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Rutile and Topaz in Precambrian Gneiss Jefferson and Clear Creek Counties, Colorado

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Abstract

Disseminated rutile and major amounts of topaz have been identified in Precambrian topaz-quartz gneiss northwest of Evergreen, Colo. The rutile occurs in quartz-topaz-sillimanite gneiss that forms a stratigraphic unit which is 11 to 100 feet thick and is identified along strike for more than 7,000 feet. Three composite chip samples taken across this unit contain 2.2 to 4.2 percent of rutile, by weight, in grains averaging from 0.1 to 0.3 millimeter in size. The topaz content, by weight, in the same samples ranges from 23 to 67 percent.

INTRODUCTION

Significant amounts of rutile and topaz have been found in an unusual sillimanitic topaz-quartz gneiss in the central part of the Front Range, west of Denver, Colo. This gneiss forms an apparent stratigraphic unit in a metasedimentary sequence of strikingly varied lithology. The principal known occurrence is about 6 miles northwest of Evergreen, Colo., in the Squaw Pass 7½-minute quadrangle (fig. 1). Other gneiss layers in this immediate area contain rutile in small amounts, though regionally sphene and ilmenite are the principal titanium-rich accessory minerals.

The rutile was discovered by microscopic examination of thin sections by D. M. Sheridan in March 1968 in the course of detailed studies of Precambrian rock as a part of a program of regional mapping of the central Front Range by the U.S. Geological Survey, and identification was confirmed by X-ray diffraction study by W. N. Sharp and J. W. Adams. The preliminary geologic investigation of this deposit has been made in cooperation with S. P. Marsh under a comprehensive research program authorized by the Office of Emergency Planning and undertaken by the Department of Interior under the Defense Production Act for the purpose of developing a domestic source of rutile.

GEOLOGIC ENVIRONMENT

The area of rutile occurrence lies within the block of uplifted Precambrian rock that forms the core of the Front Range of the Rocky Mountains. The bedrock is composed of folded gneisses of high metamorphic grade and of granitic plutons intruded into the gneisses during a complex history of Precambrian tectonism and metamorphism.

The structural framework in the metasedimentary gneisses was largely developed by plastic folding during regional metamorphism that recrystallized the rocks to a mineral assemblage characteristic of the upper part of the amphibolite facies. During this metamorphic episode, broad folds of westerly to northwesterly trend were initially formed and were subsequently modified in certain areas by folds of more northerly direction. The intrusion of bodies of Boulder Creek Granodiorite late in this period of tectonism has been isotopically dated (Peterman, Hedge, and Braddock, 1968) at about 1.7 b.y. (billion years); this date in effect marks the end of the major regional metamorphic period. Structural complexities introduced by folding and cataclastic deformation about 1.45 b.y. ago, at about the time of intrusion of the Silver Plume Granite and related rocks, are regionally important but have not been recognized in the part of the Squaw Pass quadrangle under consideration here. Major faulting of northwest trend, the "breccia reef" faults of Lovering and Goddard (1950, p. 79), has a Precambrian ancestry, and movement recurred intermittently into the Tertiary.

The rutile-bearing rocks are a part of a gneissic sequence of east-west strike and near-vertical dip. This belt, apparently homoclinal in structure, extends more than 5 miles from Santa Fe Mountain, 2½ miles west of the report area, eastward towards the mountain front, though the stratigraphic continuity of lithologic units within the belt is broken by northwest-trending faults. Minor folds and mineral lineations in this area trend N. 50° W. to N. 85° W., which indicates that the dominant folding took place during the early period of Precambrian deformation. Elsewhere in the Squaw Pass quadrangle large-scale isoclinal folding is suggested by the distribution of marker units in the gneissic sequence. Major isoclinal folds have not been recognized in the area of this report (fig. 1). Five miles to the southwest, the metasedimentary sequence is intruded by the Mount Evans batholith of Boulder Creek Granodiorite. Crowding during intrusion may have contributed to the folding of the gneisses and perhaps may have steepened the dip of the layers, but it modified the shape of folds rather than caused them.

STRATIGRAPHY OF THE GNEISSIC ROCKS

The rutile-bearing sillimanitic topaz-quartz gneiss is one of a series of distinctive lithologic units that

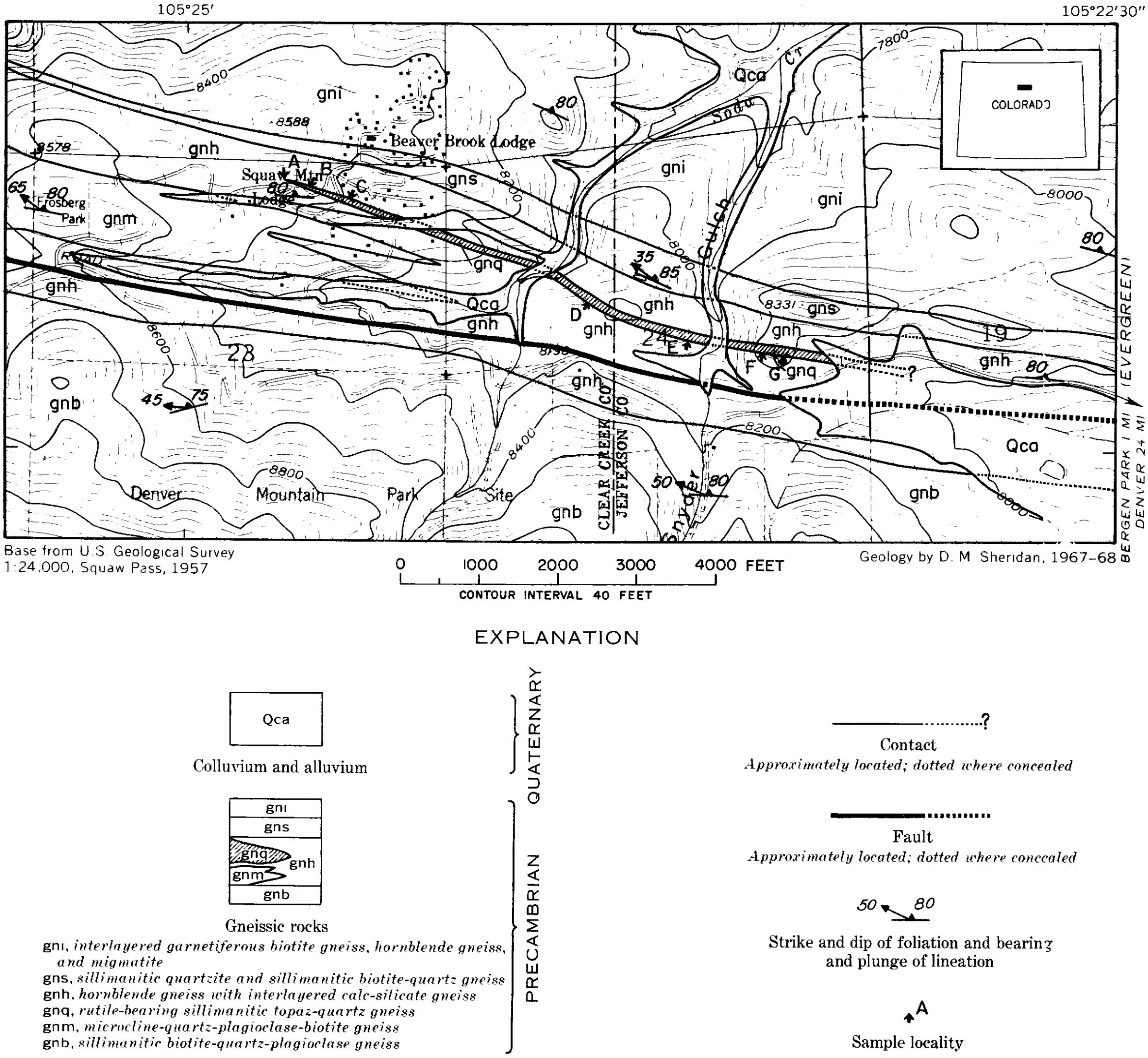

Figure 1.—Preliminary geologic map showing principal rutile and topaz occurrence, Jefferson and Clear Creek Counties, Colo.

have been mapped within the report area. The stratigraphic sense—top versus bottom—of the sequence can be best inferred from broad fold patterns outside of this area, and on this basis the tops of the beds are believed to lie to the north.

The lowest stratigraphic unit, the sillimanitic biotite-quartz-plagioclase gneiss along the southern edge of the area (gnb, fig. 1), is a part of a major unit about 5,000 feet thick. The rock is generally sillimanitic and is dominantly composed of quartz, plagioclase, and biotite, and variable amounts of microcline, muscovite, and garnet. Lenses of calc-silicate rock and hornblende gneiss are contained within the unit. Thin sections of microcline-bearing varieties commonly show microcline and sillimanite as an apparently stable pair, and this is interpreted as indicating that the regional metamorphic grade reached the uppermost level of the amphibolite facies.

The hornblende gneiss unit (gnh, fig. 1) that lies next in the sequence is of varied mineral composition but is characterized by hornblende, plagioclase, and clinopyroxene. The unit is about 1,500 feet thick in the eastern part of the area, if it is assumed that the bedding-plane fault contained within the unit has minor stratigraphic displacement. Layers containing about equal amounts of hornblende and plagioclase are abundant and intergrade with units containing clinopyroxene and varying amounts of epidote, sphene, quartz, and other minerals. A distinctive stratigraphic horizon about 100 feet below the top of the unit is marked by lenses of anthophyllite-garnet-cordierite rock or by layers of cordierite-bearing sillimanite-biotite gneiss. The uppermost part of the unit is a garnetiferous sillimanitic biotite-quartz gneiss.

To the west, the hornblende gneiss unit interfingers and intergrades with a microcline-quartz-plagioclase-biotite gneiss unit (gnm, fig. 1). This microcline gneiss unit is about 1,000 feet thick in the western part of the area and can be traced westward for more than 4 miles. The unit is more granitic in appearance than the other gneisses, and foliation is defined by oriented biotite flakes in a medium-grained quartz-feldspar rock, rather than by marked compositional banding.

The sillimanitic topaz-quartz gneiss unit that contains the principal rutile concentrations (gnq, fig. 1) is a lenticular layer within the hornblende gneiss unit. The layer is about 100 feet thick from sample locality D to locality G (fig. 1), but it thins to about 11 feet at locality B and grades westward into a feldspathic gneiss with high quartz content. The topaz-quartz gneiss layer is recognized over a strike length of more than 7,000 feet and is 80 feet thick at the point where it is covered by surficial materials. The layer may continue eastward under the alluvium as much as 5,500 feet before it intersects a major fault of northwest trend.

A unit 30 to 500 feet thick (gns, fig. 1), which lies stratigraphically above the hornblende gneiss unit, is composed of sillimanitic quartzite and sillimanitic biotite-quartz gneiss and has been traced about half a mile east of the report area. Discontinuous lenses of these rocks persist westward at this stratigraphic position for almost a mile west of the report area. Fibrolitic needles of sillimanite form interlensing laminae between granular quartz septa. Sillimanite makes up about 20 to 30 percent of the quartzite and about 10 to 20 percent of the biotite-quartz gneiss. Variable amounts of biotite, feldspar, and muscovite are found. Rutile is a characteristic accessory mineral in amounts of a few tenths of a percent.

Above the unit of sillimanitic quartzite and gneiss are interlayered gneisses of varied mineralogy that have been grouped into a composite unit (gni, fig. 1) for purposes of mapping. The lowermost layer, immediately above the quartzite, is composed of garnetiferous sillimanitic biotite-quartz gneiss and is about 200 feet thick. Above this are layers of complexly interbedded hornblende-plagioclase gneiss; calc-silicate gneiss containing clinopyroxene, epidote, hornblende, plagioclase, and other minerals; biotite-quartz-plagioclase gneiss; and migmatitic masses rich in feldspar and quartz. This unit of interlayered gneisses is at least 5,000 feet thick and is the uppermost lithologic unit in the report area.

RUTILE-BEARING SILLIMANITIC TOPAZ-QUARTZ GNEISS

The principal known concentrations of rutile and topaz are contained within the sillimanitic topaz-quartz gneiss unit (gnq, fig. 1). The rock is almost white, with creamy or red tones. Medium-grained white or glassy quartz layers 2 millimeters to 4 centimeters thick alternate with discontinuous thinner layers of finer grained granular topaz-rutile rock and with radiating aggregates of prismatic or fibrous sillimanite. The rock closely resembles a sillimanitic quartzite in appearance and the topaz layers are not readily distinguished in the field except by their greater density. The rutile is easily seen with a hand lens and is concentrated in thin layers colored pale red by the tiny splendent rutile crystals.

All the rock types in this unit are very light colored and are white, with glistening grains, where unweathered. Other than the red to orange rutile grains and weathered pale yellow apatite grains, all the minerals are white or light gray. The rock lacks the black-sand laminae (magnetite, ilmenite, garnet) characteristic of quartzites in the gneissic succession; it lacks the dark brown to black biotite flakes that dot almost all the quartz-feldspar rocks; it lacks even the feldspar grains common to all the quartz-rich rocks.

PETROGRAPHY

White, fine- to medium-grained gneisses composed chiefly of quartz and topaz and lesser amounts of sillimanite, rutile, and apatite are common (modes 2, 3, 4, table 1) in the topaz-quartz gneiss unit. Thin sections show that these gneisses are composed of alternating quartz-rich and topaz-rich layers. Quartz and apatite occur in irregular anhedral grains 1 to 5 mm across; the topaz characteristically occurs in slightly smaller rounded grains flattened parallel to the foliation. The topaz grains commonly exhibit healed cross fractures marked by bubbles concentrated in planar zones that are parallel to the basal cleavage of the topaz grains. These fractures are rudely perpendicular to the foliation of the rock. The rutile grains are commonly anhedral or subhedral, and some are intergrown with topaz or sillimanite. The largest quartz grains contain rutile needles, and a few tiny equant euhedral rutile crystals.

The topaz-quartz gneisses intergrade with interlayered sillimanitic topaz-quartz gneiss, characterized by prismatic sillimanite (mode 5, table 1). The prismatic sillimanite crystals are as much as 3 cm long but are slender and generally are only 1 or 2 mm^2 in cross-section area. These crystals form irregular to radiating aggregates flattened parallel to the foliation, but they lack linear orientation. Certain sillimanitic quartz gneiss laminae (mode 6, table 1) contain fibrolitic sillimanite with linear orientation. These needles are replaced in part by topaz and, less commonly, by randomly oriented prismatic sillimanite.

Pegmatitic stringers or segregations within the quartz gneiss (mode 7, table 1) are composed mainly of quartz and coarsely prismatic sillimanite. Much of the quartz is coarse-grained and rutilated and is

Table 1.--Modal analyses, in volume percent, of samples from the rutile-bearing sillimanitic topaz-quartz gneiss unit and its stratigraphic equivalent

[Modes calculated from 1,000 points each. Tr, trace. Sample localities shown in fig. 1]

	1	2	3	4	5	6	7
Sample locality --	A	B	B	D	E	G	G
Quartz-----------	41.2	10.6	61.2	68.2	5.5	49.4	84.4
Topaz------------	----	70.8	35.8	30.1	71.9	.4	.6
Sillimanite------	----	1.0	----	----	18.2	44.8	12.0
Rutile-----------	.6	2.7	2.0	1.7	3.1	2.7	1.7
Apatite----------	----	13.0	.2	----	.4	1.3	.5
Zircon-----------	Tr	.3	.1	Tr	Tr	Tr	Tr
Muscovite--------	.5	1.1	.7	----	.9	1.4	.5
Biotite----------	----	----	----	----	----	----	.3
Kaolinite--------	----	.5	----	----	----	----	----
Plagioclase------	57.6	----	----	----	----	----	----
Hematite---------	Tr	----	----	----	----	----	----

1. Plagioclase-quartz gneiss.
2. Topaz-quartz gneiss.
3. Quartz-topaz gneiss.
4. Quartz-topaz gneiss.
5. Sillimanite-topaz-quartz gneiss.
6. Sillimanite-quartz gneiss.
7. Pegmatitic quartz-sillimanite rock.

segregated into lenses as much as 5 cm thick. Bent sillimanite prisms 5 mm across and as much as 3 cm long occur in bundles curving around the quartz lenticles. Rutile is intergrown with the sillimanite and is especially abundant in apatite-rich stringers.

West of the pinchout of the topaz-quartz gneiss unit, a light-gray plagioclase-quartz gneiss is found at the same stratigraphic position and seems to lack both topaz and sillimanite but contains 0.6 percent of rutile (mode 1, table 1). This lithologic type has not been mapped as a part of the topaz-quartz gneiss unit.

Certain mineralogic details observed in thin section seem to be critical in the interpretation of the origin of the rutile-bearing sillimanitic topaz-quartz gneiss.

1. Fibrolitic sillimanite is absent, is partly replaced by topaz (fig. 2), or is partly recrystallized to prismatic sillimanite. As the fibrolitic sillimanite is linearly oriented parallel to small-scale folds related to the early period of folding, it is believed to have formed during the regional metamorphism. The topaz and prismatic sillimanite are younger than the fibrolitic sillimanite and therefore are interpreted as being younger than the regional metamorphism.

2. The rutile grains are molded around topaz (fig. 3) and are intergrown with prismatic sillimanite (fig. 4). The rutile therefore seems to have crystallized after the principal regional metamorphism, at the same time as the topaz and prismatic sillimanite. The rock cannot represent a

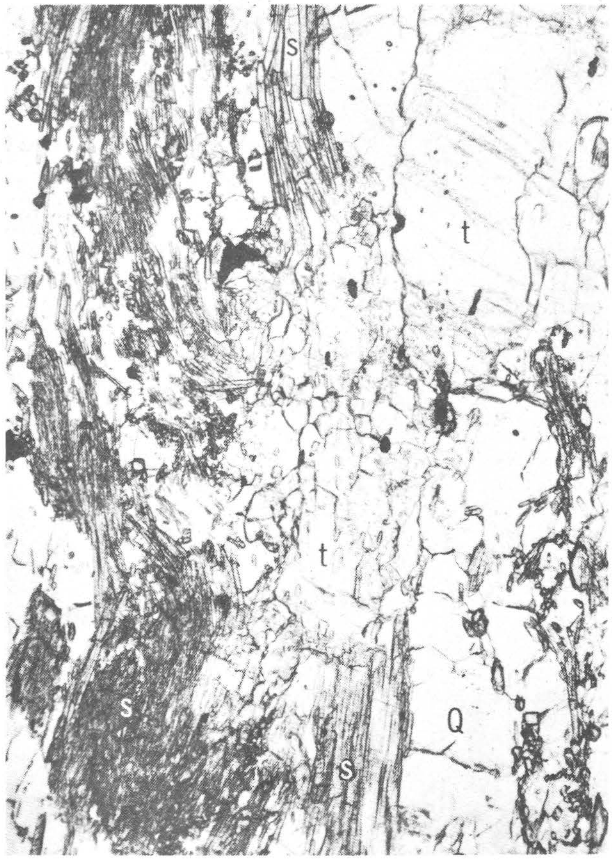

Figure 2.—Fibrolitic sillimanite replaced in part by topaz. Magnification, X40. Q, quartz; s, sillimanite; t, topaz.

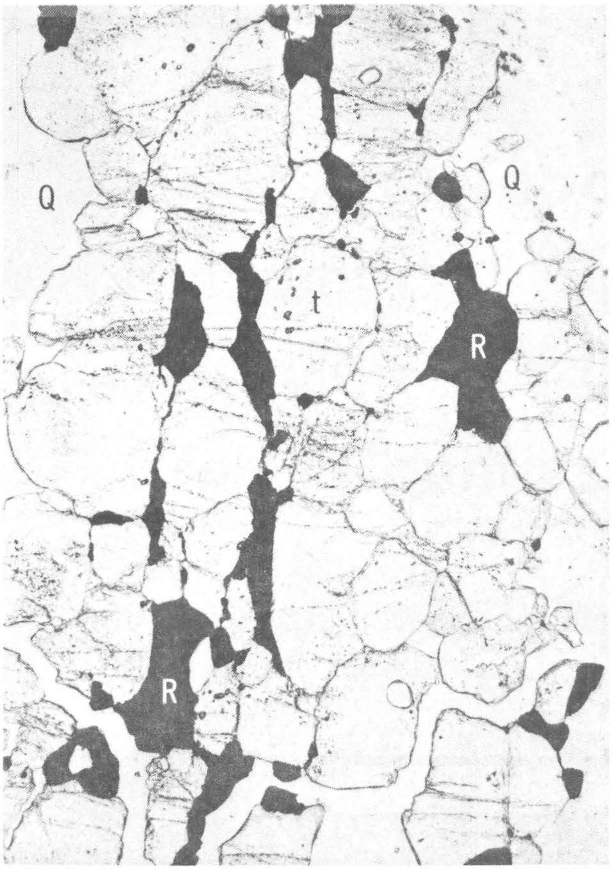

Figure 3.—Rutile grains molded around topaz grains. Magnification, X 40. Q, quartz; R, rutile; t, topaz.

Figure 4.—Prismatic sillimanite intergrown with rutile. Magnification, X 40. B, biotite; Q, quartz; R, rutile; s, sillimanite.

fossil rutile placer, although the rutile may have formed from titanium already within the rock at the time of regional metamorphism.

3. Although magnetite, ilmenite, and sphene occur in rocks bordering the topaz-quartz gneiss, these minerals do not occur in the same rock with rutile. The rutile-bearing rocks are essentially free of ferromagnesian minerals.

RUTILE AND TOPAZ CONTENT

A series of samples was taken to evaluate the rutile and topaz content of the principal outcrops (table 2). Samples R-1, R-3, and R-6 are composites of a large number of rock chips taken across the entire layer at the only three localities where it crops out fully (fig. 1). Samples R-2A, R-4, and R-7 are grab samples taken at localities where outcrops are sparse, and they may not represent the average composition of the unit.

Each sample was crushed, ground, and screened, and the part between 60 and 150 mesh was washed and sonically cleaned to remove adhering particles of dust. One hundred and fifty grams of this material was split into heavy and light fractions in bromoform (density 2.8). The weights of the heavy and light fractions were recorded, and percentages were calculated (table 2). Further mineral separation using the Frantz isodynamic separator and a laboratory micropan device yielded an almost pure rutile fraction. Other magnetic concentrates also contained small amounts of rutile, and the weight of this rutile was added to that of the pure fraction to calculate the rutile percentages given in table 2. The topaz percentages were obtained by a similar procedure. Because of losses of material to other fractions of the sample during separation, the percentages quoted are conservative estimates of the actual rutile and topaz contents of each sample processed. The major source of error in evaluating the rutile and topaz contents of the topaz-quartz gneiss unit almost certainly lies in the field sampling procedure. Core drilling or other physical exploration would be required to adequately sample this unit.

Semiquantitative spectrographic analyses of rutile concentrates from the sillimanitic topaz-quartz gneiss unit show that the content of niobium and iron in the rutile is low. The rutile samples contained less than 5 percent impurities, and these impurities were almost entirely made up of sillimanite and topaz.

Table 2.--Mineralogic composition, in weight percent, based on mineral separates from rutile-bearing topza-quartz gneiss

[Determinations by S. P. Marsh]

Sample	Locality (in fig. 1)	Heavy fraction (density >2.8)	Light fraction (density <2.8)	Topaz	Rutile	Thickness of unit sampled (feet)
			Composite chip samples			
R-1	B	74	26	67	4.2	11
R-3	G	36	64	23	3.9	80
R-6	E	50	50	36	2.2	100
			Grab samples			
R-2A	C	65	35	51	0.6	---
R-4	F	43	57	22	1.4	---
R-7	D	52	48	42	1.0	---

Table 3.--Semiquantitative spectrographic analyses of rutile concentrates from the sillimanitic topaz-quartz gneiss unit

[A. L. Sutton, Jr., analyst]

Sample	Locality	Nb (ppm)	Fe (percent)
1	B	500	0.3
2A	C	700	.5
3	G	500	.5
4	F	500	.5
6	E	500	.5
7	D	1500	.7

CHEMISTRY

Semiquantitative spectrographic analyses were made by J. C. Hamilton of heavy (density >2.8) and light (density <2.8) fractions separated from the sillimanitic topaz-quartz gneiss. The rock is abnormally low in iron, calcium, sodium, potassium, and it contains less than 1 part per million of beryllium, an element that is frequently concentrated in topaz greisens. Small amounts of tin (0–15 ppm), niobium (0–15 ppm), molybdenum (0–7 ppm), and rare-earth elements were detected.

GEOLOGIC INTERPRETATION

The topaz-quartz gneiss is mineralogically simple, chemically unusual, and rather undistinguished in appearance. Quartz, topaz, and sillimanite are the only abundant minerals and rutile, apatite, and zircon are the only characteristic accessory minerals. These minerals clearly formed at the expense of the previously formed regional metamorphic suite. Chemically, the rock has a very high fluorine content and in comparison with other quartz-rich gneisses in the Front Range is unusually low in the alkali metals, alkaline earths, and iron. The chemically resistant character of the minerals in the rock, the high fluorine content, and the depletion of several common elements suggest that the topaz-quartz gneiss is the product of fluorine metasomatism. The high fluorine, aluminum, and titanium contents suggest that these elements were added or enriched during the metasomatism. According to this hypothesis, a gneissic progenitor, probably a sillimanitic quartz-rich gneiss, was attacked by hot fluorine-rich solutions that swept the rock clean of many of the common elements and minerals, left a resistant assemblage of zircon, quartz, and sillimanite, and added rutile and the topaz and apatite.

Rutile is apparently stable in this gneissic sequence only in rocks deficient in both iron and calcium. Gneisses adjacent to the topaz-quartz gneiss contain both ilmenite and sphene, but no rutile. Rutile is an accessory mineral (½ percent) in several other gneiss layers, notably the sillimanitic quartzite unit (gns, fig. 1). This unit probably also underwent limited metasomatic alteration, as it contains no magnetite, ilmenite, or garnet but does contain rutile and small amounts of topaz.

GEOPHYSICAL DATA

Preliminary aeromagnetic data show that the report area lies on a strong linear east-west magnetic gradient. The anomaly is interpreted (Peter Popenoe, oral commun., 1968) as indicating a steeply dipping contact or a major fault that marks the north boundary of a relatively magnetic block. The anomaly extends from the mountain front about 20 miles west into the range. The occurrence of plutonic rocks to the south of the report area suggests that the anomaly marks a steep contact between plutonic and metasedimentary rocks at depth. The geophysical data are the strongest direct evidence for a major subjacent igneous mass from which fluorine-rich solution could have been derived.

ECONOMIC IMPLICATIONS

Rutile is an important industrial mineral and source of titanium, and topaz and sillimanite are raw materials for refractories and ceramics. Most rutile is obtained from beach sands, and most of it is imported. Topaz and sillimanite are members of a group of aluminosilicate minerals—also including kyanite, andalusite, and dumortierite—that has steady demand for production of mullite and other uses. Minerals of this group are produced domestically and also are imported.

Considering the content of rutile in the topaz-quartz gneiss as determined thus far, and considering the purity of the rutile, the gneiss warrants investigation as an ore of rutile, especially since it might also yield a saleable topaz product. Tests to determine the recoverability of the rutile and topaz would be required; but first, much more extensive investigations than the preliminary studies reported here would be required to determine the character and distribution of the rutile and topaz and their average content in the gneiss unit. Further study of the deposit to the extent permitted by the limited exposures is planned, but the grade of the deposit probably could be determined satisfactorily only by means of core drill holes through the gneiss unit.

The discovery of rutile in the topaz-quartz gneiss suggests that a part of the central Front Range is favorable for prospecting for rutile and that the search should be concentrated on white sillimanitic quartz-rich gneisses.

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