Mineralogy of the Lemhi Pass Thorium and Rare-Earth Deposits

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INTRODUCTION

The Lemhi Pass thorium and rare-earth deposits are in a northwest-trending structural zone on both sides of the Continental Divide in Idaho and Montana (Figure 1). The district ranges in elevation from 4,000 feet to 9,000 feet above sea level.

Thorium was first discovered near Lemhi Pass in 1949. Subsequent discoveries have extended the district along the trend to the northwest in two additional areas known as North Fork and Diamond Creek. Veins crop out sporadically in an area about 70 miles long by 8 miles wide. Bedrock is almost everywhere concealed beneath a deep cover of soil and mantle; natural exposures of veins are rare. Concealed veins, detected by surface radioactivity, have been exposed by trenching with bulldozers.

GEOLOGY

Host rocks are quartzites and phyllites of the Precambrian Belt Series, and gneisses and schists, which are either more highly metamorphosed rocks of the same Series or, perhaps, older rocks. To the northwest, some veins extend to the borders of the Idaho Batholith of Cretaceous age. At the southeast end of the district a small, anomalously radioactive granitic intrusion of Tertiary (?) age is exposed over an area of about two square miles.

Hand samples of this rock contain as much as 22 parts per million U_3O_8, 140 parts per million ThO_2, and anomalous amounts of rare earths. The rock consists essentially of orthoclase, microcline, quartz, and biotite. Accessory minerals are white mica, mostly sericitic; magnetite; plagioclase; epidote; and zircon. A black mineral gave an X-ray powder pattern near artificial iron niobate (Smith, J. V. ed., 1966) and is being investigated by Arden Larson, a former colleague. All samples are stained pink or red by hematite. Thorium content increases with degree of red coloration.

No thorite was found in a limited mineralogic study of the granite. X-ray spindles were made of clusters and discrete crystals of pink to red and pale yellow tetragonal minerals extracted from the granite. These are commonly stubby, with prism faces absent or poorly developed. All proved to be zircon, as did a larger crystal which was gray on the outside with a yellowish center. The thorium content of the zircons was not determined. Most of the thorium and rare earths are believed to occur in the zircon, probably mostly in the red variety, since other likely host minerals are extremely sparse.

Diorite dikes and sills commonly occur in the vicinity of the thorium veins but show no consistent relation to them. The veins intersect some of these dikes and locally adjoin others. The diorite shows weak thorium mineralization only near its contact with the veins. Thorium in the dikes may be primary but could well be secondary, since supergene concentration of thorium is evident in most veins. A. L. Anderson (1961, p. 54) describes the dikes as greenish-gray, medium-grained diorite containing
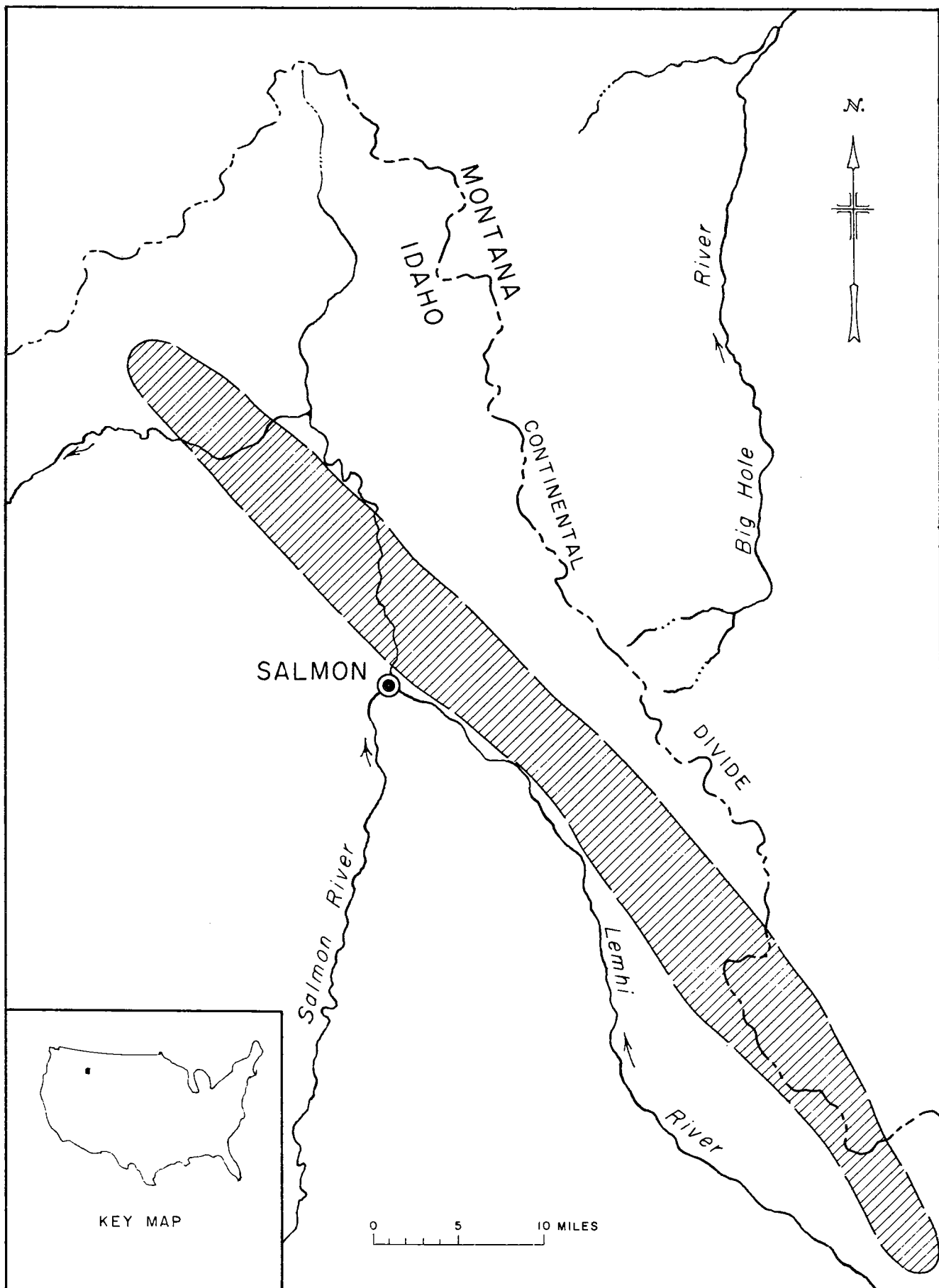
Figure I.   Index Map of the Lemhi Pass Area

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distinguishable crystals of hornblende and biotite despite rather intense alteration. Feldspar grains are chalky white and considerably altered. Chlorite and epidote appear to be alteration products. Exposures are highly weathered, but hydrothermal or possibly deuteric alteration appears to have preceded weathering.

Some dikes contain roughly spheroidal masses of calcite averaging perhaps a centimeter in diameter. The calcite may be an alteration product, but no pseudomorphs or other evidence of systematic replacement of any other original mineral were observed. At the outcrop, one dike consists of about 50 percent calcite. Weathering and limited exposure and sampling preclude firm conclusions as to the origin of the calcite, but it may be related to carbonate minerals in the thorium veins. Anderson (1960b) describes biotite ghosts in calcite from some of the thorium veins, but we did not observe similar ghosts in our limited study of the dikes. Several of the freshest samples from other diorite dikes contain blebs of calcite a few millimeters in diameter. Additional sampling, and isotopic analysis of carbon, oxygen, and strontium could possibly provide clues to the origin of the calcite. The fresher samples of diorite also contain sparse pyrite crystals about a millimeter across.

Rocks of early Paleozoic and Tertiary age overlie the Belt Series in the general area. Paleozoic limestones locally contain base-metal deposits but no significant thorium. Among the rocks of Tertiary age are the Challis Volcanic Series, which once directly overlay the Belt Series in much of the area. Block faulting, probably of late Tertiary age, has resulted in preservation of rocks of the Challis Series in down-dropped blocks; whereas, in the upthrown blocks erosion has removed them, exposing the Belt Series with included thorium veins. Commonly observable relationships between the Belt and Challis Series are fault contacts; therefore, locations of veins beneath the volcanics cannot usually be postulated. Veins are thought to be of early Tertiary age since they cut the Laramide (?) dikes but not the Challis volcanics.

The Lemhi Pass mineral deposits may be classified into two more or less distinct types: base- and precious-metal veins with minor thorium, mostly near the western border of the district; and thorium veins with rare earths and minor base and precious metals. A. L. Anderson (1961a) states: "Most of the deposits discovered during the late wave of prospecting are not associated with earlier quartz and copper-bearing veins but are along independent zones of shearing and fracturing."

The thorium veins may be further subdivided into quartz-hematite-thorite veins and replacement deposits with monazite. Some of the quartz-hematite-thorite veins have apophyses with carbonate gangue [calcite, manganocalcite, siderite, ankerite (ferroan dolomite)] , which are richer in thorium. The district shows rough zonation, with quartz-hematite-thorite veins in quartzite and phyllite predominating toward the southeast, and monazite replacement deposits, mostly in gneiss and schist, increasingly dominant toward the northwest. The presence of the element, columbium, (Montoya, 1966, written communication) and the mineral, ilmenorutile, in the Lucky Gem monazite deposit near the northern end of the district indicates a zonal relationship to columbium-bearing rutile deposits still farther to the north. Zonation is further complicated by the presence of gold, silver, and base metals in quartz-hematite-thorite veins near the center of the district. Neither the zoning nor the types of deposits are sharply defined.

DESCRIPTION OF DEPOSITS

Most of the thorium and rare-earth veins of the Lemhi Pass district are known only from surface exposures or shallow trenches. Six have limited underground workings; one has been explored by a 200-foot adit reaching a depth of about 200 feet below the surface. A small amount of drilling has been done to similar depths.

Most of the tabular veins dip steeply (40° to 85°) southwesterly and strike northwesterly. Veins attain a maximum known width of 40 feet. Lengths of veins are unknown, but some have been traced discontinuously for nearly two miles. Veins crop out in a vertical range of about 4,000 feet and throughout a similar stratigraphic interval. Local relief exposes individual veins over a vertical range of about 2,000 feet. Maximum depths of individual veins or mineralized portions of them are unknown.

At the surface and at the shallow depths reached by exploration, most veins are characterized by abundant "limonite" (impure goethite and lepidochrosite). In apophyses with carbonate gangue, "wad" (pyrolusite and/or other manganese oxides) may be more abundant than limonite.

Previous workers (Anderson, 1961a, b; Sharp and Cavender, 1962), as well as this study, indicate that the highest radioactivity and greatest thorium content are found in limonitic zones. In these zones, and to a lesser degree throughout the depoists to the maximum depth of exploration, thorium mineralogy is obscure. Thorium minerals recognizable even microscopically are not deemed abundant enough to account for all the thorium in the richer hand samples, containing 3 percent to 17 percent ThO_2. Thorium may exist partly adsorbed on limonite and wad and partly as submicroscopic thorite or, more probably thorogummite.

Commonly the thorium mineral in limonite and wad cannot be determined by X-ray. However, some veinlets and discrete crystals of thorite or thorogummite, thought to be mostly of supergene origin, are discernable in a few of the most limonitic samples. Even these give X-ray powder diffraction patterns of poor quality but resembling those of natural thorite and thorogummite listed in the ASTM "Powder Diffraction File," Card Nos. 11-172 and 8-440, respectively (Smith, J. V., ed., 1966).

Although the samples richest in thorium invariably contain abundant limonite and wad, many samples of ore grade (more than 0.30% ThO_2) contain only minor amounts of these substances. Some of these contain discrete thorite crystals showing good crystallinity. Quite commonly in the same hand specimen or thin section, there may be other thorite crystals that are partly or completely metamict. Some of those that are partly metamict have partly recrystallized and now contain several minute crystals in various orientations within the original crystal outline. From these, it is deduced that even the discrete crystals may have become metamict and recrystallized as, or been replaced by, the hydrous variety, thorogummite.

The U. S. Bureau of Mines, Salt Lake City, Utah (Montoya, J., 1966, written communication) has identified the principal thorium mineral as altered thorite, possibly auerlite (Hidden and Mackintosh, 1888), a variety of thorite containing phosphate. Rankama and Sahama (1950, p. 519) indicate mutual substitution of thorium zirconium

and rare earths, and of silica and phosphate in the isomorphous series comprising zircon, thorite, and xenotime. Because of the difficulty in obtaining sharp X-ray patterns, as well as lack of quantitative chemical analyses of mineral separates, we have not succeeded in confirming the U. S. Bureau of Mines's identification, other than some variety of thorite. Neither have we been able to relate any variation in crystal-lattice parameters to substitution of uranium, zirconium, yttrium, or rare earths for thorium, or of phosphate for silicate. The very low uranium content of all samples, except one or two from radioactive base-metal veins, would indicate little substitution of uranium for thorium. We are here using the term thorogummite to encompass all hydrous varieties of thorite believed to be of secondary origin.

Monazite is the most abundant thorium and rare-earth mineral in the replacement deposits in gneiss and schist, where it is readily recognizable megascopically, microscopically, and by X-ray. Monazite also occurs in some of the quartz-hematite-thorite veins, and thorite accompanies it in some of the replacement deposits. Analyses of the monazite indicate an unusually low thorium content, about one percent ThO_2. Samples richer in thorium might well be found with additional sampling and analyses.

Other thorium and rare-earth minerals identified from the Lemhi Pass area are allanite, bastnaesite, ancylite,, and euxenite (Anderson, 1960b, 1961a, b), and eschynite-priorite, xenotime, and churchite (Montoya, J.). Bastnaesite may likely be secondary (cf. Wedow, 1961a), as may the similar mineral, ancylite, and the hydrous rare-earth phosphate, churchite.

Because of the tendency of phosphate minerals to incorporate thorium and rare earths; apatite, collophane, pyromorphite, and the unidentified calcium, iron, and manganese phosphates reported by Montoya may contain these elements; but none of these was analyzed.

Anderson (1960a) states that thorite, specular hematite, monazite, barite, feldspar, and quartz are invariable constituents of the veins. To these, we would add apatite or other phosphate minerals and limonite. The complete mineral assemblage (see table) resembles most closely the first (thorium-niobium-rare-earth) genetic type described by Nevskii and Koslova (1965). A few minerals characteristic of their second genetic type (thorium-beryllium-rare-earth-lead-zinc deposits) are present in the district. However, no beryl has been identified; and no significant beryllium content has been detected in many analyses of ore samples.

Anderson (1958, 1959, 1960a, 1960b, 1961a, 1961b) and Sharp and Cavender (1962) report calcite and siderite from the carbonate veins. We made X-ray identification of ankerite (ferroan dolomite) from one of the veins and Montoya (1966, written communication) reports ankerite and manganocalcite. Wad is likley to be more abundant than limonite in the carbonate veins. Massive purple fluorite, more or less intermixed with quartz, is an important gangue mineral in the Apex vein.

PARAGENESIS

Anderson (1961b) presents a paragenetic sequence for the quartz-hematite-thorite veins, from oldest to youngest: biotite; phlogopite; sericite; epidote; allanite and thorite; monazite; xenotime (?); apatite; euxenite (?); specularite; barite; feldspar; calcite; magnetite; pyrite; quartz; chalcedony. For the monazite deposits he (Anderson, 1960a) presents the sequence: biotite (two generations); actinolite; phlogopite; garnet; epidote; allanite; glaucophane; chlorite; apatite; monazite; ancylite; bastnaesite; calcite; barite; magnetite; sphene; ilmenite; ilmenorutile; rutile; quartz; pyrite; pyrrhotite; chalcopyrite. Sharp and Cavender (1962) do not give a complete sequence,
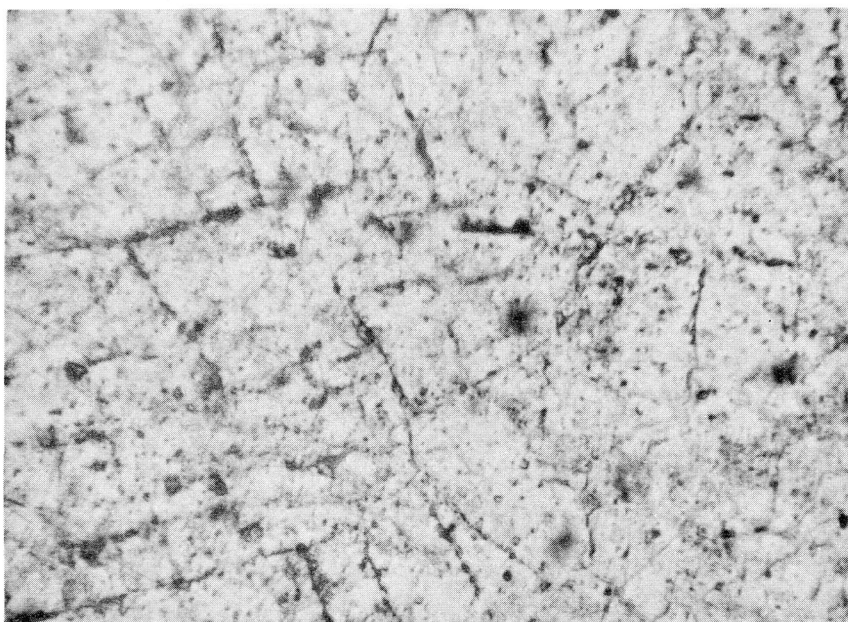
Figure 2. Thin section, Silver Queen 52B vein. Quartz with grid pattern. Ordinary light, about 65X.

Figure 3. Thin section, Silver Queen 52B vein. Late calcite filling (light gray) between earlier dark manganoan ankerite (?) and quartz (nearly white). Ordinary light, about 65X.

but consider that quartz is followed and replaced by siderite, barite, and thorite in the Wonder Lode and Last Chance veins.

These sequences will not be discussed in detail here. However, relations between quartz and carbonate minerals are of particular interest.

In a thin section from the Silver Queen 52B vein (Figure 2) quartz shows a grid pattern of opaque material suggestive of carbonate cleavage. Other sections of quartz, including some from veins in which no carbonate minerals were observed (e.g., the Cago vein), show similar but less distinct patterns. This suggests, but by no means proves, that many, perhaps all of the veins may once have contained carbonate minerals which were replaced to some degree by quartz.

Figure 3 shows two carbonate minerals and quartz from another part of the thin section illustrated in Figure 2. On the basis of X-ray identification of another sample from the same vein, the darker mineral in Figure 3 is believed to be ankerite, probably a manganoan variety. The lighter carbonate mineral, colorless in thin section, is calcite. It is later than both ankerite and quartz and may be supergene. Most of the quartz-carbonate relationships reported by others or observed in this study can be explained if quartz and carbonate are penecontemporaneous. More likely, there may be more than one generation of both quartz and primary carbonate minerals.

SECONDARY ENRICHMENT

Limonite and wad, which contain the richest thorium concentrations, are not primary minerals of the veins; therefore, the paragenesis of the most abundant thorium minerals is more closely related to the formation and concentration of those two substances than to primary mineralization. Thorium is concentrated near the surface of the earth in the weathering cycle by adsorption on hydrolysate minerals (Adams, Rogers, and Osborn, 1959) and by incorporation of resistate minerals in residual soils (Adams and Richardson, 1960). It may be similarly concentrated in the gossans of mineral veins (Wedow, 1961a, 1961b, and 1962, written communication).

Thorium in the limonitic zones of the Lemhi Pass deposits may occur in three forms: (1) As residual crystals or crystal remnants of thorite and other thorium minerals, probably metamict, weathered from the vein. These have not been definitely recognized in limonitic material but, if small and metamict, would be difficult to discern in a nearly opaque limonite matrix. (2) Adsorbed on limonite and wad. (3) As recrystallized thorogummite. Veinlets, crystals, and irregular masses of thorogummite have been recognized in the limonite (Figure 4). Furthermore, much of the thorogummite also may occur in crystals too small for recognition in the limonitic matrix. On an alpha tract plate (Figure 5) made from the section shown in Figure 4, the principal thorogummite veinlets and masses have produced correspondingly dense aggregations of tracks. However, individual tracks and small clusters are scattered throughout almost the whole area corresponding to the section. These have been produced either by submicroscopic crystals or by thorium adsorbed on the limonite.

Anderson (1958, 1959, 1960a, 1960b, 1961a, 1961b) and Sharp and Cavender (1962) reported pyrite in the deposits. Pyrite is of paramount importance in the genetic development of the deposits as known today. Although pyrite is difficult to find in the exposed
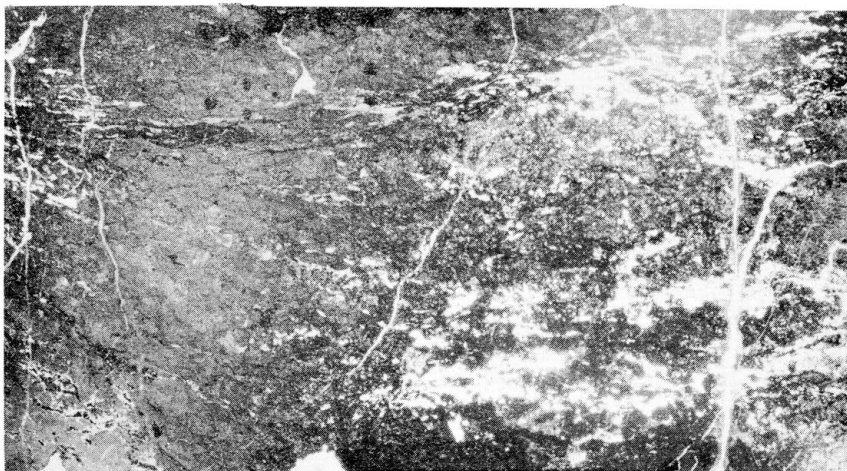
Figure 4. Thin section, Silver Queen 52B vein. Thorogummite veinlets (black) in limonitic matrix. Black spots are limonite after pyrite; narrow white veinlets, calcite; larger white patches, mostly quartz. Ordinary light, about 3X.
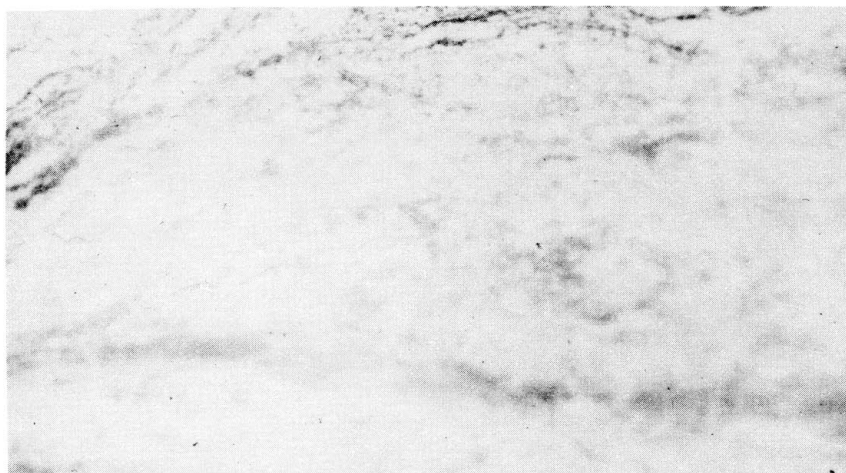

Figure 5. Autoradiograph of section in figure 4. Same magnification, mirror image.

parts of most veins, its former presence is indicated by limonite pseudomorphs some of which contain relict pyrite (Figure 6), and by "ghost" crystal outlines. Unaltered pyrite crystals were seen in a few samples. Thus it is postulated that pyrite was once more abundant than now in surface exposures and is also presently more abundant at depth.

Oxidation of pyrite produces sulfuric acid and acid sulfate solutions. These powerful solvents, even if rather dilute, can attack thorite, allanite, and other thorium minerals, especially if the crystal lattice has already been disrupted by autoradiation. Thorium from these sources remains in solution as long as conditions are sufficiently acid. But the bulk of the thorium does not move very far in solution. As the solutions are neutralized, thorium is either adsorbed on iron hydroxides which may originate from the pyrite, or it recrystallizes as thorogummite. Thus it is incorporated in the limonitic gossans of the veins, along with the more resistant minerals, including resistant primary thorium minerals. Pyrite is not, and does not appear to have ever been, very abundant and by no means accounts for all the limonite in the veins; much limonite must be derived from weathering of other ferruginous minerals, especially carbonates. But oxidizing pyrite does provide solvents for solution and limited transport of thorium.

Sulfur-isotope ratios provide further evidence of supergene enrichment. Three samples were analyzed by M. L. Jensen of the University of Utah. A sample composed of unaltered pyrite and of relict pyrite from limonite pseudomorphs from the Deer claim gave a δS^{34} value of +0.7, indicating little fractionation, and is thus typical of sulfides of hydrothermal origin. Of course, this isotopic composition could occur fortuitously within the wide range of values typical of bacteriogenic sulfides. The mode of occurrence suggests that it is, in fact, hydrothermal.

The δS^{34} of sulfur from pyrite present as coatings and disseminations in a sample from the Gage claim is -12.2. In the Last Chance vein, we found a small pocket (less than 1 g.) of galena crystals. For these, δS^{34} is -19.4. These last two values are well outside the narrow range typical of hydrothermal veins and strongly suggest biogenic fractionation of sulfur and supergene enrichment of the sulfides. Furthermore, the next cycle of oxidation of the supergene sulfides, especially pyrite, provides additional solvents for further enrichment of thorium and other metals.

ECONOMICS

Rich samples assaying from 3 percent to 17 percent ThO_2 have been collected from limonitic zones near the surface. No such rich material was found in the small amount of exploration at depths of 200 feet below the surface, but limonite coats the surfaces of most fractures, and oxidation and some thorium enrichment by supergene processes may have reached depths of a few hundred feet. Material containing more than 0.3 percent ThO_2 in veins of minable widths is present at these depths, but the character, grade and degree of oxidation are unknown below them. Depending on future demand and market, the deposits in this district have the greatest potential for thorium of any known district in the United States. Most of the reasonably assured thorium resources of the United States, 100,000 tons of ThO_2, are in the Lemhi Pass District. Possible additional resources of several hundred thousand tons of ThO_2 are estimated by projecting the persistent veins to depths of 3,000 feet.
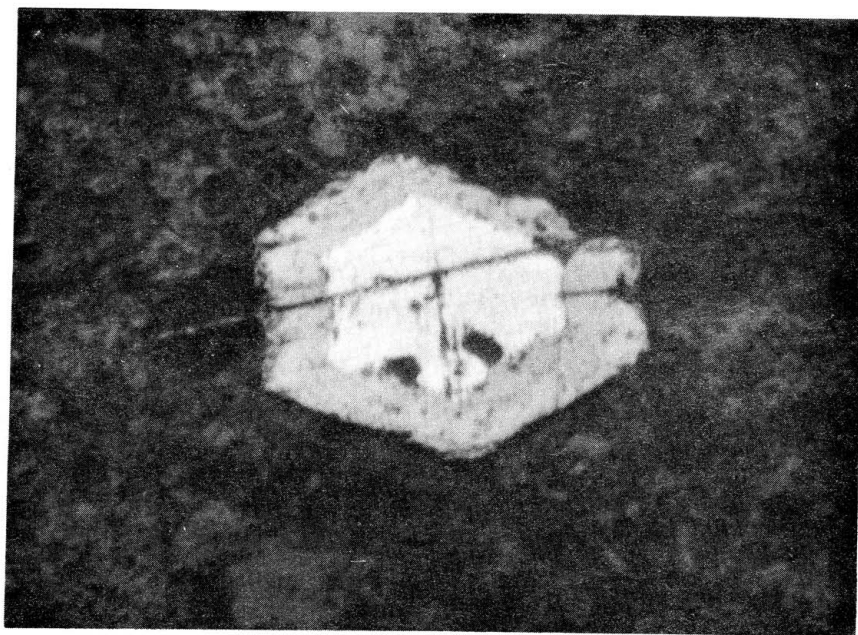
Figure 6. Polished section, Mornell vein. Limonite pseudomorph surrounding relict pyrite. Matrix is mostly quartz. Dark and light lines are scratches. Dark spots are pits in pyrite. Ordinary light, about 240X.

The accompanying yttrium and rare earths are of interest as by-products or co-products of possible thorium production, especially in view of the current demand for yttrium and europium for color television. Although samples or veins richest in thorium tend to be richest in rare earths, no consistent simple relationship between thorium and rare-earth contents is evident. As should be expected, the quartz-hematite-thorite veins, where the principal thorium and rare-earth mineral is thorite, exhibit higher ratios of thoria (ThO_2) to rare-earth oxides (RE_2O_3) than do the replacement deposits dominated by monazite. For example, a composite sample from the Shear Zone thorite vein assayed 2.31 percent ThO_2 and 0.36 percent RE_2O_3; whereas, a similar sample from the Lucky Horseshoe monazite deposit assayed 0.60 percent ThO_2 and 4.45 percent RE_2O_3. The resource of rare earths available as a by-product or co-product of thorium production is several thousand tons.

Preliminary tests by the U. S. Bureau of Mines, Salt Lake City, Utah, (George, D'Arcy R., 1966, written communication) indicate that 85 percent recovery of thorium and 50 to 70 percent recovery of rare earths could be obtained, but that an acid cure was necessary to obtain significant recovery of rare earths.

The presence of other valuable metals in some of the veins and in the district as a whole may improve the future economics of production of thorium and rare earths, even though the other metals may complicate the metallurgy. Grab samples of ore from the Wonder Lode and Black Rock veins have assayed as much as two ounces of silver per ton, with traces of gold and as much as 10 percent zinc. No silver mineral was recognized. Zinc is present in sphalerite, hemimorphite, and smithsonite.

Gold has recently been recovered by panning from some of the outcrops of the thorium veins. These operations were profitable on a short-term basis, but assays of the rock do not appear to warrant continued mining for gold alone.

During the early history of the district, copper and minor amounts of other metals were produced from the base-metal veins. These deposits are not economic as copper ores under present conditions. However, a grab sample from one of the veins assayed 6.60 percent bismuth, 1.45 percent lead, 0.12 percent U_3O_8, and 0.03 percent ThO_2, as well as 1.58 percent copper. They do not appear to have been fully evaluated for metals other than copper.

SUMMARY

The Lemhi Pass thorium and rare-earth deposits in Idaho and Montana are the largest known in the United States. The deposits are Tertiary (?) veins and replacements in quartzites, phyllites, schists, and gneisses of the Belt Series of Precambrain age. Quartz-hematite-thorite veins with yttrium-group rare earths dominate the southern portion of the district; whereas, monazite replacements with cerium-group rare earths dominate the northern part. Base and precious metals are present in some of the thorium-rare-earth deposits and in other veins of the district and along its borders. More than 70 mineral species have been reported from the district. Grid patterns in quartz resemble carbonate cleavage and suggest that carbonate mineralization may have preceded quartz in many of the veins. The dominant thorium mineral is thorogummite or auerlite, concentrated in limonitic zones by supergene processes, of which mobilization by acid solutions from oxidizing pyrite is believed to be important. In addition to being the largest thorium deposit in the United States, it also contains several thousand tons of rare-earths.

TABLE

Minerals Identified from Lemhi Pass Deposits by various investigators

Gold-.0167#
Chalcocite-07*
Galena-01#
Bornite-06
Chalcopyrite-01467
Pyrrhotite-1345
Cubanite-7
Covellite-07
Pyrite-013456#
Molybdenite-4*7
Sphalerite-07
Hematite-0123456789#
Ilmenite-14
Rutile-14
Anatase-9
Ilmenorutile-14
Cuprite-0
Black hydrous copper oxide-7
Wad (hydrous Mn oxides, pyrolusite)-078#
Limonite (goethite, lepidochrosite)-0278#
Magnetite-0134579
Euxenite-356
Eschinite-priorite-9
Fluorite-0279#
Calcite-01345679#
Siderite-4*67
Smithsonite-8
Ankerite (ferroan dolomite)-9#
Azurite-07
Malachite-017
Bastnaesite-4
Ancylite-4
Manganocalcite-9
Bismutite-#
Barite-0123456789#
Jarosite-09
Xenotime-123569

Monazite-0123456789#
Apatite—01234569#
Pyromorphite-9
Collophane (?)-9
Churchite-9
"Ca, Fe, Mn phosphates"-9
Quartz-0123456789#
Chalcedony-07#
Albite-56#   ⎫
Sodic oligoclase-57 ⎬ Feldspar
Microcline-56#   ⎭ 012369#
Andesine-#
Phlogopite-456
Biotite-013456789#
Muscovite (sericite)-03567#
Chlorite-047#
Montmorillonite-7
Antigorite (serpentine)-4*
Clinopyroxene-7
Augite-7
Chrysocolla-7
Hornblende-0179#
Epidote-14579#
Allanite-01345
Actinolite-14#
Clinozoisite-7
Glaucophane-14
Zoisite-4*
Tourmaline-09
Garnet-014
Zircon-9#
Thorite (thorogummite, auerlite)
          012356789#
Sphene-149
Allophane-7
"Unidentified Nb-bearing mineral"-9
Wulfenite-#

Key: 0-Trites and Tooker (1953)
           1-Anderson (1958)
           2-Anderson (1959)
           3-Anderson (1960a)
           4-Anderson (1960b)
           5-Anderson (1961a)
           6-Anderson (1961b)
           7-Sharp and Cavender (1962)
           8-Geach (1966)
           9-Montoya (1966, written communication)
           #-Present Study
           *-Reported to writer, not identified

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