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HYDROTHERMAL ADULARIA AT BODIE, MONO COUNTY, CALIFORNIA

BY

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This report is preliminary and has
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Abstract

Adularia occurs in gold- and silver-bearing quartz veins and in hydrothermally altered dacite host rocks of late Miocene age at the Bodie mining district, Mono County, California. Chemical analyses of vein adularia indicate a composition of 95 percent $KAeSi_3O_8$. Optical, physical, and X-ray crystallographic properties of the adularia are consistent with those of high sanidine.

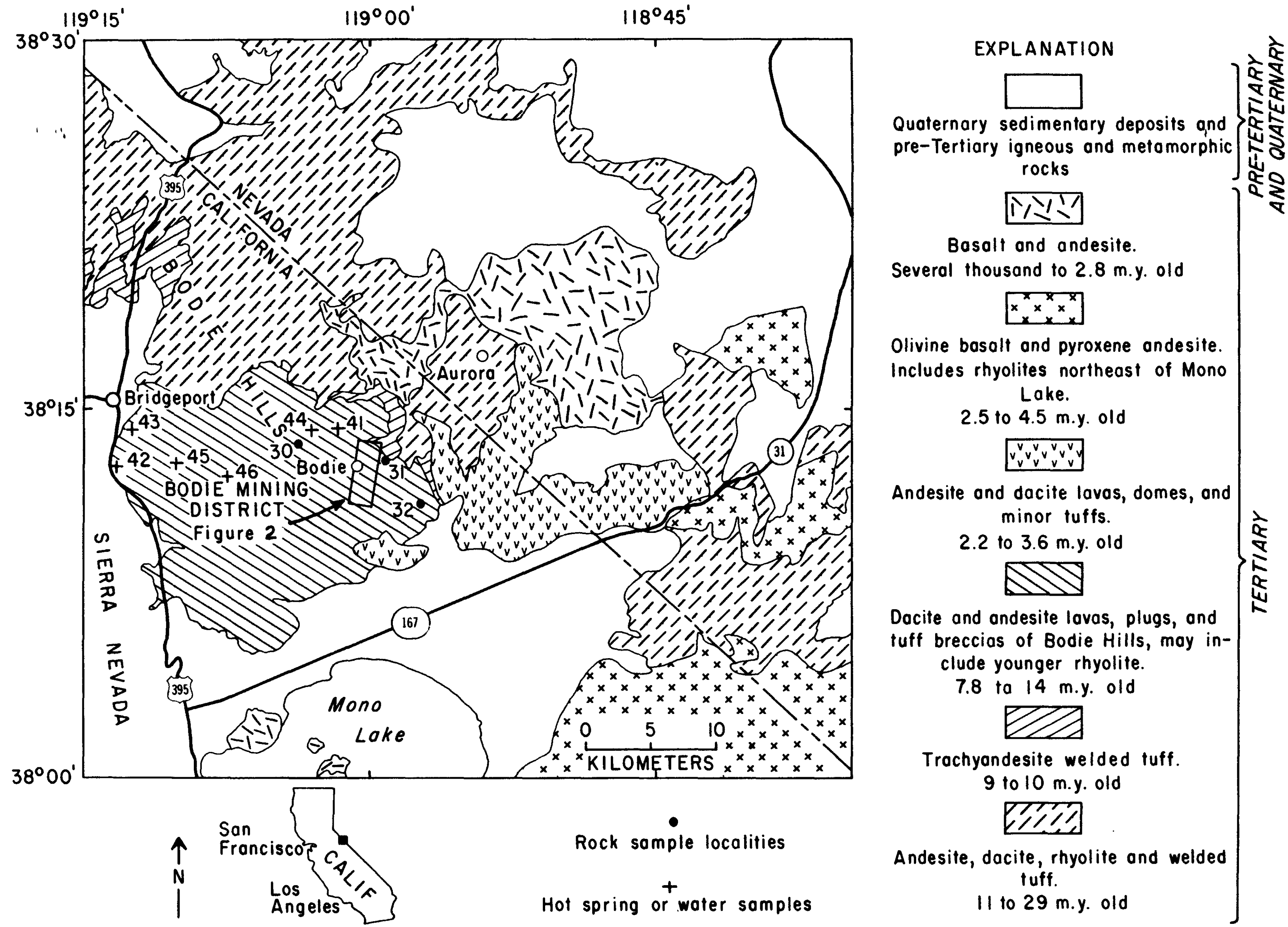
The adularia formed between 8.6 and 7.1 m.y. ago, late in the history of the Bodie Hills volcanic field, during a period of intense potassium-silicate hydrothermal alteration and gold-silver mineralization. Because replacement of intermediate host rock approached completion, it Rb and Sr content and K/Rb ratio coverage with values for the constituent adularia. Chemical and isotopic analyses of adularia and associated vein minerals, quartz and calcite, and $\delta^{18}O$ and δD measurements of fluid inclusions in these minerals indicate that a K- and Rb-rich solution of meteoric origin was the agent of alteration. Temperature (approximately 250°C), K/Rb ratio, and $\delta^{18}O$ of the solution probably remained constant during potassium metasomatism and precipitation of the adularia.

INTRODUCTION

Potassium feldspar is a product of potassium-silicate alteration in two distinctive environments: hydrothermally altered epizonal plutons of intermediate composition such as porphyry copper desposits, and in hot-spring and epithermal ore deposits (Meyer and Hemley, 1967). In the former environment the feldspar is orthoclase or microcline; in epithermal mineral deposits and hot springs, potassium feldspar is typically referred to as adularia. Adularia is the dominant feldspar in hot-spring systems having high potassium activity and temperatures of 150°-250°C (ELLIS, 1967). Adularia also occurs as a primary vein mineral associated with quartz and calcite or as an alteration product in wall rocks where it may be associated with sericite and quartz (Meyer and Hemley, 1967). Under conditions of intense potassium metasomatism, adularia may completely replace volcanic wall rock.

Adularia is a minor gangue mineral in gold- and silver-bearing quartz veins and is a common constituent of hydrothermally altered dacitic volcanic rocks of Miocene age in the Bodie mining district, Mono County, California (Fig. 1). K-Ar analyses (Silberman and others, 1972) of adularia have been useful in determining the age and duration of hydrothermal activity, and stable isotope studies (O'Neil and others, 1973) of adularia and associated calcite and quartz have provided data on the temperature and chemistry of the ore-forming fluids.

Fig. 1.--Regional geologic map of the Bodie Hills and vicinity, showing age and dominant composition of the Tertiary volcanic rocks (modified from O'Neil and others, 1973).


119°15'
119°00'
118°45'
38°30'
38°15'
38°00'
EXPLANATION
Quaternary sedimentary deposits and pre-Tertiary igneous and metamorphic rocks
PRE-TERTIARY AND QUATERNARY
Basalt and andesite. Several thousand to 2.8 m.y. old
Olivine basalt and pyroxene andesite. Includes rhyolites northeast of Mono Lake. 2.5 to 4.5 m.y. old
Andesite and dacite lavas, domes, and minor tuffs. 2.2 to 3.6 m.y. old
Dacite and andesite lavas, plugs, and tuff breccias of Bodie Hills, may include younger rhyolite. 7.8 to 14 m.y. old
Trachyandesite welded tuff. 9 to 10 m.y. old
Andesite, dacite, rhyolite and welded tuff. 11 to 29 m.y. old
TERTIARY
NEVADA
CALIFORNIA
BODIE HILLS
SIERRA NEVADA
Bridgeport
Aurora
Bodie
BODIE MINING DISTRICT
Figure 2
Mono Lake
395
167
31
30
31
32
41
42
43
44
45
46
0 5 10
KILOMETERS
N
San Francisco
Los Angeles
CALIF
Rock sample localities
Hot spring or water samples

GEOLOGIC SETTING

The Bodie mining district is located along the east margin of a complex field of Tertiary volcanic rocks (Fig. 1) in the southern part of the Bodie Hills (Chesterman, 1968; Silberman and others, 1972; Kleinhampl and others, 1975). The district is underlain by a sequence of porphyritic biotite-hornblende dacite lava flows and tuff breccias named the Silver Hill Volcanic Series by Chesterman and Gray (1966). This sequence is intruded and domed by small dacite plugs, the largest of which underlies Bodie Bluff (Fig. 2).

The dominant structure in the district is an irregular, faulted, north-trending anticline intruded by several plugs. Two prominent sets of steeply dipping faults, one striking north to north-northeast, and a second normal to it, cut all units including the instrusive bodies. The major ore-bearing veins and fractures strike northeast, parallel to one of the major fault sets. Tuff breccia within a small graben on Bodie Bluff has been downdropped along northeast-striking faults against intrusive dacite. Faulting probably occurred during and shortly after intrusion of the dacite, and ore deposition was partly controlled by the graben structure and commenced shortly after intrusion of the plugs. The major productive mines are located within and near the graben. The district is credited with production of more than $30 million worth of gold and silver (Clark, 1970).

MODE OF OCCURRENCE OF ADULARIA

Adularia has two distinct modes of occurrence in the district: (1) as a constituent of gold- and silver-bearing quartz veins, and (2) as a groundmass mineral in the hydrothermally altered dacite wall rock.

The vein adularia generally occurs in subordinate amounts intergrown with quartz and calcite. Some of the adularia occurs as euhedral crystals

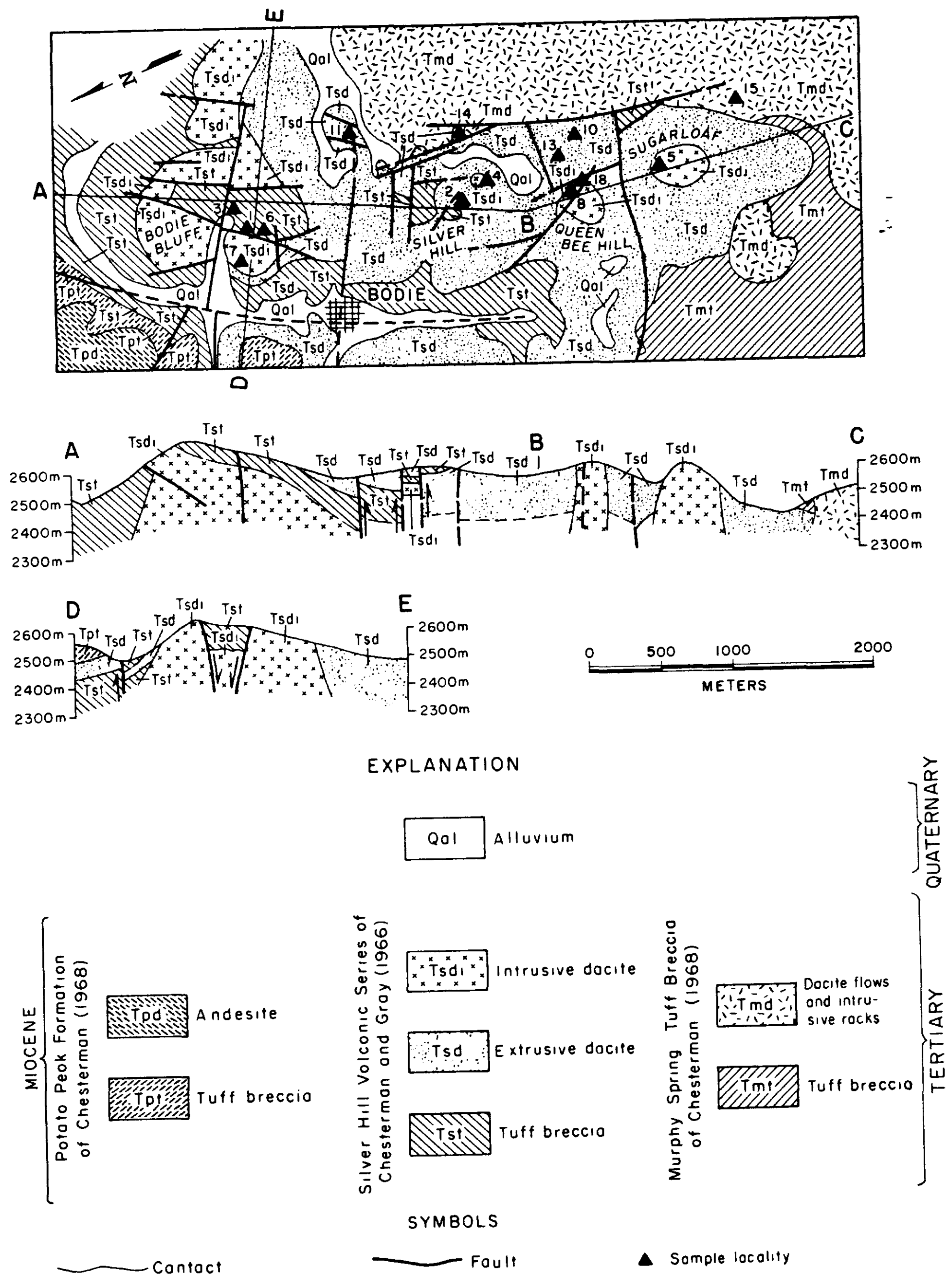


Fig. 2.--Generalized geologic map and sections of the Bodie mining district, Mono County, California (Modified from Silberman and others, 1972).

completely enclosed within quartz, but the bulk of it occurs as drusy cavity linings within the quartz veins, which in turn cut altered dacite wall rocks. In both instances the adularia crystals average about 1 cm across, although some free-growing crystals exceed 2 cm in the maximum dimension. The adularia in cavity linings is white to cream in color and exhibits well-developed crystal faces where the crystals project into the cavity. Late-forming fine-grained quartz and calcite occur locally as coatings on the adularia crystals. Ore minerals associated with adularia-quartz veins are native gold and silver, argentite, pyrite, sphalerite, galena, stephanite, and tetrahedrite.

The adularia-quartz veins in the Bodie Bluff area (Fig. 2) are generally well-defined bodies exhibiting sharp contacts with their enclosing wall rocks. However, in the center of the district, southeast of Silver Hill (Fig. 2), veins grade imperceptibly over a distance of several meters into altered wall rocks. The adularia in the latter environment does not exhibit crystal form but occurs as clear, glassy grains, rarely more than 2 mm across, in a granular aggregate with fine-grained white quartz and coarse-grained white calcite.

The groundmass adularia is extensively developed in dacitic wall rock at Bodie Bluff. The adularia in this environment is usually fine grained, glassy, and white, and shows no crystal form. Its distribution in the dacite is irregular, but concentrations of up to 20 percent of the rock occur locally adjacent to quartz veins.

The two adularias studied in this report were separated from vein samples. B-270 is coarse-grained adularia derived from a vein at Bodie Bluff; RC-D1B is fine-grained adularia obtained from vein material near Silver Hill. Descriptions of the veins have been given previously (O'Neil and others, 1973).

PHYSICAL AND OPTICAL PROPERTIES

Adularia from cavity linings in veins generally consists of prismatic crystals of pseudo-orthorhombic habit elongated paralled to the c axis. The feldspar breaks easily along 001 and has less prominent cleavages along 010 and 110. Well-formed adularia crystals commonly exhibit the c, m, and x faces; z crystal faces are rare. Vein adularia has a hardness of 6 on the Mohs scale and a specific gravity of 2.559 measured on a Berman balance.

Optical properties were determined for adularia cleavage fragments from samples B-270 using calibrated immersion oils. The optically clear adularia gave the following indices of refraction: $\alpha = 1.517$, $\beta = 1.518$, and $\gamma = 1.522$. Measurements are within ± 0.002 measured in sodium light. The birefringence is 0.005; the optic axial angle, $2V\alpha=64^{\circ}$, measured by universal stage; the extinction angle, $\alpha{:}X=6^{\circ}-12^{\circ}$; and the O.A.P. $\perp$ 010. The optical properties for B-270, particularly the low values for indices of refraction, are characteristic of potassium-rich monoclinic alkali feldspar (Deer and others, 1963).

STRUCTURE

Adularia samples B-270 and RC-D1B were analyzed by X-ray diffraction to determine structural state and unit-cell parameters. Powdered samples were mixed with reagent-grade LiF to provide an internal standard and placed in aluminum sample cells. The samples were scanned between 10° and 65° 2Θ in a diffractometer using copper radiation and a scintillation detector. Goniometer speed ($1/4^{\circ}$ 2Θ per minute) and chart speed (1/4 in. per minute) were combined to produce diffraction patterns in which 1 inch = $1^{\circ} 2\Theta$. Adularia and LiF peak centers were located with a comparator near peak tops, and absolute 2Θ values for LiF were calculated for $CuK\alpha_1$ (λ = 1.54051Å) radiation.

The structural state of any alkali feldspar polymorph is largely a function of Al-Si distribution among tetrahedral lattice positions. The degree of Al-Si ordering can be approximately determined from X-ray diffration data using the three-peak method of Wright (1968). In the three-peak method, 2θ values for the $\bar{2}04$ and 060 reflections of alkali feldspars are plotted against one another and compared directly with established trends representing synthetic alkali feldspar solid-solution series (Fig. 3). Furthermore, feldspars with anomalous unit-cell dimensions are predicted if measured 2θ values for $\bar{2}01$ disagree with $\bar{2}01$ values contoured on the $\bar{2}04$-060 plot.

Values for the adularias from Bodie are plotted on the $\bar{2}04$-060 diagram shown in Figure 3. For comparison, a vein adularia from Switzerland (Spencer B) and a synthetic sanidine (SynSanShaw) are also plotted. It is apparent from Figure 3 that Bodie adularias have the highly disordered monoclinic structural configuration usually associated with high sanidine. Both adularia samples of this study have $\bar{2}01$ values of 20.99° 2θ, suggesting unit-cell dimensions that are only slightly anomalous. The highly disordered structural state of Bodie adularia, in contrast to the Spence B adularia (Fig. 3), probably reflects more rapid cooling during and after crystallization of the finer grained Bodie feldspar.

Unit-cell parameters for Bodie adularias (Table 1) were calculated by least-squares refinement of X-ray diffraction data using a computer program by Appleman and Evans (1973). Initial unit-cell parameters for the refinement were those given for sanidine in Borg and Smith (1969, Table 34).

Unit-cell parameters for two other alkali feldspars are included in Table I for comparison with the adularias from Bodie. Cell dimensions for B-270 and RC-D1B are similar to those of synthetic sanidine but are distinctly different

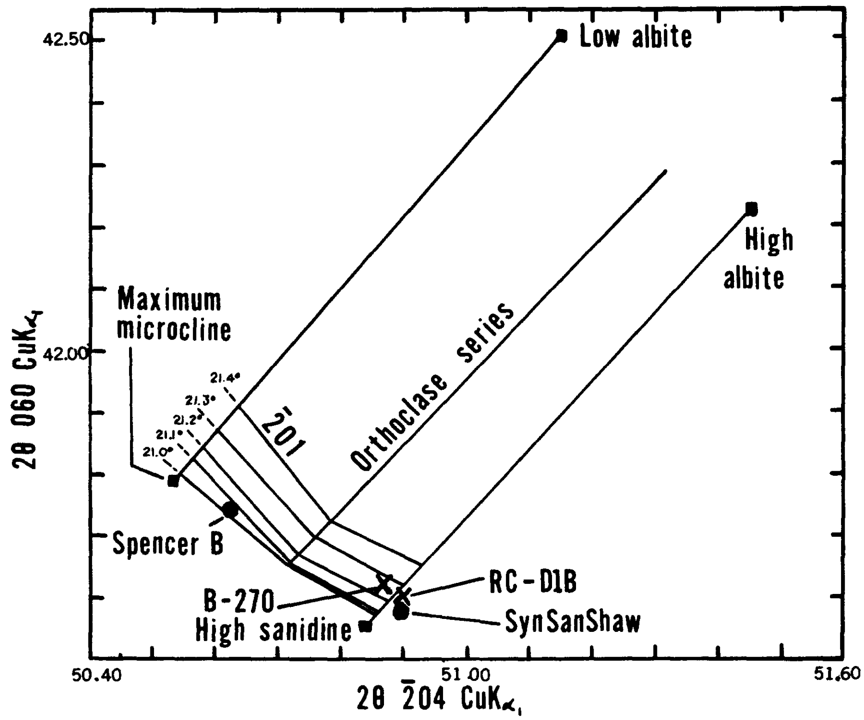


Fig. 3.--Plot of 2Θ (060) against 2Θ ($\bar{2}04$) with $\bar{2}01$ contours (modified from Wright, 1968). Connecting lines for three complete alkali feldspar solid solution series are constructed from data of Orville (1967) and Wright and Stewart (1968). X-ray data for Spencer B adularia and SynSanShaw from Wright and Stewart (1968). Both adularias from Bodie have 2Θ (201) values of 20.99°.

Table 1. Unit-cell parameters for Adularia from Bodie and other alkali feldspars

[Standard errors in brackets refer to last decimal place]

Unit-cell parameter	B-270	RC-D1B	SynSanShaw[1]	Spencer B[2]
a (Å)	8.591(1)	8.590(1)	8.606(2)	8.554(1)
b (Å)	13.008(1)	13.008(2)	13.018(2)	12.970(2)
c (Å)	7.170(1)	7.177(1)	7.172(1)	7.207(1)
α	90°	90°	90°	90°
β	116° 03.3(5)'	116° 03.4(8)'	116° 02.6(8)'	116° 00.4(6)'
γ	90°	90°	90°	90°
Volume (Å)[3]	719.86(9)	720.49(15)	721.86(16)	718.65(13)

[1]Sanidine, Or=100, synthesized by Shaw (1963); X-ray data from Wright and Stewart (1968).

[2]Adularia from St. Gothard, Switzerland; 3-inch crystal described by Spencer (1937); X-ray data from Wright and Stewart (1968).

from those of Spencer B adularia. This tends to confirm the high structural state of hydrothermal adularia of the Bodie type and suggests that adularia may have a wide range in triclinicity depending on the thermal history of the mineral.

CHEMISTRY

A chemical analysis for the vein adularia B-270 is shown in Table 2. SiU.C.$_2$, Al_2O_3, and K_2O account for more than 99 percent of the sample, but calculation of proportions of feldspar endmembers (Table 2) indicates an excess of SiO_2 beyond the amount required to balance Ca, Na, and K. This excess SiO_2 may represent contamination from fine-grained quartz intergrown with adularia, an occurrence found in many epithermal vein deposits. When the chemical analyses are corrected for the amount of SiO_2 assumed to be present as free quartz, the composition of adularia B-270 becomes $Or_{95}Ab_5An_{<0.1}$.

X-ray fluorescence analyses for K, Rb, and Sr of the two adularias from Bodie are given in Table 3. Also listed in Table 3 are K, Rb, and Sr values for two dacitic volcanic rocks, one completely replaced by quartz and adularia, the other mostly unaltered. Sample OD7604 represents the end product resulting from intense potassium-silicate alteration in the Bodie mining district. Table 3 shows that strong K + Rb enrichment and Sr depletion occur during alteration, and values may approach those of adularia in progressively more altered rocks.

Rb and Sr values for adularias from Bodie are consistent with values for hydrothermal K-feldspars from epithermal ore deposits in the Basin and Range province of the western United States (M. L. Silberman and B. P. Fabbi, unpub. data). In general, Bodie adularias have higher Rb contents and lower K/Rb ratios than volcanic and plutonic feldspars (Dodge and others, 1970; Noble

Table 2. Major element composition of adularia sample B-270

Oxide[1]	Weight percent
SiO_2	65.82
Al_2O_3	17.65
Fe_2O	.00
FeO	.00
MgO	.00
CaO	.03
Na_2O	.56
K_2O	15.54
H_2O	.06
TiO_2	.01
P_2O_5	.006
MnO	.00
Total	99.68
Weight percent of compounds:	
Or	91.8
Ab	4.7
An	.05
Qz	3.4 (by difference)

[1]X-ray fluorescence analysis, analyst: B. P. Fabbi.

Table 3. K, Rb, and Sr contents of adularia, altered dacite, and unaltered dacite from Bodie mining district

[Chemical data and sample descriptions from O'Neil and others (1973). All analyses by X-ray fluorescence. Analysts: B. P. Fabbi, L. F. Espos]

Sample	K (Percent	Rb (ppm)	Sr (ppm)	Rb/Sr	K/Rb
B-270	12.97	800	94	8.5	162
RCD1B	12.09	610	245	2.5	198
[1]OD7604	11.08	520	153	3.4	213
[2]855-40	2.59	83	890	0.1	312

[1]Sample is altered dacite, almost completely replaced by adularia and quartz.

[2]Sample is unaltered porphyritic biotite dacite.

and Hedge, 1970). The K/Rb ratio is typical of those found in pegmatites and hydrothermal deposits (Shaw, 1968). The low K/Rb ration of hydrothermal feldspars probably reflects a low K/Rb ratio in hydrothermal waters (Ellis and Mahon, 1964). Present-day hot-spring waters near Bodie, which are isotopically similar to the Bodie ore fluids, have K/Rb ratios in the same range as the adularias (O'Neil and others, 1973). These relationships suggest that a K- and Rb-rich fluid of meteoric origin was responsible for potassium-silicate alteration in at least part of the Bodie district.

STABLE ISOTOPE RELATIONS

Oxygen isotope compositions of feldspars and associated vein minerals, quartz and calcite, are summarized from O'Neil and others (1973) in Table 4. Also included are deuterium analyses from fluid inclusions in two of the analyzed quartz samples. The range of $\delta^{18}O$ values of the hydrothermal minerals is to small and the ^{18}O depletion so pronounced that a dominant if not exclusive meteoric component for ore fluid is indicated (O'Neil and others, 1973). [An estimated temperature for the ore fluid of 245°C was obtained from a fluid-inclusion filling temperature measured in quartz from sample B-270 (J. T. Nash, unpub. data, quoted in O'Neil and others, 1973)].

$\delta^{18}O$ of the ore fluids can be calculated from the $\delta^{18}O$ of the vein minerals modified by laboratory-determined fractionation factors between the minerals and water at the estimated ore fluid temperature. The $\delta^{18}O$ can also be calculated using the expression relating δD and $\delta^{18}O$ for meteoric waters (Craig, 1961). The $\delta^{18}O$ values calculated for the Bodie ore fluid by these two methods are in agreement at approximately -13. The results indicate there was little or no oxygen isotope shift in these fluids. The volume of hydrothermal water

Table 4. Stable isotope analyses of hydrothermal feldspars and associated minerals from Bodie

[Data from O'Neil and others, 1973, Table 6

Sample		$\delta^{18}O$ (SNOW)[1]	δD (SNOW)[1]
B 270	Adularia	-4.1	
B-270	Quartz	-2.6	-98.4[2]
RC-D1B	Adularia	-5.1	
RC-D1B	Quartz	-2.7	-97.6[2]
RC-D1B	Calcite	-6.5	

[1]Isotopic values are relative to SNOW (Standard Mean Ocean Water) standard for oxygen and hydrogen.

[2]Analysis of fluid inclusions contained within the mineral.

relative to the volume of rock must have been large. Thus the bulk of hydrothermal mineralization at Bodie took place in meteoric waters that were essentially unaltered isotopically.

GEOCHRONOLOGY

In general, plutonic and volcanic potassium-rich feldspars with sanidine and orthoclase structures appear to give reliable K-Ar ages, at least for rocks of Mesozoic and Tertiary age (Evernden and James, 1964; Evernden and Kistler, 1970). Bass and Ferrara (1969) suggest that feldspar originally having high-temperature disordered structures tend to develop Al-Si ordering with time, and the corresponding lattice changes result in anomalously low ages in some K-feldspars of intermediate structure. Adularias used for dating the mineralization at Bodie have highly disordered sanidine structures and should yield accurate estimates of time of emplacement of the gold-bearing adularia-quartz veins.

The K-Ar ages for three adularias from the Bodie district listed in Table 5 indicate that vein mineralizations took place between 8.0 and 7.1 m.y. ago (Silberman and others, 1972). A detailed geochronological study of the volcanic rocks in the Bodie area (Silberman and Chesterman, 1972; Kleinhampl and others, 1975) indicates that the host rocks, a sequence of andesitic to dacitic flows and tuff breccias, were erupted between 9.4 and 8.6 m.y. ago. These rocks are a local phase of an extensive suite of calc-alkaline volcanic rocks erupted between 14 and 8 m.y. ago in the surrounding region. K-Ar ages of altered rocks at Bodie indicate that inception of hydrothermal activity occurred approximately 8.6 m.y. ago (Silberman and others, 1972) when volcanic activity was waning. Cessation of hydrothermal activity and mineralization marked the end of the andesite-dacite volcanism in the region.

Table 5. K-Ar ages of adularia from adularia-quartz veins at Bodie

[Modified from Silberman and others, 1972, Table 1]

Locality No.	Sample No.[1]	Source	Mineral	Age
1	7346-1	Adularia-quartz vein	Adularia	7.1 ± 0.1
2	RCD1B	Adularia-Quartz-calcite vein	Adularia	7.7 ± 0.1
3	B-270	Adularia-quartz vein	Adularia	8.0 ± 0.2

[1] For description of samples, see O'Neil and others. (1973).

SUMMARY

During late Miocene time intermediate volcanic rocks in the Bodie mining district were subjected to hydrothermal alteration, principally by potassium metasomatism. The chemical path of progressive alteration is shown by the triangular Na-Ca-K diagram in Figure 4. Potassium-rich, highly disordered nonoclinic adularia crystallized as a stable phase in the potassium-silicate alteration zone. As replaceent of host rock approached completion, its Rb and Sr contents and K/Rb ratio approached those of adularia (Table 3, Fig. 5). Plots of K and Rb versus $\delta^{18}O$ in altered rocks, unaltered rocks, and adularia (Fig. 6) show that isotopic values also converge during potassium-silicate alteration. The constant K/Rb ratio and the K and Rb correlation with $\delta^{18}O$ imply that a large volume of fluid with constant temperature, $\delta^{18}O$, and Rb and K contents was the agent of hydrothermal alteration. Adularia from Bodie apparently crystallized in open conduits connected to an underlying epithermal hot springs environment, from waters of high meteoric component similar to water in presently active thermal springs in the district.

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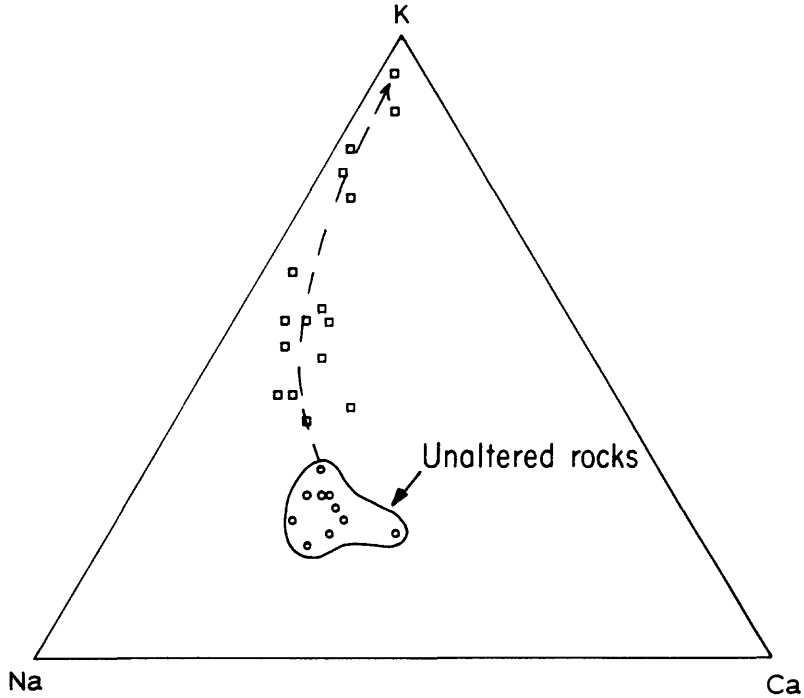

Fig. 4.--Na-Ca-K diagram calculated from major element composition of altered rocks of the Silver Hill Volcanic Series of Chesterman and Gray (1966), Bodie mining district. (O) unaltered rocks, (▫) altered rocks, dashed line on diagram shows path of progressive alteration. Modified from O'Neil and others, 1973.

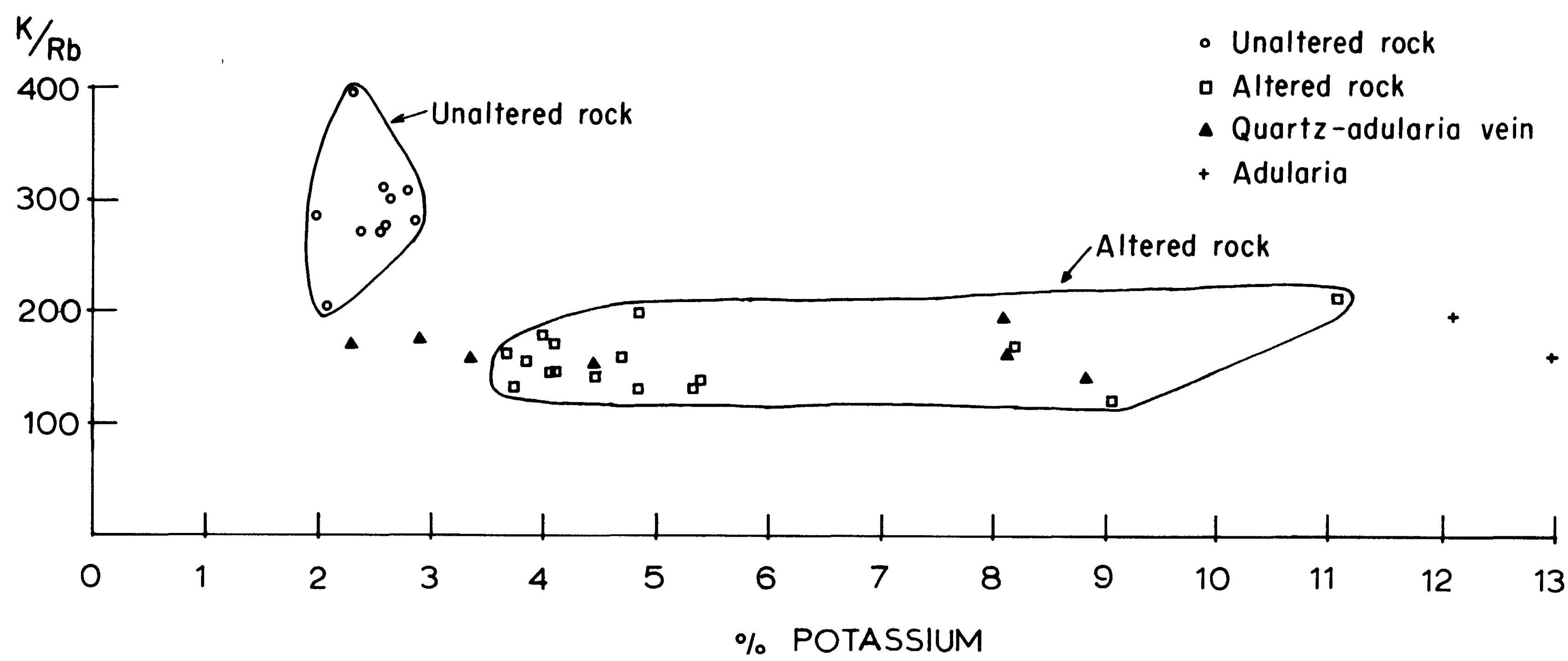

Fig. 5.--Variation of K/Rb with K content for altered and unaltered rocks of the Silver Hill Volcanic Series of Chesterman and Gray (1966), and gold-bearing quartz-adularia veins, Bodie mining district. (0) unaltered rocks, (□) altered rocks, (▲) gold-bearing quartz-adularia veins, (+) adularia. Modified from O'Neil and others, 1973.

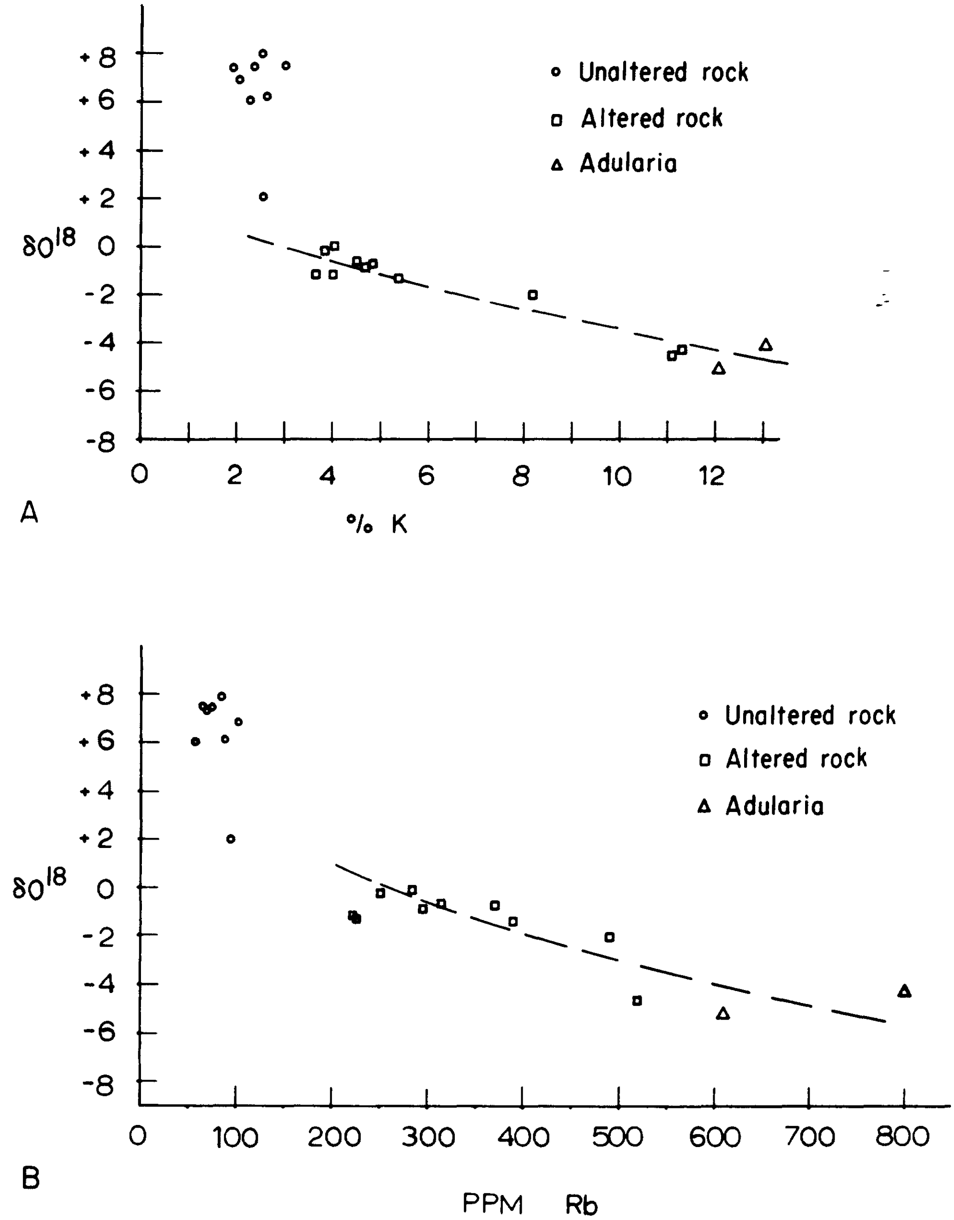

Fig. 6.-- The variation of $\delta^{18}O$ with K and Rb content for altered and unaltered rocks of the Silver Hill Volcanic Series of Chesterman and Gray (1966), Bodie mining district. A. #$\delta^{18}O$ variation with K. B. $\delta^{18}O$ variation with Rb, (O) unaltered rocks, (□) altered rocks, (Δ) adularia. Modified from O'Neil and others, 1973.

REFERENCES CITED

Appleman, D. E. and Evans, H. T., Jr., 1973, Indexing and least-squares refinement of powder diffraction data: U. S. Geol. Survey, NTIS Report PB2-16188, 67 p.

Bass, M. N. and Ferrara, Giorgio, 1969, Age of adularia and metamorphism, Ouachita Mountains, Arkansas: Am. Jour. Sci., v. 267, p. 491-498.

Borg, I. Y. and Smith, D. K., 1969: Calculated X-ray powder patterns for silicate minerals: Geol. Soc. America Mem. 122, 896 p.

Chesterman, C. W., 1968, Volcanic geology of the Bodie Hills, Mono County, California, in Coats, R. R., Hay, R. L., and Anderson, C. A., eds., Studies in volcanology--A memoir in honor of Howel Williams: Geol. Soc. America Mem. 116, p. 45-68.

Chesterman, C. W. and Gray, C. H., Jr., 1966, Geology and structure of the Mono basin, Mono County, California, in Guidebook along the east-central front of the Sierra Nevada: Geol. Soc. Sacramento, Ann. Field Trip 1966, p. 11-18.

Clark, W. B., 1970, Gold districts of California: California Div. Mines and Geology Bull. 193, 186 p.

Craig, Harmon, 1961, Isotopic variations in meteoric waters: Science, v. 133, p. 1702-1703.

Deer, W. A., Howie, R. A. and Zussman, J., 1963, Rock forming minerals, Vol. 4, Framework silicates: London, Longman Group Limited, 435 p.

Dodge, F. C. W., Fabbi, B. P. and Ross, D. C., 1970, Potassium and rubidium in granitic rocks of central California, in Geological Survey research 1970: U. S. Geol. Survey Prof. Paper 700-D, p. D108-D115.

Ellis, A. J., 1967, The chemistry of some explored geothermal systems, in Barnes, H. L., ed., Geochemistry of hydrothermal ore deposits: New York, Holt, Rinehart and Winston, Inc., p. 465-514.

Ellis, A. J. and Mahon, W. A. J., 1964, Natural hydrothermal systems and experimental hot-water/rock interactions: Geochim. et Cosmochim. Acta, v. 28, p. 1323-1358.

Evernden, J. F. and James, G. T., 1964, Potassium-argon dates and the Tertiary floras of North America: Am. Jour. Sci., v. 262, p. 945-974.

Evernden, J. F. and Kistler, R. W., 1970, Chronology of emplacement of Mesozoic batholithic complexes in California and western Nevada: U. S. Geol. Survey Prof. Paper 623, 42 p.

Kleinhampl, F. J., Davis, W. E., Silberman, M. L., Chesterman, C. W., Chapman, Roger and Gray, C. H., Jr., 1975, Aeromagnetic and limited gravity studies and generalized geology of the Bodie Hills region, Nevada and California: U. S. Geol. Survey Bull. 1384, 38 p.

Meyer, Charles and Hemley, J. J., Wall rock alteration, in Barnes, H. L., ed., 1967, Geochemistry of hydrothermal ore deposits New York, Holt, Rinehart and Winston, Inc., p. 166-235.

Noble, D. C. and Hedge, C. E., 1970, Distribution of rubidium between sodic sanidine and natural silicic liquid: Contr. Mineralogy and Petrology, v. 29, p. 234-241.

O'Neil, J. R., Silberman, M. L., Fabbi, B. P. and Chesterman, C. W., 1973, Stable isotope and chemical relations during mineralization in the Bodie mining district, Mono County, California: Econ. Geology, v. 68, p. 765-784.

Oroville, P. M., 1967, Unit-Cell parameters of the microcline-low albrite and the sanidine-high albite solid solution series: Am. Mineralogist, v. 52, p. 55-86.

Shaw, D. M., 1968, A review if K-Rb fractionation trends by covariance analysis: Geochim. et Cosmochim. Acta, v. 32, p. 573-601.

Shaw, H. R., 1963, The four-phase curve sanidine-quartz-liquid-gas between 500 and 4,000 bars: Am. Mineralogist, v. 48, p. 883-896.

Silberman, M. L., Chesterman, C. W., Kleinhampl, F. J. and Gray, C. H., Jr., 1972, K-Ar ages of volcanic rocks and gold-bearing quartz-adularia veins in the Bodie mining district, Mono County, California: Econ. Geology, v. 67, p. 597-604.

Silberman, M. L. and Chesterman, C. W., 1972, K-Ar age of volcanism and mineralization, Bodie mining district and Bodie Hills volcanic field, Mono County, California: Isochron/West, v. 3, p. 13-22.

Spencer, Edmondson, 1937, The potach feldspars. I. Thermal stability: Mineralog. Mag., v. 24, p. 453-494.

Wright, T. L., 1968, X-ray and optical study of alkali feldspar: II. An X-ray method for determining the composition and structural state from measurement of 2Θ values for three reflections: Am. Mineralogist, v. 53, p. 88-104.

Wright, T. L. and Stewart, D. B., 1968, X-ray and optical study of alkali feldspar: I. Determination of composition and structural state from refined unit-cell parameters and 2V: Am. Mineralogist, v. 53, p. 38-87.