GEOLOGY, ORE DEPOSITS, AND MINERAL POTENTIAL OF THE SEWARD PENINSULA, ALASKA

By C. L. (Pete) Sainsbury

* Open File Report

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UNITED STATES DEPARTMENT OF THE INTERIOR

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FOREWORD

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By

C. L. (Pete) Sainsbury 1/

INTRODUCTION

The writer first began geologic studies on the Seward Peninsula in 1952; between 1960 and 1971 he was continuously engaged in studies of the geology and mineral resources of the region for the U.S. Geological Survey, first in the detailed geologic mapping of the region around the Lost River tin-tungsten-fluorite-beryllium deposits, and later in the reconnaissance geologic mapping of the remainder of the Seward Peninsula. During the earlier studies, which were coordinated with field investigations of the U.S. Bureau of Mines at Lost River, large new deposits of fluorite containing beryllium minerals were found in the Lost River area, following the detection of abnormal amounts of beryllium in concentrates obtained by the U.S. Bureau of Mines during drilling for placer tin deposits at Ear Mountain, Lost River, Cape Mountain, and Potato Mountain, all in the Teller 1:250,000 quadrangle (Mulligan, 1965). Following drilling done by the Bureau of Mines around the Lost River tin mine (Berryhill, 1964) a cooperative program between the Geological Survey and the Bureau of Mines was undertaken to evaluate the large new fluorite-beryllium deposit on Camp Creek, near the Lost River tin mine

1/ President, Air Samplex Corporation

and at other new deposits found nearby by the writer between 1960 and 1963. This drilling program established that large reserves of fluorite and beryllium existed in these deposits (Mulligan, 1964; Sainsbury, 1964), and established the Seward Peninsula as a good place to seek hidden ore deposits.

Following a period of quiescence, during which only desultory prospecting was done, all the deposits in the Lost River area were acquired by Pan Central Explorations, Ltd., of Toronto, Canada, and a major drilling program was initiated in 1971. A large-scale mining operation is being considered for the Lost River area, with a projected production of several thousand tons per day of mixed fluorite-tin-tungsten-beryllium ore.

The relatively recent discovery of many of the deposits, the low degree of geologic knowledge of the Seward Peninsula, and the passage of the Alaska Native Lands Claim Bill in 1971, give great importance to past and present geologic studies of the entire Peninsula. Only when geologic maps are complete will mineral exploration be successful in finding potentially economic deposits on the Seward Peninsula. Moreover, intelligent selection of land under the Alaska Native Lands Claim Bill is largely dependent upon geologic maps and mineral resource studies largely done by the U.S. Bureau of Mines, the U.S. Geological Survey, and the Department of Natural Resources of the State of Alaska. If the large deposits in the Lost River area could be found outcropping at the surface, as they were, is it not possible that other large deposits might be found in outcrop, or exist beneath the tundra which covers much of the Peninsula? Too, the great amount of placer gold produced in the past suggests that other valuable placer ground may be found, particularly in view of the increased price of gold.

ACKNOWLEDGEMENTS

To the U.S. Geological Survey I am indebted for the opportunity to have studied the Seward Peninsula and its ore deposits for twelve years. During this time, I was ably assisted by numerous young geologists, all of whom contributed to the geologic mapping used in this report. Of these geologists, I am especially indebted to Mr. Travis Hudson, who worked with me each summer from 1968 to 1971. Other assistants were Mr. Thomas E. Smith, Mr. Thomas E. Richards, Mr. W. E. Todd, Mr. Rodney Ewing, and Mr. William R. Marsh. Mr. Reuben Kachadoorian, geologist, U.S. Geological Survey, was especially helpful during the years 1967 and 1968. The names of all these men appear on published reports, where they are responsible for much of the data. Because this report is being written to make available data not published by the Geological Survey, the writer takes sole responsibility for the maps and geologic interpretations herein presented.

Part of the Solomon quadrangle, included in this report, was mapped by Thomas P. Miller, et al, of the U.S. Geological Survey (Miller, T. P., et al, 1972), and much of the geology of that part of the Seward Peninsula is taken from his report. Because the rocks in the eastern Solomon quadrangle are equivalent to those mapped by the writer elsewhere on the Peninsula, some of the designations and ages assigned in this report are the writer's rather than Miller's. Because of the desire to maintain uniformity in geologic age assignments, and to group related rocks under similar map units, the writer second-guessed some of the map units of Miller, et al. In all cases, the writer examined rocks and believes that they represent rocks equivalent to those on the western and central Seward Peninsula.

In order to insure that the interested reader have the opportunity to pursue all possible interpretations as to the age and origin of the rocks discussed herein, a rather complete bibliography of pertinent publications is attached. The fact that many of the recent reports are by Sainsbury and co-workers, and J. J. Mulligan, indicates that few others have worked in the region during the past fifty years.

PURPOSE OF THIS REPORT

This report is written with the prime purpose of putting under one title all the geologic maps of the Seward Peninsula published in open files since 1965, to synthesize the economic geology and the mineral potential of that very important region as an aid to those presently concerned with all types of land selections and evaluations, and to speculate on areas where undiscovered mineral resources may exist unfound. Of necessity, the discussions of rock units are shorter than would be required for a scientific report; moreover, certain assumptions and conclusions based on personal observation are presented without all the background data which are too voluminous for this report.

REGIONAL GEOLOGY

General Discussion

The Seward Peninsula comprises about 25,000 square miles of diverse topography and geology. The geologic units comprise rocks of Precambrian age, including schist, phyllite, slate and limestone, thick sections of carbonate rocks of Paleozoic age, volcanigenic rocks of Jurassic age, and clastic sedimentary rocks of Cretaceous and Tertiary age. Numerous large and small bodies of granitic igneous rocks ranging in composition from diorite to two-mica granites were intruded into the older rocks in the Cretaceous. In the central Seward Peninsula, basaltic lava flows mantle large areas of older rocks.

Many writers have felt that a sharp geologic break separates the Seward Peninsula from the adjoining areas of Alaska, e.g. Miller (1972, page 2113). The writer does not agree with this conclusion, which is made to appear valid by breaking the geologic age assignments of the York Slate as soon as this general boundary is crossed. For instance, maps published by the Geological Survey of adjoining areas (Patton and Miller, 1968; and Patton, Miller and Tailleur, 1969), show no rocks definitely assigned to the Precambrian, and a most recent publication (Clark, et al, 1972) still shows the entire Seward Peninsula consisting of rocks of Paleozoic age and younger. Except for the writer's reports, which began to discuss Precambrian rocks by 1965, only the map of Miller, et al (1972), shows rocks of Precambrian age and these are based upon correlation with the rocks assigned by the writer to the Precambrian. These same rocks are mapped as Paleozoic in adjoining areas by contemporary workers (Patton, 1968). Thick carbonate units are assigned to the Precambrian by Miller, et al (1972), without supporting data. The same confusion existed in the older reports. As pointed out by Sainsbury (1969a, page 6) this apparent confusion can be explained by the failure to recognize the widespread thrusting which is characteristic of the entire Seward Peninsula, and to the fact that most rock units dated by fossils were Paleozoic carbonate rocks juxtaposed by thrusting with Precambrian rocks of different lithology.

Because of the intense tectonic deformation, most rock units were dynamically metamorphosed to varying degrees, leading to creation of rocks which appear different, but which are related. This tectonic deformation in the thrust belt, named the A. J. Collier thrust belt (Sainsbury, 1969b), led to obliteration of most of the original bedding in the Precambrian and Paleozoic rocks, to the creation of strange rock units by tectonic mixing on a large scale near major thrusts as well as by transfer of materials along the thrusts, and made it almost impossible to date rocks by the criteria of superposition. Practically any rock unit can be found both above and below any other rock unit. An attempt to build up a geologic column using superposition as a criteria leads to an infinitely long column (see page 56), which on critical examination, can be reduced to a relatively few lithologic units once the effects of the tectonic metamorphism are considered. To further complicate the issue, the only method of age dating of rocks, except the work by Sainsbury, Hedge, and Bunker (1970), and Bunker, Hedge and Sainsbury (unpublished), has been K^{40}/A^{40}. The limitations of this method of dating rocks that have been even moderately deformed or thermally metamorphosed is so well known as to require no discussion. The results of work by Lee, et al (1970), who dated tectonically deformed rocks in Nevada by this method, and showed that the ages were highly discordant and depended entirely upon the relative distance from major overthrust faults, is cited to support the writer's conclusion that K^{40}/A^{40} age dating of most rocks on Seward Peninsula, possibly excluding undeformed intrusive rocks, is of little value, and serves mostly to befuddle the issue. To illustrate, biotite schist in the Bendeleben A-6 quadrangle was dated by both whole-rock rubidium-strontium methods, and by potassium-argon methods. An age of

100 M.Y. was obtained by potassium argon methods (unpublished data by Carl Hedge and John Obradovich, on rock collected by Sainsbury, U.S. Geological Survey). Once the whole-rock rubidium-strontium age dating method was applied, a Precambrian age was soon established for many rocks on the Seward Peninsula (Sainsbury, Hedge and Bunker, 1970, and unpublished data).

In the York Mountains of the western Seward Peninsula, the Paleozoic rocks are both unmetamorphosed and well exposed. Here, detailed study, abundant fossil collections, and many obviously transitional rock boundaries, has led to the establishment of unquestionable late Precambrian and Lower Paleozoic rocks, and to the recognition of the transitional boundary between the York Slate and the overlying Kanauguk Formation, a thin-bedded argillaceous and dolomitic limestone of the probably Late Precambrian age (Sainsbury, 1969). In the York Mountains the thrust sheets too are well exposed, and a long list of criteria were developed that enabled recognition of thrust sheets elsewhere on the Seward Peninsula where rocks are more deformed and thermally metamorphosed; and where evidence for thrusting is more obscure.

The geologist who maps in tectonically deformed areas can either face the problem of depicting the complex structure by mapping of contacts in detail, and by showing even small exposures of rocks which are out of place, or he can map broadly, ignoring the anomalous details that "clutter the map" and raise questions to an interpretation of simple structure and stratigraphy. The small-scale maps that accompany this report show the small areas of anomalous rocks even though it was not possible to draw structural sections showing how these anomalous rocks got there. For more detailed maps, the reader is referred to the larger-scale maps by Sainsbury and co-workers listed in the bibliography. For independent verification of the thrusts near Nome, the reader is referred to a report by Herreid (1970) who, following a few days spent studying thrusts elsewhere on the Seward Peninsula, was able to delineate thrust plates, and to recognize the widespread and major lithologic variations of the rocks caused by thrusting (p. 10).

Because the distribution of placer gold and many small copper deposits on the Seward Peninsula is controlled by the lithology of the York Slate, and by migration of materials along and near thrusts, it is of economic as well as scientific importance to recognize the relations noted above.

STRATIGRAPHY

General Discussion

The known and assumed stratigraphy of the rocks of the Seward Peninsula is summarized in this report. The stratigraphy reported here represents the writer's last conclusions, in part published elsewhere, and in part not before published. Several differences from previous published reports may be noted. Specifically, it is now known that the chloritic schists of the Seward Peninsula represent rocks of mafic composition and volcanic affinity definitely intercalated in the York Slate (Casadepaga Schists), as well as an unknown amount of mafic rocks which may be of much younger age, possibly as young as Early- to Mid-Cretaceous. This represents the present view of the writer, and also that of Herreid (1970, page 8). Rocks of the younger group probably are represented by relatively massive and undeformed gabbro bosses and stocks which intrude thrust sheets of Paleozoic carbonate at many places on the Seward Peninsula. Rocks of essentially similar composition, but which are dynamically deformed to blueschist and related rocks (Sainsbury, Coleman, and Kachadoorian, 1970) are widespread in the Seward Peninsula. Such rocks are most common in the outcrop areas of the York Slate, and in chloritic schist belts that trend north-south across the western and central Seward Peninsula. Such belts are marked by major magnetic anomalies, which are well shown on aeromagnetic maps published by the State of Alaska. Individual gabbroic bodies in these belts yield very sharp and distinct magnetic anomalies within the general highs that correlate with the chloritic schists. By reference to the geologic maps that accompany this report, several distinct belts of chloritic schists can be noted, the most continuous of which begins at the coastline west of Nome, wraps around the west end of the Kigluaik Mountains, and continues northward to the Chuckchi Sea, a distance of more than 100 miles. Another belt of chloritic schists with numerous gabbro bodies lies east of Nome in the Nome and Solomon quadrangles. This belt, which is about 30 miles wide, is truncated by the east-trending Kigluaik Mountains, and no metamorphosed equivalents of these rocks occur in the mountains. Smaller north-trending belts are represented by the Casadepaga Schists of Smith (1910, p. 76), shown on my map of the Solomon Quadrangle as pEcs. Numerous rock samples from this belt demonstrate a clearcut volcanic origin for these rocks, for thin sections show relict clasts of volcanic rocks in which flow textures are clearly visible.

A second belt of lithologically similar rocks trends up the Fish River in the Solomon quadrangle; it is separated from the Casadepaga

Schist by a belt of York Slate that is tectonically deformed. To the south, these two belts seem to merge north of Bluff, but here the rocks are quartz-rich, and contain fewer gabbro and metagabbro bodies. Elsewhere on the Seward Peninsula, rocks of similar composition form smaller outcrop areas, generally associated with York Slate, and for the most part elongated in a northerly direction. Because the chloritic schists were involved in the thrusting, and because they are for the most part intensely deformed and recrystallized, the original nature of the rocks, whether volcanic or intrusive, cannot always be told. Moreover, because the rocks contain limestones which are completely recrystallized and generally highly schistose, it cannot be told whether the limestones are intercalated in the schists, or whether they are thrust slices. Because all the original bedding is destroyed, a contact between schist and limestone may appear conformable, but this is due only to the dynamic metamorphism. Any piece of limestone within the schists that was subjected to the intense dynamic metamorphism caused by thrusting would be smeared out and appear interbedded in the schist if parallelism of contacts and schistosity was used as a criteria for bedding.

Many lines of evidence indicate that most of the chloritic schists are of Pre-Paleozoic age, or at least older than the Ordovician limestones of the York Mountains. In a few exposures, dikes intruded into the Kanauguk Formation (pEl map unit) are offshoots of the chloritic schist, and are converted to chloritic schist. Such exposures are seen at the western end of the York Mountains, Teller B-5 quadrangle, and at several places in the Solomon D-6 and C-6 quadrangles. At many places, slivers of chloritic schist are enclosed by Paleozoic marble; some of these are probably thrust slivers, but some may represent dikes converted to schist during thrusting. Additional lines of evidence to indicate a pre-Paleozoic age for most of the chloritic schists are:

1. Most of the chloritic schists are enclosed in the York Slate, of Precambrian age.

2. Many gradiational boundaries from chloritic schist to slate are found.

3. Rock units which represent rocks midway chemically between slate and gabbro are found throughout the Seward Peninsula; some are mapped separately, such as rocks of the P€clq map unit. Unfortunately, such rocks may in part be the result of tectonic mixing of slate and mafic rocks, so that this assumed gradational lithology is not definitive.

4. Large expanses or amounts of chloritic schist are never found in Paleozoic marble, as would be expected if all the chloritic schist is derived from intrusive mafic rocks younger than Precambrian.

5. Fragments of garnet-glaucophane rock are found in thin marble schist, as are lenticular masses of garnet-glaucophane rock, suggesting that mafic material was originally interbedded in the limestone.

6. If the chloritic schists represent metamorphosed mafic intrusive rocks younger than Precambrian, the belts of chloritic schist should be traceable through the Kigluaik Mountains, which they are not.

On the other hand, small bodies of hornblendite are known in the Bendeleben Mountains and east of the Darby Mountains; these could well represent metamorphosed mafic rocks of pre-Mid-Cretaceous age. Taken together, the above facts warrant the conclusion that most of the chloritic schists of the Seward Peninsula were originally mafic volcanic and volcaniclastic rocks interbedded in the York Slate.

York Slate (Formerly Slate of the York Region)

The York Slate is the most widespread geologic unit known on the Seward Peninsula, especially when its various metamorphic equivalents are so recognized and properly assigned to this formation. It is the rock unit most important with respect to placer gold, for the maps that accompany this report clearly show that all the main placer gold deposits lie on or near the York Slate. This is discussed more fully in the section on Economic Geology.

For the most part, the York Slate consists of a black, massive-to-slaty rock characterized by an extremely high silica content, generally exceeding 80 percent, and reaching as high as 92 percent, as shown by chemical analyses. However, numerous variations exist, and thick beds of graywacke in places exceed several hundred feet in thickness, such as in the drainage of Skookum Creek, Teller C-5 quadrangle (Sainsbury, 1969a, p. 7). Calcite locally becomes abundant, and is especially notable in the upper part of the formation, where numerous thin but continuous limestones are intercalated in the slate. Such limestones where not intensely deformed can be told from the Paleozoic limestones by the ubiquitous grains of silt-sized quartz, which are rare or lacking in the Palcozoic limestones. Locally, the York Slate in weathered outcrop takes on a slight greenish tinge, and unless examined carefully, such rocks may be erroneously assigned to the chloritic schist. Generally, however, all variants of the York Slate retain a significant content of either carbonaceous dust or graphite. Where strongly sheared by thrusting, the York Slate becomes blacker, seemingly more carbonaceous, and weathers to distinctive rounded hills covered by very black soil (p€sgs map unit). This is the Puckmummie Schist of Smith (1910).

The changes in the York Slate caused by tectonic deformation near major overthrusts are especially notable, and unless they are recognized lead to the improper assignment of such rocks to other rock units. In undeformed and unmetamorphosed exposures, the clastic texture of the York Slate is clearly evident, original bedding is preserved, and the microscope shows that the rock is composed principally of silt-sized quartz grains with abundant carbonaceous material. Such rocks more properly should be called quartzite than slate, and this term has been used by some writers, but the present writer is following the older writers who first described the rock unit and named it the "Slate of the York Region." Where moderately deformed, the rock becomes a carbonaceous, glistening phyllite with numerous small white vitreous quartz veinlets. With increasing dynamic metamorphism, the phyllite becomes increasingly deformed, small folded quartz veins are common, and crinkled S-2 planes are easily seen with the naked eye. With increasing nearness to major overthrust sheets, the phyllite displays an increasing number of folded and fractured quartz veinlets, graphite is continuously expelled, and the color lightens. At the base of the overthrust sheets, as much as several hundred feet of white quartz gneiss is developed, and consists almost entirely of thin sheets of light, granular quartz with but a few specks of graphite.

The interested reader is referred to the area west of the Penny River, in the Nome C-2 quadrangle, where the changes described are clearly evident as one approaches the base of the thrust sheet of Paleozoic carbonate rocks converted to marble (Sainsbury, Hudson, Ewing and Marsh, 1972; Herreid, 1970). Older writers, and most newer workers on the Seward Peninsula, failed to recognize that all these diverse rocks are merely tectonic equivalents of the York Slate. On the maps that accompany this report, the tectonic equivalents of the York Slate, where mapped separately, are shown as the p€st map unit. Because all such facies grade imperceptibly into the adjoining types, no contacts are shown between these units in most places. The symbol p€st on the maps shows that the York Slate is intricately deformed in that area. Maps published by Herreid (1970), who mapped northwest of Nome in the Nome C-2 and D-2 quadrangles, clearly show these lithologic variants of the York Slate.

Because the York Slate carries placer gold almost everywhere, and because visible gold is seen at times in the small quartz veins in the deformed slates, one can assume that some of the placer gold of the Seward Peninsula is derived from gold originally present as a syngenetic constituent of the slate. However, the richer placers are caused by addition of gold derived from gold-base-metal veins of much younger age (see pages 70 to 76).

Casadepaga Schists

This name was applied by Smith (1910) to the chloritic schists of the Solomon area. As noted previously, these rocks clearly were derived principally from volcanic rocks originally intercalated in the York Slate. For a good description, see Smith (1910).

Nome Group

This name was applied by early workers (Brooks, Richardson, and Collier, (1901) to the rocks near Nome that consist of chloritic schist with included limestones, marbles, and marble schist. Sainsbury's mapping in this area shows that thick carbonates are probably metamorphosed Paleozoic rocks, and the term Nome Group was restricted to rocks of probable Precambrian age (Sainsbury, 1972). These rocks consist of greenish schists with numerous thin layers of marble and marble schist, most of which contain numerous quartz grains. All these rocks are intruded by numerous dikes, plugs, and sills of altered mafic rocks. For the most part, these rocks (shown as p€nc in the published map of the Teller 1 : 250,000 sheet, Sainsbury, 1972) are shown on the maps of this report as the p€cl map unit. Most of the schists are composed of magnesian chlorite, epidote, albite, quartz, calcite, amphibole, and sphene. Locally, garnet and glaucophane occur, particularly in the east part of the Teller quadrangle. In the Nome, Teller, and western Bendeleben quadrangles, the intercalated marble schists display abundant dragfolds overturned to the east or northeast, reflecting the eastward tectonic transport of the thrust sheets of the Collier Thrust Belt. More than one S-plane is seen in all of these rocks, clearly recording two metamorphic cycles. A puzzling and bothersome fact is the numerous gabbroic intrusives which seem to be clustered within the Nome Group rocks, but which also are found intruding thrust sheets of Paleozoic carbonate rocks. Such gabbros may be as young as pre-Mid Cretaceous. This problem is discussed in Sainsbury, Hummel, and Hudson (1972).

Schist and Gneiss

All early workers in the western Seward Peninsula believed that high-rank gneisses in the Kigluaik Mountains, and surrounding schists, were older than the York Slate and the Nome Group. This view was also held by Sainsbury (1972) prior to the last two years of field work, when the gneisses in the Kigluaik and Bendeleben Mountains were examined in detail. It is now the writer's opinion that both the Tigaraha Schist (Moffit, 1913, p. 21) and the Kigluaik Group (Moffit, 1913) are largely the highrank equivalents of the York Slate, with possibly some older rocks included. Along the Kigluaik and Bendeleben Mountains, the York Slate grades imperceptibly into the schists, all of which contain much graphite, and the gneisses are seen to occur mostly as mantles around the large granitic intrusive rocks. Even within the gneisses, all of which are quartz-rich, graphite occurs as clots, blebs and blocks ranging up to several feet across, some of the larger blocks are intruded by granitic dikes. In the absence of gneisses of intermediate or mafic composition, by reference to the clearcut relation of gneiss around large granitic intrusives (see maps with this report), to the ubiquitous graphite and the gradations from slate to schist to gneiss, the writer presently believes that the Tigaraha Schist, the Kigluaik Group gneisses, and similar rocks elsewhere in the entire Seward Peninsula are largely metamorphosed York Slate. That these gneisses have been dated by the whole-rock rubidium-strontium method as clustering around 750 M.Y. clearly establishes the Precambrian age of the rocks, and also adds support to the Precambrian age of the York Slate (Sainsbury, Hedge and Bunker, 1970).

The schists and gneisses, especially the schists, are of economic importance in that they host the potentially commercial graphite deposits that occur on the north side of the Kigluaik Mountains in the Teller quadrangle.

Kanauguk Formation (pEl map unit)

This formational name is here applied to a distinctive and thick sedimentary formation which overlies the York Slate with a transitional contact. Consisting of rhythmically interbedded dolomitic limestone and argillaceous limestone, the Kanauguk Formation forms bare limestone hills of distinct orange color, covered by thin curved plates of limestone. The color is so distinctive that outcrops of the formation can be recognized miles away. The transitional boundary from York Slate to the beds of the Kanauguk Formation is well exposed at the west end of the York Mountains (Sainsbury, 1969), where the transition from slate to limestone is gradational over several hundred feet. Slate reappears in the Kanauguk Formation in small amounts well above the base. The transitional beds are generally included within the overlying Kanauguk Formation on the maps that accompany this report. Although the beds of the Kanauguk Formation are usually folded and cut by ubiquitous thin vitreous quartz veinlets, excellent exposures of the unfolded beds are seen in the sea cliffs at Cape Riley, about five miles southwest of Teller in the Teller quadrangle (Sainsbury, 1972). Elsewhere on the

Seward Peninsula, large areas are underlain by this formation, particularly good exposures being seen in the Bendeleben and Solomon quadrangles at the following localities: over much of the Bendeleben C-5, D-5 and C-4 quadrangles; in the area between the Inmachuk River and the Kugruk River; along the Kugruk River in the Bendeleben D-5 quadrangle in the high cliffs of meander cuts, where the unit is moderately schistose; in the Solomon quadrangle between Eldorado Creek and the headwaters of the Casadepaga River, where the formation forms part of a thrust sheet that overlies York Slate and chloritic schists; in the hills east of Council that culminate in Mt. Wick and thence in a belt southeastward to the Darby Mountains. Deformed rocks of this formation form a belt more than two miles wide on the northeast end of the Darby Mountains which is overlain by a folded thrust sheet of Paleozoic carbonate rocks converted to white-weathering dolomite.

The overriding importance of the transitional boundary from York Slate to the limestones of the Kanauguk Formation cannot be over-emphasized, for it is the only transitional contact which can be found throughout the Seward Peninsula in rocks of Precambrian or Paleozoic age. Even a glance at the maps that accompany this report shows that York Slate and Kanauguk Formation rocks are always found together, one never occurring over large areas without rocks of the other formation being nearby. Recognition of this boundary, as well as the variations which occur in both formations as a consequence of tectonic deformation, allows the proper assignment of many units, and leads to the recognition of thrust relations not otherwise evident. For instance, whenever massive carbonate rocks overlie the York Slate, there must be either an unconformity or a thrust-fault contact between the two units. This relationship was not evident to the early workers on the Seward Peninsula; limestones of the Kanauguk Formation have been mapped with Paleozoic carbonates at many places.

Summary of Precambrian Rocks

The oldest rocks of the Seward Peninsula probably are the York Slate, its tectonic equivalents, and the gneisses and schists in the Kigluaik, Bendeleben, and Darby Mountains that most probably are derived from it. Included within the York Slate as original mafic volcanic rocks, were rocks now called the Casadepaga Schist, and probably other metamorphosed mafic rocks of intrusive and extrusive origin now converted to chloritic schists of diverse composition. Some of these schists are blueschist facies rocks characterized by glaucophane and garnet. Because gneisses derived from the York Slate yield whole-rock rubidium-strontium age dates of approximately 750 M.Y., which age is the youngest possible age, the York Slate is considered by me as unquestionably of Precambrian age, as are the Casadepaga Schist, and most of the chloritic schists of the Seward Peninsula.

The age of the Kanauguk Formation cannot be definitely established, but because it is transitional with the York Slate, it unquestionably is at least in part of Precambrian age. Within both the York Slate and some chloritic schists are thin marbles and marble schists which also are of Precambrian age. Fossil-like forms were occasionally observed in some of these limestones, but no identifiable fossils were found. These limestones can be differentiated from the Paleozoic limestones only by the presence of numerous quartz grains, and transitional boundaries.

There are no other rocks of proven Precambrian age on the Seward Peninsula.

PALEOZOIC ROCKS

Rocks of proven Paleozoic age are widespread over the Seward Peninsula, but most are deformed and recrystallized except in the York Mountains of the western part. It should be noted that all rocks dated by fossils in the Seward Peninsula as of Paleozoic age are carbonate rocks, or thin shale intercalated in carbonate rocks. Because the Ordovician, Silurian, Devonian, and Mississippian rocks are all dated by fossils, and are carbonates, it again follows that thick units of non-carbonate rocks cannot legitimately be assigned to the Paleozoic unless they are younger than Devonian and probably younger than Mississippian. Unless dated by fossils, no rocks of non-carbonate lithology can be fitted into a sensible stratigraphic column. This is a fundamental fact of Seward Peninsula geology.

In the following pages, a brief description of the known Paleozoic rocks is given. For detailed information, the reader is referred to reports listed in the bibliography.

Cambrian System

No rocks of proven Cambrian age are known on the Seward Peninsula. Rocks which may be of Cambrian age include the upper part of the Kanauguk Formation, and thin-to-medium-bedded limestones, dolomitic limestones and argillaceous limestones in the area between the Don and American Rivers in the Teller quadrangle. These rocks outcrop continuously over an area of several hundred square miles, and include infolded Ordovician limestones, as well as large exposures of the Kanauguk Formation. That these rocks are part of a thrust sheet is proven by small windows of Devonian and Ordovician rocks within the carbonate belt. Because of the complex structure, the similar appearance and lithology of the limestones, and the lack of fossils, the detailed stratigraphy of these carbonates was not delineated, and all were grouped by Sainsbury (1972) into a map unit designated OpEl, signifying a possible age from Late Precambrian to Ordovician. Because many of the beds contain fossil worm casts and worm trails, it is possible that the Cambrian system is represented.

Ordovician System

Rocks of Ordovician age were identified by the earliest workers on the Seward Peninsula (Brooks, Richardson and Collier, 1901; Collier, 1903; and others). All were grouped under the name Port Clarence Limestone. Because the Port Clarence Limestone was subsequently shown to contain rocks ranging in age from Late Precambrian to Devonian, Sainsbury recommended that the term Port Clarence Limestone be abandoned (Sainsbury, 1971, p. 1).

The known fossiliferous Ordovician rocks of the Seward Peninsula are restricted to the York Mountains, in the Teller quadrangle, where they are continuously exposed in a belt twenty miles long and ten miles wide. Lying with thrust-fault contact on the Kanauguk Formation and York Slate, as well as upon themselves, the Ordovician rocks are the remnants of a thrust sheet that originated south of the York Mountains, and moved into place after the main thrusting of the Collier Thrust Belt. The north thrusting terminated prior to the injection of granites dated as approximately 75 M.Y. in the York Mountains.

Detailed work in the York Mountains clarified the stratigraphy of the Ordovician System (Sainsbury, 1969), and it was determined that at least 7000 feet, and possibly 13,000 feet, of fossiliferous limestones are of Early Ordovician age. The lower part consists of thin-to-medium-bedded argillaceous and sometimes dolomitic limestone. These grade upward into a thick sequence of massive calcitic limestones, also of Early Ordovician age. The time boundary from Lower to Middle Ordovician rocks is marked by a distinctive pink limestone that grades into a thin black shale; both units are highly fossiliferous (Ross, 1965; Sainsbury, 1969).

Other fossiliferous Ordovician rocks are exposed in klippen at several places elsewhere in the York Mountains; all are limestones. The Upper Ordovician rocks are exposed at the east end of the York Mountains in thrust sheets of the low hills west of the Don River. They are medium-bedded, dark gray limestones and dolomitic limestones that are highly fossiliferous (Sainsbury, 1969c; Kindle, 1911; Sainsbury, Dutro and Churkin, 1970). Because of the gray color, the numerous fossils, most of which are silicified, and the distinctive dark color of the slopes underlain by these limestones, they are easily recognized even in small outcrops, and were found at isolated places elsewhere in the York Mountains.

It should here be pointed out that the possibility exists that rocks of Early Orodvician age in the York Mountains may represent different facies in part juxtaposed by thrusting.

The Ordovician rocks are of importance because they host the main tin-tungsten-beryllium-fluorite deposits of the Lost River area, and because the calcitic limestones are locally very pure, and would be suitable for industrial use. Rocks which are probably of Ordovician age were mapped elsewhere on the Seward Peninsula, but were unverified by fossils. Most are deformed, and in part converted to marble, but specific areas of limestones which the writer believes to be of Ordovician age, and correlative with rocks in the York Mountains, are as follows:

1. The folded limestones overlain by a thrust sheet of York Slate on the south side of Kougarok Mountain, west of the Kougarok River.

2. Limestones, dolomites and marbles in the thrust sheet south of the Taylor River, a fork of the Kougarok River, particularly those in the northwest part.

3. Much of the limestone and marble in the main thrust sheet south of the Inmachuk River in the Bendeleben quadrangle.

4. Most of the carbonates in the thrust sheets transected by the west headwaters of the Casadepaga River and south of the Kruzgemapa River near Salmon Lake, in the Solomon quadrangle.

5. Much of the carbonate rocks in the thrust sheets west of the Penny River, and between the headwaters of the Snake River and the Nome River in the Nome quadrangle.

6. Parts of the carbonate belt along the east front of the Darby Mountains in the Solomon quadrangle.

In most of these rocks, relict fossils were observed, and units identical to those studied meticulously in the York Mountains could be found, but in a more deformed and metamorphosed state. On this map, and all other maps of the writer, rocks shown as of Paleozoic age yielded some sort of fossil remains, though most were too deformed or recrystallized for identificiation.

Silurian System

Rocks of known Silurian age on the Seward Peninsula are known only on one mountain top west of the Don River, in the Teller B-4 and B-5 quadrangles. They are described by Sainsbury (1969c; and by Sainsbury, Dutro and Churkin, 1970). Without exception they consist of highly fossiliferous limestones that appear conformable above the Upper Ordovician beds, but which may be disconformable over them, as fossils suggest that Upper Ordovician beds are succeeded by Middle Silurian beds. However, there is a gradational contact between the gray Ordovician beds and the lighter Silurian beds, and the writer is inclined to think that the Silurian beds may include Early Silurian rocks.

The Upper Ordovician and Silurian rocks together exceed 1000 feet in thickness in this exposure, the Silurian being over 800 feet thick. Rocks of definite Silurian age are unknown elsewhere on the Seward Peninsula, and no other exposures are known which could justifiably be assigned to the Silurian. If they exist, they will most likely be found either in the carbonate belt along the east front of the Darby Mountains in the Solomon quadrangle, or in the highly deformed carbonate rocks north of the Koyuk River in the eastern Bendeleben quadrangle (see map this report).

Devonian System

Rocks of known or suspected Devonian age are known at many isolated spots on the Seward Peninsula; all are similar, and consist of medium-gray to dark-gray limestone with interbeds of gray-black shale. It is possible that rocks assigned to the Mississippian System on the western tip of the Peninsula (Sainsbury, 1972, who followed older writers [Collier and others, 1908]), may belong to the Devonian System. Fossils collected by Collier were assigned to the Mississippian, but fossils from the same area collected by Sainsbury were from rocks similar to known Devonian rocks elsewhere, and the fossils were not identifiable and could be referrable to either the Devonian or the Mississippian. Rocks dated by fossils as of Devonian or Devonian? age are found at several localities, and other exposures of similar rocks, some of which carry fossils suggestive of Amphiphora, are known elsewhere.

In the Teller quadrangle, rocks of Devonian age are exposed in a small window west of the American River, where they overlie by thrust-fault contact limestones of late Early Ordovician age. The Devonian rocks are dark-gray, medium-bedded, sparry limestones with sparse fossils. The underlying Ordovician rocks are the light-colored to pinkish limestones which underlie the thin shale of Middle Ordovician age in the York Mountains (Sainsbury, 1969a, p. 30). Other Devonian rocks with mashed fossils are known in the Bendeleben C-5 quadrangle in the thrust sheet of carbonate rocks west of the large exposures of Kanauguk Formation. These mashed beds are overturned east, and consist of dark-gray limestone with thin, disconnected shale bits. Similar rocks with fossils suggestive of Amphiphora occur as a small klippe on the highest hill north of the North Fork of the Kougurok River, where fossils collected in 1967 were determined to be of Devonian age. The two small klippen of sheared limestone east of the granite at Serpentine Hot Springs (Serpentine Granite) also contain fossils suggestive of Amphiphora, and Amphiphora-like fossils are found in small klippen of dark limestones north of the east-flowing section of the Kugruk River, in the Bendeleben D-2 quadrangle. Highly fossilerous dark limestones with interbeds of shale and some sandy beds are exposed at creek level beneath a lava flow on this same section of the Kugruk River (see map of Bendeleben quadrangle). A preliminary determination of these fossils by J. Thomas Dutro, Jr. (written communication), suggests a Devonian age. Beds quite similar are exposed about one mile further upstream, and also contain sparse fossils.

Fossils of Devonian age were found in the thrust plate of dark limestone and shale that overlies the Kanauguk Formation east of the Kugruk River several miles south. Rocks of Devonian age are shown by Miller, et al, 1972, to form an almost continuous belt along the east front of the Darby Mountains in the Solomon and southeastern Bendeleben quadrangles. Fossils of Devonian age were collected from some of these rocks (oral communication, T. P. Miller, 1971). However, the writer believes that not all of these rocks are of Devonian age, but some are rocks lithologically similar to Devonian rocks known elsewhere, notable in that they contain dark shale beds. On the maps that accompany this report, most of the carbonate rocks east of the Darby Mountains are shown as of Paleozoic age, undifferentiated. The writer examined most of these rocks on the ground, and believesthat large parts of them are referrable to the Ordovician System, but as all are deformed and highly metamorphosed in parts, the Ordovician age cannot be established.

Boulders of highly fossiliferous dark limestone occur in a placer mine pit on the Kugruk River south of Chicago Creek.

In summary, wherever Devonian rocks are known, they are similar, and consist of dark gray, sparry limestones with thin shale beds, as well as discontinuous "chips" of shale. Amphiphora is a common fossil but corals also are known as are Bryozoa. Hence, limestones which are not lithologically similar are not assignable to the Devonian without fossil evidence. For the best exposures of Devonian rocks, interested readers are referred to the outcrops on the Kugruk River; to those east of

Nutmoyuk Creek in the Bendeleben B-1 quadrangle; to the beds north of the North Fork of the Kougarok River on the mountain top, and to rocks in the window in the Teller C-3 quadrangle.

Mississippian System

If rocks of definite Mississippian age can be established on the Seward Peninsula, they would be of utmost importance in correlation between rocks in the thrust sheets that cover the west tip of the Lisburne Peninsula, east of Point Hope, some 150 miles north of the Seward Peninsula, and the thrust sheets of the Seward Peninsula. Unfortunately, no direct correlation is yet possible, because the only rocks of Mississippian age dated by fossils on the Seward Peninsula are on the shoreline just west of Deering in the Kotzebue quadrangle (not included with this report). These rocks were examined by the writer in 1969 and 1970, and consist of light-colored dolomite similar to that near major thrust faults all over the Seward Peninsula. The writer also examined the Mississippian rocks west of Cape Thompson and along the Kukpuk River on Lisburne Peninsula, but cannot make a certain correlation. However, the rocks on the Seward Peninsula originally were limestones, as are most of the Mississippian rocks on the Lisburne Peninsula. If Mississippian rocks exist on the north coastline of the Seward Peninsula, they will be found east of Deering, around the mouth of the Kugruk River, and farther east. Unfortunately, the rocks exposed on the beach in this area are intensely deformed (personal observation), and although limestones are seen, it is possible that any fossils will be too deformed for determinations to be made.

As noted above, the limestones near Wales on the western tip of the Seward Peninsula are lithologically similar to rocks of known Devonian age elsewhere on the Seward Peninsula, and their assignment to the Mississippian System must await better fossil collections, which, however, are not likely to be found.

Pennsylvanian System

No rocks of this system are known anywhere on the Seward Peninsula.

Permian System

Metavolcanic rocks of Permian age are shown by Miller, et al, 1972, to outcrop in several places along the Kugruk River, the Koyuk River, and along the east front of the Darby Mountains, in the southeastern Bendeleben and eastern Solomon quadrangles. Miller also shows a small area of Permo-Triassic rocks on the north side of the Koyuk River in the Bendeleben B-2 quadrangle.

The writer examined these rocks in parts of the Bendeleben quadrangle, as well as along the Kugruk River to the north. Along the Kugruk River the small exposures of metavolcanic rocks are intensely sheared, and largely converted to glaucophane schist. Bits of chert are found in the creek gravels nearby. Elsewhere, the rocks are very similar to the Jurassic metavolcanic rocks which are widespread for more than 100 miles to the east (Patton, 1967). Tentatively the writer assigns the metavolcanic rocks of the Solomon and Bendeleben quadrangles to the Jurassic rather than to the Permian, based solely upon lithologic similarity and the proximity of known Jurassic rocks. It should be noted that rocks of Permian age near Cape Thompson on the Lisburne Peninsula some 150 miles northeast are cherts and siltstones. The cherts are green to tawny, and resemble the chert fragments found in gravels of the Kugruk River (personal observation). Triassic rocks in the Lisburne Peninsula everywhere contain thin-bedded limestones in which the fossil Pseudomonotis is always found. Whether the Permo-Triassic rocks shown by Miller north of the Koyuk River in the Bendeleben quadrangle are lithologically similar and carry Pseudomonotis is not known to the writer. Miller does not describe them or list them in the stratigraphic column.

MESOZOIC ROCKS

Triassic System

As noted above, chert fragments in gravels of the upper Kugruk River resemble Permian cherts more than 100 miles away. The writer knows of no rocks of Permo-Triassic or Triassic age on the Seward Peninsula. The Permo-Triassic rocks shown by Miller, et al, 1972, on the north side of the Kugruk River in the Bendeleben B-2 quadrangle are not described in the explanation accompanying that report, and hence the lithology of the rocks is unknown. This age assignment is accepted with reservation, but not necessarily with doubt.

Jurassic System

The Jurassic System is represented on the Seward Peninsula by metavolcanic rocks of dark gray-green color and mafic composition. Such rocks that outcrop in the thrust melange along the east side of the Darby Mountains, and northward into the Koyuk River basin are assigned to the Jurassic in this report, although Miller, et al, 1972 assign these rocks to the Permian. The rocks on the ridgeline north of the Koyuk that Miller shows as Permian are assigned by the writer to the Jurassic. These rocks are but mildly metamorphosed, and a volcanicalastic texture is well preserved locally. In hand specimen, the rocks are almost identical to many of the Jurassic metavolcanic rocks in the adjoining Candle quadrangle. In the absence of definitive data, it seems more probable that these rocks are Jurassic in age. Somewhere, there must be a contact between Jurassic rocks of the Candle quadrangle and the Paleozoic carbonate rocks of the Solomon and Bendeleben quadrangles. The writer interpreted the volcanic rocks of these last two quadrangles to be of Jurassic age. This determination is strengthened by the fact that bedded rocks of Cretaceous age, which are widespread in the Candle quadrangle, also are found in the easternmost Solomon and Bendeleben quadrangles.

Cretaceous System

Rocks of Cretaceous age outcrop in a discontinuous series of outcrops east of the Darby Mountains, and at scattered localities along the Kugruk River. At the latter localities, the rocks are highly deformed, dip steeply, and outcrop mostly in the lowermost exposures along the river. Higher hills to the east and west consist principally of Precambrian rocks, including the York Slate and the Kanauguk Formation. A major normal fault, with altered and brecciated rocks several hundred feet wide on the borders, follows the north part of the Kugruk River. The York Slate to the east is highly deformed and locally garnet bearing, with foliation planes dipping west, and with numerous small-scale folds overturned to the east. These rocks are similar to those elsewhere on the Peninsula where they are near to major overthrust faults. The relations along the northern part of the Kugruk River suggest that the Jurassic and the Cretaceous rocks may represent a window beneath a thrust sheet of Precambrian rocks which overrode them from the west.

Several distinct types of rocks assigned to the Cretaceous are found in a belt running from the headwaters of the Kugruk River south along the east front of the Darby Mountains. Although Miller, et al, 1972 mapped these rocks as a rather continuous belt, the map that accompanies this report shows that the Cretaceous rocks are faulted and are in places cut out entirely. The Cretaceous rocks, which are dated only by lithologic similarity to rocks further east in the Candle quadrangle (Patton 1967) are here divided into several distinct units, as follows:

1. A conglomerate consisting mainly of rounded carbonate boulders, pebbles and sand (map unit Klcg), with subordinate cobbles of Jurassic volcanic rocks, York Slate, chloritic schist, and other lithologic types older than Mesozoic. Many of the carbonate cobbles are dolomite, some similar to the "zebra rock" (a banded dolomite with alternating thin bands of white and dark dolomite) which in the York Mountains always is found near major thrust faults (see photograph in Sainsbury, 1969a, p. 39). In the headwaters of the Kugruk River, this conglomerate overlies Jurassic volcanic rocks; further south, it overlies Paleozoic carbonate rocks, and in one place in the Solomon quadrangle, it is apparently overlain by Paleozoic limestone as a result of thrusting. This unit, here named the Spruce Creek formation, from the good exposures in the head of Spruce Creek, a headwaters stream of the Kugruk River in the Bendeleben B-2 and C-2 quadrangles, is at least 200 feet thick, but its total original thickness is unknown because much of the formation is eroded.

2. A unit of rhythmically interbedded graywacke sandstone and siltstone in beds from a few inches to a few feet in thickness (Kss map unit),

which is exposed only in the extreme southeast corner of the Bendelben quadrangle, and the extreme northeast corner of the Solomon quadrangle. These rocks are correlative with similar rocks mapped by Patton (1967) in the Candle quadrangle to the east, and referred by him to the Cretaceous.

3. A unit of medium-gray to dark-gray limestone, sandy limestone, and subordinate shaly limestone exposed at scattered localities along the Kugruk River. The dating of this rock is uncertain, but the fact that coal fragments are associated with it suggests that it is of Cretaceous age. Its thickness is unknown.

Tertiary or Cretaceous Rocks

Rocks which are assigned either to the Late Cretaceous or Early Tertiary outcrop at several places on the Kugruk River between Mina Creek and Chicago Creek (TKs map unit). All these rocks are coal-bearing, and consist of sandstones and shale, with sandstone predominating. Coal from these beds has been mined at Chicago Creek, and south of the mouth of Reindeer Creek. The coal is lignitic or sub-bituminous in rank, and was used locally as well as in steamships. The lithology of the rocks has been described by Collier, et al, 1908. Fossil determinations of broad-leaf plants suggest a Late Cretaceous age for the beds, but they may be as young as Early Tertiary.

Tertiary System

Rocks of unquestionable Tertiary age are found outcropping only at isolated spots in the Tertiary basins in the western Bendeleben quadrangle. Rocks of Tertiary age consist of lignitic beds overlain by gravel in the northeast bank of Turner Creek, and in one trenched pingo west of the

Noxapaga River. These beds are here named the Noxapaga Formation (map unit Tc), and they are distinguished from the Kougarok Gravels of Hopkins (1963, p. C30), which also have been assigned by Hopkins to the Tertiary. After detailed observations of the relations between the coal-bearing beds and the Kougarok Gravels, the writer concludes that the Kougarok Gravels are principally of Pleistocene age, and that they overlie the Noxapaga Formation with slight angular unconformity.

Mining operations on Dahl Creek, a west tributary of the Kougarok River, were described by Collier and others (1908, p. 300-306). They record the presence of a large lignified log in a deep shaft on Dahl Creek. Another shaft (see Hopkins, 1963, p. C30) penetrated 189 feet of white quartz gravels on Dahl Creek.

Hopkins divides the Kougarok Gravels into three members: An upper one of gravel; a middle one of lignitic coal and fireclay; and a lower gravel. The lower two units are assigned to the Tertiary (Hopkins, 1963, p. C34), and the upper to the Pliocene-Pleistocene. The writer examined all of the outcrops described by Hopkins in the Dahl Creek-Noxapaga River area (the type locality of the Kougarok Gravels), and concluded that only the coal-bearing beds and underlying conglomeratic sandstones and gravels can be assigned to the Tertiary. The very thick quartz gravels exposed at Brakes Bottom on Dahl Creek and near the Kougarok airstrip four miles north display innumerable fossil ice-wedge casts, and are unquestionably of Pleistocene age (a view presently held by Hopkins also - personal communication, 1973). These gravels, the type locality of the Kougarok Gravels, overlie York Slate that is hydrothermally altered to clay-sericite-quartz rock at several places on Dahl

Creek. A deep shaft there penetrated more than 200 feet into such rock without reaching unaltered York Slate. The scattered fragments of lignitic wood in these gravels are interpreted by the writer to have been eroded from the lignitic beds of the Noxapaga formation bowed up in pingos while the gravels were being deposited, and to have no bearing on the age of the white quartz gravels at the type locality of the Kougarok gravels.

To summarize, the lignitic beds of the Tertiary basin, and any underlying beds, which consist of claystone, sandstone and possibly weakly-lithified gravel or conglomerate, as reported by Hopkins to have been found on Turner Creek (page C30) in a shaft, are of Tertiary age, and are here redefined as the Noxapaga Formation. This leaves the name Kougarok Gravels for the unconsolidated, quartz-rich gravels exposed in the type locality at Dahl Creek. These unconsolidated gravels extend up the Kougarok River, the Noxapaga River, and as far west as Imuruk Basin in the Teller quadrangle. As defined here, the Kougarok Gravels are of Pleistocene age.

Small exposures of coal-bearing beds on Coal Creek, a tributary of the Sinuk River west of Nome, were described by Collier and others (1908, pp. 83-85), and assigned to the Tertiary. These beds may ultimately prove to be of Cretaceous age, based upon the fact that they are highly deformed.

Fragments of lignite coal in creeks near Omilak, in the eastern Bendeleben quadrangle, suggest that a Tertiary basin may underlie the extensive glacial deposits on the south side of the Bendeleben Mountains.

Quaternary Rocks

Rocks of Quaternary age on the Seward Peninsula are principally basalts and pyroclastic rocks, some of which may be as old as the latest Tertiary, but which are mostly of Pleistocene and Recent age. The igneous rocks are described in the section on Igneous Rocks, pages 36 through 38.

The only lithified rocks of unquestionable Quaternary age known on the Seward Peninsula were mapped by Sainsbury (1969, p. 32) on the south front of the York Mountains. These rocks are conglomerates that lie upon the York Terrace, and that represent old deltaic deposits laid down from streams that flowed from the York Mountains southward into the sea which covered the York Terrace.

Unconsolidated deposits of Pleistocene age are widespread over the Seward Peninsula (see maps with this report); they consist of glacial moraine and outwash gravels, of several ages, that lie as thick and extensive blankets on the south and north side of the Bendeleben and Kigluaik Mountains, and in a more restricted area on the north side of the York Mountains. For up-to-date information on these deposits, see report by Hopkins, et al, and by Sainsbury in Hopkins, editor (1967).

The main problem in dating rocks of Pleistocene age, which should be mentioned here, is that most workers on the Seward Peninsula have not recognized an Early Wisconsin glaciation. Two major advances of ice in the Wisconsin are recognized worldwide. A glaciation of early Wisconsin age was mapped by Sainsbury in the York Mountains (1967b) and is probably represented by looping terminal moraines in McCarthy's Marsh in the Bendeleben quadrangle.

Hopkins, et al (1960) have described unconsolidated deposits of Plio-Pleistocene age near Nome that were encountered in the sub-surface by dredges. These deposits do not outcrop at the surface.

IGNEOUS ROCKS

The igneous rocks of the Seward Peninsula are for the most part confined to batholiths of acidic composition in the Darby, Bendeleben, and Kigluaik Mountains, and to stocks of acidic composition at scattered localities on the Seward Peninsula. Mafic rocks of gabbroic composition are widespread within the areas of York Slate and chloritic schists, and occur sparingly elsewhere. Serpentine has been mapped by Miller, et al, 1972, at one place east of the Darby Mountains. Basalts and pyroclastic rocks cover large parts of the Bendeleben quadrangle, and are found at isolated places elsewhere on the Seward Peninsula. Certain of the intrusive rocks are of particular economic importance with respect to deposits of tin-tungsten-fluorite and beryllium on the western Seward Peninsula, and have been a factor in localizing richer placer gold deposits within the general expanses of the York Slate. Some of the igneous rocks, principally of granitic composition, are unusually rich in thorium (Bunker, Hedge and Sainsbury, in publication). These rocks occur as small stocks principally along the north front of the Kigluaik and Bendeleben Mountains (Kgf map unit); they are characterized by a high content of allanite, and are probably best classed as pyroxene granites, for they contain small amounts of orthopyroxene. The intrusive rocks are described very briefly here.

Intrusive Rocks of Precambrian Age

Intrusive rocks of probable Precambrian age consist of small bosses of mafic rocks intruded into the York Slate and the chloritic schists within the York Slate. In parts of the western Seward Peninsula, these rocks consist of highly altered gabbro, locally converted to garnet-glaucophane rocks of the blueschist facies, at other places they are relatively fresh-looking. They are not of economic importance, but they may have been the source of platinum known in deep gravels in creeks mined for gold south of Teller, as well as some of the placer gold in that area. Herreid (1970) records a suggested relation between placer gold and one such gabbroic rock.

These mafic rocks are dated as Precambrian in age because of their unusual abundance in the York Slate, their sparing occurrence in the Kanuguk Formation, and their total absence in the Paleozoic carbonates of the York Mountains. Too, such gabbros are extremely rare in other thrust sheets of Paleozoic age elsewhere on the Seward Peninsula. But because mafic intrusives of gabbroic composition do occur sparingly in carbonates of probable Paleozoic age, and because many of the gabbros in the York Slate are quite fresh, the possibility must be left open that all the gabbros are younger than Paleozoic, and that their distribution in the York Slate and the chloritic schists is due to an unknown vagary of these rock units.

Paleozoic Igneous Rocks

No intrusive rocks of definite Paleozoic age are known on the Seward Peninsula, although Hummel (1962) has mapped dioritic rocks near Nome which are metamorphosed, and which have minor copper deposits associated. Two such intrusives are shown on the map of the Nome quadrangle which accompanies this report; they are in the headwaters of the Nome River west of Salmon Lake (Mgd map unit). They are medium to coarse-grained diorites with crushed feldspars, and definite contact-metamorphic aureoles in which chalcopyrite occurs in small amounts. Because they occur in rocks of presumed Precambrian age, and are undated, these intrusive rocks could be of any age from Precambrian to Pre-Early Cretaceous.

A single small granitic dike that is deformed and schistose occurs in the chloritic schists in the Teller B-1 quadrangle. It predates the thrusting, which is of Early Cretaceous age, but cannot be more closely dated.

Two large masses of gneissic leucocratic rocks occur in the Bendeleben quadrangle. Both intrude the York Slate, both have been dated by whole-rock rubidium-strontium methods by Carl Hedge, U. S. Geological Survey (Hedge, Bunker and Sainsbury, 1969), and give age dates of approximately 435 M.Y. Because there is some question that these rocks may be contaminated rocks in part derived from York Slate largely replaced by potassium feldspar derived from an underlying Cretaceous intrusive rock, these rocks are shown as of Paleozoic or Cretaceous age (map unit KpEgno). Small amounts of placer gold occur around one of these gneisses (the Kiwalik Mountain stock) in the eastern Bendeleben quadrangle. The second mass, west of the Serpentine Granite, is similar. No other rocks of similar composition are known on the Seward Peninsula.

MESOZOIC INTRUSIVE ROCKS

Large batholiths of granitic rocks, and innumerable small stocks and bosses of similar composition, were intruded into older rocks of the Seward Peninsula during the Mesozoic Era. Most of these rocks probably are of Mid-to-Late Cretaceous age. The older of these granitic rocks are represented by garnet-bearing granite gneiss in the Kigluaik Mountains (map unit Kgn), and by coarse-grained granite stocks with crushed feldspars and gneissic borders (map unit Kgns) on the north side of the Kigluaik Mountains and the west end of the Bendeleben Mountains. These rocks are all biotite-bearing, ranging in composition from granite to monzonite.

The larger intrusive granitic rocks form batholiths that are elogated north-south along the foliation and strike of thrust belts in the Darby Mountains, but which elsewhere tend toward a more circular outline. Most of these batholithic rocks range from granite to monzonite, and Miller, et al, 1972, have differentiated several discrete batholiths of different composition in the Darby Mountains, where alkalic rocks occur, similar to alkalic rocks widespread in the Candle and Selawik quadrangles east of the Seward Peninsula. This easterly belt of alkalic rocks has been described in some detail by Miller, (1972), and the alkalic rocks in the Darby Mountains are presumably of similar composition.

The main intrusives are briefly described below:

Kigluaik Igneous Complex

(Map Unit Ki)

This complex forms a mass about 15 miles long and approximately seven miles wide near the west end of the Kigluaik Mountains. It is a composite body ranging from diorite to quartz-monzonite. The diorite forms a distinct border facies much darker in color than the rest of the intrusive. The coarse-grained diorite contains hornblende phenocrysts as much as one-half inch in length. At the northwest end of the complex, a medium-grained granite forms a small apophyse extending west into the surrounding gneiss. Dikes of diverse composition cut the complex; they range from mafic dikes containing abundant pyroxene through greenish medium-grained andesites to monzonite. Large xenoliths of irregular shape and mafic composition occur sporadically in the intrusive; some carry specks of scheelite, and they are interpreted as blocks of tactite stoped into the magma.

Kuzitrin Batholith

(Map Unit Kgk)

This body of biotite granite and biotite quartz-monzonite occupies a large area in the central part of the Bendeleben quadrangle, where it is in large part covered by basalts. It is a coarse-grained rock containing large phenocrysts of orthoclase feldspar, and with a silica content ranging from 70 to 72 percent. Semiquantitative spectrographic analyses of the rock show a low content of tin, which serves to separate this granite from the younger tin granites of the Seward Peninsula, some of which are mineralogically and texturally similar.

Bendeleben Batholith

(Map Unit Kgm)

This leucocratic intrusive rock, of quartz-monzonite composition and medium to fine grain, is separated from the Kuzitrin Batholith by a belt of migmatites and gneisses. In appearance, it is unlike the Kuzitrin Batholith, and it locally contains hornblende. No ore deposits are known to be associated with this intrusive.

Pargon River Gneiss-Mantled Intrusive Complex

(Map Units Kg and p gn)

This intrusive complex, cut by the Pargon River, in the central Bendeleben quadrangle, is similar in many respects to the Kigluaik Igneous Complex. Although mantled by leucocratic paragneisses, a sharply-defined intrusive of dioritic composition is well exposed in the lower parts of all the tributaries of the Pargon River. The diorite is medium-grained, and contains abundant hornblende. At most localities, the diorite is cut by fine-grained, leucocratic dikes similar to the allanite-bearing Kgf intrusives elsewhere. At the northwest end, around Dillon Creek, the diorite is cut by a medium-grained biotite-hornblende monzonite. Small bodies of porphyritic granitic biotite orthogneiss similar to the Kgns intrusives at the west end of the Bendeleben Mountains, are found around the margins of the diorite, and locally are intruded by the diorite. The relations of the intrusive types suggest that this complex may be a reactivated gneiss dome.

Serpentine Granite

(Map Unit Kgs)

This granite, referred to in older reports as the "granite of Serpentine Hot Springs" is here formally named the Serpentine Granite. It forms a stock of irregular outline about seven miles across in the northwest part of the Bendeleben quadrangle. Intruded into the York

Slate, the granite displays sharp borders with the surrounding rocks, a relation shown by other similar tin-granites on the western Seward Peninsula. The stock has been studied in detail by Travis Hudson, who reports that it consists of five facies, all closely related (Hudson, PhD thesis, Stanford University). Most of the stock is a coarsely porphyritic biotite granite which stands in sharp relief above the surrounding rocks. On the east side of the granite, a complexly faulted area with notable alteration, geochemical anomalies and outcropping galena has been studied in detail (Sainsbury, Hudson, Kachadoorian and Richards, 1970). Humboldt Creek, which heads against this altered area, contains placer gold deposits that also carry large amounts of cassiterite. Mining operations in the past have recovered only gold, but sufficient cassiterite occurs in the gravels to be worthy of recovery (Sainsbury, Kachadoorian, Smith and Todd, 1968).

A regional gravity map (D. F. Barnes, U. S. Geological Survey) shows a broad gravity low over the Serpentine Granite and extending off to the southwest beneath the auriferous gravels of Washington Creek, the west headwaters of the Kougarok River. Analyses of the granite show sufficient tin to ally this granite with the other tin granites of the western Seward Peninsula, as does the associated cassiterite in placers. A strong radiometric anomaly on the north margin of the east end of the granite has not been evaluated on the ground.

<u>Asses Ears Granite</u>

This name is formally applied to the granite stock in the north-central part of the Bendeleben quadrangle near Cloud Lake, north of Imuruk Lake. It consists of coarsely porphyritic biotite granite with orthoclase phenocrysts as much as 1.5 inches in length. The texture varies somewhat, with areas of granite that contain large phenocrysts in close proximity with other rocks with orthoclase phenocrysts not more than one-half inch in length. At the west end, the granite intrudes a thrust sheet of Paleozoic limestone, and hybrid rocks are developed in the granite. The limestone is converted to marble with wollastonite and other contact-metamorphic minerals for some distance from the contact. A few altered fault zones trending north cut the granite, and tourmaline and quartz were introduced along some. Analyses of the vein material shows but small amounts of tin, probably because the Asses Ears Granite is not a typical tin granite. The granite has been described most recently by Herreid (1968).

Placer gold has been mined along the Inmachuk River, and part of the Pinnel River, that drain the area north of the granite, which consists of York Slate (Collier, et al, 1908). Although the gold is probably derived from auriferous base-metal lodes, such as are exposed at Hannum Creek, the usual relation found elsewhere on the Seward Peninsula is evident: wherever biotite granite is intruded into the York Slate, important placer gold deposits are found nearby.

Kugruk Stock

(Map Unit Ki)

This name is formally applied to the granitic intrusive that forms the hill west of the confluence of the Kugruk River and Independence Creek. The stock intrudes the York Slate, and is surrounded by a marked hornfels zone, with some calc-silicate rocks. It is a medium-to-coarse-grained leucocratic granitic rock of somewhat variable composition, ranging from monzonite to quartz-monzonite in composition. The base-metal deposit being developed by Mr. Riney Berg, discoverer of the Bornite copper deposit in the Kobuk valley, is probably related to this intrusive. The Berg base-metal deposit is a distinct vein trending northwest, similar to that at Hannum Creek. The ores consist of argentiferous galena that carries notable quantities of gold (Riney Berg, personal communication). The fact that this stock intrudes the York Slate and has base-metal ores associated on one side suggests that placer gold may exist in other streams that drain the intrusive. The intrusive is probably of Cretaceous age.

Kiwalik Stock

(Map Unit KpEgno)

This stock, discussed previously on page 39, is a gneissic intrusive with a high potash feldspar content and biotite folia imparting a distinct metamorphic fabric to the rock. Chemically, the stock is granite gneiss. Probably part of the potash has been introduced later than the main part of the stock, and, in fact, much of the exposed rock may be of metasomatic origin. Whole-rock rubidium-strontium age dates suggest an age of about 435 M.Y. (Sainsbury, Hedge and Bunker, 1970), which may be caused by the hybrid nature of the rocks sampled.

A slight amount of placer gold has been mined from creeks draining the north and east sides of the stock, but no primary deposits are known.

Other Intrusive Rocks

The outlines of the large intrusive bodies in the extreme southeast part of the Bendeleben quadrangle, and the eastern Solomon quadrangle, have been taken from the map of Miller, et al (1972). These writers also give a brief description of the stocks, and their descriptions are not repeated here. The names and chemical classifications of the intrusives are after Miller. Of note is the occurrence of syenite in the Dry Canyon stock, and of alkalic dikes nearby. The existence of such rocks, and the known uranium-bearing minerals in streams nearby (Gault, et al, 1953), suggests that deposits of primary uranium minerals may be found near or within this stock.

The Windy Creek stock, named by Miller, et al, (1972), is a composite granitic intrusive that contains syenite, monzonite and quartz monzonite. Much of the stock is altered and cut by veins which are marked by quartz and limonite [(Sainsbury, Curry and Hamilton, 1973,) geologic map (mapped in 1969) and (Miller, et al, 1972)]. A well-marked radiometric anomaly outlined from the air by the writer and Carl Bunker, U. S. Geological Survey, lies within the stock but has not been investigated on the ground (unpublished data).

In addition to the geochemical anomalies, mostly of molybdenum, found by Miller, Grybeck and Hudson (1971), around the west side of the stock, and the radiometric anomaly, the strong fault that bounds the west side of the stock is heavily mineralized with fluorite (personal observation) at the northwest end. A satellite boss northeast of the stock has argentiferous galena associated in altered fault zones striking northwesterly. This galena was found by

Mr. Martin Jettón, a contract helicopter pilot flying for the U. S. Geological Survey in 1971 (personal communication, M. Jettón, 1971). It is entirely possible that other mineralized veins or faults surround this stock, for most of the stock was staked by a large company for lode deposits during 1969-71. No placer gold has been mined around the stock. Because the valleys nearby were glaciated, it is probable that placers were removed, except on the northeast side where thick gravels mantle the bedrock to a considerable depth, caused by alluviation of the Tubutulik River valley upstream of a lava flow that blocked the main valley.

Dike Rocks

The known dike rocks on the Seward Peninsula are widespread and highly varied. Only the economically important ones which give a clue to possible mineral deposits are discussed here.

On the western Seward Peninsula, the tin deposits at Lost River are associated with rhyolite porphyry and lamprophyre dikes which post-date the intrusion of the tin granites (Knopf, 1906; Lorain, Thorne, and others, 1946; Sainsbury, 1964). The lamprophyres are contaminated rocks derived from diabase dikes, and the introduction of the tin-tungsten-fluorite ores of the Lost River district followed closely after the injection of the lamprophyre dikes. It is notable that the dikes are injected in a structural belt about seven miles wide marked by numerous normal faults striking about N. 85 E. across the district (Sainsbury, 1969a). Although several other sets of strong faults cut the rocks of the district, and a few contain rhyolitic dikes, they are barren of ore deposits. This same relation of ore with altered dikes or fault zones of a particular set can be noted elsewhere on the Peninsula.

In the Bendeleben quadrangle, a well-marked series of altered dikes of Tertiary or Latest Cretaceous age has been mapped on the west end of the Bendeleben Mountains (see map with this report). For the most part, these dikes are fine-grained granitic dikes that weather to a distinct tan color. Almost all are altered from their original composition, but wherever they were found and sampled, they gave good geochemical anomalies for copper, lead, silver, zinc and molybdenum. In the Bendeleben B-4 quadrangle, several old prospect pits and short adits were driven on altered dikes of this type that strike northerly to north-easterly. Several display notable amounts of galena, chalcopyrite, and sphalerite. None of these deposits have been described before.

In the Kigluaik Mountains north of Nome, altered dikes occupy faults of a set trending almost due north. The altered dikes are heavily replaced by chalcedonic silica, but the content of metals is very low.

In the Hannum Creek area of the Bendeleben quadrangle, at least one fault of a strong set striking northwest is mineralized for more than two miles, and alteration along others nearby suggests the possibility of other, deeper deposits.

The main mineralization on the east side of the Serpentine Granite is found along strong faults, without noticeable dikes, that strike northwest. As pointed out in the discussion of the Windy Creek pluton, the main mineralization is along faults striking northwesterly, but these do not contain dikes.

In summary, one can deduce that the late dikes of the Seward Peninsula were injected along faults of distinct sets that vary in orientation at various places on the Peninsula. Dikes as well as wall-rocks of faults were mineralized. However, the sets of faults and dikes striking northwesterly and north-northeasterly seem to have been most important in localizing ore deposits.

Volcanic Rocks

The extensive volcanic field in the central part of the Bendeleben quadrangle has been described by Hopkins (1963), and the descriptions are not repeated here. The oldest rocks are pyroclastic rocks with inter-bedded basalts. Hopkins (oral communication) has obtained a potassium-argon age date of slightly over three M.Y. for these basal basalts. Successively younger flows continued to be erupted until the Lost Jim flow was extruded perhaps only a few hundred years ago. According to Hopkins, all the flow rocks fall into the category of olivine basalt or andesite. Of some note are the large number of inclusions of dunite in some flows.

It is perhaps worthwhile to note that many vents that gave rise to olivine basalts occur in the granite of the Kuzitrin Batholith, and that there has apparently been insignificant contamination of the basalt by granite.

The volcanic rocks are of economic importance in a negative way, for they have buried auriferous gravels, and disrupted the older drainage patterns that undoubtedly contained auriferous gravels. In fact, an old channel beneath the basalt on the north side of the Inmachuk River is being mined for placer gold.

STRUCTURAL GEOLOGY

Thrusting

All the early workers on the Seward Peninsula recorded observations to show that many of the schists and slates were highly deformed, that they displayed numerous small-scale folds overturned east, and were cut by many faults. Smith (1910, p. 18) recognized thrust faulting in the Nome area; Smith showed a photograph of the thrust plate of Paleozoic (probably Ordovician) limestone on Mt. Dixon, in the Solomon D-5 quadrangle, that overlies the York Slate, but called the thrust an unconformity. Collier (1902, p. 18) was the first to note that the limestones of the York Mountains were probably not in formal stratigraphic position above the underlying rocks. Sainsbury recognized that thrust sheets are present throughout the Seward Peninsula, forming a great belt of thrusting which he named the A. J. Collier Thrust Belt (Sainsbury, 1969b, p. 2595). Numerous lines of evidence can be used to establish the Collier Thrust Belt in addition to the obvious thrust plates of the York Mountains and smaller-scale features listed later:

1. Thrust sheets in the York Mountains are mapped in numerous localities (Sainsbury, 1969, 1969b, and 1972). However, most of the thrust sheets involve thrusting of Ordovician rocks over older rocks, or over themselves. In the York Mountains, the Precambrian is nowhere thrust over the Ordovician. This does not invalidate the thrusting, but it does set these younger thrust sheets aside from the main thrust sheets elsewhere, for the thrust sheets in the York Mountains are relatively undeformed, contain unmetamorphosed limestones, and were apparently thrust northward over older thrust sheets. Thus, they represent an isolated block of limestones thrust into place from the south, covering the older eastward

thrusting in the only part of the Seward Peninsula where totally unmetamorphosed rocks with diagnostic fossils exist. Numerous exposures of the Kanauguk Formation and the York Slate at the base of thrust sheets of Ordovician limestone in the York Mountains display large dragfolds overturned to the east, showing tectonic transport to the east. If such eastward thrusting had been impressed upon the Ordovician rocks of the York Mountains it would be clearly discernible, which it is not. Therefore, two distinct ages and directions of thrusting are recorded on the western Seward Peninsula in the York Mountains; the older involved eastward transport, and the younger involved northward transport of thrust sheets.

2. Two small windows occur in the large expanse of limestones of undifferentiated Precambrian and Early Ordovician age in the central Teller quadrangle. One window exposes fossiliferous Devonian limestone, the other exposes the extremely diagnostic dark shale of the lowest Middle Ordovician of the York Mountains.

3. In the eastern Teller quadrangle, on Kougarok Mountain, a thrust sheet of intensely deformed graphitic, chloritic schists of Precambrian age clearly overlies folded carbonates that contain relict fossils. The limestones are probably Ordovician in age.

4. In many areas, such as south of the Inmachuk River in the Bendeleben quadrangle, large thrust sheets of carbonates with locally observable relict fossils sit upon the York Slate, with no intervening Kanauguk Formation, which everywhere overlies the York Slate when the two are in normal stratigraphic position.

5. Large belts of marble, similar to that cutting diagonally across the central Bendeleben Mountains, lie in such position as to appear interbedded in the metamorphic rocks which are mostly derived from the York Slate. Yet nowhere else on the Seward Peninsula can the York Slate be demonstrated to contain such large thicknesses of limestone in normal stratigraphic relation. Hence, it can be argued that these marbles represent thrust slices of Paleozoic carbonate of thrust sheets more deeply buried than those that display carbonates with relict bedding and fossils. The lower sheets have been brought into view by uplift and erosion along the axis of the Bendeleben and Kigluaik Mountains.

6. The intense schistosity of parts of the York Slate and the chloritic schists, and the ubiquitous overturning of dragfolds, plus the multiple S-planes clearly recorded in most of these rocks, cannot but represent a strong tectonic deformation extending across the Peninsula.

7. Cubic miles of dolomite have developed from calcitic limestones throughout the Seward Peninsula. The relations in the York Mountains clearly show that this dolomite is solely of tectonic origin, for it is, without exception, coicident with major thrust faults, or to a lesser degree with normal faults that intersect thrust faults at shallow depth. The general effect is that dolomitizing solutions always moved along thrusts, tending to migrate upward along any fracture. The fact that most of the ore bodies in the Lost River area lie within undolomitized limestones is convincing evidence that the dolomite is unrelated to mineralizing fluids. The dolomite often lies as an undeformed tabular mass which lies essentially undeformed between lower and upper plate rocks that are intricately deformed. A similar situation is recorded by Korn

and Martin (1959) in the great thrust belt in the Naukluft Mountains of Southwest Africa (the Unconformity Dolomite).

8. Thrusting has produced large masses of strange rocks which cannot be made to fit into the known stratigraphy of the Seward Peninsula. That these strange rocks are generally calcite schists containing variable amounts of chlorite, phengitic mica (a muscovite with unusually high silica), graphite or quartz that always occur where massive carbonates overlie York Slate or chloritic schists serves to establish them as tectonically mixed rocks. Chemical analyses from the lower, middle and upper parts of such rocks show a chemical gradation within the mixed rocks correlative with nearness to upper or lower plates. Large tectoliths of overridden rocks lie well up in the carbonates. Very often, the thrust sheets of carbonate that overlie the highly siliceous York Slate are replaced along the thrusts by fine-grained silica that resembles quartzite, and that has been so called by many early workers. Locally, however, as on the east side of Kougarok Mountain in the eastern Teller quadrangle, large bulbous masses of such silica have replaced upward into the carbonate of the thrust sheet for hundreds of feet. Almost without exception small amounts of copper oxide are found in such replacement silica, but the copper minerals practically never extend into the lower plate rocks. Sainsbury named such deposits "tectogenic deposits" because they are formed during thrusting from material that migrated out of the rocks being deformed. Hence, they are syngenetic with respect to the thrusting and were formed during, and as a consequence of, thrusting. Such deposits are discussed further in the section on Ore Deposits.

9. Within many large masses of carbonate rocks ranging from those unmetamorphosed to those totally metamorphosed to marble, one can find fragments of exotic rocks, but normally these are slate or chloritic schist. Such foreign rocks range from small fragments to large slivers hundreds, or even a thousand, feet in length. An excellent place to see a large mass is in the limestone of Mt. Dixon in the Solomon D-5 quadrangle (see 1:63,360 scale geologic map by Sainsbury, Hudson, Ewing, and Marsh, 1972). Here a thin slice of York Slate lies along the thrust midway up the northwest shoulder of Mt. Dixon, isolated in thick carbonate above and below. A second place to see slate in carbonate is in the small thrust sheet of Paleozoic carbonate with relict fossils that overlies the York Slate east of the placer gold mine on Humboldt Creek, east of the Serpentine Granite. Here, a thin line of discontinuous fragments of York Slate is bleeding out of the limestone. The fragments are highly deformed, lineated, and crinkled, and are definitely York Slate.

Sainsbury named such fragments "tectoliths." They occur at many places on the Seward Peninsula, and were at first very puzzling. In fact, those found early in the mapping were not recognized for what they are - tectonic fragments - and were used as evidence for a widespread glaciation (Skull Creek Glaciation), named from the type locality on the ridge of limestone southeast of Black Mountain in the Teller B-4 quadrangle (Sainsbury, 1967b). This glaciation probably should be abandoned, for the true nature of the tectoliths is now evident - they are foreign rocks dragged into limestone of thrust sheets during the thrusting, and not necessarily glacial erratics as originally assumed.

10. The last and perhaps most important evidence of thrusting involves what might be termed (à la R. H. Jahns, personal communication, 1969) "disjunctive geology," or the unusual geologic pattern displayed by the Seward Peninsula and certain other thrust belts, where outcrops of rocks can seldom be traced for any distance before being lost for some unexplainable reason (other than fold structure). A glance at the maps that accompany this report, or other larger-scale maps published by the writer and co-workers (see bibliography) shows no patterns of rock distribution consistent only with folding or normal faulting.

In published papers, and in papers presented before the Alaska Geological Society, and at the Geophysical Institute of the University of Alaska, the writer discussed the unusual tectonic style of the Collier thrust belt, and noted the large-scale transfer of magnesium and silica along the thrusts. These relations were at first difficult to accept. Dr. L. A. Warner of the University of Colorado furnished a reference to similar tectonic thrusting in Southwest Africa documented by Korn and Martin (1959). Reading this paper, it seemed almost as if the Seward Peninsula had been placed in the Naukluft Mountains totally exposed and uncovered by tundra. The similarity between the Collier thrust belt and the thrust terrane exposed in the Naukluft Mountains of Southwest Africa will be the subject of a later paper. Anyone interested in the descriptions and maps of the Collier thrust belt should also read Korn and Martin's paper.

Of equal importance is the "disjunctive" geologic section which results if one attempts such a section without recognition of the thrust relations. To illustrate, using only the single two formations whose stratigraphic position is unquestionable - the York Slate and the overlying Kanauguk Formation, one sees the following section (going up-section) depending upon where in the thrust belt the exposure is mapped:

a. York Slate-Kanauguk Formation-Early Ordovician limestone (normal)
b. York Slate-Middle Ordovician limestone
c. York Slate-Early Ordovician limestone
d. York Slate-Devonian limestone
e. York Slate-quartz chlorite schist-Paleozoic limestone
f. York Slate-schistose limestone-chloritic schist-Ordovician limestone
g. York Slate-chloritic schist-Ordovician limestone
h. York Slate-Paleozoic limestone-York Slate-Paleozoic limestone
i. York Slate-quartzite-dolomite-limestone
j. Kanauguk Formation-Devonian limestone

This stratigraphic column could go on forever, with the base of the column being either York Slate, Kanauguk Formation, chloritic schist, or tectonic calcite schist, and followed again by almost every other rock type known on the Peninsula. This, of course, is only explainable by thrusting.

Of almost equal importance are the criteria evident at thrust contacts examined in the field. At places, as in the York Mountains, all the following criteria could be observed at thrust contacts. Elsewhere, several of the criteria could be observed, but at some places only one or two of the criteria could be applied. The criteria for thrust faults are:

a. A planar contact that transects bedding in upper and lower plates. The term planar as used here means horizontal or nearly horizontal contacts.

b. A planar contact that transects the lower plate, and cuts out known stratigraphy in the upper plate, e.g., Devonian limestone over York Slate, even though it may parallel bedding in the upper plate.

c. Brecciation of the rocks along a planar contact, and, in limestone, development of dolomite marked by a topographic bench.

d. Brecciation of dolomite along a planar contact cutting bedding.

e. Bodies of replacement silica in limestone or dolomite above planar contacts thought to be thrusts.

f. Planar contact cutting off large folds in either the overlying or underlying plate.

g. Oversteepening of beds in the upper plate as the thrust is approached, with the oversteepening being consistent with the direction of tectonic transport and resulting drag.

h. Development of "spaghetti structure," or innumerable small-amplitude folds mashed up, where upper plate rocks of massive carbonate overlie thin-bedded limestones.

i. Presence of tectoliths, especially in carbonate plates overlying slate or chloritic schist.

j. Float bits of copper oxide associated with silicified limestone above planar contacts.

k. Development of distinct benches along planar contacts.

l. Lines of springs associated with planar contacts, especially where the upper plate is carbonate rock.

m. Cutting off of dikes or gabbro bodies at planar contacts.

n. Increase of lineation, foliation, ptygmatically-folded quartz veinlets at a planar contact where carbonate overlies York Slate.

o. Development of quartz gneiss in York Slate at planar contacts between York Slate and any other type of rock, excluding chloritic schist.

p. Abrupt termination at a planar contact of thin limestone or marble beds in the York Slate.

q. Presence of minor placer gold deposits along creeks that follow a planar contact of slate and massive carbonate.

When the widespread occurrence of most of the above listed criteria (1 to 10 and a to q) are noted throughout the Seward Peninsula, one cannot explain them satisfactorily except by the widespread thrusting.

It should be here noted that the writer has applied the same criteria to rocks in the adjoining Candle, Kotzebue, and other parts of the Norton Bay quadrangles, and has proven that thrusting extends from the west into those areas. This information, however, is based upon work done for private companies, and the details cannot at this time be released.

Once sufficient contacts have been examined, calling upon the known stratigraphy and the tectonic features described, the thrust relations become apparent. However, careful mapping of contacts and of the tectonic styles along them is required to prove the thrusting.

Folding

In addition to the folding of limestones of the upper plate rocks of the York Mountains, where chevron folds with horizontal axes are developed, and where large-scale over-steepening of beds is well shown along the Rapid River thrust fault, many small-scale folds are observed over the Seward Peninsula. Owing to the widespread thrusting, and the metamorphism of the limestones to marble, many folds are either broken up, or obliterated. However, relict bedding dipping steeply can be observed at many localities, such as in the klippe of Devonian limestones north of the North Fork of the Kougarok River in the Bendeleben quadrangle. There can be little doubt that many of the limestones were folded into numerous large-scale folds that were then cut off by thrust faults.

Perhaps the largest folds preserved in the York Slate are seen at two localities. The large expanse of York Slate northwest of Nome forms a north-trending anticline whose west limb is cut off by the Penny River fault zone. These beds are relatively unmetamorphosed, especially at the northeast headwaters of the Penny River, where the axis of the anticline is well exposed on the ridgeline.

A second large fold in York Slate is well exposed on the drainage of Skookum Creek in the Teller C-5 quadrangle, where massive graywacke beds several hundred feet thick dip steeply east.

Within the limestone thrust sheets of the York Mountains, the relations at many thrusts are very unusual in that north-dipping beds are cut off cleanly by the thrust, without associated folding of the beds. On "Thrust Mountain" in the northwest headwaters of the Don River, six distinct thrusts are marked by lines of brecciated dolomite in calcitic limestones of the late Early Ordovician sequence. The thrusts and dolomite zones dip south at very low angles, almost perpendicular to the bedding of the limestones, which dip steeply north, yet the beds are cleanly cut off at the thrusts with practically no deformation. The effect is as if the limestone was stressed along the future line of thrusting, and suddenly shattered before folding. The writer uses the term "shatter thrusting" for such thrust relations; similar brecciation of dolomite lying along thrusts has been described by Korn and Martin (1959).

Following the thrust faulting, which largely is responsible for the distribution of rocks in north-south belts east of the York Mountains, broad uplift and folding along an east-west direction took place along the Kigluaik and Bendeleben Mountains, exposing the high-rank metamorphic rocks now outcropping within these ranges. The broad warp along the Kigluaik Mountains was named the Kigluaik Arch by Hummel (1962). As noted previously (page 10), the Kigluaik Mountains interrupt the belts of chloritic schists striking into them, and the large belt of chloritic schist in the Nome area wraps around the west end of the Kigluaik Mountains in a broad fold pattern, lying between the York Slate and the gneisses of the mountains, and continues northward to the Chukchi Sea.

The Darby Mountains are topographically high because they are marked by large batholiths of granitic rocks trending north. The intrusive rocks unquestionably were intruded along the strike of thrusts and folds trending north-south. These intrusive rocks are the southeast continuation of a belt of granitic rocks that contain alkalic intrusive rocks, and that continues from the Darby Mountains northward then eastward along the west side of the Cretaceous basin to the east in the Candle and Selawik quadrangles (Miller, 1972). Most of the rocks in this plutonic belt are monzonite or quartz monzonite, but syenite and nepheline syenite is common in small stocks and bosses, as are dikes of numerous other types of alkalic rocks. For the most part, folds tend to parallel the strike of the larger intrusive masses in the Solomon quadrangle, as does the strike of the lineation and foliation along the intrusives.

The Darby Mountains plutonic belt cleanly cuts off the east-west trend of intrusive rocks exemplified by the numerous stocks and small batholiths along the Kigluaik and Bendeleben Mountains, but rocks referred by me to the York Slate continue eastward of the Darby Mountains, and may reappear on the east side of the Koyukuk Basin near Ruby, where tin placers are associated with granitic rock that intrudes a highly siliceous slate identical in appearance to the York Slate (personal observation, 1972).

Folded Thrust Plates

Although many of the thrust faults are horizontal or nearly so, folded thrust plates are observed at many places. The degree of folding is highly variable. On Kougarok Mountain in the Teller quadrangle, the thrust plate of chloritic schists that overlie Ordovician (?) limestones is folded into a sharp fold plunging north.

South of the Inmachuk River, in the Bendeleben D-3 quadrangle, the thrust sheets of Paleozoic carbonates are gently folded, and their distribution is in large part controlled by normal faults.

On Mt. Kwiniuk, in the southeastern Solomon quadrangle southwest of Elim, a thrust plate of intensely deformed York Slate is but gently folded, and is thrust eastward over Paleozoic carbonate rocks.

In the Bendeleben A-1 quadrangle, a highly folded thrust plate of dolomitized Paleozoic carbonate overlies the deformed Kanauguk Formation. Although Miller, et al, 1972, show the south end of this plate to be a normal fault, the map that accompanies this report shows clearly that the south margin is a warped sheet of brecciated dolomite overlying the Kanauguk Formation.

Herried (1970, p. 11) describes the folded thrusts at the base of the thrust plates of Paleozoic (?) carbonates west of the Penny River near Nome.

Numerous other areas of large and small-scale folding have been documented on the Seward Peninsula by almost all workers since 1901, and their descriptions are not repeated here. As a final remark, it should be noted that the Cretaceous rocks of the Cretaceous basin to the east are involved in the thrusting along the east margin of the Darby Mountains, and throughout the basin are folded into sharp folds trending northeast to north (personal observation, and Patton, 1967). This deformation is interpreted by the writer to have occurred during the waning stages of the eastward thrusting of the Collier Thrust Belt.

Faulting

The maps that accompany this report, and the many detailed maps published elsewhere by the writer and his assistants between 1964 and

1972, show that the rocks of the Seward Peninsula were cut by numerous and extensive normal faults, which also cut the thrust plates. In certain areas, such as the York Mountains, several distinct trends are well exposed; at other localities, such as the Inmachuk area of the Bendeleben quadrangle, two sets of roughly conjugate faults are well marked. In the Nome quadrangle, strong faults trending north-northeast cut northwest-trending faults, and the northeast-trending faults have guided ore deposits that contributed to the extreme richness of the placer gold deposits nearby. In the Solomon area of the west-central Solomon quadrangle, the most numerous faults trend northwest, although others trending northeast are well marked. Here, the known auriferous veins and stibnite-base metal veins lie along faults of the northwest-striking set. Again, these veins have localized the richer placer gold deposits.

Faulting has continued into the Quaternary on the Seward Peninsula, as shown by the faulting of the Tertiary volcanic rocks (Hopkins, 1963) and by active faults which cut glacial deposits along the entire north front of the Kigluaik Mountains. A strong east-west fault bounds much of the south side of the Bendeleben Mountains also, where it locally cuts the glacial moraine.

Thrust Melanges

The term melange is applied to large areas of rocks so broken as a result of faulting that individually mappable units bear little relation to adjoining rocks. In other words, map units cannot be carried in sensible relation to other units which also can be mapped locally. At many places, the thrusting on the Peninsula has totally disrupted the carbonate belts, but two areas should be mentioned particularly. In these areas, the 'disjunctive geology' brought about by thrusting is so intense as to have created large linear zones which qualify as thrust melanges.

Perhaps the most noticeable is the zone in the Bendeleben quadrangle east of the main carbonate belt just east of the Kougarok River. Along this belt of rocks, which is several miles wide at places, the lithologic units are so disjointed that it was necessary to map the rocks as a special tectonic unit in which York Slate, Devonian (?) limestone, Kanauguk Formation, chloritic schist, and other Paleozoic limestones are intricately intermixed (map unit p€sls). The unit is marked by the tendency to find York Slate in close proximity to disconnected exposures of all the other rocks. Furthermore, the aeromagnetic maps of the area show this zone to be marked by a disjunctive magnetic pattern, with highs sharp and clear which cannot be related to mafic rocks outcropping at the surface, and to elongated magnetic highs which strike along the zone of thrusting. Numerous well-marked high-angle faults also trend along the zone.

A belt of similarly disjointed rocks follows the east front of the Darby Mountains, and continues northward across the east end of the Bendeleben Mountains. Along this belt, which contains the most continuous unit of tectonic dolomite of the entire Seward Peninsula, slivers of York Slate, Kanauguk Formation, Paleozoic limestone, Jurassic volcanics, and the conglomerate and siltstone-graywacke beds of the Cretaceous System are intricately mixed by thrusting.

A smaller belt of such thrust melange follows along the Iron Creek area of the Solomon D-5, D-6 quadrangles, reaching from a large mass of chloritic schist to the east side of the Paleozoic carbonates east of

Iron Creek. In this belt, the melange is in part controlled by a set of normal faults, but the limestone of the Paleozoic carbonates of the thrust plates is unusually schistose, and slivers of marble schist and chloritic schist are common in the Paleozoic carbonates.

Mention should be made here of the Kugruk Fault zone, which is exposed well in some of the meander cuts of the Kugruk River. Along the Kugruk River, rocks of Paleozoic and Mesozoic ages outcrop in the valley bottoms along a wide zone of faulting. The observed faults dip steeply, but the relation of York Slate in all the highlands east and west of the river suggests that a thrust sheet overlies the rocks exposed lower down on the streams.

Summary of Structural Geology

Rocks of the Seward Peninsula were thrust eastward in Early to Mid-Cretaceous time resulting in a jamming of the Seward Peninsula eastward into the rocks of the Cretaceous basin. The rocks of the Cretaceous basin were also folded during the late stages of the thrusting. Following the thrusting, large and small masses of granitic rocks were intruded through the thrust sheets. These probably range in age from Mid-to-Late Cretaceous, as determined by potassium-argon age dates only (Miller, et al, 1972; Miller, 1972). These ages are open to question until such time as they are confirmed by whole-rock rubidium-strontium age dates, but not necessarily erroneous.

Following the main episode of thrusting by an unknown time interval, the thrust sheets of unmetamorphosed limestone of the York Mountains were emplaced from the south, for these thrust sheets are unfolded, and the thrusts either are essentially horizontal, or dip to the south. This second period of thrusting predates the intrusion of the tin granties of the York Mountains, which have been dated by K/Ar methods as of Latest Cretaceous age, or 75.1 ± 3.0 M.Y. (Lanphere, in Sainsbury, 1969, p. 61). Because the tin granites post-date all the major thrusting, it is likely that the K/Ar age is reasonably correct, but again the age should be confirmed by Rb/Sr dating.

After both episodes of thrusting, normal faults of several different sets, some of which are of Quaternary in age, cut the thrust sheets. Folding and minor warping has continued until the present, but no large basins of Tertiary age were formed, the largest being that in the west-central Bendeleben quadrangle. These rocks, which possibly are of Eocene age, are almost completely covered, but appear to be unfolded.

In the light of the paper by Korn and Martin (1959), and other writers now lost to view in the blind embracing of the 'new' plate tectonics, it is tempting to assume that the thrust sheets represent masses of rock sliding eastward into the downwarped area to the east that became the Cretaceous Basin. Such an interpretation is not ruled out by the available data, but several lines of evidence must be considered before a final decision is made. First, it must be noted that the rocks of the Cretaceous basin are themselves folded into sharp folds trending northeast, parallel to the long axis of the basin. However, the folds tend to be overturned east over most of the basin. If the folding of the Cretaceous rocks were a result of gravity sliding toward the deeper parts of the basin, folds on the east side should be overturned west. Secondly, it remains to be seen if the rocks in the Ruby area are on the east side of the Cretaceous Basin, which I believe correlate with the

York Slate, are deformed by thrusting, with a direction of tectonic transport toward the northwest or west. If the Paleozoic and Late Precambrian rocks of the Seward Peninsula were sliding off eastward into the basin, there should be rocks on the east side that were sliding off west into the basin. Third, one must consider the possibility that the new concept of plate tectonics has been operative in this part of Alaska in an as-yet-unknown way to produce the thrusting eastward toward the Cretaceous basin. Plate tectonics may have been involved, namely, the jamming together of Alaska and Siberia, possibly as a hinge area as large plates rotated outward in opposed directions as the oceanic plate moved northeastward and then northward under the continental plates. However, the Collier thrust belt and larger-magnitude features cannot be explained within the confining walls of the geologic facts displayed on the Seward Peninsula.

ECONOMIC GEOLOGY

The Seward Peninsula has produced large amounts of placer gold, in Alaska ranking next to the Fairbanks district in total production (Cobb, 1973, p. 61). All the domestic production of tin in important amounts has come from placer mines on the western Seward Peninsula (Mulligan, 1959), and the Lost River area contains the only sizeable domestic reserves of lode tin (Sainsbury, 1969, p. 63). Associated with the lode tin deposits are very important lodes containing fluorite and beryllium minerals; these are under development at the present time (Annual Report, Lost River Mining Corp., Ltd., 1971). The total market dollar value of the metals contained in these deposits runs into the billions of dollars. Smaller veins of lode gold, base metals, fluorite and barite, and antimony, have been explored elsewhere on the Seward Peninsula but no large mines have been developed. Numerous occurrences of copper have been noted on the Seward Peninsula, but only a few tons of copper ore have been shipped. Taken as a unit, the Seward Peninsula seems especially favorable for the discovery of lode mineral deposits, yet only at Lost River are large lode deposits known.

Understanding of the geologic factors that account for the distribution of lode and placer deposits of particular types on the Seward Peninsula has developed slowly. Some of the relations, such as the tendency for placer gold to occur near the contacts of massive carbonate rocks and York Slate (or its equivalent) were noted by most of the early geologists who worked on the Seward Peninsula but they did not realize that thrusting was a major factor. From the beginning of geologic work, it was realized that tin deposits were related to isolated stocks of biotite granite known on the western Seward Peninsula (Knopf, 1906). That these stocks represent a distinct episode of intrusion of granitic rocks of relatively young age, and with unusual amounts of tin and beryllium, has only recently been proved (Sainsbury, Hamilton and Huffman, 1968).

During the years between 1940 and the discovery of the major fluorite-beryllium lodes near Lost River, exploration on the Seward Peninsula was almost without exception restricted to the work done over the years by the

U.S. Bureau of Mines (see Bibliography, especially reports by Mulligan), but exploration for lode or placer deposits has never reached the level that the region deserves.

The following pages summarize the main geologic factors that govern the distribution of lode and placer deposits on the Peninsula, and point out some areas where exploration might be most productive.

Placer Gold Deposits

For the most recent summary of the main placer gold districts of the Seward Peninsula, see Cobb (1973), and for detailed information of many areas, see Smith (1910), Brooks, Richardson and Collier, (1901), and Moffitt (1913). Other reports are listed in the extensive bibliography that accompanies Cobb's report.

By far the most important geologic factor in localizing placer gold on the Seward Peninsula is the York Slate. By reference to the maps that accompany this report, it is clearly seen that almost every area with numerous placer gold deposits is underlain either by large expanses of York Slate, or contains York Slate where it has been intensely deformed near faults. It can almost be said that if York Slate is absent, placer gold will not be there in important amounts. Unquestionably, much of the placer gold must have been derived from gold originally present in the York Slate.

The second factor of regional extent with respect to placer gold is the proximity of granitic intrusives in the York Slate. Again, wherever a granitic stock intrudes the York Slate, one finds that placer gold was mined in some streams nearby. If outcropping granite is not evident, there are geologic signs that granite is present at shallow depth, as at Dahl Creek, Hannum Creek and at Potato Mountain. At many localities, placer gold is associated with hydrothermally altered York Slate along fractures marked by quartz veins, sericitic alteration, and with fresh sulfide minerals in the placers nearby. Of especial note are the placers of the upper Kougarok area, where the dredge piles at Taylor, and the exposed bedrock, display widespread sericitic-clay-quartz alteration along veins. Placer concentrates from Washington Creek, the west headwaters of the Kougarok River, contain cassiterite along with numerous grains of pyrite, galena, and a silvery sulfide containing mostly silver, tin and bismuth (personal observation and unpublished analytical data of the U. S. Geological Survey). As noted previously on page 43, gravity data suggests that the Serpentine granite extends southwesterly under this area, and rocks clearly metamorphosed thermally, with development of calc-silicate rock, are found on the west side of Kougarok Mountain.

The mixed gold-cassiterite placers of Humboldt Creek east of the Serpentine Granite have been mentioned, and the first placers mined on the Anikovik River in the western Seward Peninsula more than 100 miles west yielded gold and cassiterite (Cobb, 1973, p. 98).

This relation of placer gold and intrusives that either outcrop or are buried shallowly by bedrock is so clear that one may conclude that many streams that head against intrusives, such as those on the north side of the granite north of the curve of the Kugruk River in the Bendeleben quadrangle, or on the north side of the Serpentine granite, most probably will contain some placer gold. However, such placers are unlikely to be rich unless other geologic factors discussed below have also been operative in the drainage basin.

Certain placer deposits of gold occur in areas where clearcut signs of intrusive rocks are lacking, but where York Slate is present and highly deformed. The most clearcut relation of this sort is in Budd Creek and nearby streams in the eastern Teller quadrangle, where small placer gold deposits are localized immediately downstream from, or along, a thin sliver of York Slate bounded by faults. No lode deposits of any kind are known to be associated. The cinnabar reported in these placers by local residents is most likely dark-red hematite, which is common in dredge concentrates. The relation between placer gold and tectonism involving the York Slate is evident along Telegraph Creek in the northwestern part of the Solomon quadrangle. Deposits large enough to sustain dredge operations occur here, yet the total yield was relatively small, and the deposits were not rich (Smith, 1907). No lode deposits, except some very small tectogenic deposits of copper oxide are known in the vicinity of the placers. All the placer gold is localized along a section of the drainage basin underlain by York Slate.

Of greater importance are the large and rich placer gold deposits in the Council area of the central Solomon quadrangle. The geology here is complex, with York Slate, Kanauguk Formation, and Paleozoic limestone intricately intermixed by both thrust faulting and normal faults. Again, there are essentially no known lode deposits nearby, but the York Slate is intensely deformed and recrystallized with innumerable small quartz veinlets apparent. No intrusive rocks are associated, but the Pargon gneiss-mantled dome lies a few miles north, and is surrounded on the south side by the York Slate. Because the placer deposits continue up the creeks toward the Pargon intrusive until they are buried by moraine, one may surmise that these placer deposits may have extended into the area of the Pargon dome.

The geologic factor that combined with one or more of the above to produce the larger and richer placer gold deposits of the Seward Peninsula, in the Nome area, is clearly demonstrated by the map of the Nome quadrangle that accompanies this report. This factor is the presence of continuous fault zones cutting York Slate, which are marked by numerous gold-bearing sulfide veins exposed at places in the valleys of Anvil Creek, Penny River, cutting across the Nome River upstream from the Anvil Creek fault, and across the lower reaches of Osborn Creek (Osborn Fault). Many sulfide-bearing veins are known in Anvil Creek, and along the upper reaches of the Penny River (personal observation). Smaller veins are known near the Engstrom Fault, northeast of Engstrom's camp, and locally in Osborn Creek (personal observation and previous writers). These major faults all cut the York Slate, and some continue into chloritic schists nearby. Almost without exception, the richer placers lie near to outcropping gold-bearing base-metal veins in York Slate. As soon as one passes out of the slate belt in almost any direction, placer gold falls off rapidly. Even though some recent writers have attempted to relate the placer gold deposits of the Nome area to glacial deposits (Nelson and Hopkins, 1972), the relation discussed here are so obvious that if moraine is called upon to furnish the placer gold, it merely means that detrital gold derived from the eroding lodes was incorporated into the moraines, or was ground up to produce the extremely fine gold of the Nome beaches. Glacial moraine is widespread northwest of Nome, but placer deposits there are small, and lie on York Slate beneath the moraine. It is noticeable that the beach placers of the Nome area are largely confined to beaches on the belt of York Slate lying between the Penny River fault and the Osborn Fault some 15 miles southeast.

In the Solomon area, large deposits of placer gold were dredged following early sluice-box mining. Although placer deposits were mined to a limited extent over much of the outcrop area of the York Slate, which extends in a continuous belt north from Solomon (Smith, 1910), most of the deposits were of low grade. Only in the lower reaches of the Solomon River, and up Big Hurrah Creek, were the placers notably rich. As in the Nome area, both auriferous quartz veins, as at the Big Hurrah mine, and gold-bearing antimony-lead-silver veins, as on the ridge north of Big Hurrah Creek (Stepovich Mine) are correlative with the area of richer placer gold deposits.

The gold placer deposits on Hannum Creek, the west headwaters of the Inmachuk River, are found downstream from a lode that lies along one of a series of strong faults trending northwest. The lode is marked by sulfide-bearing vein material as much as several feet thick. Within the vein, galena, pyrite, arsenopyrite, chalcopyrite, sphalerite, gold and silver are visible or shown by analyses. Although the vein is covered by tundra for much of its length, trenches in the tundra expose the underlying silt, which yields strong geochemical anomalies for antimony, copper, lead, zinc and silver. The vein, which dips steeply southwest, is exposed in a caterpillar tractor cut on the northwest bank of Hannum Creek, a short distance upstream from the Foster camp. It is notable that early geologists on the Seward Peninsula predicted the existence of a hidden vein at precisely the point it was found (Collier, et al, 1908). Other strong faults in the general area may be found to be auriferous. The mineral deposits may be related to a granitic intrusive that probably underlies the thin-bedded shaly limestone on the ridgeline some five to seven miles northwest of Hannum Creek. There the limestone is partly converted to tactite, which clearly points to a nearby heat source.

The last factor which has governed the distribution of placer gold on the Seward Peninsula is the distribution of glaciers. At places where rich placers of gold or tin might be expected, notably downstream from the Lost River tin mine, placers were small and yielded only a minute fraction of the tin or gold which must have entered the stream from eroding lodes. The rich placers of tin with minor gold that were mined near Potato Mountain, and in the deep channel of Cape Creek, on the westernmost Seward Peninsula, were preserved because the regions were not glaciated during the Wisconsin glaciations which were so widespread in the York, Kigluaik, Bendeleben, and Darby Mountains. The moraines of these glaciers may contain minute amounts of gold, but no placers of any importance on the Seward Peninsula occur in moraine. In fact, some rich placers, as in the Council area, disappear when moraine is reached.

Consideration of the above factors will lead the astute prospector or mining man to hidden deposits of placer gold, or will serve to eliminate large parts of the unexplored areas of the Seward Peninsula as a target area for hidden placer gold deposits. Conversely, where placer gold concentrates are found to contain visible grains of such minerals as galena, chalcopyrite, sphalerite, or arsenopyrite, the probability exists that bedrock lodes are nearby, which, however, may not necessarily be of economic size or grade.

Kougarok Gravels

The Kougarok Gravels and their relation to the underlying Tertiary rocks was discussed on page 33. Several hundred pounds of the Kougarok Gravels were panned in the gravel pits at Brakes Bottom and just east of the Kougarok airstrip, Bendeleben B-6 quadrangle. Small amounts of placer gold were recovered from all samples panned; the estimated grade of the gravels being 10¢ to 15¢ per cubic yard at the old price of gold ($35.00/oz.). Streambeds in the gravels contained flakes of gold to pin-head size and larger.

Because some of the placers on Dahl Creek, as at the Alexander placer mine, seem to be located in concentrations of gold related to old slip-off slopes of stream meanders, it is possible that many such placer deposits lie buried in the Kougarok Gravels. Because the Kougarok Gravels have been removed for an unknown extent by erosion of the Kougarok River, resulting in a high cutbank almost 100 feet high west of the Kougarok River, it is a distinct possibility that much of the gold originally present in the Kougarok Gravels was concentrated in old meander patterns between the present Kougarok River and the high gravel bluffs. This information has been freely given to many people, including local prospectors, miners, and company representatives, and in 1973 a large number of placer claims were staked to cover a section of these lower gravels (oral reports, Nome, Alaska). The source of the gold in the Kougarok Gravels is likely to have been auriferous quartz veinlets in the York Slate. These veinlets probably furnished the quartz pebbles in the Kougarok Gravel, and the recovery of many gold nuggets with quartz still attached up and down the Kougarok River supports this source.

Placer Tin Deposits

Placer tin has been mined in notable amounts from Buck Creek and the upper reaches of the Anikovik River near Potato Mountain at the northwest end of the York Mountains, and at Cape Creek, near the village of Wales at the west tip of the Peninsula. At Cape Creek, the placer tin is derived from small lodes that are found near or within the biotite granite of Cape Mountain (Cape Mountain Granite). At Buck Creek, the placer tin occurs in gravels overlying the York Slate, which is cut by a granitic dike, and which contains numerous small veins of altered slate that contain tourmaline, cassiterite, and sulfide minerals (Mulligan, 1965). These placers produced more than 2200 short tons of metallic tin, and were by far the largest placer tin mines known in the North American continent, even though small by comparison to placer deposits in the world's major tin districts.

Elsewhere on the Seward Peninsula, small amounts of placer tin occur in stream gravels near the biotite granites at Lost River, Brooks Mountain, Black Mountain, and Ear Mountain in the Teller quadrangle, but preliminary drilling by the U. S. Bureau of Mines suggests that no rich deposits exist (Mulligan, 1965, 1959).

In the Bendeleben quadrangle, cassiterite is found, sometimes in sub-economic amounts, in placer gold concentrates in the headwaters of the Kougarok River, near the Serpentine Granite, and in small amounts in concentrates from the Inmachuk River.

During the writer's work on the Peninsula, fragments of altered dike rocks containing visible cassiterite were found on bars on the Serpentine River north-northwest of Kougarok Mountain (Marsh, Sainsbury, Hamilton, and Ewing, 1972). John Mulligan, U. S. Bureau of Mines, has reported previously (oral communication, 1964), that Eskimos had reportedly obtained a fist-sized nugget of cassiterite in a stream in this general area years ago.

In 1969 the writer found fluoritized tactite in several small outcrops on the ridgeline north of Igloo Creek, an east tributary of the American River in the east part of the Teller quadrangle. Analyses of these rocks by John C. Hamilton, U. S. Geological Survey, disclosed high values (up to several thousand ppm) of tin, beryllium and base metals in these rocks (Sainsbury, 1972). The tactite is a certain indicator of a nearby granitic intrusive, but the surrounding hillslopes are mantled completely by tundra, and no outcrops of granite were observed. It is likely that placer cassiterite and gold exist, but possibly deeply buried, in gravels of the small creek draining this area.

As noted on page 75, tactite on the ridgeline northwest of Hannum Creek probably lies above a buried granite. The streams draining northward to Kotzebue Sound from this area should be drilled for placer gold and cassiterite, although the gravels will likely be deep.

Placer Platinum

Placer platinum, reportedly secured from deep channels of Gold Run, south of Teller, was shown to me in 1967 by a prospector who requested to remain anonymous. Credence is given to the possibility that some platinum may exist in this area because of the rather unusual concentration of mafic intrusives in the York Slate in the drainage of Gold Run (see geologic map of the Teller quadrangle, Sainsbury, 1972). Many of these intrusives are altered complexly, and most contain silica in the range of 40-44 percent, indicating that they are sufficiently mafic to be accompanied by platinum. The area could most logically be prospected for platinum by securing samples of placer gold concentrates from operators in the area, and analyzing them for platinum-group metals.

Placer platinum has been reported in gravels near the intrusive complex at Granite Mountain, east of the Kiwalik River in the Candle quadrangle. Bedrock in the area is principally altered mafic volcanic rocks of Jurassic age, and there are numerous oxidized areas that contain strong geochemical anomalies and, locally, substantial amounts of galena and base-metal sulfides (Miller and Elliot, 1969). In spite of the unusual concentration of altered bedrock, placer gold deposits in the area were small, shallow, and of marginal grade (personal reports from former operators). The platinum may be derived from the decomposition of mafic inclusions in the metavolcanic rocks, for fragments of dunite, pyroxenite, and eclogite can be observed in the stream gravels.

If platinum exists elsewhere on the Seward Peninsula, it most likely will be in the drainages of the streams off the west end of the York Mountains, where an unusual concentration of mafic intrusives exists in the York Slate.

Placer Cinnabar

Cinnabar in small amounts has been reported from the gravels of Budd Creek, a tributary of the American River, from Dome Creek and Auburn Creek in the Solomon quadrangle (Smith, 1909, p. 335), and has been observed by the writer in placer concentrates from Bering Creek, a south tributary of the Right Fork of the Bluestone River south of Teller. Some of the placer gold from this area is amalgamated with mercury, suggesting that native mercury may be found associated with the cinnabar. Because the placer gold concentrates from this area contain numerous grains of sulfide minerals, and because some of the gold nuggets contain robinsonite (?), a complex sulfide containing tin and bismuth, it is likely that both the gold and cinnabar are derived from lodes nearby.

Placer Uranium Minerals

Only a small amount of uranium in lode deposits is known on the Seward Peninsula, and that at Brooks Mountain, just north of the Lost River mine (West and White, 1952). A strong radiometric anomaly is associated with the north contact of the east lobe of the Serpentine Granite (Sainsbury, Hudson, Kachadoorian, and Richards, 1970), but the mineral responsible for the anomaly has not been sought. Placer concentrates from within the granite, but outside the drainage area of the anomaly, that were obtained by Moxham and West (1953), were but slightly radioactive.

Placer and panned concentrates from streams draining the south end of the intrusive complexes of the Darby Mountains, and from streams on the east side of the alkalic intrusive at Granite Mountain, in the Candle quadrangle (east of the area covered by this report), contain notable amounts of a complex mineral that contains uranium, titanium, and niobium (Gault, et al, 1953). Because of the known large primary uranium-thorium deposit in Greenland in alkalic rocks, and because of a similar deposit known elsewhere (personal observation), it is likely that other primary deposits of uranium and thorium may exist in the Darby Mountains. It is possible that streams near alkalic bodies of some size might contain placer concentrations of uranium or thorium minerals, but owing to the rapid leaching of uranium in the surface environment, it seems only remotely likely that economic concentrations of placer uranium minerals will be found. It is much more likely that thorium-bearing minerals will be found in substantial concentrations in stream gravels, but there is little market at present for thorium.

LODE DEPOSITS

Lode deposits of tin and tungsten in the Lost River area were discovered in 1903, but were never successfully mined at a profit. These deposits, and others like them, but of smaller size, were described by Knopf (1906) and numerous other writers. The results of early diamond-drilling for deep deposits at Lost River by the U. S. Bureau of Mines were described by Heide (1946). The results of mining at the Lost River mine between 1950-1954 were described by Sainsbury (1964), and by Lorain, et al (1958). Discovery of weakly mineralized lodes at Black Mountain was reported in Sainsbury and Hamilton (1967), and work around the other tin granites on the Seward Peninsula by the Bureau of Mines and the Geological Survey are reported by Mulligan (1959) and by Killeen and Ordway (1955).

Following the discovery of the large fluorite-beryllium lodes in the Lost River area by the writer during the years 1961-1964, and exploration by the U. S. Bureau of Mines at Lost River mine (Berryhill and Mulligan, 1964), several private companies acquired ground and explored some of the beryllium-fluorite deposits for their beryllium potential. After the large beryllium deposits at Spor Mountain, Utah, were discovered and proven to be of economic grade, interest in the Lost River deposits waned. In 1969, interest again mounted in the deposits because of their fluorite content, and the activity has continued until the present time. For good descriptions of the fluorite-beryllium deposits, the reader is referred to Sainsbury (1969). Probably the greatest exploration value of the new deposits is the demonstration that large ore deposits that outcrop at the surface still remain to be discovered on the Seward Peninsula, for the fluorite-beryllium deposits outcrop for thousands of feet - the largest, on Camp Creek, is within view of the mine buildings at Lost River tin mine, where mining for tin has been in progress at times since 1903.

Except for the exploration activity at Lost River, very little exploration for lode deposits has been done on the Seward Peninsula since 1965, except for the activity of Mr. Riney Berg on Independence Creek in the Bendeleben quadrangle, and in the Nome area. Mr. Berg is systematically drilling many of the better-known vein deposits of gold-bearing base metal ores. A few diehard prospectors and claim owners continue to do assessment work at old properties.

Lode Tin Deposits

These deposits contain cassiterite as the principal ore mineral. The cassiterite is accompanied by variable amounts of tungsten, copper, lead, zinc and silver. At Lost River, fluorite and beryllium minerals occur with the tin-tungsten deposits. Only tin has been produced in the past, but future mining will have to recover tungsten, tin, and fluorite to be profitable. In the Lost River area, both the tin and beryllium-fluorite lodes are found principally along fractures of a well-marked fault system striking about N. 85 E. across Lost River. The main deposit at Lost River is localized in two rhyolite porphyry dikes above a cupola of biotite granite. Part of the underlying granite has been greisenized, and carries cassiterite and numerous sulfide ore minerals. Above the granite the limestone into which the granite was intruded is intricately veined by fluorite, and other veins with lesser amounts of tin, tungsten, fluorite and beryllium minerals. This veined limestone is referred to as the Cupola Area in early reports, and is called the No. 1 ore zone by the present developer of the property, Lost River Mining Corporation, Limited.

The lode tin deposits known elsewhere on the Seward Peninsula are closely associated with stocks of biotite granite, and most tin prospects presently known occur at or near the margins of the granites, usually in a definable structure such as a fault or altered dike rock. In spite of substantial exploration in the period 1903-1928, none have proved to be sufficiently large or rich to appear economic to mine. The writer believes that if minable ore-shoots exist, they will probably lie along faults such as those that cut the Ear Mountain Granite of the Teller quadrangle. At least two altered fault zones in this granite have been trenched on the surface. These contain but minor amounts of tin, but they are bordered by zones in which the K-feldspars are noticeably reddened. Such a reddening of feldspars is characteristic of some veins in Cornwall, England, which lie deep within the granites as blind orebodies, some of which are very rich, as at South Crofty mine (personal observation).

All the tin granites of the Seward Peninsula are relatively young, if dates secured by K/A methods are reliable. Several age dates secured by the Geological Survey (Brooks Mountain Granite) and by private companies (oral communications to the writer) lie between 74 and 78 M.Y. These ages are distinctly younger than K/A ages quoted by Miller, Patton and Lamphere (1966), and Miller, et al, (1972) for the larger batholiths of the Darby Mountains. The tin granites are distinctly enriched in tin and beryllium compared to the other intrusive rocks of the Peninsula, except for the alkalic rocks of the Candle and Selawik quadrangles east of the Seward Peninsula. By some as yet unexplained vagary of geochemistry, alkalic rocks at many places of the world contain more tin than the tin granites, yet no commercial tin deposits are generated by these alkalic magmas. Many Russian academicians hold that tin deposits are associated with late-stage post-orogenic granites intruded on the stable-platform side of geosynclines, a relation which seems valid for the Seward Peninsula.

If so, the true tin granites of the Seward Peninsula should trend northerly, and then easterly, around the Cretaceous basin, and undiscovered tin deposits may exist north of the alkalic rock belt of the Selawik quadrangle. That the Koyukuk Cretaceous basin may be bordered by tin deposits is suggested by the tin deposits near Ruby on the eastern side of the Kuyokuk Basin, and by tin anomalies near granitic intrusives elsewhere (Patton and Miller, 1970).

Fluorite-Beryllium Deposits

In terms of tonnages of ore and in potential dollar value the fluorite-beryllium deposits of the western Seward Peninsula exceed by far all other known lodes on the Peninsula and in potential dollar value outrank the combined value of all placer gold produced on the Peninsula. The Camp Creek orebody found by the writer and drilled initially by the U. S. Bureau of Mines (Sainsbury, 1964; Mulligan, 1964), contains more than 6,000,000 tons of proven reserves grading over 30 percent CaF_2 (number 2 ore zone of Lost River Mining Corporation, Ltd., Annual Report, 1971), and the deposit is open along strike and downdip. Extremely large reserves of mixed fluorite-tin-tungsten-beryllium ore that is suitable for open-pit mining lie in the Cupola Zone (number 1 ore zone) above the cupola of granite beneath the Lost River mine. Initial diamond-drilling of fluorite-beryllium-tin-tungsten deposits along the Rapid River Fault (Sainsbury, 1969) has been confined to but one zone of outcropping ore, whereas three other ore zones more than 3000 feet in outcrop length have not even been carefully sampled yet.

The beryllium-fluorite deposits consist of discrete veins, stockworks, and tabular bodies associated with brecciated limestone and dolomite along the Rapid River thrust fault, especially where lamprophyre dikes intrude the thrust. The ore minerals consist principally of fluorite and chrysoberyl, with minor amounts of the beryllium minerals euclase, bertrandite and phenacite. Although some of the beryllium deposits are far from tin deposits and known granites, the district as a whole shows a gradation along strike from tin deposits to transitional veins containing tin and beryllium minerals, to beryllium-fluorite deposits. The gangue minerals consist principally of beryllian diaspore, muscovite mica, an unusual tourmaline (non-pleochroic), and minor amounts of manganese and iron oxides. The deposits are totally lacking in quartz, which appears only on the extreme outer limits of the deposits. The deposits formed by replacement of limestone and minor dolomite. For a complete discussion of this unusual type of deposit, see Sainsbury (1969). In spite of the geochemical anomalies of beryllium found around other tin granites on the Seward Peninsula, the writer feels that other large deposits are unlikely to be found outside the Lost River area because most other areas have been examined without finding similar fluorite-beryllium ore.

Base-Metal Deposits

Deposits of base-metal sulfide minerals that often contain gold are known at several localities on the Seward Peninsula. In this report, these deposits are separated from the copper deposits, which are unrelated, and which formed in a very different way.

The known base-metal deposits consist of two distinct types. The most common are vein-type deposits that contain one or more of the following: galena, stibnite, pyrite, arsenopyrite, sphalerite and gold. In these the gangue is most often quartz. Veins of this type are usually formed along faults, and they may have sharp walls, or assay boundaries. Such veins are well exposed in the York Slates near the town of Solomon, along and near the Anvil Creek fault, along the Penny River fault, and at the Riney Berg property near Independence Creek. Veins that contain principally galena are found at the Omilak and Foster properties on the west side of the Darby Mountains (Mulligan, 1962). Other vein deposits occur along altered dikes west of the Pargon River in the Bendeleben Mountains, in faults at Hannum Creek, and at Iron Creek in the Solomon D-6 quadrangle. Many of these veins, especially those containing stibnite, display substantial amounts of gold, and have localized placer gold deposits. At present, the only active exploration known to the writer is that by Riney Berg at Independence Creek and on Iron Creek, northeast of Nome, although some diamond-drilling was done north of Nome in 1970.

One vein-type copper deposit was found during the field work in 1971 in the headwaters of Independence Creek in the Bendeleben C-1 quadrangle. It consists of a vein about four inches thick of solid chalcopyrite in a limestone cliff on the north side of the creek, and lies above a very large magnetic anomaly which conceivably could be related to the diorite south of Spruce Creek. This area was reportedly staked up by a large American company in 1972.

A second copper deposit that consists of numerous small veinlets of chalcopyrite, pyrite and chalcocite, with associated malachite and azurite, occurs in a limestone klippe (?) north of Kougarok Mountain in the Teller C-1 and D-1 quadrangles. Known locally as the Ward Copper Mine, this property shipped a few tons of copper prior to World War I. Several patented claims cover the outcrop area of the limestone klippe (?) which measures about one mile long. At the north end of the klippe (?), silica has replaced the limestone above the thrust. This silica carries a notable amount of malachite and azurite. At scattered localities elsewhere on the property, old pits disclose veinlets of copper-bearing sulfide minerals. These pits tend to lie near the base of the limestone, and the veins are not distorted, showing that the veins probably formed after the thrusting. Spectrographic analyses of the ores show notable amounts of arsenic, antimony and tin, which takes these veins out of the class of tectogenic copper deposits discussed later.

The second major type of base-metal deposits are represented by deposits northeast of Nome, in the drainage basin of the Sinuk River. Staked originally as iron deposits, these deposits are in reality gossans that overlie limestone and dolomite that contains veinlets of base-metal sulfide minerals, especially galena and sphalerite. The deposits have been known since the early days of mining on the Peninsula, but later work by Mulligan and Hess (1965) and by Herreid (1970) has expanded the knowledge of the deposits. At least one new deposit was staked after Herreid (1968) outlined some large geochemical anomalies near the road leading from Nome to Teller.

The deposits lie within limestone and dolomite which is thought by Herreid and the writer to represent metamorphosed thrust sheets of Paleozoic limestone, as well as in limestone that the writer believes is intercalated in the chloritic schists of the Nome Group rocks. Several of the gossans are of substantial extent, and some are covered by old patented mining claims. Many smaller gossans are localized along distinct faults striking northwest, which have sliced up the thrust sheets. Recent geologic maps of the area by Herreid (1970), and by Sainsbury, Hudson, Ewing and Marsh (1972), show clearly the relations of the gossans to faults, and the report by Herreid discusses the geochemical anomalies associated with the gossans.

Such large areas of gossans with ore minerals are unknown elsewhere on the Seward Peninsula. The size of the gossans, the known type of mineralization beneath the gossans, and the undisputable structural control by faults of some of the deposits suggests the strong possibility of large, probably low-grade, base-metal deposits. The absence of rich placers near the gossans is probably a result of glacial scouring.

Disseminated galena is widespread in the metamorphic rocks on the ridgeline leading west to the altered dikes on the west side of the Pargon gneiss dome. The extent is unknown, but small cubes of galena were observed by the writer over a stratigraphic interval of several hundred feet while traversing this ridgeline. The known deposit is very low grade, but the other small prospects in limestone intercalated in the metamorphic rocks in the general area give some interest to the disseminated galena.

Mention should be made of the known occurrence of europium in the concentrates from the Serpentine River, west of Kougarok Mountain in the Teller 1:250,000 quadrangle (Marsh, Sainsbury, Hamilton and Ewing, 1972). Europium is a rare element used in picture tubes of colored television sets; a recent spurt in price to almost $1800.00 per pound of europium-chloride suggests that other, new uses have been found. Because most of the world's europium of commerce is obtained as a by-product of monazite processing, and as no primary europium minerals are mined, the possibility of the existence of commercial deposits of placer europium monazite on the Seward Peninsula should be emphasized. Such placers may contain gold, cassiterite, and rare-earth elements. In such a placer, the europium-bearing monazite could be but a minor percentage of the heavy minerals, yet could represent a large dollar value.

According to Guigues and Devismes (1969), and William C. Overstreet (personal communication, 1971), europium monazite occurs as small grains of dark color in schists or hornfels near granitic intrusives. The grains seen by the writer from concentrates from the Seward Peninsula are dark, rounded, ovoid grains mantled with curved flakes of white mica. Because the europian concentrates from the Serpentine River in the Teller quadrangle came from a portion of the drainage that heads against a large expanse of chloritic schist, the suggested geologic relations are similar to that from which such europian concentrates have been obtained elsewhere in the world (W. C. Overstreet, personal communication, and Guigues and Devismes, 1969).

Geologic relations similar to those in the Serpentine River area occur at many other localities on the Seward Peninsula. Numerous tin-granites intrude slate, schist and limestone on the Peninsula, and placer deposits nearby have yielded gold and cassiterite. The mineral xeontime containing europium is obtained commercially from cassiterite placers in Malaysia and Thailand (Flinter and others, 1963), and xenotime is known from the Seward Peninsula (personal observation). Hence, it is possible if not probable that europian minerals may be found in economic amounts on the Seward Peninsula.

Fluorite and Fluorite-Barite Deposits

Several deposits of fluorite and fluorite-barite veins of a type distinctly different from the beryllium-bearing lodes at Lost River are known on the Seward Peninsula. All were found since 1968.

A fluorite-barite deposit along the Nome-Teller road in the Nome C-2 quadrangle was staked by Charles Volkheimer of Nome, and is locally known as the Sinuk River Barite deposit. The deposit has been described by Mulligan (1965), by Herreid (1966), who outlined a strong geochemical anomaly of lead and zinc in the soils of the area, and most recently by Brobst, Pinckney and Sainsbury (1971, p. D-1 to D-8). This last report shows that the deposits contain, in addition to barite, fluorite, goethite, galena, sphalerite, boulangerite, and associated silver and gold. The deposit occurs in marble schist at the contact above chloritic schist, and the marble locally is dolomitized. The barite and fluorite is intergrown in irregular masses and pockets within the marble and dolomite, and the underlying schists are bleached and altered. The barite is of high quality, but is distributed irregularly in the marble, and a large-tonnage operation would require milling of the ores. Fluid inclusion studies by Pinckney suggest that the deposits formed between a temperature of about 240° and 260° C. Herreid interprets the limestone and marble of the deposit to represent a thrust sheet, but Sainsbury believes that it represents sheared limestone originally intercalated in the chloritic schists.

Two fluorite pipes were found in the Kigluaik Mountains by the writer and his associates in 1967 (Sainsbury, Kachadoorian and Smith, 1970). They occur in the streams that form the west headwaters of Lake Creek, in the

Nome D-2 quadrangle. The largest pipe outcrops in a small gully cut into altered metamorphic rocks, and measures some 30 feet by 12 feet in the outcrop exposed. The fluorite is coarsely granular, and is accompanied by pyrite. Spectrographic analyses of the fluorite disclose but small amounts of antimony, copper, lead and zinc. The second pipe also contains coarsely crystalline fluorite with pyrite and fine-grained silica, and contains but small amounts of metallic ions.

A fluorite deposit of some promise was found in the Darby Mountains along the fault that bounds the west side of the Windy Creek pluton. At the single place where it was examined by the writer, it consists of numerous small quartz veins containing colorless to greenish fluorite intimately intergrown with quartz. Some vein material is as much as three feet wide, and can be traced for several hundred feet, although the fluorite content is variable. The vein lies within claims staked by representatives of Placid Oil Company, who hold several hundred claims covering the vein and the altered intrusive rock to the east, in the area where geochemical anomalies were reported by Miller, et al, 1971.

Tectogenic Copper Deposits

This term is introduced here to cover deposits of both metallic and non-metallic minerals that were formed during the thrusting of the rocks of the Seward Peninsula from materials mobilized from the surrounding rocks during thrusting. Hence, they are younger than the surrounding rocks, but do not represent introduction of metals from outside the system as do epigenetic deposits. Such copper deposits are widespread on the Seward Peninsula, and have long puzzled the prospectors who always found that the deposits soon bottomed at shallow depth. The only metal of economic value known in the deposits is copper, although in a broad sense large deposits of silica and dolomite are most characteristic of them.

The tectogenic copper deposits are best known along the thrust belt of limestone east of Iron Creek in the Solomon D-6 quadrangle, although they have been noted at many places elsewhere. Here, several pits and groups of pits are found in silicified limestone at the base of the thrust sheets of carbonate rock that forms a belt that continues southeast for many miles. The thrust sheets overlie chloritic schist, which near the thrust is intensely sheared. The silica has completely replaced the limestone, giving a rock described by the old-time geologists as "quartzite." This replacement silica grades upward into limestone or marble irregularly replaced by silica, and at one property, the Wheeler "mine", silica has migrated some distance into the overlying limestone of the thrust along fractures. In all the deposits examined, the copper mineral is malachite, which appears in traces to amounts large enough to catch the eye. No other ore minerals are ever found in this type of deposit on Iron Creek, or in the some two dozen or more deposits of similar habit found elsewhere on the Seward Peninsula. That the copper is derived from the overridden rocks is suggested by the following criteria:

1. The copper minerals are confined to the silicified base of the thrust sheets, and never extend downward into the underlying rocks.

2. Copper sulfides are never found in the silicified rocks, even when large boulders are cracked apart. Because of the strong frost action,

and the cold climate, fresh sulfide minerals occur at the surface everywhere on the Seward Peninsula where sulfide-bearing veins are known.

3. Although extensive sheets and large bulbous masses of replacement silica are common at the base of thrust sheets of carbonate rocks that have overridden the highly siliceous York Slate, such silica is usually barren of copper minerals. Where the thrust sheets of carbonate overlie the chloritic schists, which were derived from basic rocks, copper oxides are almost everywhere apparent in small amounts. The relations suggest that copper-rich rocks had to be deformed by thrusting to yield the mobilized copper.

4. Because the mobilized silica probably represents an environment of rather high oxygen activity, only copper oxides are formed.

5. Spectrographic analyses of numerous ores of the Seward Peninsula establish the fact that notable amounts of metals such as lead, zinc, silver, antimony, arsenic, tin and bismuth occur in all veins of epigenetic origin. On the other hand, spectrographic analyses of copper-bearing tectogenic deposits shows copper to be the only introduced ore element.

6. The replacement silica bodies are similar to the replacement bodies of dolomite found over the Seward Peninsula at the base of thrust sheets of carbonate, where limestone has been thrust over the Kanauguk Formation. Such dolomites also are of tectogenic origin, but they contain few copper deposits. The single possible exception to this rule is shown on the eastern front of the Darby Mountains in the Bendeleben A-1

quadrangle where, at the head of Copper Creek, schistose limestone at the base of a folded thrust sheet of limestone that is almost totally converted to dolomite carries visible bits of malachite.

7. The fact that no veins similar in mineralogy to the tectogenic deposits are found anywhere on the Seward Peninsula proves that these deposits are of unusual origin. Their relation to thrusts suggests that the relation is solely tectonic.

8. Two large bulbous masses of replacement silica occur in the limestone of the thrust sheets of carbonate rocks south of Kougarok Mountain in the Teller-C1 quadrangle, where the thrust sheets overly chloritic schists. Copper oxides, principally malachite, are found disseminated in this silica even at the ends of adits almost 100 feet long driven into the more southerly of these two masses. Semi-quantitative spectographic analyses of this ore disclose only copper, but secondary copper minerals from the Ward Mountain deposit to the north, where copper sulfides occur, show notable amounts of lead, zinc, arsenic and antimony. Obviously, the copper was introduced into the large masses of silica as the oxide that was unaccompanied by other metals.

Although the emphasis here has been on the slight amounts of copper found in the replacement siliceous bands, the obvious thing of greater importance is the immense volume of mobilized silica represented by the large silicified sheets known over the Peninsula. If this silica was introduced epigenetically, where did it come from? Again, semiquantitative analyses of the silica show no foreign metals such as copper, lead, zinc, silver and tin. The source rocks of the silica obviously were impoverished in these metals.

The concept here proposed easily explains the puzzling features which bothered prospectors, miners and geologists who have worked on the Peninsula. In view of the proposed origin of the tectogenic ore deposits, they would have to bottom at the base of the silicified thrust sheets, without extending into the underlying, unsilicified rocks. Further, they would have to be of low grade, because the primary source, the chloritic schists, contained only a very small amount of copper.

The concept of tectogenic ore deposits will no doubt be vigorously attacked. However, the writer has seen many other deposits in a different part of the world which are similar to those on the Seward Peninsula in that they occur along or near thrusts, they contain only oxide minerals among which are malachite and azurite unaccompanied by sulfides of any sort, and they do not penetrate downward any appreciable distance below the thrusts. A future report will discuss these deposits.

Lode Gold Deposits

As recorded by many of the early workers on the Seward Peninsula, gold has been noted both in the small quartz veins which occur in deformed York Slate, as well as in larger fissure veins at many places on the Peninsula. It has already been pointed out on pages 13 to 15 that small amounts of gold must be present in most of the York Slate. Furthermore, most placer gold deposits yield gold nuggets intergrown with quartz.

Many of the base-metal veins are also auriferous, some being notably rich in gold. In the Big Hurrah area, stibnite-gold veins contain much gold, selected hand specimens of stibnite assaying as high as several ounces gold per ton. The base-metal veins in the Nome area have yielded much of the gold in the richer placers, for visible gold often can be seen in the lodes (personal observation). Moreover, on some creeks the miners have mined creek gravels which became eluvial gravels as the placer gold left the streambed. Sluicing the eluvial gravels up the slopes, the miners locally uncovered auriferous base-metal lodes rich enough in gold that the veins were mined to shallow depths (personal observation).

The placer gold on Hannum Creek was derived from the erosion of an auriferous base-metal lode, and the base-metal vein at the Riney Berg deposit between Independence Creek and the Kugruk River is reported to have high gold values at depth (Pearce Walsh, oral communication, 1973). Most of the base-metal veins that occur in York Slate on the Seward Peninsula probably carry some gold.

The first lode gold mine on the Seward Peninsula, and the only one to date successfully operated for a period of years, is the Big Hurrah gold mine on Big Hurrah Creek, a tributary of the Solomon River in the western Solomon quadrangle. This mine operated for several years between 1906 and 1911; in later years the tailings were treated by cyanidation and yielded considerable gold. The mine is developed along a strong vein of banded quartz striking northwesterly in the York Slate (formerly known as the Hurrah Slate in this area). The vein is complex; at the surface it is a continuous vein of banded white quartz as much as six feet wide. At a depth of less than 200 feet, the vein is intersected by at least two thinner veins dipping less steeply to the southwest. All the veins are auriferous, and were mined. Scheelite occurs in notable amounts in the quartz (personal observation). During the 1950's, some additional mining was done on the vein, but fire destroyed the shaft timber and the headframe, and the mine has not been reopened. Reserves of unmined ore unquestionably remain in the mine.

By reference to the geologic map of the Solomon quadrangle that accompanies this report, it can be seen that other prospects in the area also lie along northwest-trending faults in the York Slate, but none have been explored at depth. It is possible that one or more of these veins might be auriferous.

MISCELLANEOUS LODE AND PLACER DEPOSITS

Tungsten

Mention should be made of the widespread occurrence of scheelite in stream gravels over much of the Seward Peninsula. The scheelite probably is derived principally from quartz veins, some of which are known to contain scheelite (personal observation). The quartz veins at the Big Hurrah gold mine contain notable amounts of scheelite, for channel samples cut by the writer in 1952 contain as much as .09 percent WO_3. Scheelite in small amounts occurs in the altered limestone around the Lost River tin mine, in altered limestone around the granites at Cape Mountain and Ear Mountain, and probably around other granitic rocks intruded into limestone. In the Kigluaik Mountains, tactite zones locally are conspicuous, but they have not been examined for scheelite. Placer concentrates from the Darby Mountains area contain considerable tungsten, and because the large masses of intrusive rocks there are in contact with limestone over large areas, it is possible that commercial deposits of tungsten exist unfound.

Bismuth

Native bismuth has been known on Charley Creek, in the Nome D-2 quadrangle for many years. Samples secured in the Kigluaik Mountains were found to contain anomalous amounts of bismuth, sufficiently often to suggest that a bismuth-rich province corresponds with the west and southwest side of the Kigluaik Mountains, extending over parts of the Nome D-3, C-2 and C-3 quadrangles. One sample of mineralized rock from Martha Creek, in the Nome D-2 quadrangle, contained over 5000 ppm of bismuth, as well as high values in lead, boron, antimony, tin and tungsten.

Uranium

The known lode deposit of uranium at Brooks Mountain, in the Lost River area, has been mentioned, as well as the radiometric anomaly on the border of the east lobe of the Serpentine Granite. The tin granites of the Seward Peninsula are abnormally radioactive compared to the other intrusive rocks, including syenite. Where the granites are extensively altered to clay minerals, as at Brooks Mountain, the uranium is leached, resulting in a marked radiometric low. It is possible that such leached areas may be surrounded by a zone enriched in uranium, as suggested by the known uranium minerals at Brooks Mountain.

Mention has been made also of the possibility of primary deposits of uranium and thorium in the alkalic igneous rocks of the Darby Mountains, as well as the known radiometric high near the Windy Creek pluton of the Darby Mountains (see map with this report). Radiometric maps of the Serpentine granite area, as well as others in the north part of the Selawik

Mountains east of the Seward Peninsula, based upon total gamma-ray counts obtained by aircraft flying several hundred feet above ground level, show many anomalies that the writer terms "fictitious relative anomalies." Several such anomalies that were checked by Sainsbury and Mr. Carl Bunker, U.S. Geological Survey, were found to be caused by exposed granitic rocks surrounded by tundra. A fictitious total gamma-ray "anomaly" is created by the shielding effect of the tundra over the highly radioactive tin granites which are bare beneath the "anomalies." Consequently, airborne radiometric maps should be interpreted in terms of the effects of local rock types, as well as the blanketing effect of the cover. It should also be pointed out that in radiometric work using airborne multi-spectral channels capable of delineating anomalies caused by uranium, thorium, and potassium, the presence of a radiometric anomaly not caused by uranium is not a valid reason for a decision to abandon the anomaly without ground work. Uranium leaches rapidly in surface waters of even slight acidity, and most tundra waters are acid. All radiation anomalies, even if caused by thorium, should be checked on the ground by soil sampling.

Graphite

The known graphite deposits of the Seward Peninsula lie along the north front of the Kigluaik Mountains, in highly graphitic biotite schists which are probably derived from the York Slate. Before World War I, the deposits had been explored by a few short adits and pits. All the deposits lie near the Kigluaik Fault, and the schists dip steeply north. Graphite occurs as both sooty graphite replacing the schists, and as pods and lenses as much as a few feet across. Some of the graphite definitely is of commercial grade, and future exploration is likely to disclose additional reserves at known deposits, as well as finding new ones. The area of better deposits is covered by claims held by residents of Teller. For a more detailed description of the deposits, see Coats (1944).

PROSPECTING METHODS

This report will be terminated with a short but necessary discussion of the methods required to find both hidden and outcropping ores on the Seward Peninsula.

Most of the known lode and placer deposits on the Peninsula were found by tedious footwork. The oldtimers traced float to its source and found the Lost River tin deposits, but missed the larger and more important beryllium deposits. The beryllium deposits were found during detailed geologic mapping in an area nearby to one which was known to contain anomalous amounts of beryllium in many stream sediments (Sainsbury, et al, 1961).

Most of the geochemical exploration done by companies and by some government workers on the Seward Peninsula since 1960 has been by the use of stream sediment surveys. In fact, during the Heavy Metals Program of the U. S. Geological Survey between 1967 and 1971, stream sediments were used almost exclusively for geochemical exploration, as witnessed by the numerous reports published between 1967 and 1972 (personal observation).

There can be no doubt that geochemical prospecting using stream sediments alone may be effective in some areas of the world, and possibly in all areas of the world where complex sulfide ores exist.

That geochemical prospecting using stream sediments would be effective in finding the Lost River tin deposits, or the beryllium-fluorite lodes nearby, was demonstrated by surveys reported in Sainsbury, et al, (1961) and in Sainsbury, Hamilton, and Huffman (1968). Conversely, the study of the area around the Serpentine granite, reported by Sainsbury, Hudson, Kachadoorian and Richards (1970), showed conclusively that stream sediment surveys were totally inadequate in finding the source of the placer tin in Humboldt Creek, as well as the mineralized lodes nearby. If the large amounts of cassiterite in the gravels of Humboldt Creek had not been known by the appearance of cassiterite in placer gold concentrates, <u>the geochemical survey using stream sediments would have failed utterly to disclose the tin or the galena-bearing lodes</u>.

The literature on geochemical prospecting cites numerous cases where stream sediments proved inadequate or totally useless in finding deposits of heavy resistate minerals at many places in the world, even in areas of temperate or tropical weathering. To apply such techniques in the Arctic and sub-Arctic, where mechanical weathering is by far the most important factor in the destruction and dispersion of mineral deposits, is to invite, failure of the prospecting program. The popularity of the stream sediment method can be accounted for because it successfully found porphyry copper deposits in arid or temperate climates, and to the fact that it is relatively easy to secure a sample.

It is probably safe to say that where mineral deposits, such as at Lost River and near Granite Mountain (Miller and Elliot, 1968), are accompanied by large masses of altered rock containing clay minerals and iron oxides, stream sediments probably will give some indication of the nearby orebody. But in the search for such minerals as cassiterite, columbite-tantalite, scheelite, wolframite, and minerals containing the rare earths, stream sediment surveys are not dependable. Samples of stream sediments taken immediately downstream from a vein of solid chalcopyrite which outcrops on a vertical cliff alongside the headwaters of Independence Creek give no indication of the copper. Because so much of the Arctic is mantled by silt and loess not derived from the underlying rocks, the use of the minus 80 mesh fraction of stream sediments in geochemical prospecting probably insures that many interesting areas will remain undetected.

In 1964, we collected numerous samples of soils and stream sediments in the Potato Mountain area of the western Seward Peninsula, including the Buck Creek drainage that had produced more than 2000 tons of tin metal from placers. Analytical results on the samples collected showed but very low values of tin (unpublished data, U.S. Geological Survey). The U.S. Bureau of Mines, by use of the gold pan, traced cassiterite in stream gravels and soils to its source on the slopes of Potato Mountain, where trenches subsequently disclosed mineralized veinlets in bedrock (J. J. Mulligan, 1965).

The above examples are sufficient to support the writer's position that in geochemical exploration on the Seward Peninsula, and elsewhere in the Arctic, a meaningful exploration program must make use of the gold pan, and analyses of panned concentrates.

A modified basket sampler pictured in Sainsbury, Curry and Hamilton (1973, p. 15) was used experimentally to sample the low brush along the depressions in the tundra-covered hills. Samples were collected by flying the aircraft a few feet above the vegetation while the sharp-edged basket collected a sample consisting of hundreds of leaves and twigs. Such a sample closely approaches a statistically accurate average of the vegetation. The twigs and leaves are ashed, and analyzed spectrographically. Preliminary results suggest that this method is capable of detecting base-metal deposits covered by tundra and as much as several feet of frozen silt (personal observation). The basket sampler used with the aircraft has also been applied in the sampling of conifer tops similar to those in the northern spruce forests. The interested reader is referred to the report by Eakins (1970), that the primary uranium-thorium deposit at Bokan Mountain, southeastern Alaska, could have been found by tree-top sampling.

The basket cutter has been tried in collecting a bulk sample of the grasses and sedges typical of the tundra taiga on the Seward Peninsula, but with inconclusive results. Apparently, the grasses are poor collectors of base metals. It should be noted, however, that the tundra plants near the Lost River tin mine gave good geochemical anomalies for many metals, both individually and as a "tundra clump" representing all the plants of the local tundra (Sainsbury, Hamilton, and Huffman, 1968, p. F33-F37). Research is continuing into methods of airborne geochemical sampling.

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