, and mica. The rock is an oosparrite and is the only oolitic limestone recognized in the field or in the laboratory.

Numerous other thin sections of massive limestone disclose that these thick beds of the quiet-water facies are characterized by a very small amount of terrigenous material and by a very high percentage of calcite. The limestone for the most part is micrite or rudite composed of clasts of micrite (or pelletal limestone) surrounded by clear sparrite. Near faults, the massive limestone is dolomitized over wide areas, and the rock resembles sedimentary dolomite despite its obvious fault control.

Fossils collected from limestones of the quiet-water facies just described consist of brachiopods from the thin-bedded rocks and cephalopod siphuncles from the massive beds. All determinations of age fall into the Canadian (Early Ordovician) or into the early Llanvirn (late Early Ordovician) (table 3).

TABLE 3.—*Fossils with stratigraphic value from the quiet-water facies (Lower Ordovician limestone and argillaceous limestone), central York Mountains*

Field No.	USGS No.	Locality No. (pl. 1)	General location	Position in Ol map unit	Fossils	Age [1]
61–ASn–141	D1050 CO	5	Headwaters, Lost River	Near base	Ellesmeroceritidae [2]	Definitely Gasconade.
61–ASn–G48		74	Ridge north of Cassiterite Creek	Upper part	New species, Flower [2]	New species, undoubtedly late Canadian.
61–ASn–199		77	Center fork, Cassiterite Creek	do	Coiled cephalopod, probably Tarphyceratidae.	Probably Canadian, but identification uncertain.
61–ASn–158A	D894 CO	20	do	do	Small endoceroid siphuncle [2]	Probably Canadian.
61–ASn–170	D909 CO	23	Ridge, south fork Cassiterite Creek.	Center part	Colied cephalopod, new [2] species, Flower.	Undoubtedly middle or late Canadian.
61–ASn–173	D1420 CO	23B	Ridge between Tin and Cassiterite Creeks.	do	*Ellesmeroceras*, not identical with *E. bridgei*, new species, Flower.	Early Canadian, Gasconade.
64–ASn–a29		2	Ridgeline east of Lost River mine	Uncertain	Coiled cephalopods [2]	Cannot be older than Demingian, or younger than Chazy.
61–ASn–226		32	Ridge east of south fork of Tin Creek.	Lower part	Large high-spired murchisoniids,[3] large pleurotomariaceans.	Might be *Plethospira*, which occurs first in the late Early Ordovician, or *Omospira*, which occurs in the Middle Ordovician.
61–ASn–242A	D904 CO	35	West shoulder of Cassiterite Peak	do	Two endoceroid siphuncle fragments [2]	Probalbly Canadian.
61–ASn–12	D908 CO	6	About 0.6 mile west of mouth of Lost River.	Upper part(?)	Ostracodes, rare; brachiopods, probably [4] Rhynchonellid; brachiopods, probably Orthid.	Probably Middle Ordovician or younger.
61–ASn–372C	D893 CO	46	Ridge, head of southwest fork of King River.	Middle part(?)	*Apheoorthis*, new sp., *Lecanospira*(?) sp.[4]	Low, but not lowest Ordovician.
61–ASn–371	D903 CO	47	Float, base of ridge, southwest fork of King River.	do	New genus and species, Flower [2]	Should be middle or late Canadian.
62–RJR–21	D1048 CO	69	Float, west headwaters of King River.	do	Ellesmeroceratidae [2]	Definitely Gasconade.
61–ASn–386	D907 CO	48	Fourth creek above mouth, east side of King River.	do	New species, Flower [2]	Early Canadian.
61–ASn–352	D905 CO	45	Ridgeline, head of east fork of Price Creek.	Center part(?)	*Finkelnburgia*, new sp., closst to [4] *F. bellatula*.	Very low Ordovician.
62–ASn–633A		58	East headwaters of York Creek	Base	*Ellesmeroceras* [2]	Same as 61–ASn–141 (Gasconade).
62–ASn–RJR18	D1067 CO	71	Headwaters of northeast fork of Kanauguk River.	Uppermost	*Hystricurus? sainsburyi* Ross *Niobella kanauguki* Ross *Nileus* cf. *N. armadillo* (Dalman) *Harpides* sp. Ross (1965, pl. 8)	Early Ordovician.
62–RJR–20	D1070 CO	90	Float, middle fork of Kanauguk River.	Middle part(?)	*Apheoorthis* sp.[4], *Finkelnburgia*(?) sp.[4]	Do.

[1] Condensed from full fossil report.
[2] Identified by Dr. Rousseau Flower, New Mexico Institute of Mining and Metallurgy. For later work and classification of these new species, see Flower (1968).
[3] Identified by E. A. Yochelson, U.S. Geological Survey.
[4] Identified by R. J. Ross, Jr., U.S. Geological Survey.

339–932 O—69——3

During deposition of the quiet-water facies, the supply of terrigenous material to the basin of deposition was cut off, and waters became clearer and deeper, as indicated by the cephalopod siphuncles and by the lack of shallow-water features such as crossbedding, ripple marks, and clastic limestone.

At the top of limestones of the quiet-water facies is a section of distinctively pink even-bedded limestone (fig. 6) that contains a large amount of trilobite fragments and, unlike any of the underlying rocks, weathers light gray to light bluish gray. These rocks, which form the uppermost beds of Early Ordovician age, have not been delineated separately on the map, but their color is so distinctive that they cannot be mistaken. They have an aggregate thickness of about 200 feet and are of importance because they occur in small outcrops in two places (in the fault block between Lost River and Curve Creek, and north of Anderson Creek on the east boundary of the quadrangle) ; this allows the assignment of overlying dolomitized limestones to the Middle Ordovician.

A massive bed in the pink limestone is seen in thin section to consist of calcite in grains ranging from 0.008 to 0.02 mm in diameter, with local areas of clear sparry calcite of coarser grain size. The sparse

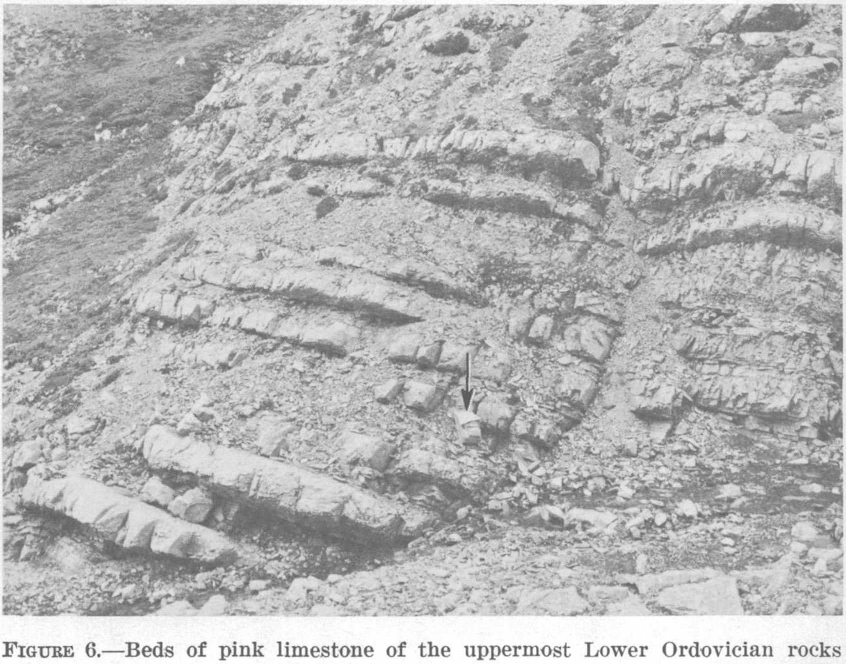


FIGURE 6.—Beds of pink limestone of the uppermost Lower Ordovician rocks where exposed at the base of the mountain in the west headwaters of the Kanauguk River. Scale shown by packsack (arrow) in lower center.

insoluble residue consists of twinned plagioclase feldspar. A few curved sections of trilobite glabellas are noticeable in hand specimens.

Fossils from the pink limestone unit, collected by the writer and identified by R. J. Ross, Jr., U.S. Geological Survey, are trilobites and graptolites of late Arenig and early Llanvirn age (latest Early Ordovician). The trilobites were described by Ross (1965).

LOWER AND MIDDLE ORDOVICIAN ROCKS

SHALE AND LIMESTONE

Black shale overlies the pink limestone conformably and with a contact that is gradational through several tens of feet. The shale is 20–50 feet thick, except where it is intricately deformed near thrusts, and is succeeded by a thick section of medium- to dark-gray limestone which weathers to smooth slopes that are distinctively dark yellowish-brown to dusky yellowish brown. For several dozens of feet above the shale the gray limestone contains thin partings of black shale. Near the base, the limestone is flaggy (fig. 7) and contains ⅛ to ¼-inch-thick bands of carbonaceous or silty limestone. Some beds contain rounded to reniform clots as much as one-half inch across composed of minute grains suggesting globigerina, and some contain discoid

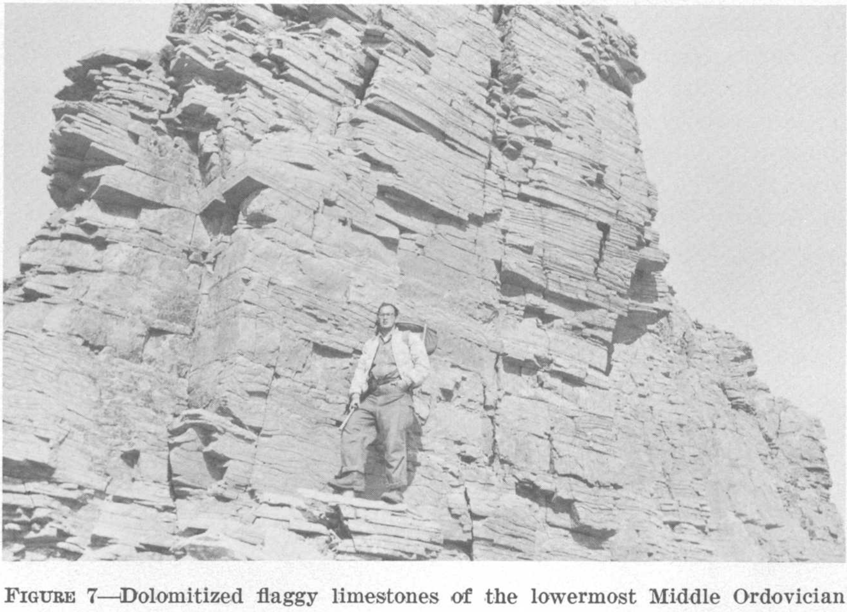


FIGURE 7—Dolomitized flaggy limestones of the lowermost Middle Ordovician (Llanvirn Stage) rocks above the graptolitic shales on the mountain on the southeast flank of the granite of Brooks Mountain.

lenses of medium-light-gray chert. About 200 feet above the base, a 6-foot-thick bed of limestone similar to that in the pink limestone recurs. The gray limestone is extensively dolomitized near faults, and the weathered dolomite gives a distinctive buff color on hillslopes. Fragments of trilobites are common throughout the gray limestones, as are graptolites in the shaly partings.

The pink limestone of the quiet-water facies and the shale and limestone of the limestone and shale unit form isolated patches in an east-west belt across the central part of the York Mountains. All the exposures are cut off on the north by major faults; exposed beds which form a large hill west of the Mint River (section *P–P′*, pl. 1) are 2,400 feet thick. Fossils from these rocks are listed in table 4.

MIDDLE ORDOVICIAN ROCKS

DARK LIMESTONE

Rocks younger than those just described occur in the upper klippe on the mountain west of the Mint River (pl. 1). Although the rocks consist of medium-bedded medium- to dark-gray limestone and some light-brownish-gray limestone, both lithologically similar to some of the older limestones, they contain a distinctly different fossil assemblage. A key fossil as determined by Dr. T. E. Bolton of the Geological Survey of Canada, is *Labyrinthites* sp., which, according to him (written commun., 1964), is "limited to the Ordovician, probably the Middle Ordovician."

All the rocks in the klippe dip 30°–50° N., and locally they are completely dolomitized. About 1,250 feet of beds is exposed in the klippe, and the beds are fossiliferous throughout. The fossils that date the rocks as Middle Ordovician (table 4) were obtained from near the top of the beds that form the top of the mountain.

TABLE 4.—*Fossils from the upper Lower and lower Middle Ordovician limestone and shale (map unit* Olsh*), and the Middle Ordovician limestone (map unit* Odl*), central York Mountains*

Field No.	USGS No.	Locality No. (pl. 1)	General location	General position in map units	Fossils	Age [1]
61-ASn-203B	D899 CO	3	Base of cliffs, mountain between Casserite and Anderson Creeks.	Base	*Anomalograptus* [2] [3]	Early Middle Ordovician (Llanvirn).
61-ASn-203	D898 CO	27	Mountain between Cassiterite and Anderson Creeks.	Very near base	*Phyllograptus* cf. *P. anna J. Hall* [2] *Isograptus caduceus* cf. var. *armatum* Ruedemann. *Didymograptus* of the *bifidus* type, but with more widely spaced thecae. *Didymograptus* sp. (an extensiform species, but not *D. extensus*). *Glossograptus*? sp. *Loganograptus* n. sp.	Early Llanvirn—Probably equal to the zone of *Paraglossograptus etheridgei* of Berry (1961).
61-ASn-201		26	do	About 250 ft above base.	Tiny euomphaliform gastropods;[4] moderately high spired gastropod.	Post Early Ordovician.
62-RJR-19	D1068 CO	71	Headwaters of northeast fork of Kanauguk River.	Near base	*Didymograptus* cf. *D. extensus* Hall [2]	Middle and late Arenig.
61-ASn-234	D901 CO	34	Hill, south of stream that is south of the south headwaters of Anderson Creek.	Well above base	*Triarthrus* sp.[2] *Hystricurus sainsburyi* Ross *Nileus* cf. *N. armadillo* (Dalman) genus and species indeterminate; pygidium suggestive of *Bathyurellus*	Ordovician, probably late Llanvirn. Some should be a little older.
61-ASn-483	D900 CO	54	Head of north fork of Kanauguk River.	do	*Isograptus caduceus* cf. *I. c.*[2] var. *divergens* Harris.	Llanvirn, zone 6-7 of Elles and Wood, younger than 61-ASn-203, 203B.
63-ASn-860	4280 CO	1	Klippe on hill between east headwaters of Skookum Creek and Mint River.	Near top of exposed beds.	New species, Flower [5] *Proteoceras obliquum* and *P. tubulara*; *P.* species.[6] *Labyrinthites* sp.[7]	Probably Middle Ordovician. Early Middle to early late Middle Ordovician.

[1] Condensed from full fossil report.
[2] Identified by R. J. Ross, Jr., U.S. Geological Survey.
[3] Ross, R. J., Jr. (1967).
[4] Identified by E. A. Yochelson, U.S. Geological Survey.
[5] Identified by Dr. Rousseau Flower, New Mexico Institute of Mining and Metallurgy.
[6] Identified by W. A. Oliver, Jr., U.S. Geological Surey.
[7] Identified by Dr. T. A. Bolton, Geological Survey of Canda.

UNDIFFERENTIATED MIDDLE AND UPPER ORDOVICIAN ROCKS

The youngest rocks of the mapped area are restricted to a fault block shown at the extreme east edge of plate 1. These rocks continue in an unbroken belt to the Don River, some 4 miles east of the area of plate 1, where several fossil collections of Kindle (1911) and Collier (1902, p. 21) were assigned to the Early Silurian. New work east of the area of plate 1 and fossil collections have shown that the rocks are principally of Late Ordovician age, but do include some Silurian rocks, thus establishing an unbroken sequence of Ordovician rocks.

In the mapped area (pl. 1), complete dolomitization has obliterated color and textural differences which to the east allow assignment of rocks to the Middle or Late Ordovician. Hence, on plate 1 these rocks are shown as undifferentiated Middle and Upper Ordovician.

SUMMARY OF ORDOVICIAN ROCKS

Deposition of limestone continued in the mapped area almost unbroken throughout Early Ordovician time and into early Middle Ordovician time. During this span, beds of limestone and argillaceous or dolomitic limestone aggregating at least 8,000 feet, and possibly 12,000 feet, in thickness were deposited in a marine basin. During earliest Ordovician time, the limestones were deposited in a shallow-water environment which received abundant terrigenous material. The basin gradually deepened, and by late Early Ordovician time a thin graptolitic black shale was deposited. After deposition of the black shale, the basin probably shallowed somewhat, and limestone was deposited during at least some of (and probably all of) Middle Ordovician, Late Ordovician, and Early Silurian time.[2] The graptolites collected in this study are readily correlated with those of the European section.

PLEISTOCENE ROCKS

Rocks of Pleistocene age occur in the central York Mountains only as scattered patches less than a square mile in area along the inner margin of the York terrace. The rocks are cemented conglomerates which represent lithified deltaic gravels overlain by continental gravels. In an earlier paper (Sainsbury, 1967), the conglomerates

[2] Continuing work on the Seward Peninsula has shown that carbonate rocks of Late Silurian, Early Devonian, Devonian, and Mississippian age are present in thrust slices of the Collier Thrust Belt, showing that the deposition of carbonate rocks continued, possibly unbroken, from Ordovician to Late Mississippian time at least.

and other Pleistocene deposits were discussed in detail, and the age assignments were justified on the basis of fossil and geomorphic data. Only the main conclusions of the earlier paper are summarized here.

Two marine terraces are well preserved on the western Seward Peninsula, and both record interglacial sea level stands. The oldest, the York terrace (York Bench), which is mostly between 175 and 210 meters (580 and 700 feet) above sea level, is of Yarmouth(?) age, as suggested by marine fossils in marine conglomerate on the terrace surface, and by the absence of evidence for a high sea level stand separating it from the next younger terrace, the Lost River terrace, of Sangamon(?) age. The planed rock surface of the Lost River terrace stands about 6 meters (20 feet) above sea level, and records a sea level height approximately the same as that of the sea which cut terraces that have been dated as Sangamon at Nome, some 145 kilometers (90 miles) east (Hopkins, McNeil, and Leopold, 1960). Prior to the cutting of the Lost River terrace, the York terrace was uplifted more than 100 meters (328 feet) and warped gently.

In the York Mountains, glacial deposits record two widespread glaciations, both of which are probably Wisconsin in age. The older glacial deposits of the York Glaciation were much more widespread than the younger deposits of the Mint River Glaciation. Much later, in Recent time, a climatic cooling caused ice or snow fillings of north-facing cirques and produced protalus ramparts. At the northwestern end of the York Mountains, the distribution of limestone drift suggests that an ice sheet occupied lowlands of the southernmost Chukchi Sea and Bering Strait area and forced valley glaciers flowing north from the York Mountains to turn west along the mountain front.

If the minimum amount of uplift of the York terrace is added to the present depth of water in the Bering Strait, the resulting water depths are so great as to indicate that a seaway existed in the Bering Strait throughout early Pleistocene time, or until the uplift of the York terrace in Illinoian time. Because uplift probably did not extend as far south as Saint Lawrence Island, it is probable that migration routes for land animals and plants lay well south of the Bering Strait prior to Illinoian time.

The main Pleistocene events recorded by erosional features and deposits in the central York Mountains are summarized in figure 8. A diagrammatic cross section through the marine terraces is shown in figure 9.

STRUCTURE

Throughout the mapped area, the structure of the York Mountains is dominated by imbricate thrust faults and by several sets of normal faults, some of which are major faults with vertical displacement exceeding 1,000 feet (for example, Kanauguk fault). Folds large enough to map are practically restricted to the rocks of pre-Ordovician age, or to the vicinity of low-angle faults. The geologic structure of the York Mountains was interpreted by Steidtmann and Cathcart (1922, p. 32) as a great faulted syncline trending north; their interpretation was based upon the fact that the older slates surrounded the younger Port Clarence Limestone on three sides. The geologic map of the present report (pl. 1) shows clearly that the limestones of Ordovician age

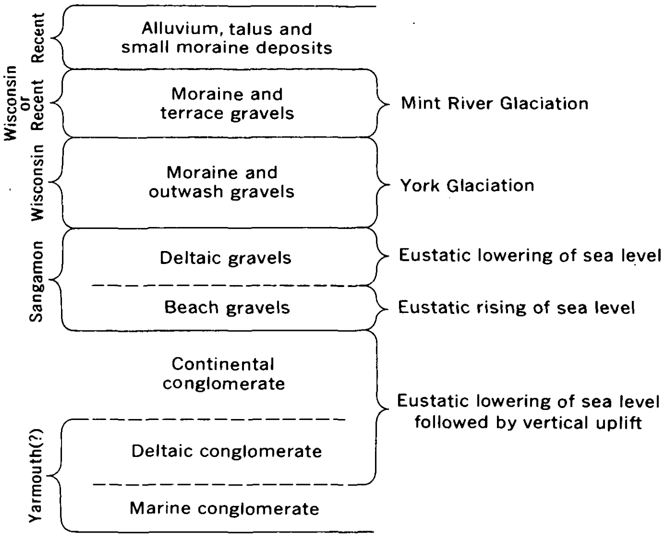


FIGURE 8.—Stratigraphic record of the main Quarternary events recorded in the York Mountains.

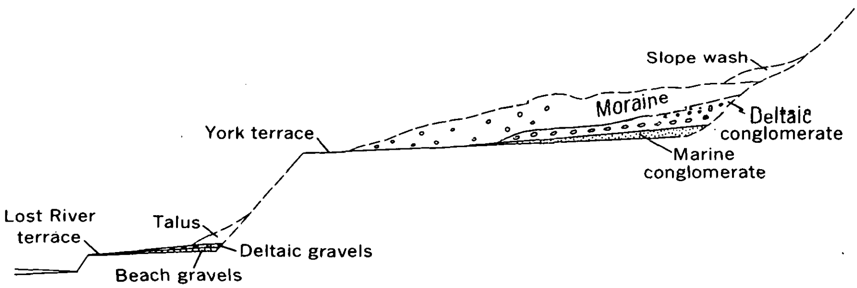


FIGURE 9.—Cross section through marine terraces near the Lost River.

are everywhere in fault contact with the pre-Ordovician rocks. Mapping to the east by the writer in 1965 to 1968 has shown that this relation exists as far as the Bendeleben Mountains 100 miles to the east. From these facts it is concluded that the York Mountains are carved from a small segment of a series of thrust sheets of much larger extent (the Bendeleben Mountains are east of the area shown in fig. 1). The delineation of the extent of thrusting is a challenging problem for the future.[3]

[3] This newly delineated thrust belt has been named the Collier thrust belt to honor A. J. Collier, whose pioneer mapping in the western Seward Peninsula in 1901 led him to conclude that the limestones of the York Mountains were not in normal depositional contact with the underlying rocks (Collier, 1902). Thrust sheets of the Collier thrust belt extend throughout the Seward Peninsula.

THRUST FAULTS

Two main thrust faults are named, and several others are shown. The north front of the York Mountains is bounded by the Mint River thrust (fig. 10), which locally is a zone of imbricate thrusts. West of the east headwaters of the Mint River, the thrust separates limestone of pre-Ordovician age from limestone of late Early Ordovician age; to the east, upper Lower Ordovician limestone is thrust over slate. Where the thick-bedded limestones of the Lower Ordovician sequence are thrust over thin-bedded limestone the lower plate rocks are intensely dragfolded for several hundred feet below the fault plane. In many places where thrusts are within thicker bedded limestones, the thrust is a zone of macrobreccia as much as 200 feet thick (fig. 11) that consists of jumbled angular blocks of limestone commonly with a high percentage of cavities between blocks. At Camp Creek, such a porous zone has been important in localizing fluorite-beryllium deposits. The rocks of the upper thrust plates for the most part are but slightly

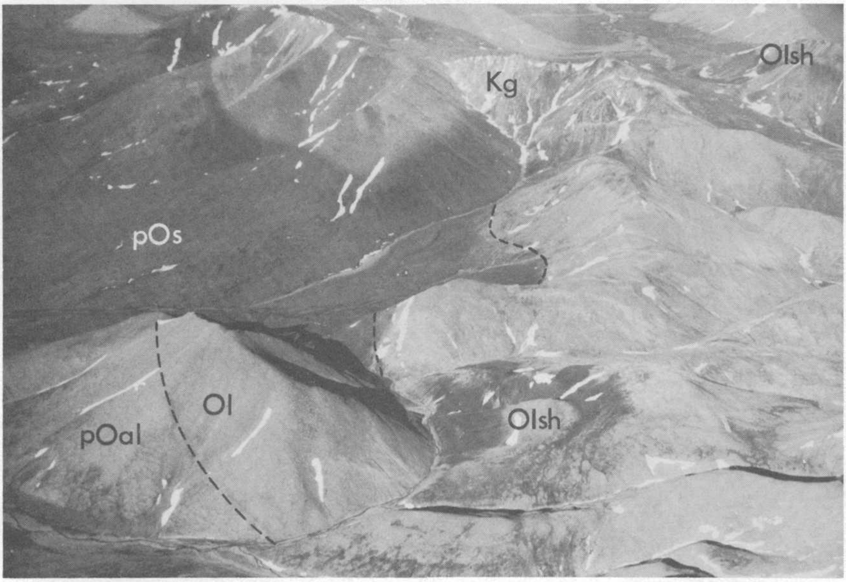


FIGURE 10.—Mint River thrust east of the Mint River. Rocks below thrust are red-weathering argillaceous limestone of pre-Ordovician age (pOal), those above are of late Early Ordovician age (Ol, Olsh). View east. Brooks Mountain in left background. Dark area in center foreground is infolded shale of the Olsh map unit. Cross section *B–B'* (pl. 1) passes through folds at right angles. Kg, granite; Olsh, limestone and shale; Ol, massive to medium-bedded limestone; pOal, thin-bedded argillaceous and dolomitic limestone; pOs, slate, graywacke, and siltstone. See explanation of geologic map (pl. 1) for complete lithology of units.

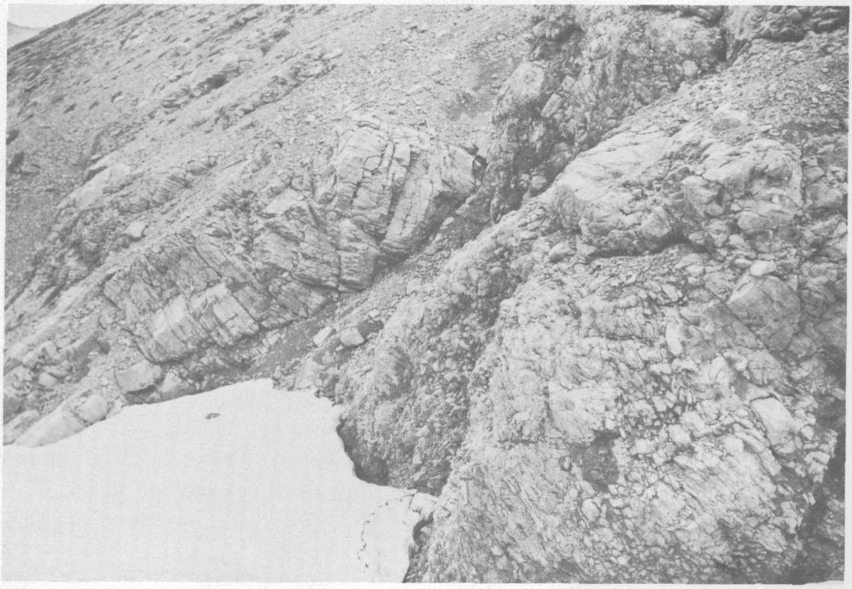


FIGURE 11.—Tectonic breccia near a thrust fault, showing disoriented blocks of limestone.

folded, and only locally is major fold structure developed. Between the East Fork of Grouse Creek and the headwaters of the Anikovik River (northwestern part of pl. 1), chevron folds are well exposed in upper plate rocks, and these folds involve the thick-bedded limestones of latest Early Ordovician age (fig. 12). Elsewhere, the generally north dip of the upper plate rocks is noteworthy. (See cross sections, pl. 1.)

In the south half of the mapped area, a second major fault (Rapid River fault), dipping 25°–40° S., is interpreted as a thrust fault; this interpretation is based upon the steepening of beds at the fault plane in one area (fig. 13). The steepening of beds near the fault is a characteristic feature in the upper plate of the Mint River thrust and indicates that rocks of the upper plate moved north or northwest. Although the cross sections (pl. 1) would be easier to explain if the Rapid River fault were interpreted as a low-angle normal fault, the steepening of beds shown in figure 13 is believed by the writer to be diagnostic of northward movement of the upper plate. In addition, the Rapid River fault continues east of Lost River, and, although complex, it becomes a flat fault on the hill south of Camp Creek, where another fault dipping gently southeast lies beneath it. Both faults are believed to be thrusts.

FIGURE 12.—Chevron fold involving medium- to thick-bedded limestones of the Ol map unit; ridge trending northwest between the headwaters of the Anikovik River and the east headwaters of Grouse Creek. Fold axis is almost horizontal.

FIGURE 13.—Rapid River fault in the south tributary of the Kanauguk River, showing steepening of beds in the upper plate. View east.

Rocks of the upper plate along much of the Rapid River fault are dolomitized; this causes a sharp color break at the fault (fig. 14). The dolomitization, especially in thick-bedded rocks, has created a banded light and dark "zebra rock" that throughout the area is confined to rocks near major faults (fig. 15).

Elsewhere in the mapped area, thrust faults mark the boundary between thick-bedded limestones and thin-bedded limestones. At these places it is evident that the thick-bedded limestones were rêlatively competent, and thrust planes commonly were localized at their base, where locally only minor movement occurred.

The general north dip of all the rocks raises the question as to the possibility of unrecognized isoclinal folding of the rocks with concomitant development of thrust faults. Although the limestones are lithologically monotonous through thousands of feet of section, there are several repetitions of recognizable contacts (for example, the pink-limestone–shale contact), and wherever exposed, these contacts are right side up. So too are the major lithologic units (for example, slate is always below the argillaceous limestone unit). Moreover, the knobby-surfaced limestones common in the Ordovician rocks give unmistakable topside evidence (clay has settled between the "knobs"),

Figure 14.—Rapid River fault where it enters the drainage basin of the Rapid River. Light color above fault plane is caused by weathering of granular white dolomite that has replaced medium- to thick-bedded limestone of the Ol map unit. View west.

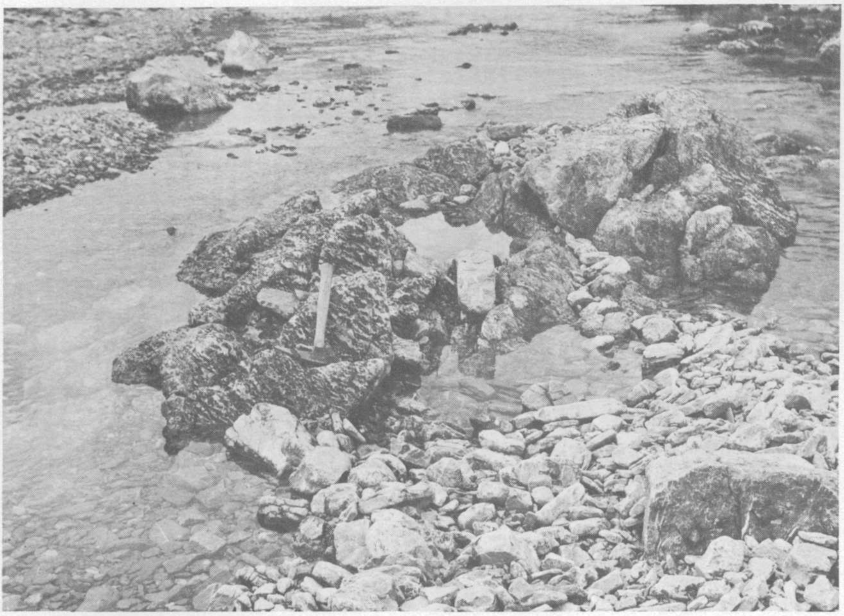


FIGURE 15.—Banded dolomite ("zebra rock") that replaced medium-bedded calcitic limestone; bed of Rapid River.

and all known exposures indicate that the beds are right side up, with the exception of beds near major faults. Too, one is tempted to speculate that several of the mapped thrusts are one folded thrust. Again, although the relations are not entirely clear in each situation, it is not possible to join the two major thrusts (Rapid River and Mint River) as a single folded thrust, for this would require overturning of large parts of the section, which does not exist. These conclusions are reinforced by mapping to the east, where the same relations are observed. However, mapping in 1967 about 75 miles to the east, between the American and Kougarok Rivers (not shown on pl. 1), has shown that upper plate rocks are intricately folded and moderately metamorphosed, and are interlayered with thrust slices of lower plate rocks.

NORMAL FAULTS

Literature dealing with faults in the Lost River area has been synthesized (Sainsbury, 1964a, p. 9–10), and it was shown that three distinct sets of normal faults cut the rocks. Continued geologic mapping has shown that these fault sets are of regional extent, and were of great importance in localizing ore deposits. New information allows revision of age assignments of the faults, however, and an additional set has been recognized.

The strongest of four sets of normal faults strikes N. 65°–85° E., and individual faults dip vertically or steeply south or north, although south dips prevail. These faults are commonly downthrown to the south, with displacements not exceeding a few hundred feet. Most of the dikes in the mapped area are intruded along faults of this set, and most of the dikes are appreciably younger than the faults. However, faulting has recurred along some dikes.

A second strong set of faults strikes N. 20°–60° W., with downthrow to either east or west on different faults. This set is expressed particularly well along the south front of the York Mountains west of Lost River. Only a few dikes intrude faults of this set. West of King River, faults of this set cut lamprophyre dikes injected in faults of the N. 65°–85° E. set.

A third set of faults, which includes some faults that are continuous for many miles and which cut faults of the sets already noted, strikes almost north. Most of the faults in this set dip steeply, and downthrow to either side is common. No dikes are known to occur in faults of this set, and no known mineral deposits are localized by them.

The youngest normal faults, and those with greatest displacement, are exemplified by the Kanauguk and York faults. On the Kanauguk fault, which dips 30°–60° S., the south block is downthrown more than 1,250 feet, for the rocks of the limestone and shale unit are cut off completely. On the York fault, which is well shown on the York terrace east of Lost River, downthrow to the south may amount to 5,000 feet, based on the displacement of the mapped contact between rocks of the quiet-water and shallow-water facies north and south of the fault. Both the York and Kanauguk faults are somewhat arcuate; the overall strike averages almost east. The Kanauguk fault cannot be mapped certainly in the area of the headwaters of Lost River, where the rocks are extensively dolomitized and fractured. East of the area of plate 1 the York fault flattens and dips shallowly south; thus, it may be a reverse fault that turns into a thrust. Several other faults that dip less than 50° S. are known, and these both cut and are cut by north-trending faults. For the most part, however, faults of all the other sets are cut and displaced by the Kanauguk and York faults. No dikes were injected into them.

Around the granite stocks at Brooks Mountain and in Tin Creek, small faults are developed radially. A few rhyolite and lamprophyre dikes are injected into these faults, and some of the dikes and faults cut the granites.

Many dikes have intruded the faults that trend N. 65°–85° E., but some dikes continue unbroken across faults of younger sets and prove conclusively that injection of dikes took place after most of the faulting. In the Lost River mine, the Cassiterite dike contains the main tin and tungsten ore shoots, and the ore is cut by a postmineralization normal fault along the dike, which proves recurrent faulting. The faults are important economically because they have been the main channels for ore-forming solutions. Subsequent movement on faults already intruded by dikes caused the dikes and wallrocks to shatter and thus to become favorable channels for mineralizing fluids.

AGE OF FAULTING

The thrust faults are intruded by all igneous rocks younger than pre-Ordovician. At Brooks Mountain, the granite stock of Late Cretaceous age pierces the Mint River thrust, and as the youngest rocks in the mapped area are Middle Ordovician in age, the thrusting cannot be here dated more closely than post-Middle Ordovician and pre-Late Cretaceous. However, east of the mapped area, limestones of probable Devonian age are involved in the thrusting.

Some of the normal faults cut the granite stocks, but none displace geomorphic surfaces of middle Pleistocene age (York terrace). Hence, some of the normal faulting occurred between Late Cretaceous and middle Pleistocene time, but much of it preceded the intrusion of the plutonic rocks.

IGNEOUS ROCKS

Igneous rocks within the mapped area can be grouped according to two distinct criteria: age (pre-Ordovician and Late Cretaceous or Tertiary(?)) and composition (granitic, mafic, or hybrid). East of the mapped area, nepheline basalt lava flows of Pleistocene age are exposed. These lavas are not discussed in this report.

PRE-ORDOVICIAN ROCKS

The igneous rocks of pre-Ordovician age are restricted mostly to the outcrop area of the slates of the York region, although in two places they intrude the thin-bedded argillaceous and dolomitic limestone of pre-Ordovician age. These pre-Ordovician igneous rocks form small plutons, sills, and narrow dikes, and most can be classed as medium- to coarse-grained gabbro. They were described by Steidtmann and Cathcart (1922, p. 19) as follows:

> The pre-Ordovician basalt, gabbro, and olivine gabbro are fine- to medium-grained compact rocks which were intruded as dikes, sills and stocks into the slate before the limestone was laid down. They were folded with the slate and limestone and in general show a marked schistosity due to the development of nearly parallel columns of secondary hornblende. They are remarkably alike in grain, color, composition and alteration, and undoubtedly come from one parent magma.

The gabbro commonly contains small flecks of chalcopyrite and pyrrhotite and sufficient magnetite to deflect the compass. Mulligan (1959, p. 15) reported chromite in placer concentrates from the west end of the York Mountains; its source is unknown. In the headwaters of the Anikovik River (pl. 1) numerous hills are formed of gabbro, and geologic mapping shows that many of the hills are remnants of a sill, or several sills, injected near the top of the "slate of the York region." The sills must have covered many square miles. Although the gabbro is abundant in the slates, it is far less abundant in the overlying rocks, for it intrudes the overlying argillaceous limestone in only a few dikes, all of which are cut off by thrust faults.

Microscopic examination of thin sections of gabbro shows that most of the pyroxenes have an optic angle of 40°–60°, and classified by optic angle and beta index of refraction are augite or ferroaugite in composition (Hess, 1949). The gabbro contains abundant leucoxene, opaque iron ores, and labradorite (fig. 16). Near faults, gabbro bodies locally are sheared and serpentinized; along some faults the gabbro is extensively replaced by sideritic carbonate.

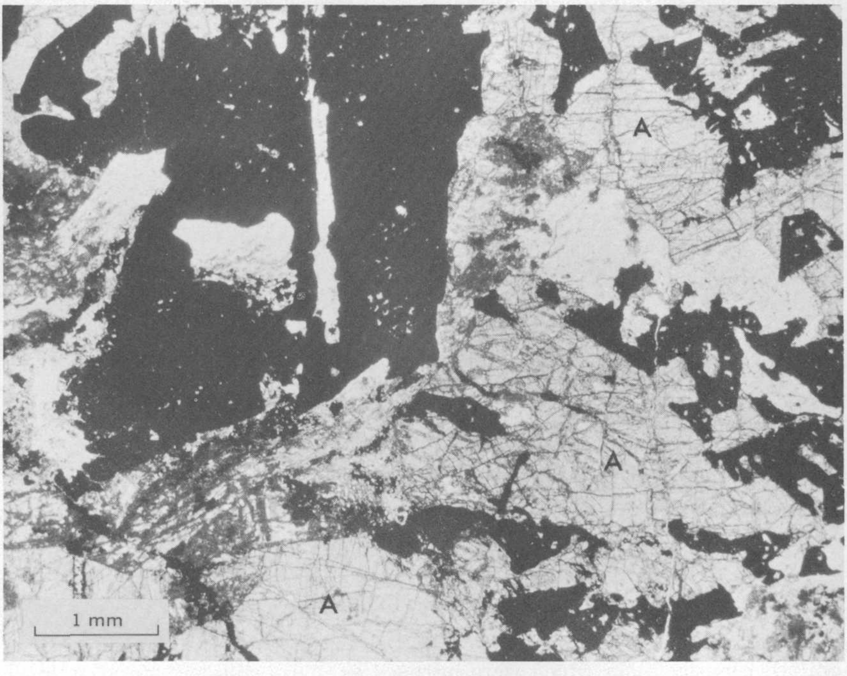


FIGURE 16.—Coarse-grained gabbro from sheared dike; west end of the York Mountains. Large augite phenocrysts (A) and titaniferous magnetite (black), partly altered to leucoxene, in groundmass of granulated augite and labradorite. Crossed nicols. Specimen 61–ASn–477.

The abundance of gabbro in the slates and the dearth of it in the overlying argillaceous limestones suggest that intrusion of gabbro had virtually ceased by the time the argillaceous limestone was deposited.

UPPER CRETACEOUS OR TERTIARY(?) ROCKS

The younger intrusive rocks comprise medium- to coarse-grained stocks of biotite granite, medium- to fine-grained dikes of rhyolite, granite and porphyry, and numerous lamprophyre dikes.

GRANITE STOCKS

Granite forms two stocks exposed in the mapped area (pl. 1) and one that is known only from subsurface exploration. Chemical compositions of the granites from the western Seward Peninsula are shown in table 5. The stock exposed at Brooks Mountain is porphyritic biotite granite, locally tourmalinized, in which phenocrysts of orthoclase as much as 2 inches in length are common, and in which the biotite generally contains abnormal amounts of radioactive inclusions. Along joints and fractures, and irregularly, the granite is extensively tourmalinized; at other places, notably along shears, it is kaolinized. The kaolinized shears commonly contain hematite, and they are faintly radioactive. Most of the granite is reasonably homogeneous, although locally the amount of biotite and the proportion of phenocrysts of orthoclase vary. Quartz crystals are euhedral to subhedral, and smoky to faintly amethyst in color. Additional information on the mineralogy and texture of the granite was given by West and White (1952), who also described the associated uranium deposits, by Knopf (1908), and by Steidtmann and Cathcart (1922), who described the tin deposits near the granite.

The granite that forms a small boss exposed in Tin Creek is medium-grained biotite granite with associated tin deposits (Knopf, 1908) and beryllium deposits (Sainsbury, 1963). The finer grain size is probably due to more shallow deroofing of the granite which at its present stage exposes only the finer grained border facies. Along joints, the granite contains quartz and minor cassiterite; in an irregular area at the northeast end, it is greisenized along fractures, kaolinized locally, and contains cassiterite and numerous sulfide minerals. Near lamprophyre dikes that intrude the granite it is argillized.

At the Lost River mine, exploratory workings intersect granite that has been previously described (Sainsbury, 1960, p. 1486–1489). The granite, which is locally greisenized and locally only faintly sericitized, is probably a cupola of a larger body. It is medium- to fine-grained biotite granite, with faint sericitization of the feldspars, and contains thin cassiterite-sulfide-mica veinlets along joints.

Elsewhere on the western Seward Peninsula, biotite granite forms stocks at Cape Mountain, Ear Mountain, and Black Mountain; for the most part, the granites are coarse-grained biotite granite, locally tourmalinized, with chilled border facies and with associated cassiterite and sulfide deposits.

All the known granites of the western Seward Peninsula were sampled during this study, and the chemical analyses of the granites are shown in table 5. The granites at Brooks Mountain, Tin Creek, Cape Mountain, Black Mountain, and Ear Mountain were sampled by breaking fresh boulders in the beds of creeks that drain the granites and then selecting randomly about 100 pounds of material, which was crushed and quartered. The granite at Lost River was obtained from the freshest material on the dump from an exploration drift that penetrated granite in the Lost River mine.

Silica content of the granites ranges from 71.3 to 76.5 percent (table 5). The stock exposed in Tin Creek, which has quartz along joints, is the most silicic of the stocks, and the granite dike from Black Mountain is the most silicic rock (pl. 2). The distribution and content of trace elements in the granites in relation to the geochemistry of the area were shown and discussed by Sainsbury, Hamilton, and Huffman (1968).

TABLE 5.—*Chemical composition, in percent, of granites of the western Seward Peninsula*

Laboratory No.	162978	162979	162980	162981	162982	———
Field No.	60-ASn-145	60-ASn-90	60-ASn-52	60-ASn-67	63-ASn-BM-24B	41-AC-192
Locality	Brooks Mountain	Cape Mountain	Tin Creek	Lost River	Black Mountain	Ear Mountain
Type of sample	Bulk chip [1]					Chip [2]
SiO_2	71.3	73.8	76.5	74.8	74.3	73.93
Al_2O_3	14.4	13.6	12.8	12.9	14.0	14.70
Fe_2O_3	.56	.37	.10	.13	.27	.41
FeO	1.4	1.3	.82	.62	.54	1.40
MgO	.80	.55	.10	.53	.06	.48
CaO	1.1	.87	.44	1.2	.50	.50
Na_2O	4.1	3.5	4.1	3.3	3.4	4.27
K_2O	5.3	4.8	4.3	4.5	5.6	3.54
H_2O-	.18	.00	.26	.55	.00	.00
H_2O+	.56	.73	.27	.75	.80	.34
TiO_2	.21	.18	.02	.01	.13	.12
P_2O_5	.06	.04	.00	.00	.00	.04
MnO	.05	.04	.03	.10	.03	Trace
CO_2	<.05	<.05	<.05	<.05	<.05	--------
Sum	100	100	100	99	100	99.73

[1] Rapid rock analysis, by P. L. D. Elmore, S. D. Botts, G. W. Chloe, Lowell Artis, H. Smith, and Cyrus Feldman.
[2] Standard rock analysis, by Cyrus Feldman.

DIKE ROCKS

Many mafic and rhyolitic dikes, some strongly altered and metasomatized, strike mostly northeast to east and are concentrated in a zone a few miles wide that crosses the mapped area in a direction about N. 80° E. Many of these dikes are intruded along normal faults, a few cut some of the granites, and some radiate from granite, as at Brooks Mountain and Tin Creek. Because the dikes mark fractures which have been reactivated, and along which ore solutions rose, they are extremely important in pinpointing possible mineralized areas, and all known dikes are shown on plate 1. Only a few of the dikes are mineralized, however.

RHYOLITE DIKES

The rhyolite dikes in general are light-colored porphyritic rocks composed mainly of quartz, orthoclase, and albite. In hand specimens, the unaltered rhyolitic rocks are grayish white to pale green. The grain size varies; some rocks are almost entirely crystalline, and others are best described as rhyolite porphyry with small phenocrysts of quartz, or, in some, feldspar, in an almost glassy groundmass. The rhyolitic dikes range in thickness from less than 1 foot to 55 feet in local "swells." The principal named rhyolitic dikes in the Lost River area are the Cassiterite, the Ida Bell, the Hidden, the Rust, and the Dalcoath. Other smaller ones are known, and all are shown on the geologic map (pl. 1), where the larger are named.

Some of the dikes cut the granites, as at Brooks Mountain and Tin Creek. Most of the rhyolitic dikes are injected into fractures of the N. 60°–85° E. set. Locally, both rhyolite and lamprophyre are injected into the same fracture. Rhyolitic dikes are more numerous near granite stocks, and probably they are genetically related to the granite.

The Cassiterite and Ida Bell dikes contain the main ore shoots of the Lost River mine. The Cassiterite dike can be traced for about 9,000 feet from Lost River to the ridge on the west side of Tin Creek. The Ida Bell can be traced from Lost River eastward for about 9,500 feet, and it cuts the Cassiterite dike on the low ridge west of the Lost River mine. The Cassiterite dike ranges in thickness from a few feet to as much as 20 feet; the Ida Bell, from a few feet to 55 feet. Near the tin deposits, as at Lost River mine, the rhyolite dikes are changed to quartz-topaz greisen. To the east of the mine they have been metasomatized and largely replaced by adularia and quartz, with minor fluorite and white mica. During greisenization, sodium and potassium were removed (for chemical analyses, see Sainsbury, 1960, p. 1942), and the present study has shown that this material moved outward and upward on the dikes, altering them to the adularia-rich facies.

Of especial interest are carbonate breccias that are cemented by rhyolite or by medium- to coarse-grained granite. A photomicrograph of one such breccia (fig. 17) shows that the carbonate fragments have reacted only slightly with the magma, which suggests either that the granite crystallized at a low temperature or that it was largely crystallized before it was injected along breccias.

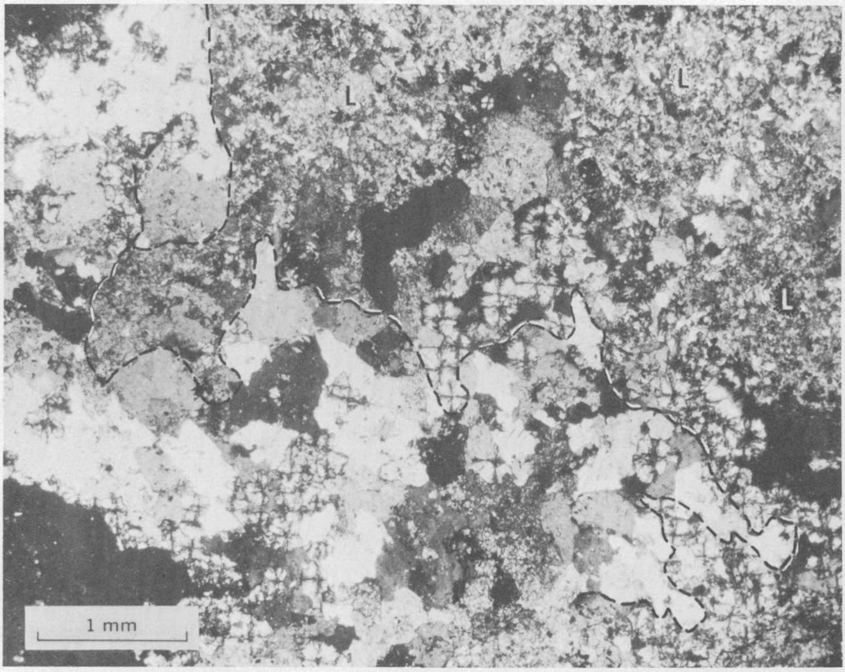


FIGURE 17.—Dike-cemented breccia; Lost River mine area. Medium-grained granite cements fine-grained limestone fragments (L). Note spherulitic wollastonite(?) on margins of limestone fragments. Crossed nicols. Specimen 62–ASn–737B.

LAMPROPHYRE DIKES

In this study, special attention was given to dark dikes, which are widespread throughout the mapped area and which are closely associated with the beryllium-fluorite lodes. Most of the dikes are fine- to medium-grained rocks of fresh appearance characterized by xenocrysts of quartz and orthoclase and by xenoliths of coarse-grained granite (fig. 18), which give the dikes a pseudoporphyritic texture. All have chilled borders. They range in size from small lenticular dikes less than 50 feet long to large dikes thousands of feet long. Most are injected into faults of the N. 60°–85° E. set, or along joints.

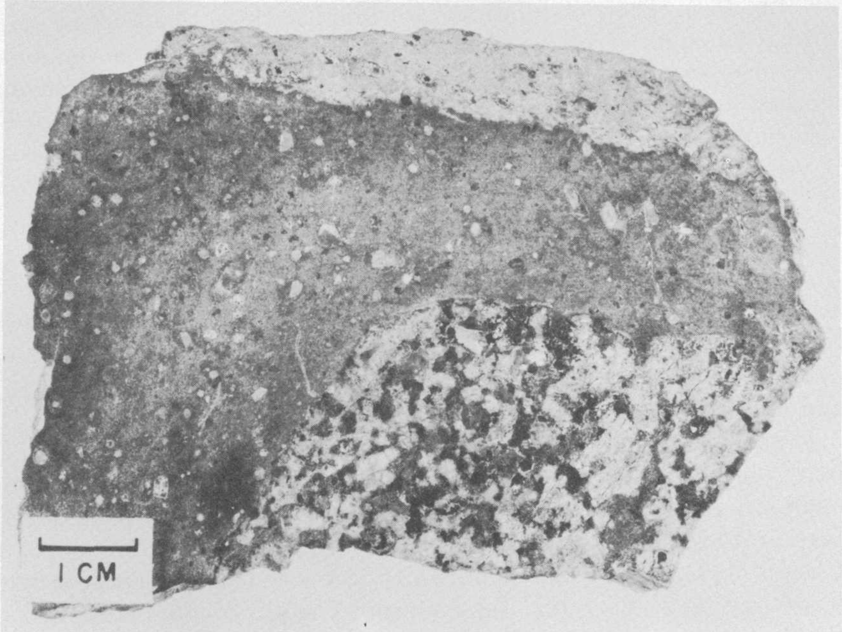


FIGURE 18.—Xenolith of coarse-grained granite (lower right; specimen 62–ASn–RR11) in lamprophyre dike (specimen 62–ASn–RR11A) on Rapid River. For chemical analysis of the xenolith see table 6.

Locally they are concentrated near granite (as at Tin Creek), in fractures of the set trending N. 60°–85° E.

Mineralogically the dark dikes are varied, but almost all contain two generations of pyroxene, the older constituting partly resorbed phenocrysts and the younger being confined to the groundmass. The groundmass consists chiefly of andesine or labradorite laths, with abundant biotite and carbonate. Most dikes contain pyrite, opaque iron ores, and sphene; a few contain chlorite, uralitic hornblende, and serpentine (?), which suggests altered olivine. In some dikes the biotite flakes have distinctly muddy-green centers, and brown rims; in others the biotite is all brown. All the dikes contain ilmenite(?) and leucoxene, or large crystals of sphene, much of which is altered badly. Staining sawed slabs with sodium cobaltinitrite solution reveals that in the groundmass potassium feldspar ranges from almost zero to as much as 20 percent and that it increases near granitic xenoliths. In short, the dark dikes exhibit textural and chemical features characteristic of lamprophyres; for example, fresh appearance coupled with abundant carbonate and pyrite, a high proportion of K_2O and Na_2O for the low silica content, and a high titania content (Métais and Chayes, 1963, p. 156). Their association with granitic rocks that contain abnormal amounts of rare elements such as beryllium, tin, boron, and lithium (elements normally lacking in dark, mafic dikes) presented an unusual opportunity to investigate their origin with the help of trace elements in the light of current theories as to the origin of lamprophyres (Knopf, 1936; Chaterjee, 1959).

CHEMICAL COMPOSITION

Analyses of several of the lamprophyres show that they are characterized by high contents of CO_2, H_2O, K_2O, and Na_2O and a low content of SiO_2 (table 6). Spectrographic analyses of several show that they contain trace elements in unusual associations, notably tin and beryllium associated with nickel, chromium, and copper.

In table 6 are shown the chemical composition and norms of several lamprophyres. The norms were calculated by computer. Some of the analyses, and therefore the resulting norms, would be considered too inaccurate for precise petrology if standards as noted by Métais and Chayes (1963, p. 156) were required. However, in this paper, the writer is attempting to show that the lamprophyres are contaminated rocks that are not genetically related to granite, and the standards of accuracy are sufficient for comparison of the rock analyses in table 6. Below the norms, essential minerals of the mode are listed. Owing to the extremely fine grain of the groundmass of many of the dark dikes, modal analyses were not made.

The chemical composition of the rocks shown in table 6 is compared graphically on plate 2 with that of the granites shown in table 5. The writer believes that the lamprophyre dikes originated by mixing of diabase with granite, and the discussion following is keyed directly to the dikes shown in table 6 and on plate 2. Two of the dikes, shown on the left of plate 2, are typical of the dark dikes which are widespread throughout the mapped area and which in chemical composition, mineralogy, and texture can be classed as diabase. A photomicrograph of a sample of the most mafic dike (sample 62–ASn–755) is shown in figure 19. These diabase dikes typically are fine-grained even-textured rocks without xenocrysts of quartz or potassium feldspar, and all contain a high percentage of pyroxene, both as phenocrysts and, more commonly, as subhedral crystals in the groundmass. Chemically, they are equivalent to diabases of the continents or continental margins, with silica in the range 48–52 percent, and Na_2O+K_2O usually under 5 percent. (See Barth, 1952, p. 189, for analyses of comparable diabases.) Certainly they are not alkalic rocks. Their composition contrasts markedly with that of the most mafic lamprophyre (sample 41–AC–66), which, although of comparable silica content, is much

TABLE 6.—*Chemical and mineral composition of diabase dikes, lamprophyre dikes, granite xenolith, and alkalic basalt, western Seward Peninsula*

[N.D., not determined]

Rock type	Diabase dikes		Lamprophyre dikes				
Analysts	(1)	(1)	(2 3)	(4)	(5)	(1)	(4)
Laboratory No.	164673	164674	No number	D10025	D112972	160635	D100122
Field No.	63-ASn-733	63-ASn-755	41-AC-66	62-ASn-RR24	63-ASn-BM27A	62-ASn-RR20	62-ASn-TC23
Locality	East of Brooks Mountain	East of Brooks Mountain	Anikovik River	Rapid River	Black Mountain	Rapid River	Tin Creek
Specific gravity	2.68	2.63	2.62	2.76	2.77	2.81	2.77
Chemical Composition (in percent)							
SiO_2	45.6	45.0	45.70	44.58	45.86	45.0	15.02
Al_2O	16.1	16.4	18.50	16.10	14.71	13.2	15.61
Fe_2O_3	2.8	2.8	1.77	1.73	1.29	1.3	.82
FeO	5.4	6.0	7.87	6.32	6.54	4.5	7.63
MgO	7.3	7.0	4.57	4.76	6.53	8.0	4.56
CaO	12.0	11.8	8.98	10.15	8.58	10.5	7.19
NaO	2.2	1.6	3.83	1.06	1.66	2.1	3.98
K_2O	1.5	1.7	1.00	2.26	1.57	2.3	2.67
H_2O-	.13	.54	.27	.85	.32	.51	.12
H_2O+	1.7	2.5	1.21	3.51	3.72	3.1	1.38
TiO_2	1.3	1.7	2.44	9.50	1.65	1.2	1.82
P_2O_5	.05	.47	.01	.39	.74	.37	.35
MnO	.19	.16	.70	.16	.30	.10	.15
CO_2	3.7	2.1	2.99	3.08	3.89	5.5	2.07
S			.00	N.D.	.68	N.D.	N.D.
Cl			N.D.	.01	.01	N.D.	.08
F			.05	.75	.16	N.D.	.77
Subtotal	100	100	99.80	97.21	98.21	100	100.22
Less $O = F_2$				.32	.41		.34
Total	100	100	99.80	99.89	9 .80	100	99.88

See footnotes at end of table.

TABLE 6.—*Chemical and mineral composition of diabase dikes, lamprophyre dikes, granite xenolith, and alkalic basalt, western Seward Peninsula*—Continued

Normative minerals (in molecular percent)							
Rock type	Diabase dikes		Lamprophyre dikes				
	63-ASn-733	63-ASn-755	41-AC-66	62-ASn-RR24	63-ASn-BM27A	62-ASn-RR20	62-ASn-TC23
Quartz	0.000	0.000	0.000	14.633	11.897	3.434	0.077
Corundum	.000	.000	1.538	8.141	5.822	1.796	.977
Orthoclase	8.867	10.069	5.908	13.352	9.276	13.589	15.775
Albite	18.621	13.570	32.391	8.891	13.965	17.760	33.068
Anorthite	29.634	32.621	26.145	10.326	12.207	14.901	14.770
Nepheline							
Halite				.016	.016		.132
Wollastonite	2.586	4.038					
Enstatite	16.582	16.923	5.115	11.850	16.257	19.917	11.352
Ferrosilite	5.299	6.041	4.613	7.995	7.377	7.045	10.605
Forsterite	1.124	.386	4.389				
Fayalite	.396	.151	4.362				
Magnetite	4.061	4.069	2.566	2.508	1.870	1.885	1.189
Hematite							
Ilmenite	2.470	3.236	4.634	2.849	3.134	2.279	3.457
Apatite	.118	1.116	.024	.924	1.753	.876	.829
Calcite	8.417	4.787	6.595	11.553	8.847	12.508	4.708
Fluorite				1.505	.261		1.550
Pyrite					1.272		
Total	98.174	96.97	98.280	94.544	93.954	95.990	98.489
Salic	57.122	56.26	65.982	55.359	53.183	51.480	64.699
Femic	41.053	40.719	32.298	39.185	40.770	44.510	33.690
CIPW classification							
Class			II	III	III	III	II
Subclass			I	II	I	I	I
Order			5	4	4	5	5
Section							
Range			3	3	3	3	2
Subrange			4	3	3	3	4

	Main minerals (X, xenocrysts; G, groundmass; P, phenocrysts)						
	Augite (P) Plagioclase (G) Carbonate (G) Iron ores (G) Pyrite (G) Leucoxene (G)			Brown biotite Plagioclase (G) Orthoclase (X) Quartz (X) Carbonate (X, G) Calcic pyroxene (P)	Plagioclase (G) Orthoclase (X) Oligoclase (X) Quartz (X) Carbonate (G) Carbonate (replacing pyroxenes)	Plagioclase (G) Oligoclase (X) Quartz (X) Carbonate (X) Carbonate (G) Biotite (G)	Brown biotite Plagioclase (G) Hornblende Amphibole (G) Carbonate Sphene
				Sphene Pyrite Fluorite	Biotite (minor) Pyrite Chlorite	Pyroxene (P) Pyrite	Quartz (X) Iron ores
Potassium feldspar by stain	None	None		Negligible	Xenocrysts	Minor	Negligible
Optic angle of pyroxene ($2V_z$)	64°–72°			64°	Not determinable.	32°–34°	
$n\beta$ of pyroxene phenocrysts	1.69±0.008			1.68±0.005	Not determinable.	1.71±±0.005	
Type of pyroxene [6]	Augite			Diopsidic augite.	Completely altered.	Subcalcic ferriaugite.	No pyroxene
Rock classification [7]	Diabase	Diabase	Lamprophyre	Kersantite	Camptonite (?)	Kersantite	Lamprophyre

Rock type	Lamprophyre dikes—Continued						Granite xenolith	Alkalic basalt
Analysts	(1)	(1)	(1)	(5)	(1)	(4)	(1)	(5)
Laboratory No.	160633	160634	160632	D113099	163721	D100124	160631	D113003
Field No.	62-ASn-RR18	62-ASn-RR22	62-ASn-RR6	64-ASn-594	64-ASn-410	62-ASn-786	62-ASn-RR11	61-ASn-266
Locality	Rapid River	Rapid River	Rapid River	Brooks Mountain	Lost River Valley	Lost River Valley	Rapid River	Black Mountain
Specific Gravity	2.80	2.80	2.74	2.80	2.71	2.66	2.62	N.D.
	Chemical composition (in percent)							
SiO_2	51.6	51.5	52.0	56.66	55.7	56.10	69.6	43.58
Al_2O	16.2	16.1	15.8	15.30	15.4	14.78	14.5	15.27
Fe_2O_3	1.8	1.5	1.9	2.22	1.4	.96	2.3	4.32
FeO	6.5	6.7	5.8	5.00	4.9	5.51	.95	8.58
MgO	5.4	4.7	5.0	3.54	3.4	3.17	.57	7.72
CaO	6.6	7.0	6.4	5.07	4.9	5.93	.55	8.16
Na_2O	2.8	2.8	2.5	3.10	3.3	2.51	2.2	4.58
K_2O	2.4	2.2	2.7	3.33	3.3	3.62	6.7	2.34
H_2O-	.79	.55	.72	.99	.42	.27	.52	.48
H_2O+	2.4	1.8	2.4	2.62	1.9	1.55	1.4	.73
TiO_2	1.6	1.6	1.5	1.45	1.2	1.33	.43	2.94
P_2O_5	.45	.45	.44	.31	.41	.31	.13	.78
MnO	.11	.14	.10	.14	.13	.12	.02	.18
CO_2	1.4	2.5	2.6	.14	2.9	3.50	.05	.31
S	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Cl	N.D.	N.D.	N.D.	N.D.	N.D.	.01	N.D.	N.D.
F	N.D.	N.D.	N.D.	N.D.	N.D.	.18	N.D.	N.D.
Subtotal	100	100	100	99.87	100	99.85	100	99.97
Less $O=F_2$						.08		
Total	100	100	100	99.87	100	99.77	100	99.97

See footnotes at end of table.

TABLE 6.—*Chemical and mineral composition of diabase dikes, lamprophyre dikes, granitc xenolith, and alkalic basalt, western Seward Peninsula*—Continued

	Normative minerals (in molecular percent)							
	62-ASn-RR18	62-ASn-RR22	62-ASn-RR6	64-ASn-594	64-ASn-410	62-ASn-768	62-ASn-RR11	61-ASn-266
Quartz	5.405	8.953	11.229	9.649	14.627	17.893	29.518	0.000
Corundum	1.321	3.258	4.209		5.194	5.265	2.943	.000
Orthoclase	14.179	12.998	15.952	19.674	19.497	21.387	39.584	13.825
Albite	23.680	23.680	21.143	26.069	27.909	21.154	18.606	13.016
Anorthite	20.947	15.979	12.437	18.082	3.297	4.050	1.879	14.402
Nepheline								13.733
Halite				.033		.016		.082
Wollastonite				1.734				7.940
Enstatite	13.444	11.701	12.448	8.813	8.465	7.892	1.419	5.265
Ferrosilite	8.010	8.680	6.788	5.212	6.100	7.350		2.100
Forsterite								9.780
Fayalite								4.298
Magnetite	2.610	2.175	2.755	3.219	2.030	1.392	1.881	6.264
Hematite							1.003	
Ilmenite	3.039	3.039	2.849	2.754	2.279	2.526	.817	5.584
Apatite	1.066	1.066	1.042	.734	.971	.734	.308	1.847
Calcite	3.184	5.686	5.913	.318	6.595	7.960		.705
Fluorite						.341		
Pyrite								
Total	96.885	97.215	96.764	96.293	96.963	97.962	97.957	98.841
Salic	65.533	64.868	64.969	73.508	70.523	69.766	92.530	55.058
Femic	31.352	32.347	31.795	22.785	26.440	28.196	5.427	43.783
	CIPW classification							
Class	II	II	II	II	II	II	I	III
Subclass	I	I	I	I	I	I	I	I
Order	5	4	4	4	4	4	4	6
Section								
Range	3	3	3	3	1	2	1	2
Subrange	4	4	3	3	3	3	2	4

Main minerals (X, xenocrysts; G, groundmass; P, phenocrysts)

	Plagioclase (G) Oligoclase (X) Quartz (X)	Plagioclase (G) Oligoclase (X) Quartz (X)	Plagioclase (G) Oligoclase (X) Orthoclase (X)	Plagioclase (G) Oligoclase (X) Orthoclase (X, C)		Plagioclase (G) Oligoclase (X) Orthoclase (X, G)	Quartz Orthoclase Oligoclase	Nephelite (P) Olivine Plagioclase (G)
	Biotite (G) Carbonate (G, X)	Biotite (G) Carbonate (G, X)	Quartz (X) Carbonate (G)	Quartz (X) Biotite (C)		Quartz (X) Biotite (G)	Biotite ----------------	Pyroxene (P, G) Iron ores
	Pyroxene (P)	Pyroxene (P)	Pyroxene (G)	Diopsidic pyroxene (C).		Pyroxene (P) Iron ores		
	Pyroxene (G)	Clinozoisite (?G)	Biotite (G)	Iron ores		Pyrite		
	Sericite (G) Iron ores ----------------	Sericite (G) Pyrite Iron ores	Sericite (G) Pyrite Iron ores					
Potassium feldspar by stain	1 xenocryst	Xenocrysts	Xenocrysts	Xenocrysts and groundmass.	----------------	Xenocrysts and groundmass.	Major	None
Optic angle of pyroxene ($2V_z$)	50°–60°	62°–72°	Not determinable.	54°–60°	----------------	55°–60°	----------------	55°
$n\beta$ of pyroxene phenocrysts	1.69±0.005	1.70	Not determinable.	1.71±0.005	----------------	1.69±0.005	----------------	1.70±0.005
Type of pyroxene [6]	Augite	Diopside-hedenbergite.	Not determinable.	Diopside-hedenbergite.	----------------	Augite	No pyroxene	Augite
Rock classification [7]	Kersantite	Kersantite	Kersantite	Minette	Minette	Minette	Granite	Nepheline basalt

[1] P. L. D. Elmore, S. D. Botts, G. W. Chloe, Lowell Artis, H. Smith.
[2] Cyrus Feldman.
[3] Collected by Robert R. Coats, 1941; no rock description available.
[4] Christel L. Parker.
[5] Elaine L. Munson.
[6] According to classification of Hess (1949).
[7] According to the main groups as presented by Métais and Chayes (1963, p. 157).

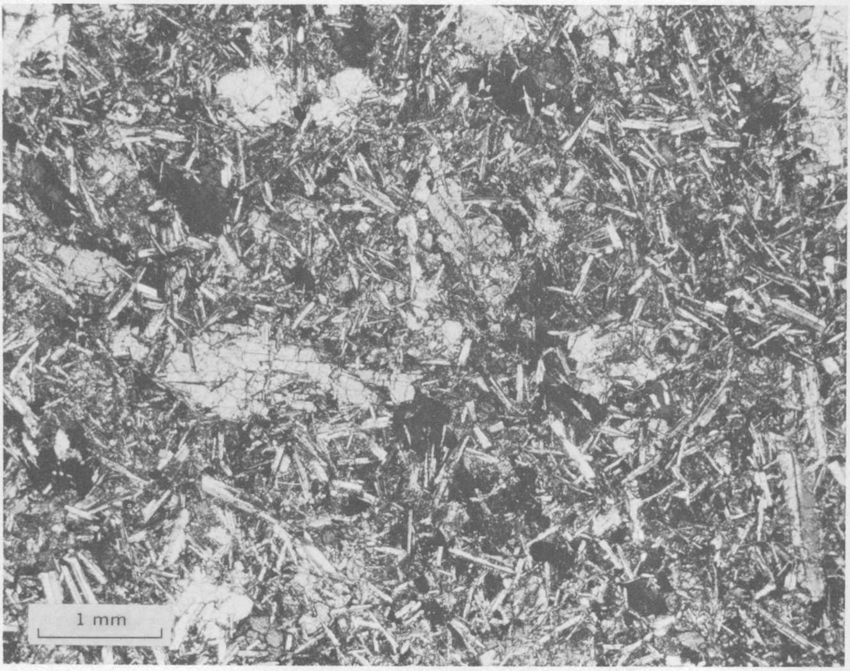


FIGURE 19.—Typical dark diabase dike without xenocrysts, showing augite phenocrysts in a pilotaxitic groundmass of plagioclase laths, green to brown biotite, and opaque iron ores. Plain light. Specimen 62–ASn–755. For chemical analysis see table 6.

higher in combined K_2O+Na_2O, FeO, and lower in combined $MgO+CaO$—features characteristic of lamprophyres—and features common, in progressively changing degree, to the other lamprophyres shown on plate 2.

The next group of dikes shown on plate 2, whose silicia content is 53–57 percent, represents dark lamprophyre dikes from areas near exposed granite or from areas where granite is believed to lie beneath the surface, as at Rapid River, Tin Creek, and Black Mountain. In thin section, it can be seen that all of these rocks contain xenocrysts of quartz and orthoclase feldspar, and most contain xenoliths of coarse-grained granite similar to that shown in figure 18. Sample 62–ASn–594, from a gray lamprophyre dike at Brooks Mountain, contains rounded and resorbed xenocrysts of orthoclase as much as 1 inch long that obviously were derived from the granite of Brooks Mountain, the only granite in the area with phenocrysts of orthoclase that large.

Samples 64–ASn–410 and 62–ASn–786 are, respectively, from the lamprophyre plug near the Bessie and Maple prospects in Lost River valley and from a thick lamprophyre near the pumphouse at the south end of the airfield at Lost River (pl. 5). The limestone around the dike from which sample 62–ASn–786 was collected is marmarized and cut by numerous veinlets of tactite and fluorite-beryllium rock; granite must underlie the area within a few hundred feet.

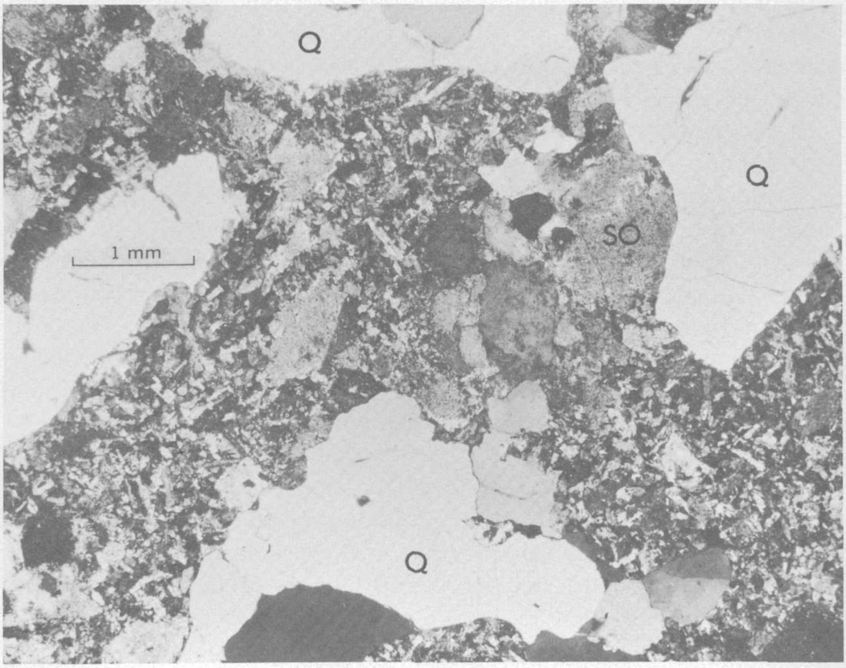
Sample 62–ASn–RR11 represents half of the xenolith in the dike in Rapid River (fig. 18). The granite of the xenolith is considerably more potassic than are the granites of the exposed stocks, and the application of cobaltinitrite stain to the specimen shown in figure 18 proves that in the surrounding lamprophyre the potassium content is higher near the xenolith.

The remaining analyses shown on plate 2 represent the biotite granite stocks, with the exception of 64–ASn–BM24, which is from a medium-grained granite dike near the northeast margin of the granite at Black Mountain (fig. 1).

Textures of several lamprophyres are shown in photomicrographs, figures 20–23, and the essential mineralogic compositions of the analyzed dikes, and their classification into the main types of lamprophyre as listed broadly by Métais and Chayes (1963), are shown in table 6.

To summarize, the following facts are cogent to the understanding of the origin of the lamprophyre dikes:

1. Many of the dark dikes in the areas not near granites are typical diabases texturally, mineralogically, and in trace-element content.
2. As the chemical composition of the dark dikes changes to conform to that typical of lamprophyres, the mineralogy of the groundmass changes so that biotite becomes common, and so that potassium feldspar can be detected by stain. This proves chemical reactions involving the material that furnished the groundmass.
3. Both xenoliths and corroded single xenocrysts are common in the lamprophyre dikes. This shows that fragments of granite, as well as single crystals from the granite, were incorporated into the lamprophyre magma, and, following (2) above, reacted with the magma.
4. The diabase dikes contain notable amounts of elements such as copper, chromium, nickel, and titanium that are characteristic of diabases, and no beryllium or tin, elements which are concentrated in, and characteristic of, the granites of the area. The hybrid rocks contain both suites of trace elements.
5. The major chemical variations shown on plate 2 are compatible with changes that would result from mixing of the two end members, diabase and granite.

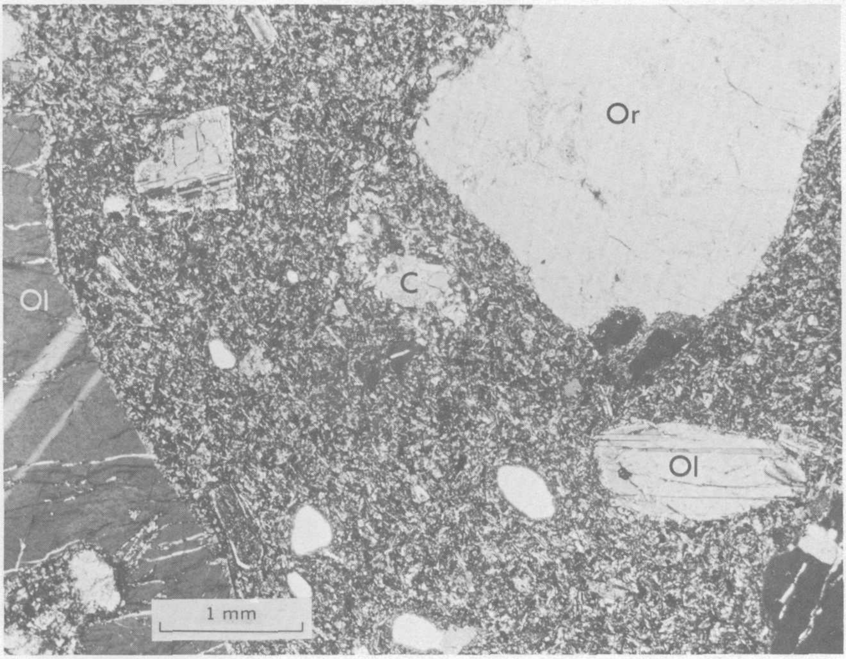


A

FIGURE 20.—Composite lamprophyre dike. A, Medium-grained facies, showing xenocrysts of quartz (Q) and sericitized orthoclase (SO) in a groundmass of orthoclase, albite, and minor biotite. Crossed nicols. Specimen 61–ASn–407.

ORIGIN

Before the origin of the lamprophyre dikes is discussed in terms of the chemical data, the salient geologic associations are summarized here. The most striking association of the lamprophyres of the central York Mountains is not that with granite, but rather with the strong set of normal faults striking N. 60°–85° E., which locally cuts the exposed granite stocks. The aggregate downthrow on the faults is thousands of feet, which suggests that a considerable time elapsed between intrusion of granite and intrusion of lamprophyre. The fact that the lamprophyre dikes in or near granite have chilled borders proves that the wallrocks were cool when the dikes were intruded. The xenoliths of coarse-grained granite in some of the lamprophyres show that these dikes encountered granite at depth, and the numerous single xenocrysts of corroded quartz and orthoclase, which are not grouped near xenoliths, suggest that much of the granite was in a form in which individual crystals were easily separated.



B

B, Fine-grained facies, showing large xenocrysts of oligoclase (Ol), orthoclase (Or), and quartz (clear, white) in fine-grained groundmass of plagioclase and green to brown biotite. Note recrystallized limestone fragment (C). Crossed nicols. Specimen 61–ASn–407A.

After the injection of lamprophyre, large ore bodies of tin, tungsten, beryllium, and fluorine were formed, in large part along the same fractures followed by the rhyolite and lamprophyre dikes. The tin lodes show close spatial association with granite, whereas the beryllium lodes are, for the most part, farther away.

It is proposed here that the lamprophyres originated by granitic contamination of typical diabase chemically equivalent to plateau basalt of the composition shown by the dikes listed on the left side of plate 2. Plate 2 illustrates a generally constant slope of the main oxides from diabase through lamprophyre to granite. In figure 24, the analyses are plotted on a ternary diagram in terms of normative minerals recalculated to 100 percent; a point below the anorthite-albite line indicates that the rock is silica deficient. The diagram demonstrates a fairly linear trend compatible with the trends displayed on plate 2.

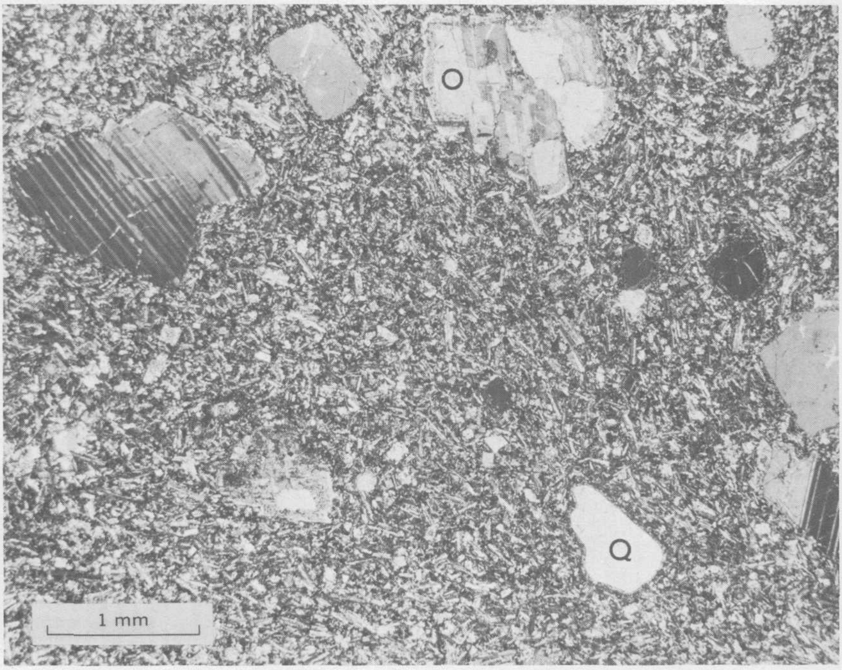


FIGURE 21.—Typical dark lamprophyre dike that cuts composite dike (fig. 20). showing greatly resorbed xenocrysts of oligoclase (twinned), oligoclase partly replaced by orthoclase (O), and quartz (Q) in fine-grained groundmass of plagioclase, green to reddish-brown biotite, minor pyrite, and opaque iron ores. Crossed nicols. Specimen 61–ASn–407B.

The trace-element content of the various igneous rocks is compared in another report (Sainsbury and others, 1968) in which the tables show that the lamprophyres contain trace elements most easily explained by mixing of granite and diabase. Furthermore, when considered in conjunction with the well-established principles of fractionation of elements among various minerals of a crystallizing (differentiating) rock, the trace elements are strong proof that the lamprophyres could not possibly have formed by differentiation from granite. The granites discussed here, when compared with other non-tin-bearing granites, are abnormally rich in beryllium, boron, lithium, and tin. It has been established by many workers (for example, Beus, 1962, p. 27) that the dark and accessory minerals of granites and late-stage alkalic rocks are strongly enriched with beryllium, owing to the large number of diadochic substitutions possible in these complex minerals. The same possible enrichments are true for tin, lithium, and boron. Consequently, if the lamprophyres had originated

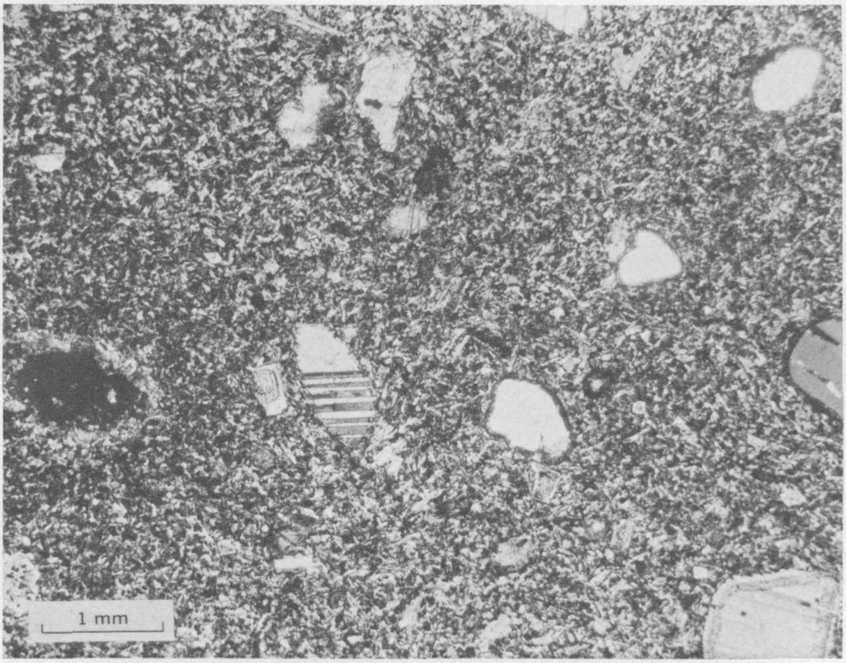


FIGURE 22.—Lamprophyre dike from area of beryllium deposits on the Rapid River, showing xenocrysts of plagioclase (twinned), quartz (clear), and orthoclase (black) in groundmass of plagioclase, green to brown biotite, carbonate, and opaque iron ores. Crossed nicols. Specimen 62–ASn-RR6. See table 6 for chemical analysis.

by crystallization of mafic minerals from a granite, they should have been enriched with rare metals as compared with the granite as a whole, but they were not.

Non-tin-bearing granites contain 4 ppm (parts per million) beryllium (Beus, 1952), 3 ppm tin (Onishi and Sandell, 1957), and 40 ppm lithium (Horstmann, 1957) ; there are no good data on boron in non-tin-bearing granites, but tin-bearing granites are generally enriched with boron as compared with other granites. The granites of the Seward Peninsula contain (range of four granites) 4–16 ppm beryllium and 8–35 ppm tin; no dependable quantitative data are available for lithium.

The chemical disequilibrium of the lamprophyres (normative olivine and free quartz in the mode) is best explained by contamination of mafic magma, and the abundant xenocrysts and xenoliths are irrefutable proof of contamination. The xenocrysts that were separated from a lamprophyre dike (63–ASn–656) near Brooks Moun-

339-932 O—69——5

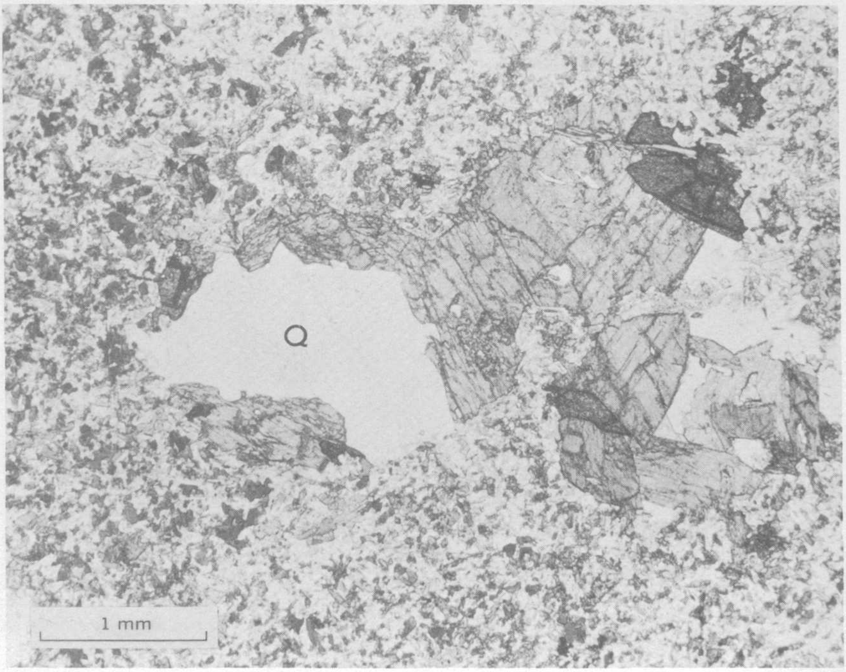


FIGURE 23.—Hornblende lamprophyre from dike near the granite at Tin Creek, showing large quartz xenocryst (Q) surrounded by hornblende, and large crystals of sphene (dark gray), in a groundmass of plagioclase, brown biotite, fibrous green amphibole, and opaque iron ores. Plain light. Specimen 62–ASn–TC23. See table 6 for chemical analysis.

tain contain the trace elements in amounts roughly equivalent to similar minerals in the granites. Because the xenocrysts are corroded, they obviously have added beryllium, boron, and tin to the lamprophyres.

All the mineralogical, chemical, and spatial associations discussed above would follow naturally if deeper mafic magma were tapped by normal faults that penetrated the cooled shells of granite stocks. Away from granites these dikes would be typical diabase; in granite they would acquire their granitic xenoliths; and in areas of hot residual granite they would also acquire isolated xenocrysts rich in beryllium, boron, and tin. Because the dikes intruded faults that also locally cut hot, deep granite rich in residual "mineralizers," ore deposits would be localized near some dikes, as is true in the central York Mountains.

It is concluded that the association of lamprophyre with granite in the central York Mountains is a purely tectonic one, in that the granites were intruded in an early part of the orogenesis and the lampro-

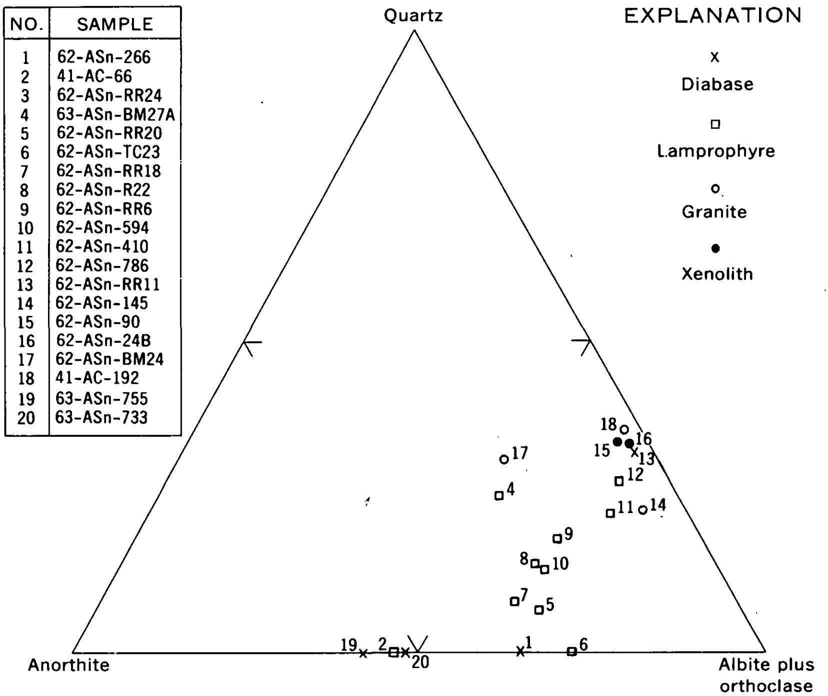


FIGURE 24.—Compositional trends in the igneous rocks of the central York Mountains. (Normative minerals recalculated to 100 percent.) (Sample 3 not plotted.)

phyres followed during a cycle of normal block faulting. A study of the association of lamprophyre and granite in Germany led Chatterjee (1959) to the same conclusion. The work discussed herein leads to the conclusion that any study of the genesis of lamprophyres as a group can be aided materially by trace-element studies.

AGE OF IGNEOUS ROCKS

The age assigned to the igneous rocks is based upon a single determination by M. A. Lanphere, U.S. Geological Survey, and T. Y. Wen, California Institute of Technology, who dated biotite from the granite of Brooks Mountain by the potassium-argon method, and who furnished the following data:

K_2O (percent)	Ar^{40}_{rad} (10^{-10} moles per gram)	$\frac{Ar^{40}_{rad}}{Ar^{40}_{total}}$	Age (millions of years)
8. 14 ± 0. 03	9. 219	0. 84	75. 1 ± 3. 0

This age is Late Cretaceous according to the presently accepted compilations of the geologic time scale.

Because the lamprophyre dikes postdate the consolidation and fracturing of the granite by an uncertain amount of time, they may be as young as early Tertiary in age. In the absence of a confirmed Tertiary age, they are shown in this report as Cretaceous or Tertiary(?) in age.[4]

Dikes and lava flows of Pleistocene age (Steidtmann and Cathcart, 1922) occur in the drainage of California River, just east of the area of plate 1. They are black fine-grained vesicular rocks locally containing olivine and nepheline. None are known in the area of this report, and they are not discussed herein, but the chemical composition of a typical specimen is compared with that of the other igneous rocks (pl. 1).

TIN DEPOSITS

ECONOMIC IMPORTANCE

Placer deposits of tin have been known in the mapped area since 1900 (Brooks and others, 1901). By 1954, some 2,200 tons of tin metal had been produced from the Seward Peninsula; production from placer deposits at Potato Mountain continued until 1960; and placers at Cape Mountain and Lost River are producing currently (1968). Commercial production from the main lode deposit at Lost River was limited to the periods 1913–14, when 3.5 tons of tin and 0.6 ton of tungsten were produced, and 1949–55, when 83.4 tons of tin was produced from placer deposits and 342.2 tons of tin was produced from lode deposits (Lorain and others, 1958). Geologic mapping of the mine, combined with assay data of the Lost River Tin Corp., enabled computation of ore reserves and resources of the mine area as summarized in table 7.

Several other tin prospects are known in the mapped area. Most are presumed to be smaller or of lower grade than the deposits at Lost River mine, but in the aggregate they may contain considerable tin. In 1965, U.S. Steel Corp. optioned the Lost River mine, as well as other claims in the area, and drilled several diamond-drill holes to test the area of altered limestone above the granite, where an open-pit operation of large tonnage might be sustained. Depending upon the cutoff grade selected and the byproduct recovery of copper, lead, zinc, tungsten, molybdenum, beryllium, and fluorite, the tonnages available for open-pit extraction exceed by probably 10 times the totals indicated in table 7.

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[4] On plate 5 in Sainsbury, Hamilton, and Huffman (1968) the lamprophyres are shown as Late Cretaceous in age.

TABLE 7.—*Tin and tungsten reserves of the Lost River mine*

[From Sainsbury (1964a, p. 50-55); NE, not estimated]

Tons ore	Average percent of Sn	Average of WO_3	Total tin (pounds)	Total WO_3 (units)
		Measured and indicated reserves		
200,500 [1]	1.3	[2] 0.125	5,200,000	--------
105,000 [3]	.76	.60	1,600,000	62,500
Total			6,800,000	62,500
		Inferred reserves		
80,000	1.5	NE	2,400,000	--------
430,000	1.0+	NE	8,600,000	--------
Total			11,000,000	--------
		Potential resources		
650,000	0.40	NE	5,200,000	--------
840,000	.26	NE	4,368,000	--------
3,000,000	.30	NE	18,000,000	--------
Large	Lower grade	NE	--------	--------
Total			27,568,000	--------
Grand total			[4] 45,368,000	62,500

[1] Tin ore only.
[2] Probably not recoverable at such low concentration.
[3] Mixed tin-tungsten ore.
[4] 23,000 short tons tin metal.

Although the total amount of tin shown in table 7 (about 23,000 tons) is only about 50 percent of United States requirements of primary tin for the year 1963 (U.S. Bureau of Mines, 1964), it represents by far the largest lode reserve of tin of comparable grade known in the United States. Continued exploration of deposits known in the mapped area, and exploration of deposits yet to be found—based upon the zonal distribution of tin and beryllium deposits—may be expected to enhance the national importance of the tin area. In 1966, geologic mapping to the east of Black Mountain resulted in the discovery of several veins containing sulfide minerals, fluorite, and above average amounts of tin and beryllium. These veins have been described in more detail in another report (Sainsbury and Hamilton, 1967).

GEOLOGY

The tin deposits consist mostly of the minerals cassiterite (SnO_2) and stannite (Cu_2FeSnS_4) associated with numerous sulfide minerals and fluorine- or boron-bearing gangue minerals. The deposits are localized along greisenized[5] dikes intruded into faults of the N. 60°–85° E. system, in numerous small veins and veinlets in limestone above granite cupolas, and in greisenized parts of granite stocks. All known deposits are associated with biotite granite, or with dikes that presumably lie above granite. For detailed descriptions, the reader is referred to Knopf (1908) and Sainsbury (1964a).

In the present study, investigation of lode-tin mineralogy was limited to X-ray determination of minerals that form sulfide assemblages in the central zones of tabular beryllium-fluorite veins. The cores studied came from holes drilled by the U.S. Bureau of Mines in the newly discovered beryllium-fluorite deposits in Camp Creek (pl. 3) and near the Bessie-Maple tin prospect in Lost River Valley, the geology of which is shown on plate 5. Drilling by the U.S. Bureau of Mines in 1964 gave valuable information on the relations between the tin and beryllium, as discussed below.

Diamond-drill hole 115, in the upper plate of the Rapid River fault (pl. 5), penetrates broken dolomitized limestone intruded by lamprophyre dikes. The hole penetrates a total of 17 feet of broken dolomite; 16 feet of fluorite with chrysoberyl and diaspore; 1 foot of virtually solid sulfide minerals that include stannite, pyrite, sphalerite, arsenopyrite, and galena; dolomite that contains fluorite and sulfides along the walls of a lamprophyre dike; fluorite-beryllium rock; and dolomite. In several other holes at Camp Creek and at the Bessie-Maple area, beryllium-fluorite deposits have a central core of sulfide minerals similar to those in drill hole 115.

BERYLLIUM DEPOSITS

ECONOMIC IMPORTANCE

Large replacement deposits of beryllium and fluorite of a type found previously only in Russia (Govorov, 1958) were found during the present investigation. By late 1964, exploration by private industry and the U.S. Bureau of Mines had shown that these beryllium deposits contain at least 4,500 tons of beryllium metal in material with more than 0.2 percent BeO (Sainsbury, 1964c). Most of the vein material contains BeO in the range 0.3 to 1.75 percent BeO. The

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[5] The term "greisen" was used originally to describe a mica-rich rock associated with tin deposits. In the western Seward Pensinula, mica is a subordinate mineral of the greisen, which consists principally of quartz, topaz, and minor mica.

amount of beryllium in the explored Alaskan deposits is about 12 times the total known United States reserves in pegmatites of comparable grade. The nonpegmatite deposits of beryllium in Utah (Staatz and Griffitts, 1961), and the Alaskan deposits show decisively that the world's resources of beryllium are not in pegmatites, as was assumed as recently as 1960 (U.S. Bureau of Mines, 1960, p. 97), although as recently as 1967 beryl from pegmatites (mostly imported) still furnished all the beryllium used by United States industry.[6] Proved domestic reserves of nonpegmatite beryllium are now sufficient to allow great expansion of the beryllium industry without fear of loss of supply sources, or of exhaustion or ore reserves in the foreseeable future.

GENERAL DESCRIPTION

The beryllium lodes described herein consist of replacement veins and veinlets in limestone or dolomite; fluorite is the major mineral in the ores, amounting to an average of about 50 percent. In bulk samples of ore, a rough correlation exists between fluorine and beryllium, the ratio F:Be approximating 115:1 in several samples, although the ratio ranges from 58 to 251, as shown in table 8, which also shows the trace-element content of typical ores. Typically the fluorite-beryllium ores display a faint to marked banding on a scale of 1–2 mm. This banding is caused by an imperfect rhythmic layering of fluorite, and fluorite intergrown with diaspore, mica, tourmaline, and chrysoberyl. The layering probably represents replacement "fronts." In some specimens, the original argillaceous bands in the limestone are perfectly preserved (fig. 25), and all evidence suggests that replacement was volume for volume. A photomicrograph of typical ore is shown in figure 26. In most ores, both chrysoberyl and diaspore form thin crosscutting cryptocrystalline veinlets that are gray to opaque in transmitted light and curdy white in reflected light (fig. 26). The diaspore in these veinlets contains as much as 2.5 percent BeO, probably in the diaspore lattice as X-ray patterns and optical examination reveal no discrete beryllium mineral. At the extreme ends of replacement lodes, the diaspore is almost barren of beryllium. From place to place in the ores, mineralogical variations occur—for instance, one specimen may contain both chrysoberyl and diaspore whereas other specimens in the same area may contain only chrysoberyl. These variations have not been investigated in detail.

[6] A plant was under construction in 1968 to process ores from the Utah deposits.

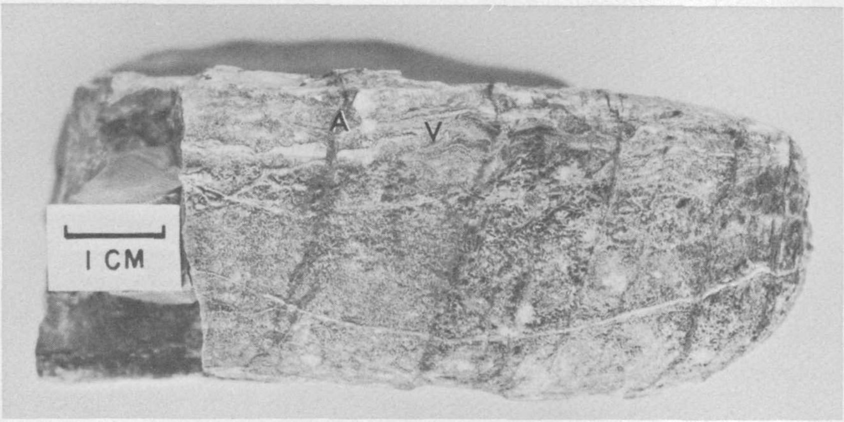
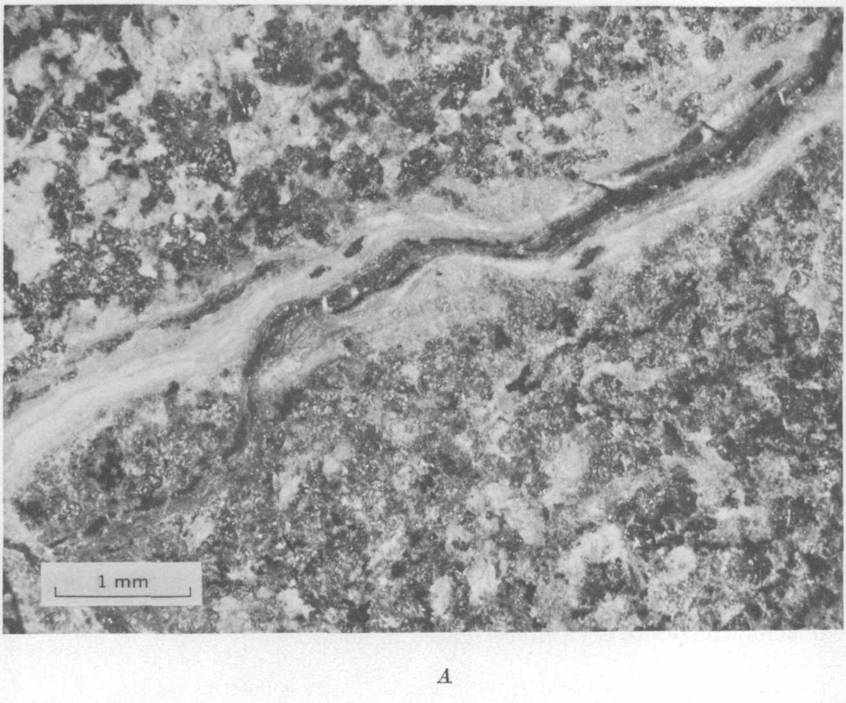


FIGURE 25.—Cryptocrystalline veinlets of curdy white chrysoberyl and diaspore cutting fluorite-beryllium rock. Dark vertical bands are relict argillaceous layers (A). Light wavy horizontal bands are diaspore-chrysoberyl veinlets (V). Note that the argillaceous bands are not displaced by the ore veinlets. Volume-for-volume replacement is suggested.



A

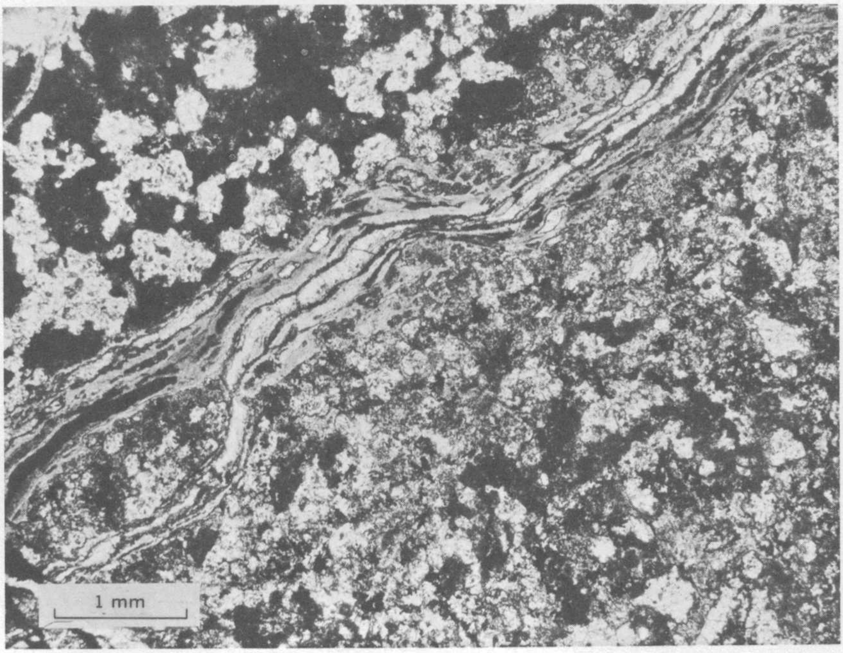
FIGURE 26.—Cryptocrystalline veinlet of curdy white chrysoberyl and diaspore cutting fluorite-beryllium rock. *A*, Oblique light; *B*, Crossed nicols. In *B*, fluorite is black; light patches are mica, tourmaline, and diaspore with chrysoberyl.

In all the ores, the mica is muscovite type, but it contains some beryllium and lithium and is here referred to as "white mica." It is, therefore, slightly different from regular muscovite and approaches the variety ephesite, which is common in the beryllium-fluorite ores discussed by Govorov (1958).

Owing to the high content of fluorite, the beryllium ores are noticeably heavy, ranging from 2.95 to 3.45 in specific gravity.

BERYLLIUM MINERALS AND PARAGENETIC SEQUENCE

Five distinct beryllium minerals have been identified in the ores. These are chrysoberyl (Al_2BeO_4), euclase [$AlBeSiO_4(OH)$], beryl ($Al_2Be_3Si_6O_{18}$), bertrandite [$Be_4Si_2O_7(OH)_2$] and helvite [$(Fe,Mn,Zn)_4Be_3Si_3O_{12}\cdot S$]. In addition, bityite [$(Ca,Na,K)\ (Al,Li,Mg)_{2-3}(Si,Al,Be)_4\ O_{10}(OH)_2$] and phenakite ($Be_2SiO_4$) are identified provisionally but have not yet been confirmed by X-ray patterns. In a preliminary report (Sainsbury, 1963) milarite(?) [$K_2Ca_4Be_4Al_2Si_{24}O_{60}\cdot H_2O$] was tentatively identified, but new work casts doubts on this determination, which was based upon the optics of a few minute grains in fluorite. It is more probable that this mineral is an unidentified fluoride.



B

TABLE 8.—*Quantitative spectrographic analyses of beryllium ores (bulk samples) and ratio of fluorine to beryllium in beryllium ores (bulk chip samples from float), Lost River area*

[Analysts: spectrographic analyses, Harry Bastron; fluorine, L. F. Rader; beryllium, Ardith Bartel, U.S. Geol. Survey. The spectrographic results have an overall accuracy of ±15 percent except near limits of detection, where only one digit is reported. Looked for but not found: Ag, Au, Hg, Ru, Rh, Pd, Ir, Pt, Mo, W, Re, Ge, As, Sb, Bi, Te, Zn, Cd, Tl, In, Co, Ni, Ga, Sc, Y, Yb, La, Zr, Th, Nb, Ta, V, Li, P]

Field No.	Lab. No. 62M-	Quantitative spectrographic analyses (in percent)														Ratio F:Be
		Cu	Sn	Pb	Mn	Fe	Cr	V	Ti	Mg	Sr	Ba	B	Be	F	
Rapid River 1	64	0.0014	0.012	0.012	0.22	0.50	0.0018	0.0024	0.029	0.80	0.048	0.012	1.2	0.24	27.6	115.0
Rapid River 2	65	.0011	.016	.048	.25	.48	.0027	.0020	.030	.90	.050	.012	1.1	.24	27.5	114.6
Bessie-Maple	66	.0008	.010	.023	.16	.26	.0002	.0008	.010	.47	.011	.0037	.016	.14	28.6	204.3
East Lost River 1	67	.0008	.014	.006	.14	.18	.0006	.0020	.019	.38	.034	.0038	.050	.25	24.4	97.6
East Lost River 2	68	.0022	.033	.004	.12	.80	.0018	.0024	.060	.75	.026	.0060	.032	.15	23.0	153.3
East Lost River 3	69	.0012	.014	.007	.18	.28	.0013	.0012	.021	1.20	.026	.0035	.039	.17	27.1	159.4
Camp Creek 1	70	.0006	.009	.007	.20	.25	.0008	.0012	.022	.50	.028	.0055	.42	.25	28.9	115.6
Camp Creek 2	71	.0011	.010	.037	.16	.41	.0007	.0009	.016	.90	.023	.0060	.75	.11	27.6	250.9
Camp Creek 3A G.D.E.	72	.0010	.015	.008	.11	.37	.0014	.0024	.025	.55	.035	.0060	.16	.20	29.5	147.5
Camp Creek 3A C.L.S.	73	.0012	.014	.008	.25	.38	.0010	.0023	.024	.85	.038	.0050	.16	.24	27.7	115.4
Camp Creek 3B C.L.S.	74	.0007	.012	.006	.18	.34	.0010	.0019	.025	.41	.035	.0085	.34	.26	28.4	109.2
Camp Creek 3B G.D.E.	75	.0009	.016	.006	.14	.40	.0012	.0021	.029	.40	.033	.0080	.19	.26	29.0	111.5
62-ASn-791	76	.0008	.017	.005	.22	.41	.0010	.0020	.019	.10	.029	.0032	.047	.54	31.2	57.8
62-ASn-792	77	.0011	.016	.015	.32	.18	.0004	.0014	.014	.49	.032	.0055	.090	.23	27.3	118.7

NOTE.—Mineralogically, the average ore consists of the following minerals, in volume percent: fluorite 45–65; diaspore 5–15; tourmaline 0–10; white mica 0-5; chrysoberyl 3–10; and minor amounts of other minerals, notably hematite and todorokite [(mn++, Ca) $Mn^{4+}O_2 \cdot 2H_2O$].

In table 9 are indexed the X-ray data of chrysoberyl, euclase, bertrandite, diaspore, and todorokite [$(Mn^{++},Ca)Mn^{4+}O_2 \cdot 2H_2O$] separated from ores. Helvite was identified by optics and staining (Gruner, 1944), and beryl was identified by crystal form and X-ray pattern, although its pattern is not indexed in table 9.

TABLE 9.—*X-ray data of minerals reported for the first time from the Lost River area*

[Braced figures signify a multiple peak]

Peak (2Θ)	Height	A	ASTM Peak	ASTM Height
Chrysoberyl [1]				
8.8	2	10.05	—	—
12.4	2	7.14	—	—
14.0	2	6.33	—	—
16.0	1	5.54	—	—
18.8	1	4.72	4.71	2
22.22	55	4.00	4.01	50
26.7	10	3.34	3.45	21
27.65	100	3.24	3.24	100
30.4	2	2.94	—	—
31.7	2	2.82	2.78	2
35.05	80	2.56	2.56	50
38.0	7	2.37	2.37	10
38.8	20	2.32	2.32	35
39.9	25	2.26	2.27	45
43.4	95	2.08	2.09	90
55.63	1	1.65	1.66	12
57.02	85	1.62	1.62	80
68.4	4	1.37	—	—
68.9	15	1.36	1.37	—
Euclase [2]				
8.1	2	10.92	—	—
11.07	3	7.56	—	—
12.38	100	7.15	7.15	100
18.4	3	4.82	4.54	4
22.3	10	3.99	—	—
23.0	15	3.87	3.84	35
24.7	60	3.60	3.58	14
26.9	8	3.31	3.34	4
27.5	20	3.24	3.22	50
30.2	2	2.96	2.94	4
31.7	7	2.82	2.87	4
32.13	12	2.79	2.77	35
35.2	9	2.55	2.54	25
36.8	15	2.44	2.44	35
37.58	5	2.39	2.38	2
39.9	3	2.26	2.28	2
43.5	2	2.08	2.07	10
44.23	1	2.05	2.04	6
45.40	8	2.00	1.99	18
50.8	15	1.80	1.79	6
55.0	5	1.67	1.68	10
Bertrandite [3]				
8.8	6	10.05	—	—
11.7	5	7.56	7.56	10
12.4	8	7.14	—	—
20.4	100	4.35	4.39	55
22.8	25	3.90	3.91	10
23.4	15	3.80	3.81	100
26.9	25	3.31	—	—
28.3	75	3.15	3.16	45
Bertrandite [3]**—Continued**				
31.4	5	2.85	2.85	6
31.8	7	2.82	—	—
35.4	8	2.54	2.54	75
35.6	30	2.52	2.52	40
37.25	3	2.41	2.42	4
38.7	1	2.33	—	—
39.6	15	2.28	2.28	20
41.0	7	2.20	2.21	6
41.5	2	2.18	2.18	4
46.0	3	1.97	1.99	6
47.2	15	1.93	1.92	4
55.8	2	1.65	1.65	4
59.5	2	1.55	1.55	6

Peak (2Θ)	Height	A	Reference Peak	Reference Height
Todorokite [4]				
9.25	100	9.56	9.63	100
18.65	50	4.76	4.80	50
26.8	20	3.33	3.35	60
28.4	18	3.14	3.08	3
37.8	5	2.38	2.38	10
42.5	3	2.13	2.13	5
Diaspore [5]				
18.8	20	4.72	4.70	100
22.25	100	4.00	3.97	60
27.70	18	3.22	3.20	10
35.00	45	2.56	2.55	20
38.15	12	2.36	2.35	90
38.8	30	3.32	2.32	30
42.4	20	2.13	2.13	20
43.5	80	2.08	2.08	60
53.6	7	1.71	1.71	5
{56.35 56.4}	15	{1.63 1.63}	{1.63 1.63}	10
57.2	12	1.61	16.2	5
{58.8 58.9}	2	{1.57 1.57}	{1.57 1.57}	20
{62.8 62.85}	10	{1.48 1.48}	{1.48 1.48}	10
{65.2 65.55 65.75}	4	{1.43 1.42 1.42}	{—— 1.42 1.42}	5
{68.18 68.22}	10	{1.38 1.37}	{1.38 1.37}	7
{70.80 73.58 73.65}	4	{1.33 1.29 1.29}	{—— 1.29 1.29}	8

[1] Separated from specimen 61-Asn-413, Rapid River.
[2] Separated from specimen 61-Asn-413D, Rapid River.
[3] Separated from specimen 62-Asn-RR-Y, Rapid River.
[4] Fragment from drill core specimen, Camp Creek, near Lost River mine. Reference specimen from Cuba, furnished by D. F. Hewett, U.S. Geological Survey.
[5] From diaspore veinlet in specimen 62-Asn-TC30. Reference specimen from Chester, Mass., furnished by F. A. Hildebrand, U.S. Geological Survey.

The first beryllium mineral to form was helvite, which occurs only in banded skarn (tactite containing abundant magnetite) consisting of bands of fluorite and magnetite (fig. 27). Jahns (1944a, p. 79) was the first to identify beryllium in a sample of this rock, collected by Adolph Knopf from Tin Creek. The skarn is similar to the helvite-bearing skarn that he called "ribbon rock," at Iron Mountain, N. Mex. (Jahns, 1944a). In the Lost River area, the helvite-bearing skarn is within a few feet of the contact of granite and limestone in Tin Creek, and is not economically significant. It has been described in detail by Knopf (1908, p. 45–49). Whereas the helvite in the Iron Mountain skarns is restricted to the fluorite bands, it is much more common in the magnetite bands in the Tin Creek rocks. The helvite forms small grains as much as 2 mm in diameter, and locally accounts for 0.45 percent BeO in a specimen. The banded fluorite-magnetite rock locally is surrounded by tactite containing hornblende, garnet, vesuvi-

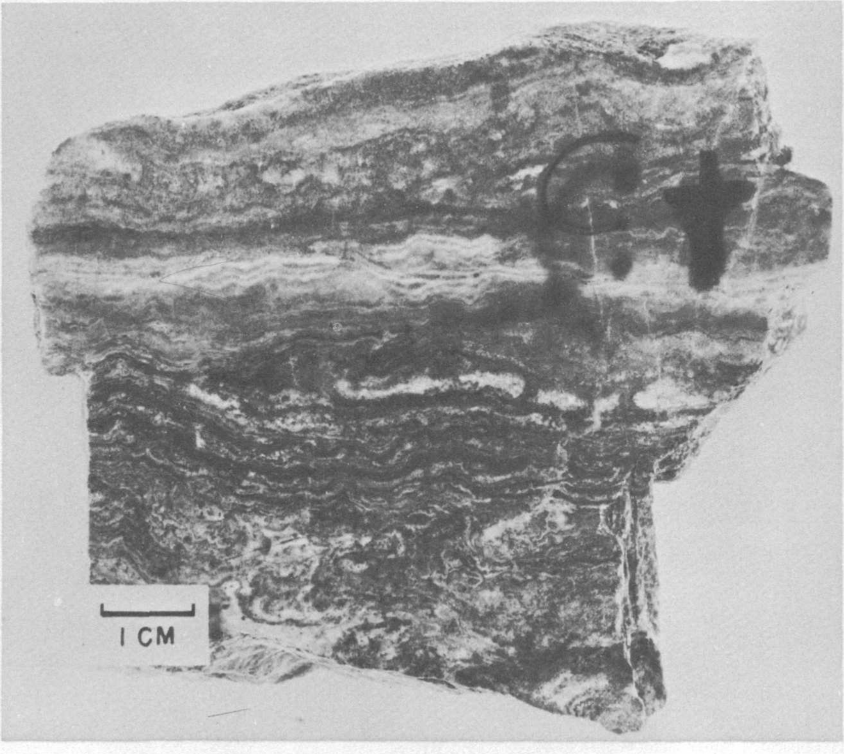


FIGURE 27.—Rhythmically banded skarn ("ribbon rock") from the contact of the granite at Tin Creek. Light bands are fluorite; dark bands are principally magnetite. Helvite occurs in isolated grains principally in the magnetite bands.

anite, fluorite, and minor other minerals. Both tactite and banded skarn locally are cut by younger fluorite-beryllium veinlets containing chrysoberyl.

By far the most common beryllium mineral is chrysoberyl, which is the second beryllium mineral in the paragenetic sequence. Pure chrysoberyl has been separated from many specimens of the banded fluorite ores; a typical separation is shown in figure 28, which illustrates that the chrysoberyl is recoverable by mechanical separation. A quantitative spectrographic analysis of a purified separate showed that it contained 19.8 percent BeO, the theoretical maximum for chrysoberyl. In thin section, the chrysoberyl is seen to occur as discrete anhedral grains as much as a few millimeters in diameter, as cryptocrystalline veinlets as much as several millimeters across (fig. 29), and in minute grains a few microns in diameter intergrown with fluorite, mica, and diaspore. Some occurs as very fine grains in cleavages or fractures in fluorite.

In veins in Camp Creek, nodules as much as 1 foot in diameter are common. These nodules (fig. 30) consist of a round to subround core

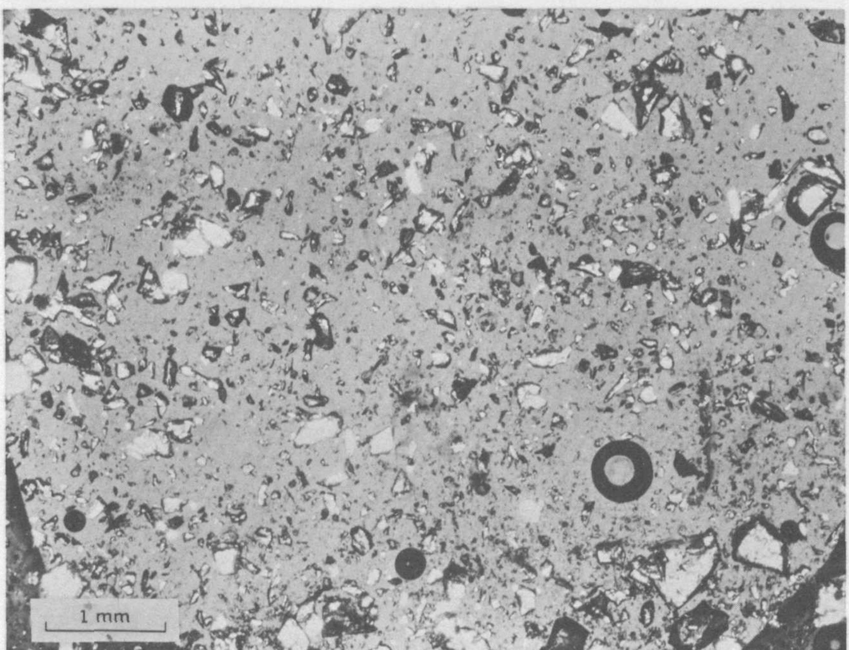
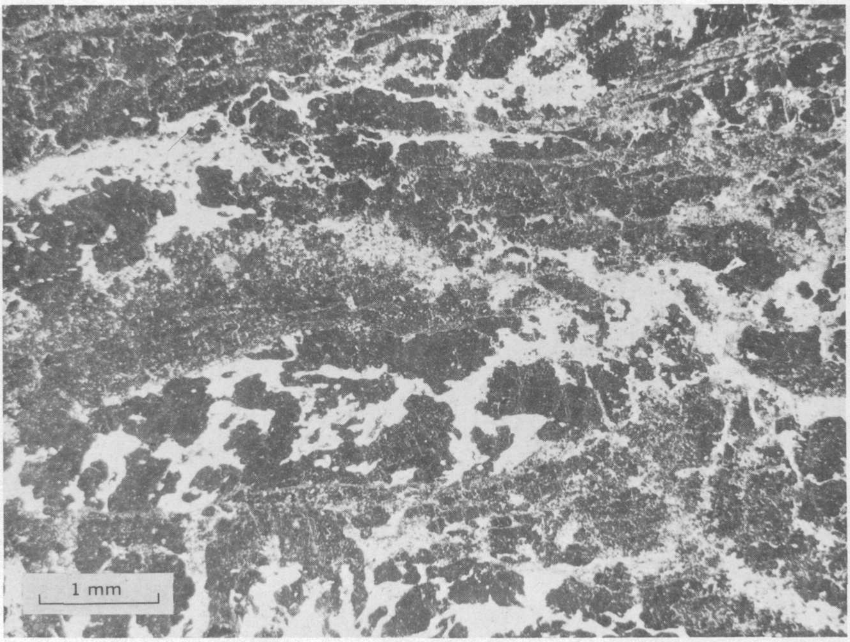


FIGURE 28.—Chrysoberyl separated from fluorite-beryllium ore from the Rapid River area. Uncrossed nicols. Separated from specimen 61–ASn–413 (fig. 29). X-ray pattern shows this to be pure chrysoberyl, illustrating that a beryllium concentrate can be prepared from fine-grained ores.

of intergrown diaspore and chrysoberyl; a surrounding zone chiefly of fluorite, mica, and todorokite; and, finally, a rind of faint purple mica with some fluorite and todorokite. These nodules represent a great enrichment of beryllium, compared with the surrounding ores, and in this respect resemble the nodules in the nonpegmatitic beryllium deposits at Spor Mountain, Utah (Staatz and Griffitts, 1961, p. 946–947).

Euclase, the third beryllium mineral in the paragenesis, is known in ores at Rapid River and Tin Creek. At Rapid River, it is confined to veinlets, generally less than 1 inch thick, of fluorite, mica, and euclase that cut the banded ores. In these veinlets the euclase forms lustrous pearly white flakes as much as 1 centimeter long. It is especially common in specimens from Tin Creek, where it is confined to veinlets of mica and fluorite that cut the banded ores, or to unusual tabular growths on banded ore (fig. 31). In the specimen shown in figure 31,



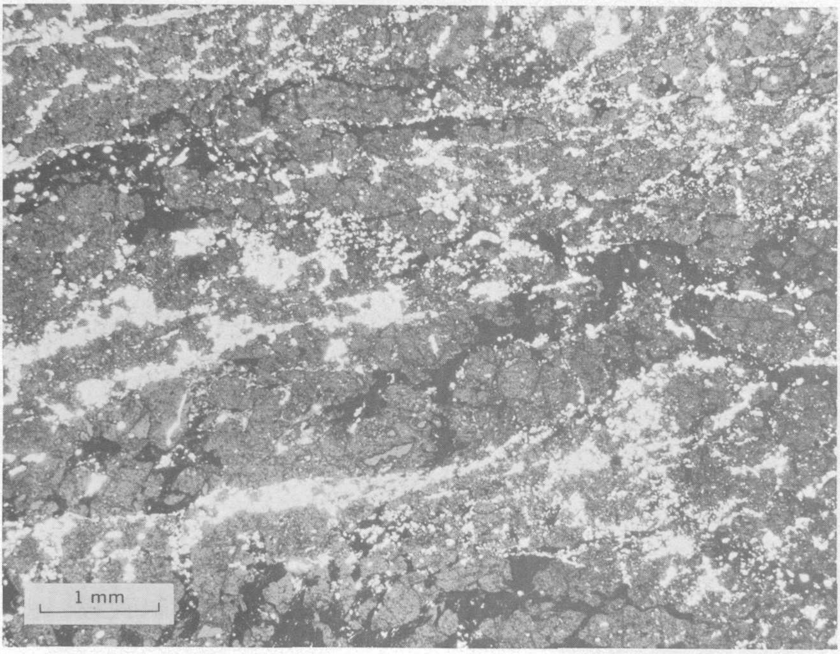
A

FIGURE 29.—Texture of typical fluorite-beryllium ore. Rapid River area. *A*, Photomicrograph showing curdlike chrysoberyl (light) in reflected light; *B*, shows same (black) in transmitted polarized light. Fine-grained intergrowths scatter transmitted polarized light, giving darkness; gray areas are fluorite; light areas are mica, tourmaline, diaspore, and minor chrysoberyl. Specimen 61–ASn–413.

the tabular growths consist of an intimate intergrowth of fluorite and mica, with the mica oriented with the (001) face perpendicular to the major plane of the growth. Euclase can be separated by gravity methods from crushed tabular growths, but in the banded ore which is coated by these unusual growths, only chrysoberyl can be recovered in this maner. The relations support the conclusion that euclase is younger than chrysoberyl.

The paragenetic position of bertrandite with respect to euclase is unclear. However, bertrandite occurs only in veinlets that cut the banded chrysoberyl-bearing ores and, hence, is younger than chrysoberyl. Bertrandite has been recovered in minute amounts (yet sufficient to give a good powder pattern as a smear on a glass slide) from veinlets of fluorite, mica, and euclase at Rapid River. It has not been identified in thin section.

Phenakite(?) has been identified optically in a few thin veinlets cutting a specimen of banded ore from Rapid River, where it is associated with minor quartz. Phenakite(?) forms small crystals about 0.05 mm in diameter, intergrown with quartz and mica. Its identification is based upon these optical constants: uniaxial positive (+); sign of elongation, negative (—); indices estimated to be between 1.65 and 1.67.



B

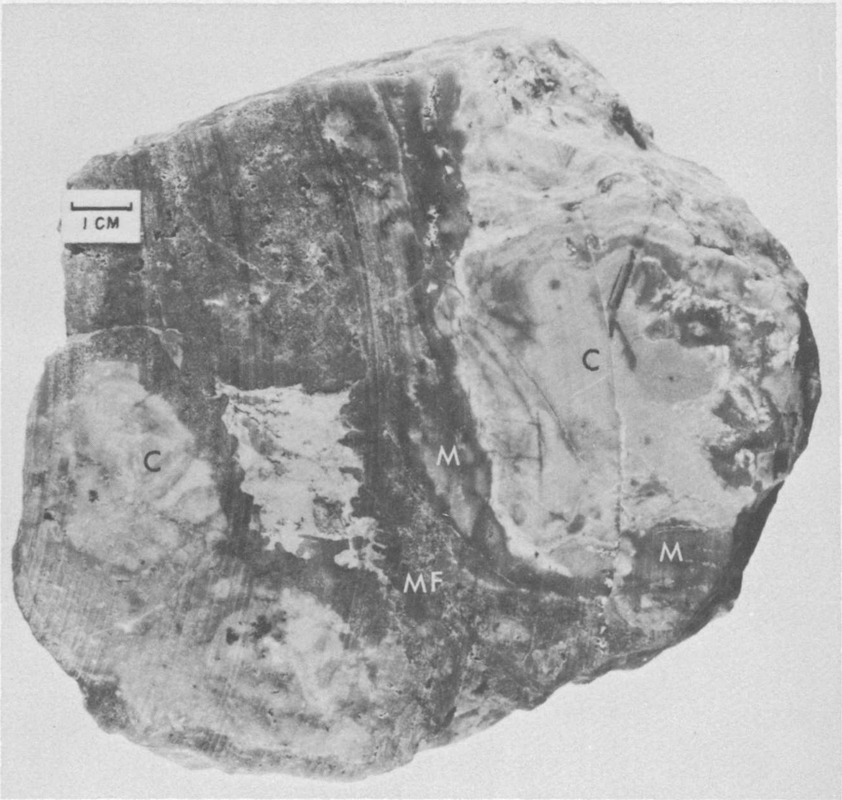


FIGURE 30.—Cross section of a nodule from the Camp Creek deposits. Light concentrically banded areas (C) consist of chrysoberyl with diaspore and minor white mica, which are surrounded by colorless fluorite (M) containing mica, diaspore, chrysoberyl, and todorokite. Rim and center are cemented by pale-purple mica with fluorite (MF) and minor todorokite (black specks).

In addition, the veinlets contain an enrichment of beryllium readily detectable with the beryllium analyzer but not attributable to any other recognized beryllium mineral. Phenakite has been reported also from drill cores from the Lost River mine (Heide, 1946, p. 25), and a few minute grains were recovered from drill cuttings from altered granite at the Lost River mine. Phenakite is younger than chrysoberyl, and probably younger than euclase and bertrandite. It is associated with quartz, a mineral totally absent from the banded ores that contain only chrysoberyl, and from the veinlets that contain euclase and bertrandite. The veinlets containing phenakite(?) have not been found crosscutting the euclase veinlets.

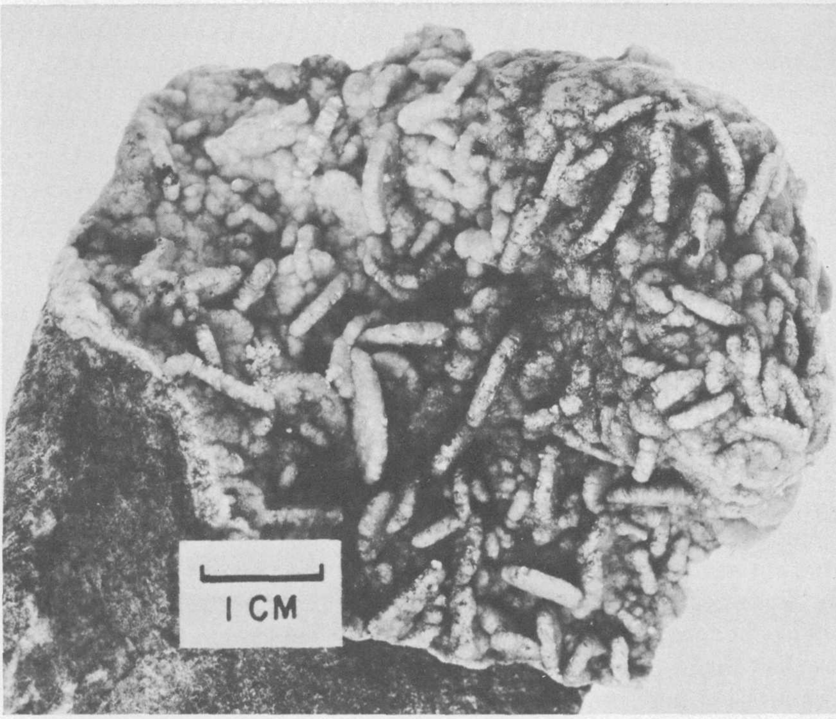


FIGURE 31.—Beryllium-fluorite ore from veinlets in marble on the south side of the granite at Tin Creek. Tabular growths consist of fluorite with white mica oriented transverse to the flat surfaces and minor euclase. Growths coat usual fluorite-beryllium rock (dark) that contains chrysoberyl, mica, tourmaline, and diaspore. Specimen 62–ASn–TC43.

Beryl probably is the last primary beryllium mineral to crystallize in the sequence. To date, beryl has been found in only one 4- to 6-inch-thick quartz-mica-fluorite vein on the surface at the Lost River mine, between the Cassiterite and Ida Bell dikes east of Cassiterite Creek (pl. 3). At two places in this vein, euhedral crystals of beryl about one-quarter inch across and one-half inch long occur in vugs. Some are coated with an earthy brown material about 2 mm thick, which was determined by X-ray to be muscovite stained by iron oxides. In the immediate mine area, quartz veins have been observed crosscutting numerous small fluorite-chrysoberyl veinlets, free of quartz, that ramify through the limestone; hence, beryl can be assumed to be younger than chrysoberyl, bertrandite, and euclase.

Mineral assemblages.—In table 10 are tabulated the mineral assemblages in which the beryllium minerals occur.

339–932 O—69——6

TABLE 10.—*Mineral assemblages in beryllium ores*

Beryllium mineral	*Associated minerals*
Helvite	Magnetite, fluorite, amphibole, minor other minerals.
Chrysoberyl	Fluorite, diaspore, white mica, tourmaline, hematite, todorokite (locally stannite, arsenopyrite, sphalerite, galena).
Euclase	Fluorite, white mica, bertrandite(?).
Bertrandite	Fluorite, white mica, euclase(?).
Phenakite	Fluorite, quartz, muscovite mica.
Beryl	Quartz, fluorite, muscovite mica.

MAIN DEPOSITS

Beryllium deposits of economic significance were found by the U.S. Geological Survey in five main areas within the central York Mountains, all of which lie within a belt a few miles wide trending about N. 85° E. across the drainage basin of Lost River, parallel to the main dike swarm (pl. 1). With the possible exception of the small veins around the granite at Tin Creek, all the deposits occur where lamprophyre dikes intrude shattered limestone or dolomite beneath the Rapid River fault. In each area, ore occurs as individual veins traceable for several hundred feet, as smaller veins and veinlets that cut the shattered carbonate rocks locally forming stockworks or pipelike bodies, and as narrow replacement veins along joints. In most areas, ore has formed along the walls of some of the lamprophyre dikes. Exploration has shown that ore widths range from a fraction of an inch to as much as 50 feet (Camp Creek) and that in four of the areas mineralization is virtually continuous for several thousand feet along the Rapid River fault. Hence, this investigation established the Rapid River thrust fault as a major ore-bearing structure, the first such mineralized thrust known on the Seward Peninsula.

Brief descriptions of the main beryllium areas are given below from west to east as follows: Rapid River, Curve Creek, Lost River valley (Bessie-Maple), Tin Creek, Camp Creek, and Lost River mine (pl. 1). In the descriptions the reader will note the zonal relation between the tin and beryllium deposits.

RAPID RIVER

The deposits on the Rapid River were discovered on public domain by the writer in 1961, and were explored by Newmont Mining Co. in 1963, after detailed geologic maps were prepared by the U.S. Geological Survey in 1962. The geology of the area of beryllium deposits is shown on plate 4. The deposits consist of veins, veinlets, and pipes of banded fluorite-beryllium rock in limestone and dolomite. The deposits are alined along the Rapid River fault for about 4,400 feet. The largest deposits lie east of Rapid River on a wide bench covered thinly by tundra and frost-riven bedrock, throughout an area some 800 feet long and 300 feet wide. Beneath the Rapid River fault, the bedrock consists chiefly of thin-bedded argillaceous limestone of Early Ordovician age, whereas the rocks of the upper plate are medium- to thick-bedded gray limestone of later Early Ordovician age. Beneath the Rapid River fault, the beds are intricately folded and broken, and drilling by Newmont Mining Co. suggests that a lower thrust some 200–300 feet vertically beneath the Rapid River fault has been important in localizing the richer ore, which forms a tabular zone dipping about 20° S. (pl. 4). The lower thrust has not been identified on the surface. A swarm of lamprophyre dikes extends through the mineralized area into the upper plate of the Rapid River fault. Most of the dikes strike about N. 80°–85° E., and most are bordered by brecciated and dolomitized limestone, locally converted to tactite. Some zones of richer fluorite-beryllium rock as much as 25 feet wide are localized along fractures that in parts contain lenticular lamprophyre dikes. (See inset, pl. 4.) At the west end of the richer ore, where a small tributary enters the Rapid River, bedrock is well exposed; the geologic relations are shown on plate 4. Here, it is seen that the lamprophyre dikes are discontinuous and lenticular, and that for the most part the fluorite-beryllium veinlets formed by replacement of limestone along the walls of joints, the attitudes of which are controlled in part by small-scale folds.

At the surface, the beryllium lodes contain mainly fluorite, diaspore, tourmaline, white mica, and chrysoberyl, with specks of hematite, and only a little euclase, bertrandite, and phenakite(?). Drill core obtained by Newmont Mining Co. from holes that intersected the beryllium ores several hundred feet below the surface contains noticeable sulfide minerals, including galena and sphalerite, and minor cassiterite associated with the beryllium ore (Peter O. Sandvik, oral commun., 1963). Toward the east end, the beryllium-fluorite veins are transitional to fine-grained silica with specks of fluorite and only minor beryllium. Hence, a vertical zonation at depth into sulfide minerals and a lateral zonation to fine-grained silica is a characteristic of the Rapid River deposits. he large number of dikes suggests also that a granite stock, or cupola, underlies the area; its depth, however, probably exceeds 500 feet, judged from the absence of contact effects in the overlying limestones.

CURVE CREEK

The deposits on the south side of Curve Creek were discovered on public domain by the writer in 1964, largely as a result of geologic projection along the Rapid River fault. The ores consist principally of silica, fluorite, and pyrite, locally with stibnite(?) and diaspore.

The beryllium content is low to moderate, reaching a maximum of 0.15 percent BeO. In these deposits, which lie within the shattered limestone beneath the Rapid River fault, the fluorite is purple to faint lilac, similar to that at the east end of the Cassiterite dike of the Lost River tin mine, several thousand feet from the tin ore shoot. Several dikes, partly altered, intrude the Rapid River fault and are oriented N. 80°–85° E. along the regional fracture pattern. The ore occurs discontinuously along the fault for about 4,000 feet, and the richer parts are near the dikes. In the absence of subsurface exploration, the zonation at depth is unknown; but the mineralogy of the ores, the purple coloration of the fluorite, and the low beryllium content correspond to the outer zone of the ore shoot of the Lost River tin mine as observed in the north headwaters of Camp Creek. No geologic maps have been prepared of this deposit, but its location is plotted on plate 1.

LOST RIVER VALLEY

These lodes were found by the writer and Thomas E. Smith in 1962 and are covered in part by claims staked in 1962 and 1964 by Lenhart Grothe and Thomas Pearson, owners of the Lost River mine, by Barbara Winkley of Bondi, Australia, and by James Tozer. The deposits on the west end of the mineralized zone lie within ground covered by old patented mining claims, known as the Bessie-Maple claims, staked prior to 1906 on a prospect containing tin and sulfide minerals (Knopf, 1908, p. 57).

The deposits occur for some 5,000 feet along the Rapid River fault where it crosses the valley of the Lost River. In this area, the fault dips south at a low angle. A detailed geologic map is shown on plate 5. The deposits have been explored by United States Smelting, Refining and Mining Co. by trenching on the east end of the mineralized zone, and by the U.S. Bureau of Mines by means of three diamond-drill holes and two trenches on the west end. Throughout the mineralized zone, steeply dipping dark lamprophyre dikes pierce the Rapid River fault, as does a lamprophyre plug.

At the west end of the mineralized zone, near the Bessie-Maple prospect, sulfide-tin deposits and fluorite-beryllium deposits are complexly interrelated; in the center part, only the fluorite-beryllium lodes are found; on the extreme east end (Tozer prospect), the fluorite-beryllium lodes give way to the east to rusty float boulders of fine-grained silica. The relations observed at the surface and in drill cores (Sainsbury, 1965b) show that at least part of the fluorite-beryllium rock lies on both walls of the sulfide veins. The sulfide assemblage, which includes stannite as a major tin-bearing mineral, and the high silver content of the sulfide ores, are characteristic of similar deposits found elsewhere in the world where silver-bearing sulfide minerals form an envelope around cassiterite deposits—for example, at the San Antonio mine, Chihuahua, Mexico (Hewitt, 1943). West of the Lost River, a float run of fine-grained silica with fluorite lies on the east end of the area of main beryllium deposits, repeating exactly the zonation to silica along strike that was observed at the Rapid River deposits.

The fluorite-beryllium deposits consist principally of the usual mixture of fluorite, diaspore, tourmaline, white mica, and chrysoberyl. Late veinlets of diaspore are rich in beryllium. The fluorite for the most part is colorless. Whether or not the ore has replaced limestone or dolomite, the mineral assemblages are the same. The wide zone of beryllium-fluorite rock on the immediate walls of the main tin deposit at the Bessie-Maple prospect is of distinctly lower grade than the usual ores (<0.2 percent BeO), a relation that is true also at the Lost River tin mine. (See p. 83 for discussion.) Elsewhere, selected large pieces of ore contain 0.1–1.95 percent BeO, but grade of potentially minable tonnages probably does not exceed 0.5 percent BeO.

In Lost River valley, zonation from tin to beryllium occurs within a few feet in a direction perpendicular to the tin veins. Along the strike of the main beryllium veins, there is zonation of sulfide minerals to fluorite-beryllium rock and thence to fine-grained silica with fluorite and locally with sulfide minerals, but it takes place through a distance of hundreds to thousands of feet.

TIN CREEK

The beryllium deposits at Tin Creek were found by the writer and Thomas E. Smith in 1962. Most of the beryllium deposits are replacement veins and veinlets in marble on the south side of the granite, whereas the tin deposits are found around the granite (pl. 6). Several trenches excavated by United States Smelting, Refining and Mining Co. have exposed replacement veinlets of fluorite-beryllium rock as much as several feet thick in marble, but most of the replacement veins are less than 1 foot thick. In places, the veinlets are especially common along fractures, some of which may be joints trending N. 70°–85° E. parallel to the dikes that have intruded the regional fracture system. At other places, replacement veinlets are concentrated at the margins of dikes which trend at high angles to the granite contact, giving the impression of a vein parallel to the dike, and described as such in an earlier report (Sainsbury, 1963, p. 11), prior to the time that trenches exposed undisturbed bedrock. Mineralogically, the beryllium lodes are more diverse than they are elsewhere, for although some consist of the usual mixture of fluorite, tourmaline, diaspore, white mica, and chrysoberyl, others contain cassiterite and numerous sulfide minerals, including stannite. Characteristic of all the veins, however, is the high content of fluorite and beryllium. In some veinlets that contain as much as several percent of tin, granular fluorite is abundant, and the beryllium content is 0.15–0.48 percent BeO, which is similar to that in the zones marginal to the tin ore shoot at the Lost River mine and at the Bessie-Maple area. In these veins, the fluorite is colorless, and there is locally a high percentage of todorokite, which accounts for the presence of as much as 10 percent manganese in the bulk ore.

Around the granite, especially on the northwest margin, banded fluorite-magnetite skarn, locally with plagioclase, hornblende, and other contact minerals, forms replacement veins and irregular masses as much as a few feet across. They were described by Knopf (1908, p. 45). Jahns (1944a, p. 79) showed that a specimen of this rock contained an anomalously high amount of beryllium, and discussed the mode of formation of similar rock at Iron Mountain, N. Mex. (Jahns, 1944b, 173–205). Farther from the granite, tactite—consisting principally of andradite, magnetite, and vesuvianite—forms irregular masses not more than a few hundred feet across. Such tactites, except where they are cut by fluorite veinlets, are generally low in beryllium. The vesuvianite, however, contains 0.05 percent BeO. Although the banded skarn locally contains as much as 0.45 percent BeO carried principally in helvite, the helvite is irregularly distributed, and the tonnage of beryllium-bearing skarn is too low to be of economic value.

The relations at Tin Creek demonstrate that some beryllium was contained in the fluids that were capable of transporting large amounts of iron and fluorine during the stage of formation of tactite. The fact that the tactite locally is cut by later veinlets richer in beryllium and containing tin and sulfide minerals suggests that the amount of beryllium in the fluids increased notably during the later stage of vein formation.

According to the scheme of zonation illustrated in figure 33, the veins at Tin Creek are transitional between the cassiterite-sulfide deposits and the beryllium-fluorite deposits that contain no sulfides but contain instead hematite and todorokite. The general absence of fluorite-beryllium veinlets around the northeast end of the granite at Tin Creek, where cassiterite-bearing greisen has replaced the granite, is anomalous. Elsewhere, such greisens are bordered by a network of veinlets containing fluorite, chrysoberyl, and tourmaline.

CAMP CREEK

By far the greatest amount of beryllium-fluorite rock in the district is exposed in the lode system in the drainage of Camp Creek, near the Lost River tin mine (pl. 3). The lode was discovered by the writer in late 1962, and in 1964 the U.S. Bureau of Mines explored the main part of the deposit by diamond-drilling, which proved a wide zone of beryllium-fluorite veins and veinlets over a length of some 2,400 feet. The eastern extension is not yet explored. Results of drilling done to date suggest that the lode is complex, but in gross outline it forms a tabular body dipping south beneath the Rapid River fault. A lower thrust fault, the Camp Creek thrust, is marked by extreme brecciation and porosity, and the beryllium-fluorite veins are more numerous and wider in the porous zone. Individual veins and veinlets are localized by: (1) a strong fracture system that forms locally a sheeted zone dipping almost vertically beneath the Rapid River fault, (2) closely spaced joints in the limestones, (3) brecciated limestones, and (4) dike walls (locally). Whether the individual veinlets continue at depth to the granite that underlies the Lost River tin mine, or are confined to the brecciated rocks beneath the Camp Creek and Rapid River faults, cannot yet be answered. From comparison with the Rapid River deposits, it is quite possible that individual veinlets continue beneath the thrusts, but that these veinlets are more numerous near the thrusts, and form a zone dipping gently south, possibly as far as the dike swarm to the south (pl. 1). The mineralized east-west-striking fault to the west of Cassiterite Creek is projected eastward along the rubble-covered slope south of Camp Creek and is joined to the fractures that offset the gray limestone beneath the Camp Creek thrust at the east end of the mapped area (pl. 3). It is emphasized that this fault is questionable. The relations at Rapid River and the probable configuration of the Camp Creek lode system are shown schematically in figure 32.

Within the explored part of the Camp Creek lode, only a few discontinuous dikes, of rhyolite porphyry and lamprophyre, have been found. Where the Camp Creek lode system approaches the Cassiterite dike (pl. 3), float runs of rhyolite are associated with abundant float of beryllium-fluorite rock; elsewhere, rich ore is found without associated dikes.

Mineralogically, the ores at Camp Creek consist of fluorite, diaspore, tourmaline, muscovite, chrysoberyl, hematite, and todorokite. The late veinlets of diaspore are rich in beryllium. At the extreme east end of the mineralized area (east of the area shown on pl. 3), a prospect first described by Knopf (1908, p. 60) contains stibnite, fluorite, and diaspore without beryllium. In this area are numerous float runs of purple fluorite with nonberyllian diaspore. A few round nodules,

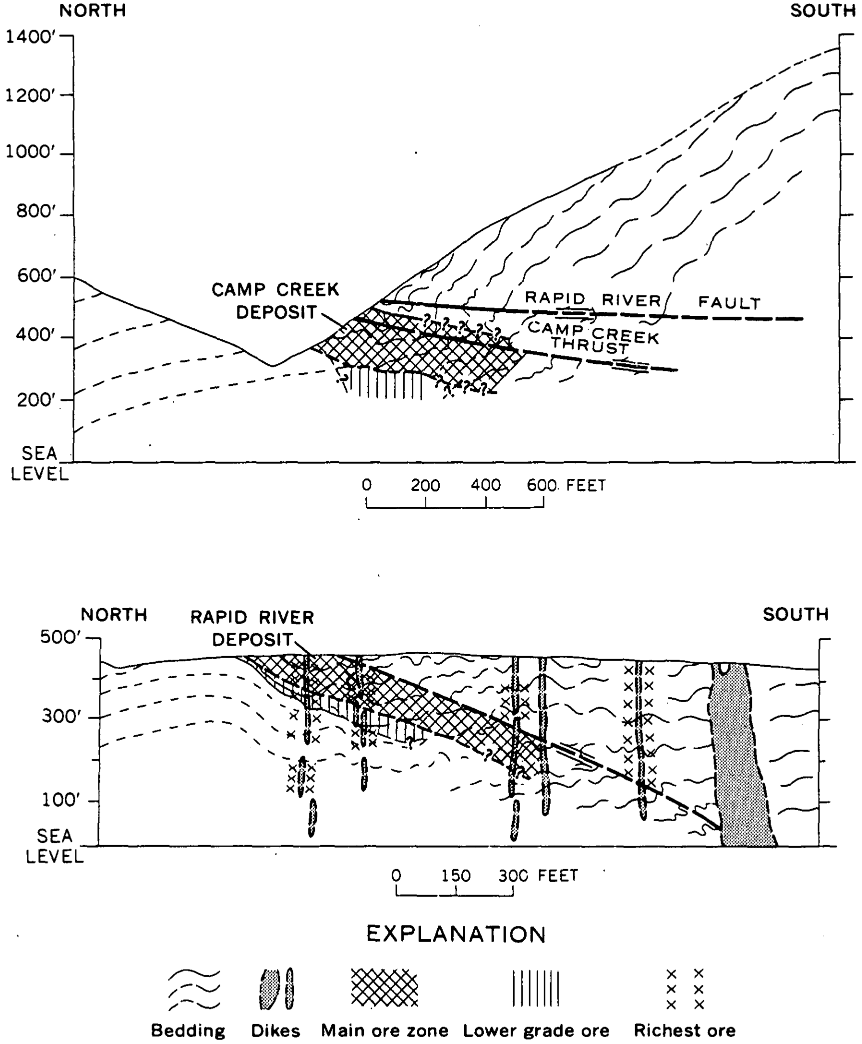


FIGURE 32.—Probable configuration of ore localized beneath thrust faults.

similar in outline to those in the main beryllium lodes (fig. 30), are found, but these consist of a core of granular fluorite with stibnite, surrounded by white diaspore and coated by a rim of lilac-colored fluorite in white mica. The beryllium content of the nodules is very low. Some drill cores from the central part of the lode intersected sulfide minerals that include pyrite and stannite. These sulfide-bearing zones are bounded by the usual beryllium-fluorite rock.

The deposits at Camp Creek demonstrate a zonation along their strike, which is shown by the progressive decrease of beryllium minerals (and total beryllium), mica, and todorokite. The diaspore become nonberyllian at the outer end, where the low-temperature mineral stibnite makes its first appearance. In this interval, fluorite grades from a fine-grained, colorless variety to a coarsely crystalline colored variety, a relation also observed elsewhere in the district. The sulfide minerals encountered by drill holes are similar to those at the Bessie-Maple deposits, and they lie in the central part of fluorite-beryllium veins.

LOST RIVER MINE

The distribution of beryllium in the Lost River mine was studied very little because of time restrictions, because the lower levels of the mine are flooded, and because the upper levels are partly filled with ice. However, some of the mine workings were accessible, and a suite of samples was available from previous work by the writer.

Throughout the mine area, the limestone is cut by innumerable veinlets ranging from a hairline to 1 foot in thickness. These veinlets include tactite, the usual banded fluorite-diaspore-chrysoberyl veins, and quartz-topaz veins, some of which contain mica and cassiterite and one of which contains mica and beryl. The large quartz veinlets cut the banded fluorite veins, and are younger.

Beryllium occurs in the mine principally in a fluorite-tourmaline-cassiterite rock that forms selvages between the topaz greisen of the tin ore shoot and the limestone wallrocks. Locally the selvages contain garnet and pyroxene with pyrrhotite, and are as much as 3 feet thick. In these selvages, beryllium amounts locally to an estimated 0.5 percent BeO, only part of which is in the form of chrysoberyl, and the tin content is as much as 3.3 percent. The tin is in cassiterite and subordinate stannite. The change in mineralogy along the strike of the selvages is unknown because the surface exposures are high above the tin ore shoot exposed by the mine workings and because the east end of the mine workings is inaccessible. It was impossible, therefore, to trace a single selvage over long distances, where mineralogical changes could be observed.

Based upon analogy with greisen deposits near Mount Antero, Colo. (Sharp and Hawley, 1960), beryllium minerals might be expected to occur in the topaz greisen of the Lost River mine. Numerous pieces of greisen on the dumps at the mine were checked with the beryllium detector, and none contained detectable beryllium. At Mount Antero, the greisen pipes formed in granite or gneisses which are cut by quartz-pegmatite veins containing beryl, and, according to W. N. Sharp (oral commun., 1965), the bertrandite in the greisen probably represents remobilized beryllium derived from beryl in the wallrock. At Lost River, the lack of beryllium minerals in the greisen may reflect the lack of such a preexisting concentration of beryllium. The fact that the greisen is bordered by beryllium-bearing fluorite suggests, however, the beryllium was available during greisen formation, and that further detailed search will reveal at least local concentrations of beryllium minerals in the greisen, as were found by Ganiev (1961) in greisen in Central Tadzhikstan, Russia.

The granite cupola below the Lost River mine is locally greisenized and locally argillized. The beryllium mineral phenakite has been identified in drill cores from this altered granite (Heide, 1946, p. 25), but the core is no longer available, and whether the argillized rock represents altered granite or altered greisen cannot be determined.

SUGGESTED ZONAL RELATION OF TIN AND BERYLLIUM DEPOSITS

The relations previously described permit the development of a concept of zonal distribution of beryllium deposits around tin deposits in carbonate rocks. The concept goes considerably beyond the general relations discussed by Beus (1962, p. 87–97), who noted the general association of skarn-type beryllium deposits with tin or tungsten deposits associated with granites that contain abnormal amounts of fluorine. A similar zoning can be inferred from Govorov's (1958) description of Siberian deposits. The main spatial and mineralogical characteristics of the zones on which the concept is based are summarized in figure 33; many minor variations probably exist within this scheme. It is noticed immediately that the zonation involves sulfide minerals, nonsulfide ore minerals such as chrysoberyl, and gangue minerals. As emphasized by Park (1957, p. 480), the gangue minerals and nonopaque ore minerals are critical in establishing zonation. Study of the opaque ore minerals alone probably would not result in the recognition of the marked zoning.

The zonal relations described in the deposits discussed in this report probably exist elsewhere in the world (Sainsbury, 1964b).[7] Not everywhere, however, will all the zones displayed at the Lost River mine be found, and hence some variations are to be expected. In some deposits, a skarn zone may occur without either the greisens or the peripheral beryllium-fluorite lodes. Moreover, it is emphasized that the skarns here considered are those relatively rare ores containing bands of magnetite and fluorite in which helvite occurs, and are not to be confused with the usual variety of skarn consisting of andradite garnet, mag-

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[7] Following written discussion of the possibility of beryllium deposits in fluorite in the tin district of Japan, the Japanese Geological Survey investigated known fluorite veins. Dr. Noburo Hida reported (written commun., 1966) that beryllium minerals were found in these fluorite veins.

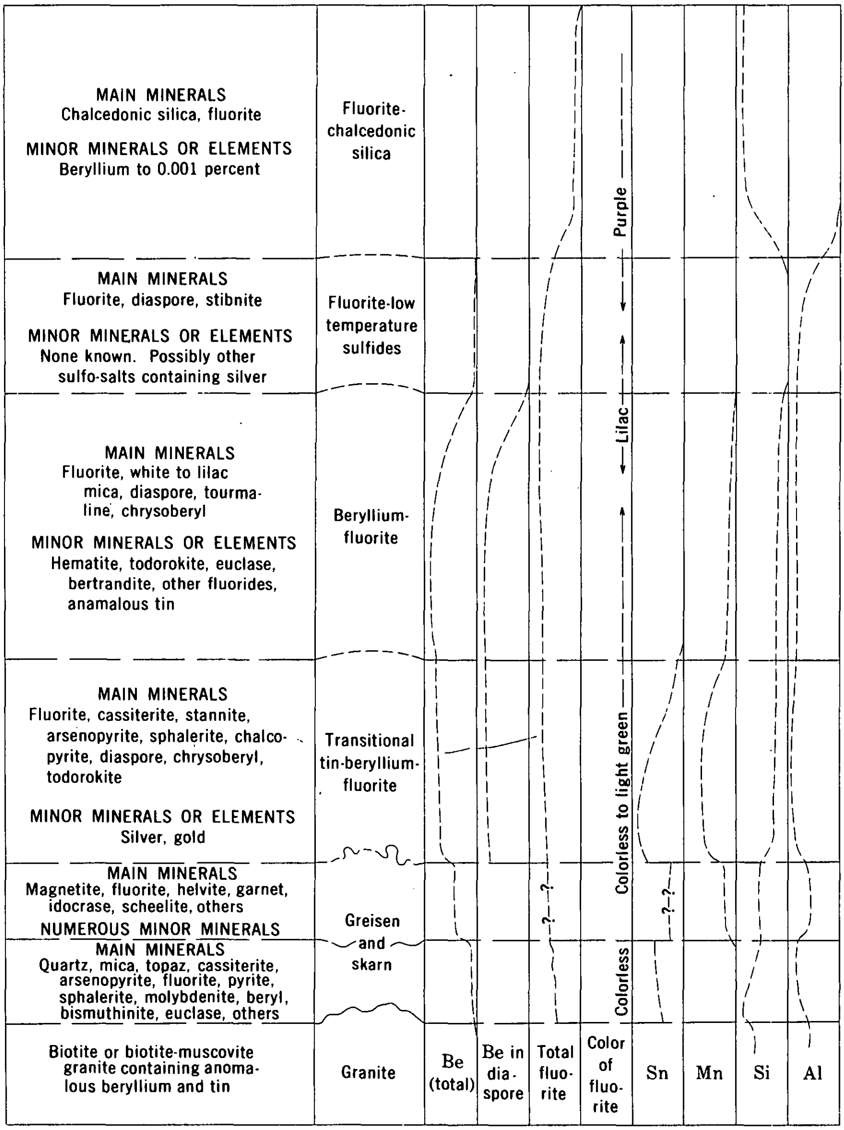

FIGURE 33.—Distribution of zones, minerals, and elements in zoned tin-beryllium deposits.

netite, and other minerals in which scheelite is common, and fluorite rare. It is proposed here that where tin deposits of the Lost River type occur in limestones, and where banded tactites containing helvites are associated, a zone of beryllium-bearing fluorite veins likely will be found peripheral to the tin deposits, reflecting broadly the zonal relations outlined in figure 33.

ORE GENESIS

Because of the difficulties inherent in the quantitative analysis of materials that contain a high percentage of fluorine, chemical analysis of such materials is expensive and is subject to considerable error. Under the direction of Lee C. Peck, Ellen S. Daniels analyzed a bulk sample of beryllium-fluorite ore from the Rapid River deposit. This ore had replaced an argillaceous limestone, which was analyzed by Christel L. Parker. Although it proved impossible to achieve analyses that totaled 99.00 percent, the analysis of the ore is presented in table 11, where the chemical composition is compared with that of the argillaceous limestone, and the gains and losses in grams per 100 cc (cubic centimeters) of rock are shown. As illustrated in figure 25, the replacement of limestone by fluorite-beryllium rock was probably volume for volume, and the gains and losses can be compared with considerable confidence.

TABLE 11.—*Chemical changes during conversion of limestone to fluorite-beryllium ore*

[Analysts: Christel L. Parker, limestone; Ellen S. Daniels, ore, U.S. Geol. Survey]

Lab No.	D100123		D100397			Change, grams per 100 cc
Field No.	62-ASn-RR23		62-ASn-RR1			
Sample type	Bulk chip, argillaceous limestone		Bulk chip, ore			
Specific gravity	2.70		3.25			
	Weight percent	Grams per 100 cc	Weight percent	Recalculated to 100 percent	Grams per 100 cc	
SiO_2	7.35	19.85	14.64	15.18	49.34	+29.49
Al_2O	2.15	5.81	18.55	19.24	62.53	+56.72
Fe_2O_3	.39	1.05	.70	.73	2.37	+1.32
FeO	.58	1.57	.22	.23	.75	−.82
MgO	2.03	5.48	1.60	1.66	5.39	−.09
CaO	47.67	128.71	40.02	41.50	134.87	+6.16
Na_2O	.05	.14	1.35	1.40	4.55	+4.41
K_2O	.42	1.13	1.21	1.25	4.06	+2.93
H_2O+	.51	1.38	2.07	2.15	6.99	+5.61
H_2O-	.09	.24	.12	.12	.39	+.15
TiO_2	.10	.27	.06	.06	.19	−.08
P_2O_5	.03	.08	.01	.01	.03	−.05
MnO	.02	.05	.14	.14	.46	+.41
CO_2	38.30	103.41	.16	.17	.55	−102.86
Cl	.01	.03	00	00	00	−.03
F	.05	.14	27.00	27.99	90.97	+90.83
Subtotal	99.75	269.34	107.86	111.83	363.44	+198.03
Less $O=F_2$	.02	.05	11.37	11.79	38.31	−142.27
Total	99.73	269.29	96.49	100.04	325.13	[1] 55.76
					−269.29	
Difference					55.84	

[1] Unaccounted for, 0.08.

In the mineral assemblages summarized in table 10 it is noteworthy that fluorite always accompanies the beryllium minerals. Certain deductions can be made from the assemblages regarding the composition of the solutions responsible for the paragenetic succession of minerals. At first, alumina must have been high, and the formation of kaolinite from diaspore probably was prevented either by a high temperature, which is unlikely, or by a high $K^+ : H^+$ ratio, which caused crystallization of mica instead of kaolinite. With progressive crystallization, silica increased in amount (or activity), and water became more abundant, as evidenced by the appearance of hydrated beryllium minerals. By the time hydrated beryllium minerals formed, alumina had decreased either in amount or in activity to such a degree that the highly aluminous minerals chrysoberyl and diaspore were no longer formed.

At Tin Creek, as elsewhere, the beryllium mineral helvite represents a special case. Its restricted formation can be explained in terms of sulfur pressures and the necessity for numerous other cations, notably iron, manganese, and zinc, to be available during its formation. The sulfur pressure (or activity) was below that necessary to convert magnetite to pyrite or pyrrhotite, but was sufficient to readily furnish sulfur to form helvite and minor other unidentified sulfides. Helvite that has been found in other places occurs in manganese veins, as at Butte (Hewett, 1937); in skarns, as at Iron Mountain, N. Mex. (Jahns, 1944a, p. 56); or in sulfide-bearing deposits that have skarn associated, as at Beaver, Utah (Sainsbury, 1963). In all these localities, the sulfides commonly include minerals of copper, lead, and zinc, as well as manganese-bearing garnets.

Using the information from the chemical analyses that show the chemical exchanges involved in creating ore from limestone (table 11) and the relatively constant mineralogy of the banded fluorite-beryllium ores and greisen deposits, we may conclude that ore deposition occurred in a system containing SiO_2, BeO, Al_2O_3, H_2O, K_2O, Na_2O, CaO, and F, as well as other minor constituents.[8] Such a system is too complex for duplication in bomb studies, and no studies involving all these components, or even five of them, have been made. Therefore, the application of laboratory studies of silicate systems to the problem of ore genesis can be used only as a general guide. Such studies, however, offer valuable information in explaining features observed

[8] Data obtained by Edwin Roedder on fluid inclusions in beryllium-fluorite ore from the Bessie-Maple prospect area show that early-stage ore solutions consisted principally of liquid CO_2. In younger, crosscutting veinlets of fluorite in the same sample, liquid carbon dioxide decreased to levels comparable to that found in many other deposits. Roedder stated (written commun., 1965) that the concentration of CO_2 in the early-stage inclusions is much higher than has been observed by him in any other ore specimen from any area.

in the ores. The minerals diaspore and mica are critical, for diaspore occurs as a coexisting phase without corundum or kaolinite throughout the fluorite-beryllium ores. The fact that koalinite does not occur is striking, for in the system Al_2O_3–SiO_2–H_2O, kaolinite and diaspore are stable together over a temperature range from 280°C to about 405°C at 10,000 pounds per square inch water pressure (Roy and Osborne, 1954, p. 879). The conditions that might account for this can be explained by chemical composition, by temperatures, or by both.

As shown by the analyses in table 11, Na_2O and K_2O were added to limestone in a substantial amount, approximating 8 grams per 100 cc of ore, during conversion of limestone to ore. East of the Lost River mine (outward from the tin-greisen deposits), the Cassiterite dike was altered to a quartz-adularia rock, which shows that K_2O was migrating outward from the greisen, beyond the zone of deposition of the greisen ores which contain abundant sulfide minerals. The lack of kaolinite can now be explained by reference to work by Hemley (1959), who investigated the system K_2O–Al_2O_3–SiO_2–H_2O. Hemley found that the stability relations between kaolinite and mica were influenced very strongly by the ration of K^+ to H^+ ions in the solution. A high ratio of $K^+:H^+$ greatly enlarged the stability field of muscovite at the expense of kaolinite, especially near the upper stability temperature of kaolinite. If the ratio $K^+:H^+$ were high in the ore forming solutions, as indicated by the large addition of K_2O and Na_2O to the ore, the absence of kaolinite can be explained on chemical grounds which fit the known facts.

In the beryllium-fluorite envelope around the greisen deposits, tourmaline becomes abundant and hematite is characteristic, which indicates that the sulfur concentration (or activity) decreased noticeably from its concentration during formation of the greisen ores, where sulfide minerals were formed; that is, to a concentration below that necessary to convert hematite to a sulfide. The greatly increased amount of tourmaline in the fluorite-beryllium ores as compared with the amount in the topaz-bearing greisens could reflect increasing alkalinity of the ore fluids, for the hydrothermal synthesis of tourmaline apparently requires alkaline or mildly acidic conditions (Smith, 1949b). It is suggested here that the deposition of sulfur in the sulfide minerals in the greisen and the reaction between solutions and carbonate wallrocks, without concomitant deposition of potassium, increased the $K^+:H^+$ ratio of the solutions and thus prevented the formation of kaolinite even though the temperature was within its stability field. The drop in acidity also allowed the increased formation of tourmaline in the fluorite-beryllium lodes. A gradual drop in acidity (lowered concentration of H^+) of the solutions accompanied the reaction between fluorine ions (or complexes) and the limestone wallrocks; for example, $CaCO_3+2F^-+HOH \longrightarrow CaF_2+HCO_3^-+OH^-$.

This reaction forms a strongly buffered solution which would tend to maintain its pH over considerable distance in the hydrothermal conduit.

At the outer ends of the beryllium-fluorite lodes, the ore solutions cooled, and stibnite was deposited with fluorite, diaspore, and mica. At the extreme ends of the vein system, continued abstraction of fluorine by reaction with carbonate to form fluorite allowed continuing breakdown of SiF_4 by hydrolysis to produce the fine-grained silica and fluorite; that is,

$$SiF_4+2H(OH) \rightleftharpoons SiO_2+2HF \quad \text{and} \quad 2HF+CaCO_3 \rightarrow CaF_2+H_2CO_3.$$

On the basis of the relations between lamprophyres and granites, the chemical and mineralogical characteristics of the various ores, and the structural history of the central York Mountains, the evolution and genesis of the tin-beryllium deposits can be summarized as follows, in chronological order.

1. Development of a tectonic belt, in pre-Late Cretaceous time, dominated by imbricate thrust faulting that carried younger rocks northward over older rocks.
2. Generation and injection of granitic magma in the tectonic belt, probably accompanied by normal faulting of the thrust plates, and injection of dikes of granitic composition into faults and fractures.
3. Cooling of the upper parts of the granites, without loss of late-stage fluids in the form of pegmatite.
4. Continued or renewed normal faulting, especially in a zone of faults striking N. 60°–85° E. through the central York Mountains, with concomitant injection of lamprophyre dikes, derived from deeper basaltic rocks, into some of the normal faults. Near granites, these basaltic rocks acquired xenoliths and xenocrysts from the granites.
5. Escape of fluids from deep parts of granites along normal faults that penetrated deeply, and along dikes. These fluids contained numerous metals probably in the form of stable complexes of fluorine, chlorine, boron, and possibly sulfur, and were probably alkaline or at most mildly acidic (Korzhinsky, 1959, p. 17–20, Helgeson, 1964, p. 1).
6. Cooling of the ore fluids to at least 600° C., and deposition of tin and tungsten in the form of cassiterite and wolframite along with numerous sulfide minerals, topaz, muscovite, and fluorite, generally in or near granites or dike rocks. Loss of fluorine from solution to wallrocks during formation of topaz

and fluorite, and addition of sodium and potassium to the solutions from altered granite wallrocks, caused rapid chemical changes in the solutions.

7. Entrance of the solutions into limestone, where the formation of fluorite from limestone increased the alkalinity of the solutions and led to deposition of beryllium minerals, diaspore, white mica, tourmaline, and minor other minerals. The high ratio of K^+ to H^+ ions prevented formation of kaolinite. Ore shoots were localized in porous zones along the thrust faults.
8. Continued movement of solutions outward in veins in limestone, where the last minerals deposited were fluorite and chalcedonic silica.
9. Renewed normal faulting, which ruptured some of the ores; for example, the tin ore shot of the Lost River mine.
10. Uplift and erosion, accompanied by formation of placer deposits of cassiterite which were removed periodically by glacial scouring.

DISTRIBUTION OF RARE ELEMENTS

As a part of this study, an attempt was made to establish the geochemical fractionation and dispersion of certain rare elements (beryllium, lithium, tin, tungsten, boron, copper, lead, zinc, niobium) in the rocks, ore deposits, and some minerals of interest in the district. These elements were traced through the supergene geochemical cycle also by sampling of soils, stream sediments, and plants near the tin-beryllium deposits in Lost River valley (pl. 5). Another report presents all the data (Sainsbury and others, 1968), and only the salient features are summarized here, as follows:

1. All the biotite granites of the western Seward Peninsula are abnormally rich in tin and beryllium, containing an average of 0.0012 percent beryllium and 0.0020 percent tin, considerably more than the average biotite granite as reported by Beus (1962, p. 26)—0.0004 percent beryllium; Shawe and Bernold (1965)—0.00065 percent beryllium; and Turekian and Wedepohl (1961, p. 187)—who reported 0.0003 percent tin in the low-calcium granitic rocks. The formation of the ore deposits can be explained as a direct result of this high content of tin and beryllium.
2. Within the granites, the rare metals are concentrated in biotite (average 0.0260 percent tin) and in heavy-mineral fractions, and are present in amounts well exceeding the amounts in the richest biotites tested by Parry and Nackowski (1960), in Nevada, or by Putman and Burnham (1963), in Arizona. Putman and Burnham found that biotites of granites contained generally less than

0.0050 percent tin, although biotite from the Payson granite contained as much as 0.023 percent tin; thus the Payson granite may be a tin-granite.

3. In minerals separated from the ores, as much as 0.7 percent beryllium was found in diaspore, 0.3 percent in tourmaline, and 0.7 percent in muscovite. Vesuvianite (idocrase) from tactite at Tin Creek contained 0.05 percent beryllium, or much less than percentages reported from other localities (Warner and others, 1959, p. 17–18; Beus, 1957, p. 25–27).
4. Samples of residual clay soil over mineralized areas (pl. 5) showed clearcut geochemical anomalies of unusually large amounts of base metals, beryllium, and tin.
5. Stream sediments proved to be infallible in indicating the mineralized drainages.
6. Ash of tundra plants was more enriched in boron, copper, and zinc than was the associated soil; and the ash was either enriched or impoverished in beryllium, niobium, and tin, depending upon the level of concentration of these elements in the soil.

SUGGESTIONS FOR PROSPECTING

The beryllium ores are not of a common, well-known type and can easily be overlooked. It seems worthwhile, therefore, to make available to future searchers experience gained by the writer during several seasons.

The fluorite-beryllium rock can be recognized visually, although some practice is needed where the host is dolomite. All the deposits discussed in this report were discovered in this manner. The chief value of the beryllium detector is to confirm the beryllium content of the ores and to trace ore zones through areas covered by tundra, or to trace ore into dolomitized limestone; but it is no substitute for careful prospecting. A prospector who has examined any of the lodes discussed herein and has become familiar with the ore has a good chance of recognizing similar lodes that crop out elsewhere.

Geochemical reconnaissance by use of stream sediments is of value for outlining broad areas that contain tin or beryllium lodes and is considered to be the best method available for prospecting in areas not covered already by such reconnaissance.[9] In our work, a bulk sample was taken of the fine-grained sediment found in the lee of boulders in most streams. Most of this sediment passed through a 40-mesh screen. If it proved impractical to secure such sediment, larger amounts of coarser material were screened to obtain sufficient material. On hillslopes without streams, sediments in rivulets, or water-

[9] See note on p. 94.

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sorted alluvium, were sampled. A dependable method using an ultraviolet light and common chemicals to determine trace amounts of beryllium (Patten and Ward, 1962) was applied in the field.

As shown by Brinck and Hofmann (1964), the background metal content of stream sediments is dependent upon the type of rock underlying the stream basin. The background content of beryllium in stream sediments from the limestone areas was determined to be less than 2 ppm (parts per million). Contents between 3 and 10 ppm are definitely anomalous, and experience shows that where values are consistently greater than 15 ppm. megascopic amounts of fluorite-beryllium vein material are present either in the stream bed or in bedrock nearby.

If values reach 30 ppm beryllium in areas without noticeable skarn in bedrock or in the streambed, veins as large as those of Tin Creek or Rapid River probably exist within a few hundred feet; if values are found in excess of 100 ppm, large quantities of ore should be found within a few dozen feet either in place or as numerous boulders in the creekbed, as is true at Camp Creek. In granite terrane, sediments may contain as much as 18 ppm beryllium (similar to the content in the granite) without associated beryllium lodes.

In prospecting new areas, particular attention should be paid to the limestone in the vicinity of granites and to limestone areas containing dikes that weather dark brown. Experience indicates that areas having numerous short dikes alined along the N. 70°–85° E. fault set are more likely to contain fluorite-beryllium deposits than are areas containing large and continuous dikes of rhyolite. Beryllium deposits are more likely to occur in rocks intruded by dark dikes than in those intruded by light-colored ones. Tin lodes, on the other hand, are most likely to be found near granite or in rocks intruded by rhyolite or rhyolite porphyry dikes. Above all, any distinctly dark-colored area in the predominantly gray or white limestone should be examined, especially if the dark area has a tinge of purple. Faint linear trends in thin alluvium on upland areas should be examined in detail.

Most of the ore is noticeably heavy because of its high fluorite content. It is more resistant to frost breaking than is most of the argillaceous limestone, and blocks as much as 6 inches in diameter can be found in float runs on gentle slopes, where the associated limestone fragments generally do not exceed 2 inches in diameter. In places the late fluorite veins cutting some of the ore are light blue to purple and thus are easily recognized. Most of the fluorite in the ores, however, is fine grained and white to grayish, and cannot be recognized easily.

Because all the promising beryllium lodes found to date are in limestone areas, the broad expanses of limestone in the York Mountains and to the east and north of Black Mountain should be prospected before attention is given to the slate outside those areas specifically discussed in this report.

The fact that all the known beryllium lodes discussed herein are of the fluorite-diaspore-chrysoberyl type does not preclude the possibility that other types may also exist.

SUGGESTIONS FOR EXPLORATION

The mining and exploration done to date on the tin and beryllium deposits, in conjunction with the geologic mapping, lead to certain conclusions that should be of value in physical exploration of deposits, either known or yet to be discovered in the central York Mountains. These conclusions should apply to similar deposits elsewhere on the western Seward Peninsula.

1. Of greatest importance to future exploration is the recognition of the zonal relation of tin and beryllium deposits (fig. 33). Outcropping beryllium-fluorite deposits may be expected to pass at depth into tin deposits that may contain economically important amounts of silver, and at greater depths into greisen-type cassiterite-sulfide deposits. On this basis, deep drilling of the sulfide-bearing fluorite south of Curve Creek may disclose a tin deposit at depth. Conversely, exploration to the east or west along the main tin ore shoot of the Lost River mine may disclose a transition to silver-bearing sulfide ores, and thence to beryllium-fluorite ores along the dike walls.

2. Throughout the district, the major lodes of beryllium-fluorite are localized where dikes intrude brecciated zones along thrust faults (fig. 32). In a previous publication (Sainsbury, 1964a), the writer had no good explanation for the shape and position of the main tin ore shoot at the Lost River mine, but the new work suggests strongly that the tin ore shoot is localized by the intersection of a thrust fault with the Cassiterite dike (fig. 31). In future exploration, any prospect that could be interpreted as a leakage above a thrust fault should merit attention. For instance, the Alaska-Chief lode on Rapid River (Sainsbury, 1964a, pl. 1) can be interpreted as a leakage above the Rapid River fault, south of the fluorite-beryllium deposits on Curve Creek.

3. Exploration has shown that the tin lodes along persistent dikes, such as at the Lost River mine, may be continuous for hundreds of feet. Where tin lodes and beryllium-fluorite lodes occur in shattered rocks along thrusts (at the Bessie-Maple prospect area, Rapid River and Camp Creek), both types of lodes may be expected to be complex, with individual veins and veinlets localized by joints, by fractures

related to the thrust faults, by dike walls and normal faults, and, to a minor degree, by contacts of dissimilar rocks; for instance, thin-bedded and massive limestone.

4. Most of the deposits of economic interest known to date lie in or near the fault set striking about N. 80° E., across the drainage basin of Lost River. This zone is intruded by abundant lamprophyre dikes which are readily visible. Both dikes and faults continue eastward out of the mapped area, and the zone should be prospected eastward toward Black Mountain, where tin veinlets in granite were found in 1963 (Sainsbury and Hamilton, 1967).

5. Dikes in areas with numerous small veinlets containing tin, beryllium, and fluorite may lie above mineralized granite, in which large tonnages of low-grade material may be available for evaluation. In this respect, the old Idaho claim area east of Lost River and around the mouth of Tin Creek merits some attention.

6. With respect to placer deposits, it is emphasized that the main placer deposits found at Potato Mountain (fig. 1) are in an area that was not glacially scoured in late Wisconsin time, and that elsewhere on the western Seward Peninsula important placer deposits should not be expected in areas—such as in Lost River valley—that were glaciated during the York and Mint River Glaciations. The glacial erosion of tin placers cannot be overestimated, for considerable work has been done in the past on placer exploration of valleys that obviously were heavily glaciated during the Wisconsin. Moreover, work in 1962, 1967, and 1968 has shown that geochemical prospecting by use of stream sediments does not find buried placers of cassiterite in the Seward Peninsula. Streams containing placer deposits of cassiterite must be evaluated by panning of material collected near bedrock. However, lode deposits of mixed sulfide-cassiterite ores are amenable to discovery by conventional methods of geochemical prospecting.

NOTE.—Work during 1967–68 in the central Seward Peninsula at Humboldt Creek, some 75 miles east of Lost River, showed that bulk stream sediments were unsatisfactory in locating quartz-cassiterite veins but that panned stream concentrates worked well.

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