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PRELIMINARY REPORT ON THE GEOLOGY AND DEPOSITS OF MONAZITE, THORITE, AND NIOBIUM-BEARING RUTILE OF THE MINERAL HILL DISTRICT, LEMHI COUNTY, IDAHO

by

E. P. Kaiser

July 1956

OPEN FILE REPORT

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature.

U. S. GEOLOGICAL SURVEY

CONTENTS

TABLES

FIGURES

PRELIMINARY REPORT ON THE GEOLOGY AND DEPOSITS OF MONAZITE, THORITE, AND NIOBIUM-BEARING RUTILE OF THE MINERAL HILL DISTRICT, LEMHI COUNTY, IDAHO

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E. P. Kaiser

ABSTRACT

Deposits of minerals containing niobium (columbium), thorium, and rare earths occur in the Mineral Hill district, 30 miles northwest of Salmon, Lemhi County, Idaho. Monazite, thorite, allanite, and niobium-bearing rutile form deposits in metamorphic limestone layers less than 8 feet thick. The known deposits are small, irregular, and typically located in or near small folds. Minor faults are common.

Monazite generally is coarsely crystalline and contains less than one percent thorium. Rutile forms massive lumps up to 3 inches across; it contains between 5 and 10 percent niobium. Rutile occurs in the northwestern half of the district, thorite in the central and southeastern parts. Monazite occurs in all deposits. Allanite is locally abundant and contains several percent thorium. Magnetite and ilmenite are also locally abundant.

A major thrust fault trending northwest across the map-area separates moderately folded quartzite and phyllitic rocks of Belt age, on the northeast, from more intensely metamorphosed and folded rocks on the southwest. The more metamorphosed rocks include amphibolite, porphyroblastic feldspar gneiss, quartzite, and limestone, all probably of sedimentary origin, and probably also of Belt (late Precambrian) age. The only rocks of definite igneous origin are rhyolite dikes of probable Tertiary age.

The more metamorphosed rocks were formed by metasomatic metamorphism acting on clastic sediments, probably of Belt age, although they may be older than Belt. Metamorphism doubtless was part of the episode of emplacement of the Idaho batholith, but the history of that episode is not well understood.

The rare-element deposits show no evidence of fracture-controlled hydrothermal introduction, such as special fracture systems, veining, and gangue material. They may, however, be of hydrothermal type. More likely they are metamorphic segregations or secretions, deposited in favorable stratigraphic and structural positions during regional metamorphism.

INTRODUCTION

The Mineral Hill district is in central-eastern Idaho, in the northern part of Lemhi County (fig. 1). It is about 30 miles northwest of the city of Salmon and is traversed by the Salmon River. A Forest Service road leaves U. S. Highway 93 at North Fork and follows the north bank of the Salmon River westward; several access roads, built by the Forest Service or for lumbering and prospecting, run north from the Salmon River road up major tributary valleys. There is no railroad in this part of Idaho; the nearest rail loading point is across Gibbons Pass, at the town of Darby, Montana, 60 miles north of North Fork. Rail loading points are also available at Armstead, Montana, 115 miles southeast of North Fork, and at Roberts, Idaho, 170 miles southeast of North Fork. Good highways lead north to Darby and Missoula, Mont., and south to Idaho Falls and Pocatello, Idaho.

The Mineral Hill district is in the mountainous part of central Idaho. The Bitterroot range extends northward from the northwestern part of the Mineral Hill area; its ridge line is followed by the boundary between Idaho and Montana. East of Salmon, Idaho, the Beaverhead range trends north-northwesterly and here also forms the boundary between Idaho and Montana. The northern end of the Beaverhead range is east of the Mineral Hill district. Between the southern end of the Bitterroot range and the northern end of the Beaverhead range is an irregular ridge running approximately east-west, to which no individual name has been given. The Mineral Hill district (fig. 2) lies on the south side of this ridge and extends southeastward across the Salmon River into the irregular mountain mass west of the town of Salmon.

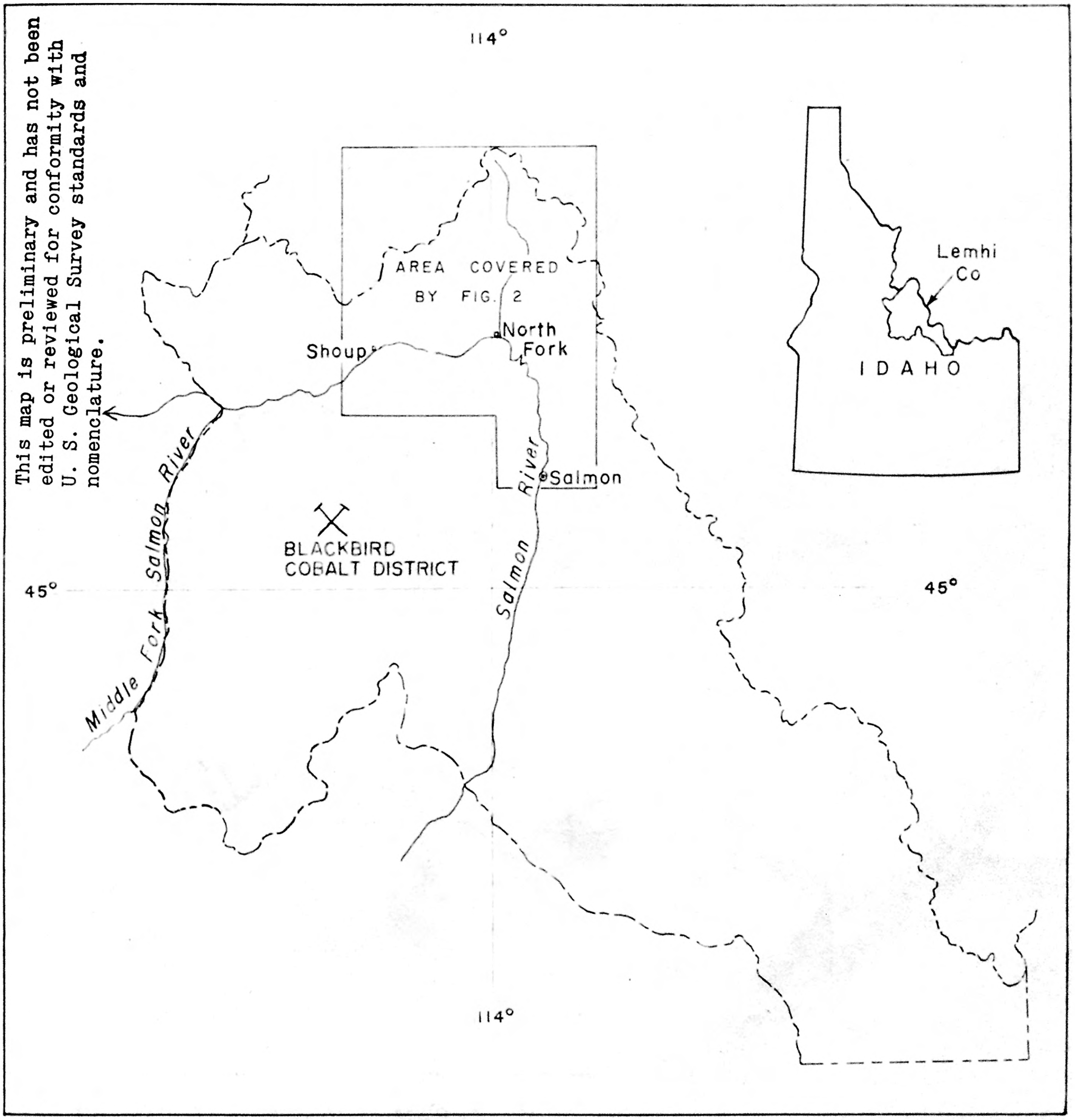

FIGURE 1.—INDEX MAP OF LEMHI COUNTY, IDAHO

10 0 10 20 30 Miles

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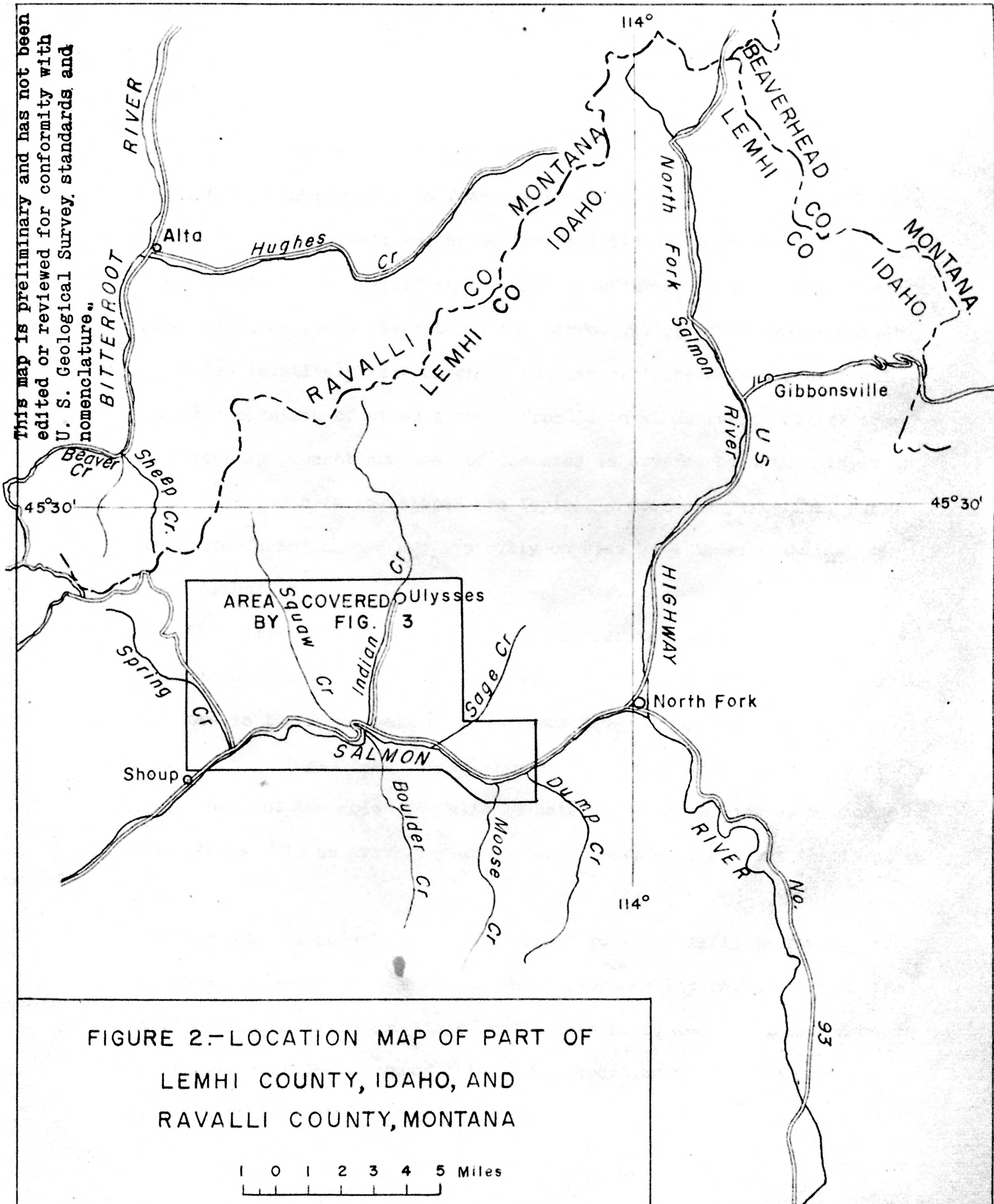

FIGURE 2.–LOCATION MAP OF PART OF LEMHI COUNTY, IDAHO, AND RAVALLI COUNTY, MONTANA

The Mineral Hill area is extremely rugged; altitude varies from the Salmon River, at about 3,500 feet, to the top of the main ridge at an altitude of about 8,500 feet, in a minimum distance of about 5 miles (fig. 3). The over-all relief of the district is therefore about 1 mile, and the local relief in the main tributaries of the Salmon River is about 2,000 feet. Except for the narrow valley of the Salmon River and a few relatively flat coves in the larger tributaries, nearly all of the area consists of steep slopes, from 30 to 40 degrees. Cliffs are only locally present and most of the area is covered by a thin layer of soil. The south-facing slopes are typically open and park-like, while the north-facing slopes are typically covered by a dense stand of evergreen timber.

The climate of the Mineral Hill district is moderately dry, and its severity depends on the local altitude. Peaches and watermelon are grown outdoors in the lower part of the Salmon River valley, while in the upper parts of the ridges heavy snows blanket the ground for many months of the year. Much of the moisture falls as late winter or spring snow storms or rain storms. In an average year the dry season starts about the first of July.

The area is underlain by metamorphic rocks, chiefly quartzite, amphibolite, and granite gneiss. Thin limestone layers, chiefly in the amphibolite, contain deposits of rutile, thorite, and monazite. Some of the rutile contains an uncommonly high proportion of niobium as a constituent of the rutile.

The Mineral Hill district originally included the gold-copper deposits of the area, especially those near Shoup. As now used the name covers a larger area and is only vaguely defined. The same name is used for the adjacent area in Ravalli County, Mont., near the old town of Alta on the West Fork of the Bitterroot River, where deposits of columbite and rare-earth carbonates have been found recently.

Previous work

The rocks of northern Lemhi County carry mineral deposits of several types, which have been studied and prospected for many years. The major report on the area is by Umpleby (1913) who gives references to reports of earlier workers. At the time of Umpleby's report the deposits of major economic interest in the Mineral Hill district were gold-copper deposits near the old towns of Ulysses and Shoup. The gold-copper mines have been shut down for many years although intermittent prospecting has continued. They are apparently localized on faults and shear zones and are not in the same areas as the rutile thorite-monazite deposits described here. The areal and economic geology of the Shoup area are described in unpublished theses by Davidson (1928) and Gray (1927). Wilson (1937) described supposed unconformities and faults in the Shoup area.

The rutile-monazite deposits were discovered in 1952 during the building of access roads for logging. When material of unusual appearance was found to be radioactive, prospecting with Geiger counters began and reached a high point during the summer of 1953. By that time, three major groups of claims had been staked and were being prospected. During succeeding years, several areas were made much more accessible by the building of cat-roads, and some trenching, pitting, and drilling were done. The occurrence of niobium in the deposits also became known, but the habit of the niobium was uncertain. The U. S. Geological Survey therefore decided to study the area in order to determine the type, habit, and extent of the deposits. The Idaho Bureau of Mines and Geology has recently issued a pamphlet based on several weeks' work in the district during the summer of 1953 (Abbott, 1954).

Present work

The area was visited briefly in the spring and summer of 1952 by W. N. Sharp and W. S. Cavender of the U. S. Geological Survey. During September and October 1953, E. P. Kaiser and D. H. Amos of the U. S. Geological Survey studied the district and made planetable maps of the two areas where most of the prospecting has been done. Because of the unusual nature of the deposits and their country rock, and the difficulties involved in the visual study of the material, many samples were collected for further study and analysis.

In the present report, localities are identified on the map by the coordinates indicated along the edges of the map. The coordinate squares are subdivided into quarters, like the subdivisions commonly used in the township-range system; for example, the southwest quarter of C-4, or SW1/4 C-4.

Geologic mapping was done during September and October of 1954 and of 1955, with the assistance of J. A. Calkins and S. Rosenblum of the U. S. Geological Survey.

ROCK DESCRIPTIONS

The Mineral Hill district is on the eastern side of the Idaho batholith and is underlain by metamorphic rocks about which little is known. The only recent detailed studies of nearby areas are those of the Blackbird Cobalt district (Vhay, 1948), which lies about 30 miles to the southwest; of the eastern front of the Bitterroot range about 50 miles to the north (Ross, 1952); and of the Salmon quadrangle (Anderson, 1956). North and northeast of the district are meta-sedimentary rocks of Belt age, of the same type as those underlying large parts of Western Montana, consisting of quartzites, fine-grained impure quartzites or siltstones, and shales or phyllites, with minor interbedded limestone, generally moderately metamorphosed. Rocks of this type, as well as more highly metamorphosed varieties, are found in the area extending southward from Missoula, Montana, across the Idaho state line to the vicinity of Salmon, Idaho. The moderately metamorphosed rocks of the Belt series near North Fork and Gibbonsville, Idaho, are separated from the more intensely metamorphosed rocks of the Mineral Hill district by a major fault trending northwesterly, crossing the Salmon River at the mouth of Dump Creek, west of North Fork. To the northeast of this fault the rocks are thrown into broad open major folds trending northwesterly. To the southwest of the fault the rocks are complexly folded, also along northwest trends, and consist of amphibolite, porphyroblastic quartz-biotite gneiss, schist, and minor interbedded limestone. The porphyroblastic gneiss locally attains the appearance of granitic gneiss, but is distributed in linear belts probably representing layers rather than cross-cutting bodies.

Within the map area there are no metamorphic gradations that might be related to the Idaho batholith to the west. Metasedimentary rocks are exposed in the Salmon River canyon westward as far as the road extends, about 20 miles.

Porphyritic rhyolite dikes of probable Tertiary age cut rocks of all other types and are chilled against them. The rhyolites are almost entirely restricted to a northeast-trending zone crossing the Salmon River about half way between the mouths of Spring Creek and Squaw Creek.

Rocks northeast of the major fault

Northeast of the major fault the rocks are fine-grained quartzite and phyllite, with definite bedding. Foliation, defined by orientation of mica, parallels bedding everywhere and is visible chiefly in the concentration of muscovite on bedding surfaces. The rocks range from feldspar-rich mica quartzite to quartz-mica phyllite. Phyllite locally contains enough calcite to effervesce with acid. Modes of two types are given in table 1.

The rocks of this series are typical of the Belt series in the northwestern states and Canada. The only features of interest here are the rare occurrence of garnet and of probable cordierite spots, as in sample 5-151D. The spots, 2-5 mm in diameter, occur in phyllitic layers a few inches thick. The garnets are colorless, index n = 1.80, probably almandite containing some spessartite.

Table 1.--Modes of quartzite and phyllite

Name	4-22-ID Feldspathic mica quartzite	5-15-ID Spotted quartz-mica phyllite
Grain size	.3mm	.05mm
Quartz	20-30	30-40
Biotite	10-15	20-30
Muscovite	30-40	20-30
Potash feldspar	5-10	---
Plagioclase, An_{15-20}	15-25	---
Zircon	<1	---
Apatite	2-5	<1
Tourmaline	<1	<1
Garnet	---	1-2
Clinozoisite	---	2-4
Cordierite (?)	---	3-5
Calcite	---	<1

Rocks southwest of the major fault

General

In contrast to the rocks northeast of the major fault, those to the southwest are chiefly amphibolitic or gneissic, and are characterized by large feldspar grains. Foliation generally is visible, but obvious bedding is uncommon. Where both can be distinguished they are generally parallel. Grain size ranges from fine, in quartzites and some amphibolites, to very coarse in some amphibolites and porphyroblastic gneisses. Structure is complex; folds, crumples, and faults are common.

The mappable rock types are described in the order shown on the map-explanation, from bottom to top.

Feldspar-quartz-biotite gneiss

The rocks in the district that have been called granite or granite-gneiss consist of feldspar, quartz, and biotite, but vary in mineral proportions, grain size, and texture. Most of the gneisses contain abundant porphyroblastic feldspar grains and have been grouped as porphyroblastic gneiss for mapping. Gneisses with more abundant biotite, more definite foliation, and nearly even-grained texture, have been grouped as streaked gneiss, especially because mappable units of streaked gneiss are useful in studying the major structures of the district.

The large bodies of gneiss consist chiefly of porphyroblastic gneiss containing small quantities of mica. Foliation varies widely; in some rocks tabular feldspar and biotite are well aligned, while in other rocks, especially toward the central part of the larger bodies of gneiss, feldspar is not elongated and mica is sparse, and the rock is nearly or quite massive.

Granite-like gneiss, similar to that in the large bodies, forms layers, some only a few feet thick, in the amphibolite. The gneiss layers do not exhibit any border effects suggesting intrusive origin, and are concordant with structures in the other rocks.

In thin sections the gneisses consist of orthoclase, albite-oligoclase, quartz, and white and black mica. Orthoclase and plagioclase show wavy extinction. Biotite typically forms streaks and clots, and may or may not be well-oriented. Where biotite is more abundant it tends to wrap around the larger orthoclase grains. In porphyroblastic gneiss, orthoclase grains up to 3 cm long are abundant, in a discontinuous groundmass of medium- or coarse-grained quartz, plagioclase, and mica. Locally the larger orthoclase grains have partial concentric rings, or rims, of plagioclase, reminiscent of rapakivi texture. Modes of two gneisses are given.

Table 2.--Modes of porphyroblastic rocks.

	4-3-ID	5-14-ID
Quartz	20-30	40-50
Microcline-perthite	30-40	10-15
Plagioclase, An_{10-30}	15-20	20-25
Biotite	5-10	8-12
Muscovite	2-4	5-10
Zircon	<1	<1
Epidote	<1	1-3
Apatite	---	<1
Sphene	---	1-3

Mica schist

The major exposures of schist are in the southwestern quarter of the map-area, where most of one definite layer, and also a body of unknown structure, consist chiefly of fine- or medium-grained muscovite-biotite schist of irregular texture. Bedding, oblique to foliation, and lineation are locally obvious, but in general foliation is the only visible structure.

At several of the prospect pits in the district, thin layers of fine-grained mica schist are exposed. The schist is heavily weathered and friable, and generally does not crop out naturally. It is probable that mica schist is a much more common constituent of the amphibolite zone than the outcrops indicate.

Quartzite

Rocks of several varieties were called quartzite in the field but most of them were found to consist chiefly of feldspar rather than quartz, for example very fine-grained feldspar-amphibole rock and garnet-bearing orthoclase-rich rock. Fine-grained laminated gneiss, quartz-rich but containing abundant mica, is mapped with the streaked gneiss.

The rocks shown as quartzite on the map are of two habits but are similar in composition, and probably differ only in structural environment. Layers of fine-grained granular feldspar-quartz rock are traceable for considerable distances in various places within and on the edge of the major amphibolite body, as shown on the map. The layers, which have been called "white rock" in the field to distinguish them from other quartzitic rocks, are from 6 inches to 200 feet thick, and in part are interlayered with other rocks, such as feldspar-quartz gneiss, amphibolite, and limestone. The "white rock" layers are concordant with other contacts, are moderately consistent in thickness except for local boudinage, and form large and small folds. Feldspar makes up from 20 to 50 percent of the rock; potash feldspar varies from a minor to a major part of the total feldspar.

A layer 100-200 ft thick is characteristic of the contacts of the major amphibolite body with adjacent rocks. The texture of the layer is generally granular, but locally it is definitely micrographic. The micrographic texture grades into granular texture and has no relation to the coarse grained simple pegmatites of the area.

In the northeastern quarter of C-4 is an area 2500 ft in diameter underlain largely by fine granular feldspathic quartzite similar in appearance to the layered quartzite of the "white rock" type. The attitude of layering, which is considered to be bedding, varies from nearly flat to vertical; but the gross structure of the layer is that of a nearly flat plate crumpled locally into steep folds. Only steep attitudes are recorded on the map.

Despite the unusually large area underlain by this body of quartzite, consideration of the gross structure and its relation to topography indicates that the body is a layer only about 200 ft thick and that it is probably continuous with the layer of "white rock" running northwest from its northwestern corner.

Elsewhere the layer at or near the contact of the major amphibolite and gneiss varies in thickness from 200 ft down to several separate layers each only 10-20 ft thick. Apparently the layer of quartzite in the northeastern corner of C-4 covers a larger area because of a combination of maximum thickness and generally flat attitude.

Limestone

Fine-grained calcite-rock forms layers or lenses up to 10 ft thick, chiefly in amphibolite but also in porphyroblastic gneiss and in streaked gneiss. Generally the rock consists almost entirely of granular calcite with little or no layered structure, white on fresh surfaces and brown-buff on weathering. Locally felted green actinolite is abundant but has no apparent relation to structure or to the rare-element deposits. Locally fine granular magnetite is abundant, especially in the vicinity of the rare-element deposits. Deposits containing one or more of the minerals monazite, rutile, thorite, and allanite occur locally; they are described in the section on mineral deposits.

At the Roberts prospect (NW1/4 of NE1/4 of C-3) calcite-rock containing monazite forms a layer about 2 feet thick in porphyroblastic gneiss. The calcite-rock layer is parallel to the gneissic foliation, and both are folded. In structure and appearance the calcite-rock of this prospect is similar to that in the other calcite-rock layers and inasmuch as the gneiss is here considered to be meta-sedimentary, the calcite-rock is also considered to be a metamorphosed limestone. Limestones in other areas of metamorphism have been described as notably resistant to metasomatic changes, for example in the older French literature on granitization.

Amphibolite

Amphibolite underlies most of the central part of the map-area and encloses nearly all of the limestone layers, which, in turn, contain all the rare-element deposits. The amphibolite is typically dark green; and ranges from fine- to coarse-grained, and from massive to schistose. All these varieties may be found in a single outcrop, without any apparent regularity. Tabular or sheeted structure, visible in many outcrops, may represent bedding, but definite bedding is generally absent. Amphibole aggregates make up from 1/3 to 2/3 of the rock; the rest is mainly plagioclase. Amphibole aggregates consist of actinolite cores rimmed by blue-green hornblende. The blue-green hornblende is not sodic but contains a slightly larger proportion of ferric vs. ferrous iron than common green hornblende. The plagioclase is anhedral and is wrapped by amphibole aggregates; in handspecimen the texture is characterized by irregularly curved boundaries of the plagioclase and by felted texture of amphibole aggregates. The following modes illustrate the variations in amphibolite.

Table 3.--Modes of amphibolite.

	44ID	53ID	34ID	35ID
Average grain size	0.05 mm	0.5 mm	0.5 mm	1-4
Amphibole	50-60	60-70	50-60	40-45
Plagioclase	15-25(An_{35})	25-30(An_{30})	35-45(An_{45})	30-35(An_{45})
Biotite	5-10	---	2	5
Quartz	15	---	---	5
Sphene	3	---	1	---
Opaque	4	4	3	6
Epidote	<1	<1	<1	3
Apatite	<1	<1	---	<1
Clay minerals	1	<1	2	<1

Amphibolite containing swarms of large subhedral crystals of plagioclase forms layers, lenses, and streaks in the even-grained amphibolite. Some of the layers may be traced for thousands of feet, although only a few feet thick; several of them are shown on the map because they offer almost the only key to the major structures of the amphibolite. The rock in the mappable layers is the same as that in less definite lenses and streaks; all have gradational boundaries with even-grained amphibolite and differ only in the presence or absence of the large feldspar grains.

Meta-diabase

Locally within the amphibolites are found fine-grained massive granular rocks of distinctive appearance, weathering brown-buff. Rocks of this type form small bodies with vague boundaries and without visible extension as layers or lenses. Characteristically the rocks are cut by random or subparallel fracture zones 1/8-1/4 inch wide, forming narrow dark welts on weathered surfaces. In thin section the rocks exhibit relict diabasic texture involving pyroxene and plagioclase. The pyroxene consists of augite and minor hypersthene; the plagioclase laths are strongly zoned, with cores of An_{45-70} and rims of An_{20-30}. The dark fracture zones consist of aggregates of amphibole replacing pyroxene. The amphibole is actinolite and blue-green hornblende, both similar to the amphiboles in the amphibolites. As in the amphibolites, the blue-green hornblende is not sodic, but has a slightly higher ratio of ferric iron to ferrous iron than green hornblende.

The composition, texture, and irregular habit of the meta-diabase suggest that it is of igneous origin, but it may be merely a metamorphic variant of the amphibolite.

Pegmatite

Simple quartz-feldspar pegmatites form irregular small bodies in the gneiss and amphibolite. None has been found in the rocks northeast of the major fault. No continuous dikes have been seen. Very rarely allanite and monazite crystals are found. In the south central part of the southeast quarter of B-4 were found several boulders of fine-grained tourmaline-quartz rock, probably of pegmatitic type.

Rhyolite

The youngest solid rock in the area, and the only one of undoubted igneous origin, is rhyolite occurring as dikes in both the intensely metamorphosed rocks and in the less metamorphosed rocks northeast of the major fault. The dikes are typically 10-40 feet thick but also coalesce to form large irregular bodies, as in the Roberts area. Although the rhyolite occurs in rocks of all types, it is restricted in two aspects.

First, nearly all of the rhyolite in the map-area is in a zone about one mile wide trending northeastward, centering on the southern part of Papoose Creek (NE corner C-3). Other rhyolite dikes occur several miles eastward toward North Fork. Concentration in zones or swarms is typical of the Tertiary dikes of the Idaho batholith.

Second, in the Papoose Creek-Squaw Creek area, rhyolite is more common in and near the "white rock" quartzite at the edge of the major amphibolite zone, probably for structural reasons.

The rhyolite consists largely of a glassy or devitrified base containing sparse phenocrysts of quartz and feldspar. Flow lines and bubble lines are common. The dikes are chilled for several inches at their borders. The feldspars are albite and potash feldspar, the latter corroded and exhibiting vague twinning patches, sericite flakes, and small albite inclusions or replacements. Sparse biotite is the only primary mafic mineral.

STRUCTURE

Major fold structures

In the Mineral Hill district a major northwesterly fault separates rocks of very different type and structure. In the moderately metamorphosed rocks to the northeast, fold structures of three types may be seen. First, the rocks as a whole, within the map-area, form a monocline dipping 40-60 degrees southwest, as part of a major anticline outside the map-area. Second, locally there are smaller folds on moderately plunging axes, chiefly in the northeast corner of the map-area and at Ulysses, where they may have some connection with the copper deposits there. Third, within a few hundred feet, measured at right angles, from the major fault, the rocks are heterogeneously crumpled, so that crumple axes are not concordant; for example, they plunge steeply in opposite directions within a short distance. The close relation of crumpling of this type to the major fault indicates that the two structures are related. Lineation is lacking from all the rocks northeast of the major fault, except in the crumpled and schistose rocks near the major fault.

On the southwestern side of the major fault the rocks, in addition to their more intense metamorphism, generally are tightly crumpled. Lineation and crumple axes are parallel and strike northwest; their plunge is highly variable. Mapping has shown that the rocks may be grouped into lithologic units, as shown on the geologic map; these units are considered to preserve at least the major features of original sedimentary units. Unequivocal bedding is not generally present; experience has indicated, however, that in most places foliation is parallel to original bedding in these rocks.

The pattern of the fold structures is given by 1) the major contacts; 2.) the keybeds: limestone, quartzite, and porphyroblastic amphibolite; and 3.) foliation and lineation. Consideration of these structural elements in conjunction with the pattern on the map indicates that the rocks southwest of the major fault form a large, complexly crumpled fold. As most of the rocks dip southwest on both sides of the fold, those on one side must, in this view, be overturned.

The clearest evidence for top-and-bottom relations of a major contact is in the area of quartzite in the NE1/4 C-4, where the contact may be mapped between the large quartzite plate, generally above the 4250-foot contour, and the gneiss surrounding it on three sides, generally below the 4250 contour. Taking into account the local steep dips, the quartzite appears to form a plate lying nearly flat, although locally tightly crumpled, and therefore probably lying right side up. On the southern side of the quartzite plate, both the quartzite and the gneiss dip northward.

To the northwest, the layer of "white rock" quartzite, with which the quartzite plate is correlated, is separated from the gneiss by amphibolite of variable thickness. If the correlation is correct, and if both rocks are of sedimentary origin, the amphibolite has presumably been squeezed out from the contact between the large quartzite plate and the underlying gneiss.

Areas of flat dips in the rocks southwest of the major fault seem to have some significance, as they coincide with areas where the layered structure of the rocks becomes confused. Their relation to faulting is described in the section on minor faults.

The top-and-bottom relations deduced in the area of the large quartzit plate are corroborated by dips near major contacts at several places, especially on the east fork of Spring Creek, in the western half of B-2. Following the interpretation discussed above, the major fold structure in the area is considered to be a synclinorium, with the thick amphibolite layer in the middle flanked and underlain by the gneiss layers and the thinner layers of streaked gneiss and amphibolite.

Minor fold structures

Complex crumpling is most common in the amphibolite and least common in the thick gneiss zones. Mapping of key beds of quartzite and porphyroblastic amphibolite in the major amphibolite layer indicates that the rock forms isoclinal folds as large as several thousand feet across and a thousand feet deep; and as small as a few inches across. The continuity of key beds, especially of limestone, is difficult or impossible to establish under these conditions; but their continuity, as far as it can be established, clearly indicates the type of folding in these rocks.

In the gneissic layers, mapping indicates that minor structures are uncommon, but the layers generally are part of large tight or isoclinal folds. In thin gneiss layers, and near contacts, gneissic foliation is not uncommonly crumpled. Rare relict tight crumpling in the major gneiss layers suggests that minor crumples have been obliterated during development of coarse gneissic structure in the rocks.

At nearly all the prospects, the limestone is folded on axes of moderate plunge; recognition of the fold structure is essential for exploration of the limestone layers. For example, at the main prospect pit in the Silver King No. 3 area, the mineralized limestone forms a shallow syncline skimming the hillside and plunging northwesterly parallel to the surface of the hillside. Exploration on the assumption that the limestone is a vein, extending downward, would probably be fruitless here.

Major fault

The intensely metamorphosed and folded rocks are separated from the moderately metamorphosed rocks to the northeast by a major fault. On the northern side of the Salmon River the fault can be traced accurately, and its relation to topography indicates that it dips about 30 degrees to the southwest. Its topographic expression elsewhere indicates that the dip is approximately constant.

To the southeast, the fault enters the complex area of the Salmon quadrangle and its extension is unknown. Anderson (1956, p. 46-47) indicates a fault of comparable type and trend along Jesse Creek, but farther south than the fault in the Mineral Hill district. To the northwest, probably the same fault has been recognized in the Sheep Creek prospect area, at the head of the West Fork of the Bitterroot River in Montana. The fault has a known length of 10 miles and a probable length of over 15 miles, and separates rock groups of different intensities of metamorphism and folding. Its displacement is unknown, but by analogy with other faults of similar type, probably approaches or exceeds a mile.

Near the Salmon River, gneiss is faulted against quartzite, and the fault can be traced accurately. In several other areas, however, notably east of Indian Creek, fine-grained quartzitic schists, of a type that occurs only near the fault, are of doubtful affiliation. They are here considered to be quartzite on the northeast side of the fault, metamorphosed to schist near the fault zone.

Minor faults

Mappable faults are both sparse and difficult to interpret. In the intensely metamorphosed rocks a fault may well be closely related to distributed shearing, and even to plastic flow. Thickening, thinning, and boudinage are undoubtedly present, and the exposure is inadequate for clear decipherment of such structures. The enigmatic disturbed zones in the NE corner of C-3 and the NW corner of B-2 probably involve faulting, shearing, and plastic flow; faults have been indicated on the map to explain, at least partially, the discrepancies across the zones. The occurrence of flat dips in these areas apparently has some relation to the type of disturbance.

Closely spaced faults of small displacement may be seen readily in two areas, which are described here as examples. In the center of B-3 is a narrow crooked valley in which a partly completed cat-tractor road leads from the Squaw Creek road northwest toward the Lee Buck No. 13-14 claims. Between the lower part of the valley and the Squaw Creek valley is a narrow rock ridge consisting chiefly of amphibolite, with layers of gneiss and limestone. The rock layers are cut by a swarm of northeasterly faults, of displacements from a few feet to 50 feet. The fault planes are rarely seen, and the faults would not be recognized except for the uncommonly distinct layering.

At the main cut of the Lee Buck No. 3 claim, above the short tunnel driven by the Molybdenum Corp. in 1954, a northeast-trending fault cuts the mineralized limestone and adjacent mica schist and amphibolite. Probably the same fault is exposed downhill to the west near the drillhole site, in the short road leading east to the tunnel portal. The limestone layer apparently is offset only a few feet, although crumpling and shearing obscure the relations. Probably both folding and faulting are responsible for the absence of the limestone layer in the tunnel workings and in the drill hole. Other faults may be inferred in the vicinity, offsetting the limestones and making it impossible to trace them for any great distance.

Undoubtedly faults of small displacement are present over much of the district. The aerial photos show a distinct northeasterly trend of short straight lines, or linears, which are probably the expression of faults like those described here.

ORIGIN OF THE METAMORPHIC ROCKS

The rocks northeast of the major fault are typical clastic sediments of Belt (late Precambrian) age. Similar rocks to the north in Montana, undoubtedly continuous with those in the present area, have been mapped by Ross (1955) as Ravalli formation of Belt age.

The rocks southwest of the major fault include rocks that, considered by themselves, fall into four categories.

1. Definitely of sedimentary origin: quartzites and laminated gneisses.
2. Probably sedimentary: limestone and mica schist.
3. Equivocal: amphibolite, porphyroblastic amphibolite, and meta-diabase.
4. "Igneous-looking" (cf. Grout 1941): streaked gneiss and porphyroblastic gneiss, which in the past have been called granite gneiss and granite.

The salient factors relating to the origin of the rocks as a whole are

1. Absence of discordant contacts.

2. Linear outcrop pattern of major rock types, indicating layered structure.

3. Interlayering of definitely sedimentary rocks and probable sedimentary rocks (types 1 and 2), with the other types (3 and 4).

The major amphibolite layer and the thin layers of amphibolite in gneiss are not of discordant type. The two most likely modes of origin are metamorphosed shaly sediment, and metamorphosed basic sill of the Purcell type (Anderson 1930, p. 24-28, and 1956, p. 38). The amphibolite contains blue-green amphibole, somewhat like that of the Purcell sills; and the meta-diabase could well be remnants of sill rock. Many of the Purcell sills are concordant with enclosing sediments for long distances. On the other hand, the great heterogeneity of the amphibolite, and the abundance of interlayered quartzite and limestone, are much more suggestive of original heterogeneous layering and therefore of original sedimentary character. In this report the amphibolite is considered, therefore, to be a metasedimentary rock.

The origin of the limestone layers is closely tied to that of the amphibolite. The limestone layers are relatively continuous, considering the complex structure, and are similar in habit to quartzite layers that are considered definitely sedimentary. The limestone is here considered also to be metasedimentary.

Porphyroblastic and streaked gneiss form layers, thick and thin, within or concordant with amphibolite. Locally gneiss is interlayered and folded with quartzite and limestone. No major discordances are present between gneiss and other rocks, and probably no minor discordances except those referable to faulting or shearing.

The layered gneiss, therefore, is considered to be of sedimentary origin, transformed into an "igneous-looking" rock by metasomatic processes (cf. Grout 1941). The great body of gneiss in the southwestern corner of the map-area (C-1 and C-2) offers little evidence of any kind, but does not differ in texture from the definitely layered gneisses to the northeast. From this point of view, the burden of proof would lie with the statement that the gneisses are igneous, rather than the reverse.

In any event, the gneisses in the southwestern corner of the map-area do not simply represent 'the beginning of the Idaho batholith' as one goes westward; for still farther west, beginning a few miles below Shoup on the Salmon River road, is a large area of well-bedded quartzitic and schistose sediments, whose relation to the batholithic contact is not established.

All the metamorphic rocks southwest of the major fault, therefore, are considered to form a sedimentary sequence. Stratigraphically the sequence is similar to that of rocks of Belt age; the abundance of Belt sediments in the general area further suggests this correlation. Stratigraphically the rocks are not similar to the Paleozoic rocks of the area and this correlation is not likely. The rocks, however, may be of pre-Belt age, like the rocks variously called Cherry Creek series and Pony series in Montana. No evidence is at hand on either side, but it is more likely that the rocks are of Belt age.

The rocks were presumably metamorphosed during the emplacement of the Idaho batholith, and faulted against the less metamorphosed rocks at or near the end of that episode.

The final elucidation of these problems will come only with complete mapping of the eastern side of the batholith and nearby rocks.

MINERAL DEPOSITS

Formerly the only known mineral deposits in the map-area were the copper-gold deposits near Ulysses, originally forming the Indian Creek mining district. The two mines with production history are the Kittie Burton mine, near the NW corner of the SE1/4 of the NE1/4 of A-4; and the Ulysses mine, near the central point of A-5. The mines have not been operated since 1923 and are entirely inaccessible. No new information can be added to the detailed description of Umpleby (1913, p. 134-138).

Radioactive deposits were discovered in 1952 and have been prospected extensively. They are described in the next section.

Deposits of rare elements

The limestone layers in the area southwest of the major fault locally contain deposits of the minerals monazite, thorite, allanite, and niobium-bearing rutile. Magnetite, ilmenite, and actinolite are locally abundant. The deposits are widely scattered but have the following features in common:

1. Of at least 30 prospects in deposits of this type, all but two are in a zone 1-1/2 miles wide extending from southeast to northwest across the map area, a distance of about 10 miles.

2. All the deposits are in limestone; nearly all are in limestones in the major amphibolite zone.

3. The known deposits are of small size and very irregular tenor.

4. All the deposits contain monazite. The monazite contains little thorium (probably averaging less than 1 percent); but is associated with thorite, or with allanite containing several percent thorium.

5. Thorite and rutile have not been found in the same deposit.

6. Rutile contains from 5 to 10 percent niobium as an integral part of the mineral. No other niobium-bearing mineral has been found, except for ilmenite, which apparently contains a small quantity of niobium (table 4).

The areas where most prospecting has been done are marked on the map by the names of the principal groups of claims. Most of the prospects are in these areas. Limestones, and therefore prospects, are generally lacking in the area of Sage Creek drainage (C-5 and C-6).

Table 4.--Spectrographic analyses of minerals from Mineral Hill district, Idaho.

Analyst, P. R. Barnett, U. S. Geological Survey

Field number	Description	Locality
3-MQ-2	Rutile, purified in Frantz separator; nonmagnetic at .25A, magnetic at .55A	Monazite Queen prospect
6-ID-3	Rutile, purified in Frantz separator; nonmagnetic at .25A, magnetic at .40A	Lee Buck No. 3 claim, 30 feet S. E. of location notice
8-ID-3	Rutile, purified in Frantz separator, nonmagnetic at .25A, magnetic at .60A	Lee Buck No. 10 claim, on ridge
5-ID-1	Rutile, purified in Frantz separator, nonmagnetic at .25A, magnetic at .40A	Lee Buck No. 3 claim, "high grade locality"
15-ID-1	Ilmenite, massive	Roberts prospect area

	Nb	Fe
3-MQ-2	10.	8.
6-ID-3	8.	12.
8-ID-3	8.	5.5
5-ID-1	3.5	20.
15-ID-1	.6	---

The prospects consist of shallow holes sunk at points of maximum radioactivity, exposing limestone layers a few feet thick. The rare minerals typically form small irregular aggregates or streaks in limestone; no gangue of quartz, calcite, etc. is present. Rather, the minerals are included in limestone like that typical of the limestone layers elsewhere. Generally only a few aggregates of the rare minerals are seen. Where more extensive openings have been made, as in the upper prospect of the Hutchingson area and in the Lee Buck No. 3 cut, the distribution of the minerals appears to be highly irregular. The Lee Buck No. 3 area has had the most exploratory work, but the discovery outcrop was not opened extensively; and the cross-cut and drill-hole are lower than the outcrop and did not cut limestone.

Radioactivity of the deposits varies widely. Where monazite is the only thorium-bearing mineral, the radioactivity is only a few times higher than average, but thorite and allanite increase the radioactivity markedly. An autoradiograph of a sample containing coarse monazite and allanite showed that most of the radioactivity was in the allanite, and very little in the monazite.

Thorite has been found only in a small area along Squaw Creek (NW corner NE1/4 B-3), at No-Name Gulch (NW corner D-7), and on the south side of the Salmon River opposite No-Name Gulch. It occurs as reddish-brown grains 1 mm or less in diameter. Monazite is honey-brown, translucent, and generally coarsely crystalline; cleavage faces 1/2 inch across are common. Rutile occurs in most deposits from the Indian Creek area northwestward, but is relatively abundant chiefly in the Lee Buck No. 1-12 claims. Rutile is dark steel-gray, massive, with higher luster than ilmenite or magnetite; no crystals or even crystal faces have been seen. Lumps of rutile an inch or two in diameter are common. Rutile contains from 4 to 10 percent niobium (Nb), as part of the rutile **crystal** structure (table 4). Polished sections have not shown any intergrown mineral such as columbite to account for the high niobium content.

Allanite is also coarse-grained, and commonly intergrown with monazite. Illmenite forms massive lumps, like rutile, but has less luster, and may be distinguished from rutile with a magnet. Powdered ilmenite is attracted by an alnico magnet, but powdered rutile is not attracted. Magnetite occurs in fine-granular streaks and disseminated grains in limestone, especially near the rare-element deposits, although the rare-element minerals are sparse or absent in magnetite-rich limestone.

In the Roberts area, the prospect indicated on the map (center NW1/4 NE1/4 C-3) contains only monazite, in a limestone layer 1-2 feet thick enclosed in gneiss. Other prospect pits expose coarse ilmenite streaks in gneiss. The Bevan radioactive prospect (west edge SE1/4 SW1/4 C-4) is in heavily weathered rock of uncertain type, but probably contains only monazite.

At most of the prospects, the enclosing limestone layer is folded either synclinally or anticlinally. On the west side of Indian Creek, for example, barren limestone layers may be traced for a thousand feet or more in a straight line, but where rare-element deposits occur the limestones are folded and cannot be traced farther in the same line. Folds at the Silver King prospects are described in the section on minor folds. The common relation of minor folding and mineralization suggests that the deposits are localized on crests or troughs of small folds. By analogy with other mineral deposits controlled by folds, the rare-element deposits may be expected to extend farthest along the axial line of the folds, rather than across the folds.

The influence of minor faults is not known. At the Lee Buck No. 3 prospect, a fault cuts the mineralized limestone, as described in the section on minor faults, but exposures at other prospects is inadequate for assessment of this factor. It is quite possible that the combination of a fault, a fold, and a limestone bed determines the localization of a rare-element deposit.

Origin

The salient features of the rare-element deposits are:

1. distribution along a zone 10 miles long, varying in altitude from 3600 feet to 7100 feet.
2. restriction of most of the deposits to a belt 1-1/2 miles wide in the middle of the amphibolite zone, stratigraphically in the upper part of the amphibolite layer.
3. variation, on the whole, from deposits with thorite but without rutile, to the southeast; to deposits with rutile but without thorite, to the northwest.
4. occurrence in limestone, probably localized by folds; absence of gangue minerals, special fracturing, or special metamorphic effects.

The deposits may have been formed in several ways: 1. metamorphism of original placer deposits of heavy minerals; 2. hydrothermal replacement; or 3. metamorphic segregation or secretion.

1. Formation from original placer deposits is considered because the suite of rare elements, and even in large part of minerals, is characteristic of the heavy mineral suites in placer sands, such as those at Elk City, Idaho. The environment represented by the limestone, however, does not allow the analogy to be carried further; and no special quartzites, from which the rare elements might have migrated, are typically associated with the deposits. This mode of origin is not satisfactory.

2. The process of hydrothermal replacement leaves clear fingerprints in some deposits, as in many veins, blankets, chimneys, etc.; but in many other deposits its identification is difficult, as in lead-zinc deposits of Mississippi Valley type, and uranium deposits of Colorado Plateau type. In the Mineral Hill district, the deposits contain no special fracturing, no gangue material, no alteration or coarsening of country rock; in short, they contain no evidence of hydrothermal activity, except perhaps the presence of the rare minerals themselves.

The occurrence of many deposits throughout a long zone, most of them in the very special environment of thin folded limestones, indicates either that there were very many fractures carrying hydrothermal solutions, many of which, in turn, happened to lead to folded limestones; or else that the body of rock as a whole was permeated with mobile material, presumably solutions, carrying the rare elements and depositing them in favorable environments. Concepts of a similar type are being considered currently in relation to Mississippi-Valley-type deposits.

3. The concept just stated, however, is essentially that of metamorphic (or metasomatic) segregation or secretion, when applied to metamorphic rocks. For application in the present area, it may be stated as follows. During metamorphism (which obviously involved high mobility, judging from the abundant growth of porphyroblasts), solutions permeated the rocks and carried appreciable, though probably small, proportions of the rare elements, either introduced along with the solutions from an unknown source, or taken up selectively from the rocks themselves. At some stage, deposition began but the only favorable environment for definite concentrations was a limestone in a certain structural setting. Stratigraphic and structural control restricted the deposits to their present position.

A similar concept, in part involving rare elements, has been elaborated by various workers. In the Mineral Hill district, distinguishing criteria are scarce or lacking; but because of the wide distribution of the deposits, metamorphic segragation is somewhat more plausible than hydrothermal activity of a more restricted type.

Economic factors

In view of the inadequate exposure and great irregularity of the rare-element deposits, the writer has not sampled them for grade estimation. As in other deposits with scattered coarse lumps of "ore-mineral", small samples are of less than no value for estimates of average grade.

The known deposits are restricted to limestone; and no limestone layer or interbedded series over 8 feet think has been seen. Most, if not all, of the known deposits are in folded zones. The known deposits, therefore, are restricted by geologic factors. Their greatest extent is likely to be along the axial line of the folds, and exploration should be directed in this trend, preferably starting at the outcrop of the deposit. Where no fold can be determined in the limestone, folds or lineation in nearby rocks should be studied to determine the preferred direction of folding. The attempt to cross-cut to a deposit, especially from collar positions above or below the outcrop, will probably miss the deposit and even the limestone layer as a whole.

Along the axial line of a fold, there probably are pinch-and-swell (sausage-and-gut) relations, both in the limestone itself and in the grade and size of mineralized rock. To date, there has been no exploration in the district directed to explore these relations.

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