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Allanite-bearing calc-silicate rocks, southern Bighorn Mountains, Wyoming: Geologic setting and resources of thorium, uranium, and rare-earth elements

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Introduction

Allanite, which is a fairly common accessory mineral in the regionally metamorphosed Precambrian metasedimentary rocks of the Horn area of the southern Bighorn Mountains, Wyoming (fig. 1), is present in sufficient amounts in certain structurally concordant calc-silicate rocks to form deposits of some economic interest. One occurrence, characterized by a radiometric anomaly of as much as 18 times background levels, has been examined in detail as part of a U.S. Geological Survey program to identify various types of potential thorium, uranium, and rare-earth element resources. No other occurrences of this type have yet been found in this area.

The allanite occurrence is located on private land owned by Wallace Ramsbottom of Kay Cee, Wyoming. It is located near lat 43°59'25"N., long 106°52'30"W. in the north-central part of the Horn (fig. 1), a blocklike uplift separated from the central Bighorn Mountain mass. A small pit was opened on the radiometric anomaly in 1955 and 300 tons of rock were shipped to a processing plant in Casper, Wyoming. Details of the milling are unknown. Hose (1954) mentioned the allanite occurrence and listed some of the minerals present. The geology of the Horn area has been studied by Palmquist (1965, 1967). The area was visited by Sargent in 1958 who prepared a detailed geologic map and studied the mineralogy of the allanite occurrence (Sargent, 1960). Armbrustmacher visited the area briefly in 1976 and further sampled the allanite occurrence.

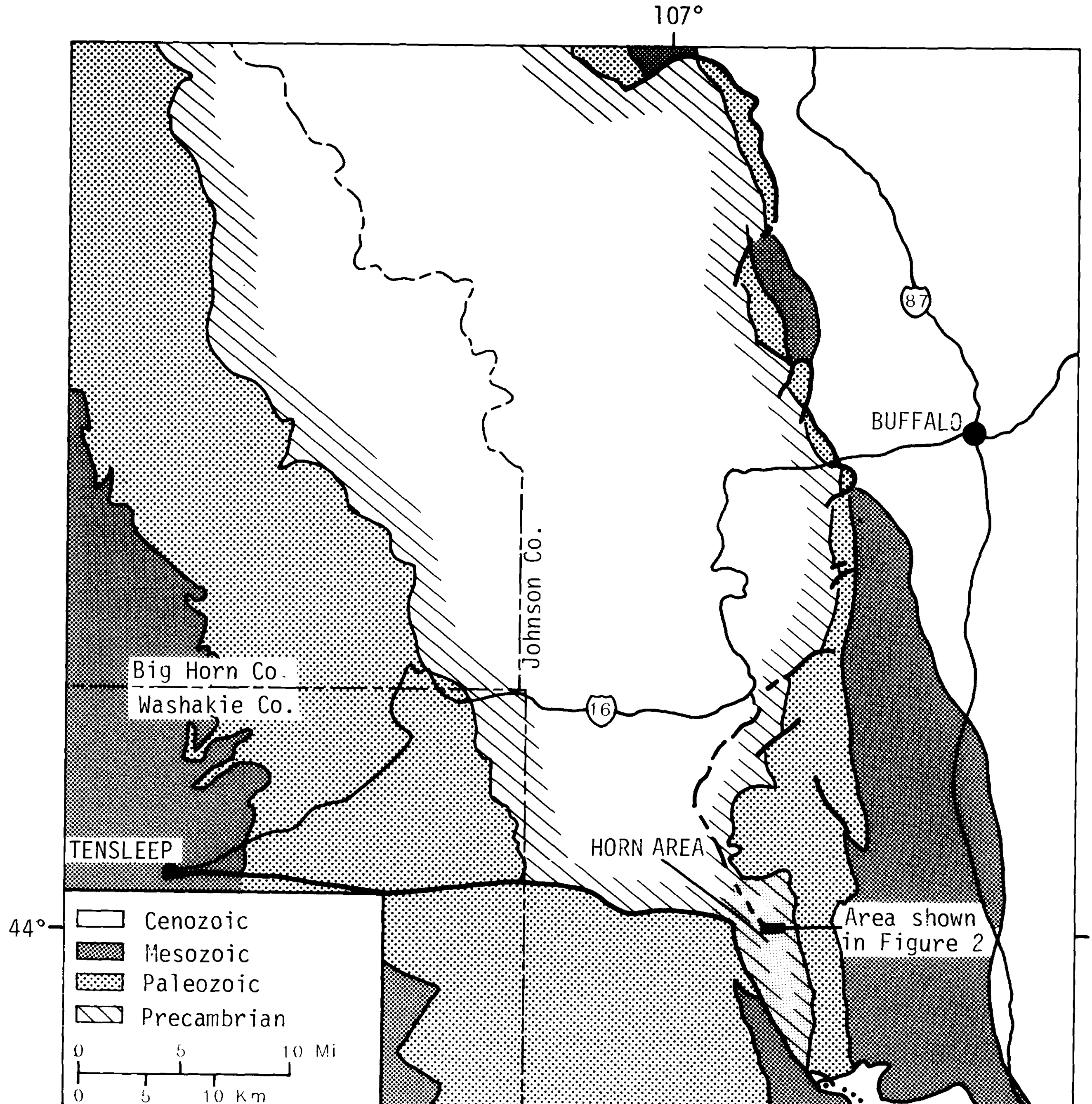

Figure 1.--Index map of southern Bighorn Mountains showing Horn area and location of allanite-bearing calc-silicate rock.

Geologic setting

The Horn is a blocklike Laramide uplift of Precambrian metasedimentary rocks in the southern Bighorn Mountains. It is separated from the Precambrian crystalline terrane of the central Bighorn uplift by the Tensleep-Beaver Creek fault. It is bounded on the western and southern sides by upwarped Paleozoic and Mesozoic sedimentary rocks. Aspects of the structure and petrology of the Horn area have been described by Palmquist (1965, 1967) and the Horn area has been placed in structural perspective by Hoppin and Jennings (1971).

The Precambrian regionally metamorphosed metasedimentary rocks of the Horn area, members of the staurolite-quartz subfacies of the almandine amphibolite facies (Fyfe and others, 1958), consist primarily of quartz-feldspar gneiss with subordinate amounts of quartz-plagioclase gneiss, feldspar gneiss, amphibolite, foliated marble, pegmatite, and the allanite-bearing calc-silicate rock. Mineralogy of these rocks is given in Table 1. The quartz-feldspar gneiss is gray to greenish gray in color and fine to medium grained. Foliation results from bands, pods, and lenses of hornblende, quartz, diopside and locally sphene. Plagioclase (An_{6-17}) is strongly altered and partially replaced by microperthite. Allanite, epidote, clinozoisite, magnetite-ilmenite, sphene, apatite, hornblende, tremolite-actinolite, diopside, calcite, zircon and brown biotite are present in minor amounts. Contacts between quartz-feldspar gneiss and the calc-silicate rock and foliated marble are generally sharp. The contacts between quartz-feldspar gneisses and all other rock types are generally gradational.

Several other varieties of gneiss can be distinguished by the variation in major constituents. Quartz-plagioclase gneiss contains quartz and plagioclase (An_{6-17}) as its major constituents and contains little or no

Table 1.--Mineralogy and abundance of mineral constituents in Precambrian metasedimentary rocks of the Horn area, Bighorn Mountains, Wyoming.

[M, major constituent; C, common but minor constituent; A, accessory mineral; -, not identified]

	Quartz-feldspar gneiss	Quartz-plagioclase gneiss	Feldspar gneiss	Amphibolite	Foliated marble	Pegmatite	Calc-silicate rock
Quartz	M	M	-	-	A	M	A
Microcline	M	A	M	A	-	M	A
Plagioclase	M	M	M	M	-	M	C
Hornblende	C	C	C	M	-	-	A
Biotite	A	A	A	-	-	A	A
Diopside	C	C	C	C	C	-	M
Garnet	-	A	A	-	C	A	M
Tremolite-actinolite	C	C	C	-	A	-	A
Epidote	C	C	C	C	A	A	A
Clinozoisite	C	C	-	-	-	A	-
Magnetite	C	C	A	A	C	A	A
Sphene	A	A	A	A	-	A	A
Apatite	A	A	A	A	C	A	A
Calcite	A	A	A	-	M	A	M
Allanite	A	A	A	-	A	A	M
Zircon	A	A	A	-	A	A	A
Phlogopite	-	-	-	-	C	-	-
Rutile	-	-	-	-	A	-	-
Pyrite	-	-	-	-	A	-	-
Olivine	-	-	-	-	A	-	-
Chondrodite	-	-	-	-	A	-	-
Chlorite	-	-	A	-	A	A	A
Brucite	-	-	-	-	A	-	-
Antigorite	-	-	-	-	A	-	-

microcline. Accessory minerals are similar to those in quartz-feldspar gneiss. Quartz-plagioclase gneiss is commonly grayish white to tan. It occurs in zones less than 6 feet in width situated between quartz-feldspar gneiss and foliated marble, or it occurs as thin lenses, pods, layers or bands which lie conformably within the marble. Contacts between the various types of gneiss are gradational. Locally weak to strong folding of intercalated feldspar gneiss and marble is common.

Feldspar gneiss typically shows a granoblastic texture although poorly developed foliation may occur. Plagioclase (An_{8-20}) is the only major constituent. Microcline, diopside, garnet, hornblende, and biotite may be present in varying amounts. Accessory constituents include magnetite-ilmenite, epidote, allanite, apatite, sphene, chlorite, tremolite-actinolite, quartz, calcite, and zircon. There is little or no quartz. Microcline, where present, replaces plagioclase and is often perthitic, especially where present in relatively large amounts. Feldspar gneiss is gray or white with a medium- to fine-grained texture. The overall thickness seldom exceeds 3 feet and is more commonly less than 1.5 feet.

Amphibolite occurs as thin lenses or layers within the quartz-feldspar gneiss and seldom exceeds 3 feet in width. Contacts between amphibolite and quartz-feldspar gneiss are sharp and straight, whereas contacts between amphibolite and foliated marble or calc-silicate rock are gradational. The lineation in this rock is due to nematoblastic hornblende. Major constituents in the amphibolite are plagioclase (An_{12-16}) and bluish-green hornblende. The centers of plagioclase grains are commonly saussuritized. Microcline, iron-stained diopside, idioblastic magnetite-ilmenite, sphene, and apatite are accessories.

The best exposures of foliated marble occur in prospect pits and trenches. The marble is most commonly dark blue to white, although local varieties of orange and yellow marble do occur. The marble ranges in thickness from less than 1.5 feet to approximately 75 feet. Foliation is formed by concentrations of phlogopite, clusters or massive bands of magnetite-ilmenite, or by preferred orientation and lineation of mafic minerals and variously colored calcite zones, particularly those that are blue or white. Parallel intercalated bands and lenses of gneissic and calc-silicate rock are common. Magnetite-ilmenite, diopside, apatite, garnet, and phlogopite occur as varietal or accessory minerals; epidote, tremolite, rutile, pyrite, olivine, chondrodite, allanite, zircon, quartz, biotite, chlorite, brucite, and antigorite occur in accessory amounts. The contact between foliated marble and calc-silicate rock is irregular and gradational. Contacts between foliated marble and all other rock types are commonly sharp and even.

The quartz-feldspar pegmatite contains plagioclase somewhat more sodic (An_{5-10}) than quartz-feldspar gneiss. Graphic intergrowth of quartz and microcline microperthite is locally well developed. The grain size of the major constituents ranges from about 0.5 to 3 in. Cataclastic texture is very common; mortar structure is developed around both quartz and feldspar and bent feldspar lamallae are common. Quartz is generally serrate at its borders and appears to be the oldest mineral. Pegmatites occur parallel to or cut across the foliation of all other rock types in the area. Although their thicknesses range from less than one inch to 10 feet, they average less than 1.5 feet. Fine-grained border phases and gradational contacts are common where the pegmatites cut quartz-feldspar gneisses. Crosscutting pegmatites commonly strike approximately N. 80° E., and dip 15°-50° southeast.

Allanite-bearing calc-silicate rocks

Special emphasis is placed on the calc-silicate rocks because they contain the greatest concentrations of allanite. A hand-held scintillometer gives radiometric readings 5-18 times greater than background readings in nearby quartz-feldspar gneisses due to the radioactive nature of the allanite. The calc-silicate rocks discussed here (fig. 2) are the only rocks of that type so far identified in the Horn area.

Calc-silicate rocks range in color from dark brown and dark green to black. Thickness of the calc-silicate rocks ranges from a few inches to about 6 feet and averages about one foot. The rocks can occur as layers, more or less conformable with the enclosing rocks, or as elongate bands, lenses or pods, also conformable (fig. 2). The calc-silicate rocks crop out about 3750 feet along strike. No contact effects or evidence of alteration are apparent.

The calc-silicate rocks have a granoblastic texture and are medium to coarse grained in thin section. Major but highly variable constituents include pale green, slightly pleochroic diopside, calcite, garnet, and allanite; minor constituents include feldspar, hornblende, biotite, and chlorite. Diopside is always present whereas the other components can be absent in parts of the calc-silicate rocks. The feldspar content is variable in amount and in type; microcline, untwinned albite, and twinned albite-oligoclase occur in variable amounts. Hornblende is primarily an alteration product of diopside and sometimes forms reaction rims where diopside is in contact with calcite. Biotite, pleochroic from neutral to dark brown, occurs as an alteration product of diopside and as scattered grains intimately intermixed with chlorite. Sphene, with a characteristic reddish color, zircon, apatite, and magnetite are accessory minerals and epidote, tremolite-

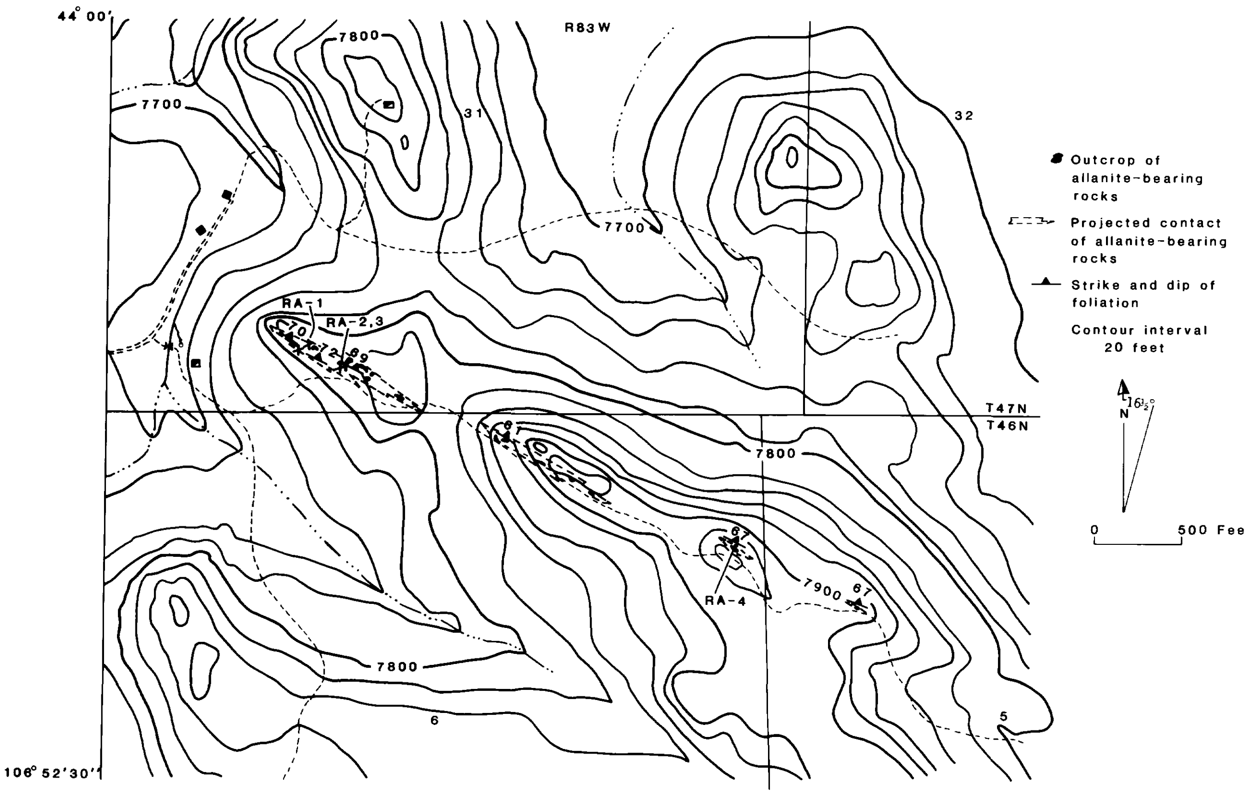

Figure 2.--Map showing distribution of allanite-bearing calc-silicate rocks, Horn area, Bighorn area, Bighorn Mountains, Wyoming.

actinolite, and hornblende are alteration minerals. Allanite is pleochroic and has a mottled color distribution due to great variation in birefringence and crude zonation. This color variation, light to dark yellowish brown and pale to medium green, may represent differences in degree of alteration or metamictization or both. Allanite usually occurs in small masses with dicussate texture but can also be homogeneously dispersed. It can be present in amounts exceeding 10 percent by volume. Most of the thorium, uranium, and rare-earth elements in the calc-silicate rocks (Table 2) reside in the allanite.

Some of the geochemical characteristics of the calc-silicate rocks (Table 2) are similar to those of carbonatites. The large amounts of rare-earth elements, niobium, barium, strontium, thorium, and other elements are found in both the calc-silicates and the carbonatites. Many other characteristics of carbonatites, such as their intrusive nature, fenitized host rocks, associated alkaline rock complexes, and other characteristics (LeBas, 1981), are not found in the calc-silicate rocks. The concordant nature of the calc-silicate rocks is also strong argument against a hydrothermal origin. The lack of associated intrusive igneous rocks weakens a contact metasomatic origin of the calc-silicate rocks even though they superficially resemble tactites or skarns. Field relationships (Sargent, 1960) strongly favor formation of the calc-silicate rock in place by regional metamorphism of impure argillaceous dolomite. The thorium, uranium, and rare-earth elements were probably enriched through a process of metamorphic differentiation not specified by the data presented here.

Partial chemical analyses of calc-silicate rocks (Table 2) show abundant rare-earth elements, thorium, and uranium; average values are 4.44 percent total REE, 0.03 percent radium-equivalent uranium (0.0355 U_3O_8), and 0.06

Table 2.--Semiquantitative spectrographic analyses, in percent, of calc-silicate rocks

[Analyst, L. A Bradley]

	RA-1	RA-2	RA-3	RA-4	Crustal Averages [1]
Fe	10	10	G	5	3.54
Mg	2	7	3	5	1.39
Ca	10	G	G	G	2.87
Ti	1	.5	.3	.3	.47
Si	G	G	G	G	30.54
Al	G	5	10	G	7.83
Na	1.5	.7	.7	.7	2.45
K	10	1.5	7	1	2.82
P	N(0.2)	N	N	2	.081
Mn	.1	.2	.15	.3	.069
B	.005	L(.002)	L	.005	.0009
Ba	.3	.07	.07	.02	.059
Be	.0007	.0007	.0005	.02	.0002
Bi	N(.001)	N	N	.05	.00002
Co	.003	.005	.003	.0015	.0012
Cr	N(.0005)	.00015	N	.0002	.007
Cu	.002	.0005	.0005	.0007	.003
La	G(2)	.5	G	.3	.0044
Nb	.05	.1	.007	.003	.002
Ni	.0015	.003	.0007	.0007	.0044
Pb	.02	.05	.03	.02	.0015
Sc	.002	-	.003	.0007	.0014
Sn	.002	N(.001)	N	.02	.003
Sr	.2	.2	.3	.07	.029
V	.03	.01	.02	.007	.0095
Y	.02	.015	.03	.015	.0034
Zn	N(.03)	N	N	.07	.006
Zr	.05	.05	.1	.015	.016
Ce	G(2)	.7	G	.7	.0075
Ga	.003	.0015	.003	.007	.0017
Li	N(.01)	N	.02	L	.003
Yb	.0015	.001	-	.0007	.00034
Nd	1	.3	1.5	.2	.003
Sm	.15	.05	.15	.05	.00066
Eu	.015	N(.01)	.03	.015	.00014
ΣLREE	7.165	1.55	7.68	1.265	.0164
ΣHREE	.0215	.016	.03	.0157	.006
RaeU	.0039	.0895	.005	.0222	.00035
Th	.092	.0245	.1185	.0099	.0011

G=>10% or value shown in parentheses
L=detected, but below limit of determination shown in parentheses
N=not detected at values in parentheses
-=not looked for
Looked for but not found: Ag, As, Au, Mo, Pd, Pt, Sb, Te, U, W, Ge, Hf, In, Re, Ta, Tl, Gd, Tb, Dy, Ho, Er, Tm, Lu

[1]Wedepohl, 1971, Table 7.3

percent thorium (0.07 ThO_2). If it is assumed that the zone of calc-silicate rocks is 3750 feet long, averages 1 foot wide, and has a depth about one-third the length (1250 feet), there is about 4,687,500 cubic feet of calc-silicate rock. A conversion factor of 11.4 cubic feet/ton, based on the specific gravity of calcite, yields 411,184 tons of calc-silicate rock. Using the average abundances of the elements, the Ramsbottom allanite occurrence contains about 285 tons of ThO_2, 145 tons of U_3O_8, and 18,250 tons of total rare-earth elements.

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