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K-Ar Age Relations of Granodiorite Emplacement and Tungsten and Gold Mineralization near the Getchell Mine, Humboldt County, Nevada *

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Abstract

A granodiorite stock intrudes complexly folded and thrust-faulted Paleozoic sedimentary rocks in the Osgood Mountains of eastern Humboldt County, Nevada. Within the metamorphic aureole surrounding the pluton, the sedimentary rocks are converted to cordierite hornfels and marble; tungsten-bearing tactites developed along the contacts of the granodiorite. Cutting the granodiorite and sedimentary rocks is the Getchell fault, along which the disseminated gold ore bodies of the Getchell mine are localized. K-Ar ages of the granodiorite, andesite porphyry, tungsten-bearing tactites, and altered granodiorite from the Getchell mine indicate that emplacement, alteration, and mineralization are all part of a magmatic-thermal episode which took place approximately 90 m.y. ago.

Introduction

THE Getchell gold deposit in Humboldt County is one of a group of disseminated gold deposits of Nevada. Other ore deposits of this type include Carlin, Cortez, and Gold Acres (Roberts et al., 1971). Structural and geochemical settings are distinctive, but the deposits show some general similarities: the presence of a fractured, permeable zone prior to ore deposition, deposition of silica replacing limestone with the introduction of gold, the presence of carbonaceous material in some of the ores, the predominance of very fine-grained to submicroscopic gold particles in the ore, and high gold-silver ratios (Roberts et al., 1971; Wells et al., 1969; Radtke and Scheiner, 1970; Hausen and Kerr, 1968). Altered igneous rocks occur within the ore zones of all the disseminated gold deposits. The importance of factors controlling ore deposition apparently varied from deposit to deposit (Roberts et al., 1971).

Although several K-Ar ages have been reported from ore zones of disseminated gold deposits at Gold Acres (Silberman and McKee, 1971) and Cortez (Wells et al., 1971) ages are not yet conclusively known for any of these deposits, and only spatial relations have been demonstrated between these ore deposits and nearby igneous rocks.

This paper reports several ages on sericite and K-feldspar from the altered igneous rock at the Getchell ore deposit and shows how these ages support the genetic association of the stock and Au deposit suggested by earlier workers and documented with geochemical data by Erickson et al. (1964). Neuerburg (1966) tentatively suggested a similar conclusion based on his study of the patterns of distribution of heavy minerals and gold within the stock.

Geologic Setting

The Getchell mine lies at the northeastern margin of the Osgood Mountains. The geology of the Osgood Mountains quadrangle, which covers the north part of the Osgood Mountains and includes the Getchell mine, was described by Hobbs (1948) and Hotz and Willden (1964). The Getchell ore deposit was described by Joralemon (1951). The geologic setting is summarized by Hotz and Willden (Fig. 1).

The northern Osgood Mountains consist of complexly folded and thrust-faulted Paleozoic sedimentary rocks intruded by a Cretaceous granodiorite stock. The stock has two lobes, a northern and a southern, joined by a thin septum; aeromagnetic data (B. R. Berger, unpub. data) substantiate the hour-glass shape. The sedimentary rocks intruded are principally argillites and limestone of the Preble formation of Cambrian age. Though not apparent in outcrop, the aeromagnetic data suggest that the stock has steep limbs dipping outward on both east and west flanks.

Dacite porphyry dikes cut the Paleozoic sedimentary rocks and are probably related genetically to the stock. In the northern part of the Osgood Mountains, andesite porphyry dikes cut both sedimentary rocks and the granodiorite. Andesite dikes cut the sedimentary rocks at the Getchell mine. They are highly sheared and hydrothermally altered in underground workings and in the North Pit of the Getchell mine. As the dikes follow the trend of the

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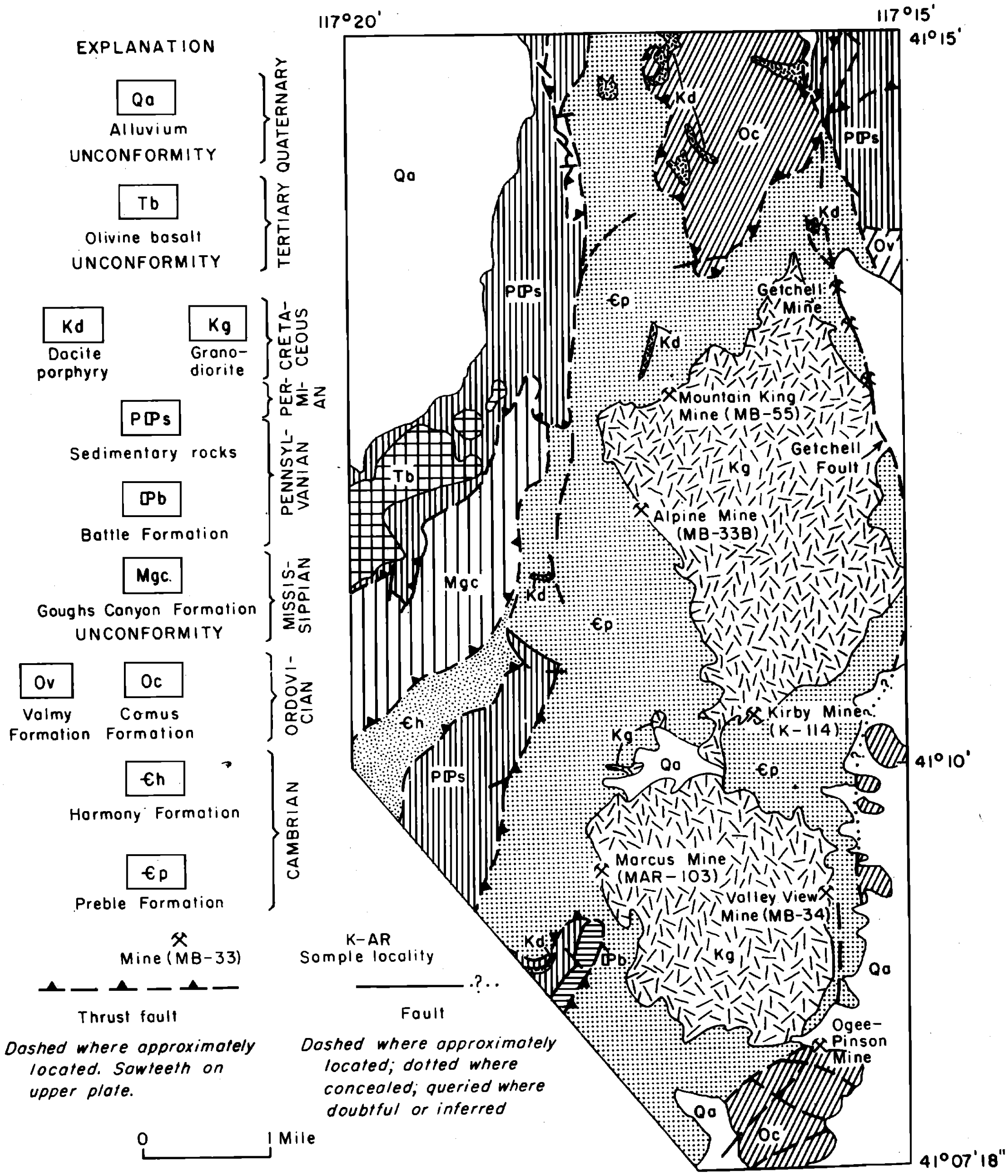

FIG. 1. Geologic map of the northern part of the Osgood Mountains, modified from Hotz and Willden (1964, pl. 1).

fault zone or occupy portions of it, their original position appears to have been controlled by an early fracture that later developed into the Getchell fault zone. Granodiorite dikes also parallel the fault zone.

There is some disagreement over the age of the andesite porphyry dikes. Joralemon (1951) suggested that the dikes are an early phase of Tertiary volcanism; Hobbs (1948) suggested that they are a later phase of the same Late Cretaceous igneous activity that produced the granodiorite stock; Hotz and Willden (1964) suggested that they are cogenetic with the granodiorite. The age of these andesitic dikes is critical because veins of gold-bearing material cut them at the Getchell mine.

The granodiorite stock has a conspicuous metamorphic aureole as much as 10,000 feet wide. The shales of the Preble formation are transformed to biotite-, andalusite-, and cordierite-bearing hornfels; the limestones to marble, light-colored calc-silicate rock, and dark-colored tactite composed of garnet, pyroxene, and other calcium-bearing silicates, along with minor scheelite. Thirteen tungsten mines

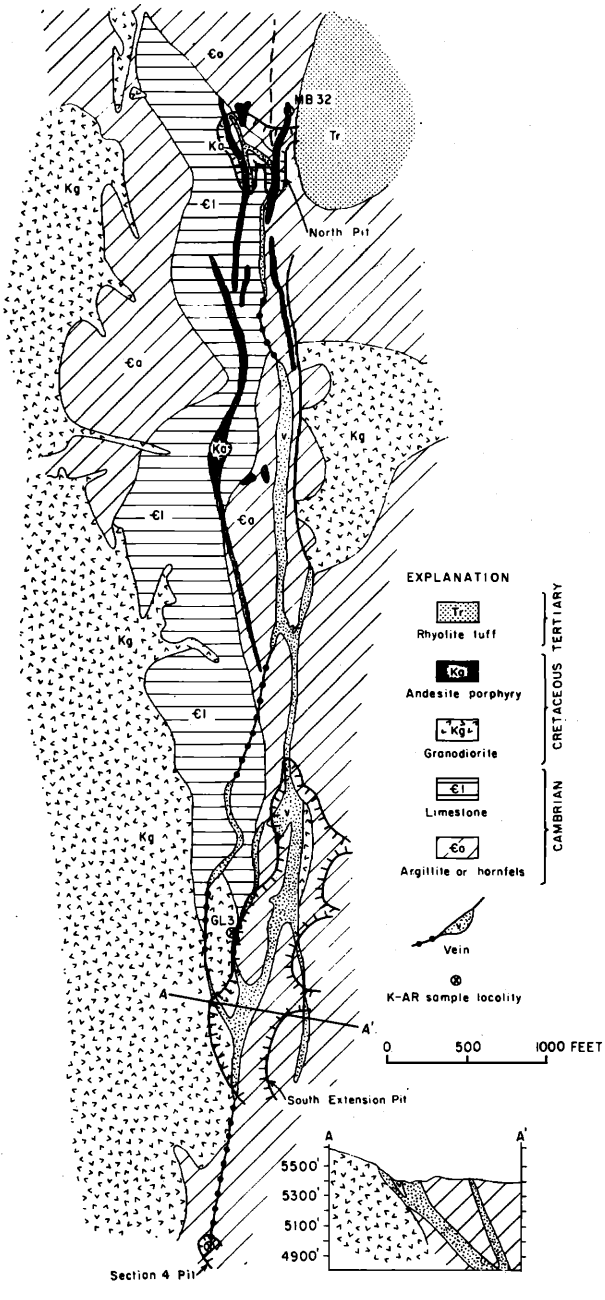

FIG. 2. Geology of the Getchell mine area, modified from Hotz and Willden (1964, Pl. 11).

located around the periphery of the stock in the tactite zone produced a total of 1,344,150 tons of scheelite-bearing ore (Hotz and Willden, 1964).

The ore is mainly scheelite-bearing tactite; powellite is accessory and metallic sulfides are present in minor amounts. Uncommon small local concentrations of molybdenite are observed in tactite close to the granodiorite contact. Pyrite, chalcopyrite, sphalerite, and galena are erratically distributed in the tactite; pyrite is the most common. At some places, scheelite is found in calc-silicate rock and altered granodiorite. At others, scheelite occupies narrow seams and/or small intensely altered areas or pockets in the granodiorite along the contacts. These small, but very rich ore pockets consist of muscovite, hydrobiotite, small quartz crystals, and scheelite. Scheelite-bearing quartz veins are found cutting the gold ores at both the Getchell and Ogee-Pinson mines.

A major structural feature of the Osgood Mountains is the Getchell fault along the eastern margin of the range (Fig. 1). Horizontal mullions and slickensides with superimposed vertical striae show that fault movement was largely parallel to the strike prior to the block faulting (Hobbs, 1948). Joralemon (1951) indicates that the latest movement was vertical. Evidence at the Getchell mine of post-mineralization movement on the Getchell fault is the displacement of Quaternary alluvium and development of slickensides on the surfaces of altered rock.

The Getchell Gold Deposits

The disseminated gold deposit is localized along the Getchell fault. In the southern and central parts of the mine area, granodiorite forms the walls of the fault zone, whereas farther north the fault cuts argillite and limestone of the Preble formation (Joralemon, 1951; Hotz and Willden, 1964). In the center pit, barren granodiorite forms the hanging wall. In the South Extension Pit, granodiorite in the footwall is partly altered (sericitic alteration) and veined by calcite and dolomite; it contains sulfides and approximately eight ppm gold. Both oxide and sulfide gold deposits occur. The oxide ore, being easily recovered, was exploited during early mining operations. The sulfide ores, which are more extensive, were mined later.

Joralemon (1951, p. 270) reported that the gold ore bodies are sheetlike masses that lie along various strands of the Getchell fault zone (Fig. 2). These masses consist of sheared and mineralized argillite and limestone cut by quartz and calcite and dolomite veins; within the fault zone, the rocks contain a soft, carbon-bearing gouge (gumbo)—minute quartz crystals embedded in a nearly submicroscopic intergrowth of quartz and amorphous carbon. The gumbo formed in the gouge zone by hydrothermal metamorphism of carbonaceous limestone and shale accompanied by the introduction of fine-grained quartz. It was a major bearer of oxide gold ore. The sulfide ores consist of carbonaceous limestone with iron and arsenic sulfides.

The arsenic sulfides, realgar and orpiment, are associated with gold in the vicinity of the Getchell mine. According to Joralemon (1951), they are the most abundant metallic minerals and are primarily restricted to the areas within the veins that contain notable quantities of gold. The gold ore contains a few thousandths to a few hundredths percent WO_3; scheelite and hübnerite have been identified. Every mineral is host for some of the gold. Pyrite, marcasite, and the carbonaceous gumbo are the most important, but gold occurs sparsely in realgar, arsenopyrite, and quartz. The gold is present largely as discrete, microscopic particles ranging from a fraction of a micron to ~1 mm. Some gold principally outside of the ore shoots may be present in solid solution in pyrite and carbon (Joralemon, 1951).

Gold occurs in the sedimentary rocks of the fault zone and in altered andesite dike rocks. Wall rocks as far as 400 feet from the ore body contain 0.01 to 0.08 ounce per ton gold and trace amounts occur farther out. The boundary for the ore deposits is economic, not mineralogic (Hotz and Willden, 1964; Joralemon, 1951). Joralemon's (1951) detailed studies of the ore deposit led him to conclude that the richest parts of the ore bodies were the main channelways through which the mineralizing solutions passed. These are also the areas of richest concentration of visible gold. Joralemon (1951, p. 299) indicates that realgar, marcasite, and economically important gold concentrations were deposited in the main channelways at nearly the same time that solutions in the other parts of the veins were depositing disseminated pyrite and submicroscopic gold in noncommerical amounts. These solutions spread out from the main channelways, altering the wall rocks—including granodiorite and the andesite porphyry dikes—and depositing small amounts of gold. South of the Getchell mine, gold occurs in economic and subeconomic amounts in silicified shale and limestone with no traces of realgar or orpiment and only minor amounts of arsenopyrite.

Geologic Estimates of the Age of Tungsten and Gold Mineralization

The tungsten deposits in the tactite zones surrounding the granodiorite stock are generally thought to be the same age as the stock. Geologic and stable isotope data (unpublished) indicate that the scheelite was deposited during the final stages of silicification by solutions sweated out of the granodiorite after emplacement. Hotz and Willden (1964, p. 86) suggest that some scheelite was deposited when the tactite was formed and that scheelite deposition continued during the waning stages of the magmatic episode.

The geologic relations of the Getchell gold deposit do not provide closely defined age limits for gold deposition. Ore deposition could have occurred any time after the emplacement of the andesite porphyry dikes. Joralemon (1951) tentatively dated the andesite porphyry as early or middle Tertiary. He suggested, on the basis of the early work of Ferguson (1929) who assigned ages to hydrothermal ore deposits in Nevada, that the Getchell gold deposit was late Tertiary. Because the ore bodies were localized in the fault zone that cut the granodiorite, Hotz and Willden (1964) suggest that the Getchell mineralizàtion was later than the emplacement and solidification of the granodiorite stock, to which they assign a Late Cretaceous age based on a Pb-α age determination of 69 m.y. (Jaffe et al., 1959, entry no. 77). Hotz and Willden consider the mineralization to be Tertiary. Estimates of the age of the Getchell gold mineralization were thus based on the assumption that the andesite porphyry dikes were considerably younger than the granodiorite, or on Ferguson's (1929) attempted classification of precious metal deposits in Nevada.

Erickson et al. (1964) demonstrate the occurrence of small amounts of tungsten in and over the gold-bearing ore. They also show that arsenic occurred in amounts to 2,000 ppm in oxidized iron-rich material from the tactite-tungsten ores; the elements As and W are common to both the tactite and gold deposits. On the basis of their geochemical studies, Erickson et al. (1964) believe that the various types of metal deposits are probably genetically related to each other and to the granodiorite intrusive mass and that they formed as successive and overlapping stages of one period of complex mineralization. Neuerburg (1966) has studied the distribution of sulfides, gold, and other heavy minerals in the granodiorite. He concludes that areas of high-sulfide concentration adjacent to the contact of the granodiorite represent points at which late magmatic mineralizing fluids issued from the stock. He demonstrates that these areas of postulated fluid exit correspond to tungsten deposits in the adjacent limestone country rocks. The gold content of the granodiorite is one to two orders of magnitude greater than that for crustal rocks or for granitic rocks of similar composition. The highest gold concentrations in the stock are in large part adjacent to the Getchell fault and to the low-grade gold deposits in the Ogee-Pinson mine several miles to the south. Neuerburg (1966) suggests that the spatial relation may indicate a genetic relation like that postulated for the association of high-sulfide concentrations and tungsten deposits.

Conversely, Roberts et al. (1971), in reviewing the occurrence of the disseminated gold deposits in north-central Nevada, suggest that the mineral assemblage of the gold deposit in the Getchell fault zone appears to indicate a distinctly lower temperature than the assemblage in the tactite-tungsten deposits, concluding that the gold deposits are con-

TABLE 1. Chemical Composition of Altered and Unaltered Granodiorite and Andesite

Oxides	MB33B	MB34	MB32	MB32A	GL3
Chemical Analyses					
SiO_2	65.9	61.7	64.9	65.2	44.0
Al_2O_3	16.8	17.8	16.9	17.0	16.8
Fe_2O_3	1.5	1.0	0.85	1.2	2.3
FeO	2.0	3.4	1.5	1.6	0.96
MgO	1.4	2.2	1.6	1.6	2.4
CaO	4.3	5.2	5.3	4.9	10.4
Na_2O	3.6	3.6	3.5	3.3	0.06
K_2O	2.8	2.8	3.3	2.7	7.8
H_2O	0.72	0.93	0.84	0.74	3.3
TiO_2	0.53	0.70	0.63	0.58	0.62
P_2O_5	0.19	0.26	0.26	0.27	0.27
MnO	0.07	0.08	0.06	0.05	0.10
CO_2	—	0.09	—	—	10.1
Total	99.8	99.8	99.6	99.1	99.1
Normative Mineral Composition (calculated on a volatile-free basis[1])					
Q	22.4	14.2	19.2	22.9	13.4
C	0.03	—	—	—	8.33
or	16.7	16.8	19.8	16.3	46.5
ab	30.8	30.9	30.1	28.5	0.51
an	21.6	24.5	21.0	24.0	—
wo	—	0.70	2.39	0.30	
en	3.53	5.56	4.04	4.06	0.93
fs	1.71	4.48	1.14	1.10	—
mt	2.20	1.47	1.25	1.77	1.64
hm	—	—	—	—	1.19
il	1.02	1.35	1.21	1.12	1.19
cc	—	—	—	—	18.1
mg	—	—	—	—	4.29
Total	100	100	100	100	97

[1] With exception of GL-3.
For sample locations, see Table 4. For descriptions, see Silberman and McKee (1971) and text. Methods used are those described in U.S. Geol. Survey Bull. 1144-A, supplemented by atomic absorption; analysts: Paul Elmore, Lowell Artis, G. W. Chloe, Hezekiah Smith, James Kelsey, and J. L. Glenn.

siderably younger, possibly early Tertiary. They emphasize, however, that the gold deposit itself has not been dated.

Geochemistry of Altered and Unaltered Igneous Rocks

Chemical analyses were made and norms calculated on rock samples recently collected by the writers: two samples of granodiorite (MB-33B, MB-34), two samples of andesite porphyry from the North Pit (MB-32 and 32A), and a sample of altered granodiorite from the South Extension Pit (GL-3) (Table 1). The samples were also analyzed semiquantitatively by spectrography (Table 2) and quantitatively for some trace elements (Table 3). Normative mineral contents of the unaltered samples are plotted on a quartz-plagioclase-orthoclase diagram (Fig. 3).

The major element content of the stock is similar to that of other granodiorites in north-central Nevada. The andesite porphyry dike is similar in composition to the granodiorite. The petrography of these rocks is described in Hotz and Willden (1964).

Two sericitized blocks of granodiorite that were mineralized in the Getchell fault zone have provided datable minerals from the gold deposit. The mineralogy and chemistry of one of the samples studied in detail is presented here as a basis of comparison for alteration studies in spatially associated igneous rocks in other disseminated gold deposits.

The block of granodiorite adjacent to the footwall of the Getchell fault in the South Extension Pit (Fig. 2) was sampled for K-Ar dating and for chemical analysis (sample GL-3). Hydrothermal alteration has resulted in recrystallization of plagioclase and partial recrystallization of orthoclase to a fine-grained felty mass of sericite (<0.01 mm in size). Coarse biotite books from the original granodiorite have been recrystallized to coarser grained sericite (approximately 0.1–0.6 mm in size), pyrite, and leucoxene. Some original orthoclase and quartz

TABLE 2. Semiquantitative Spectrographic Analyses of Altered and Unaltered Granodiorite and Andesite

Element (ppm)	MB33B	MB34	MB32	MB32A	GL3
Ag	—	—	—	—	0.7
As	—	—	—	—	10,000
Au	—	—	—	—	—
B	—	—	—	—	300
Ba	1,500	1,500	2,000	1,500	3,000
Be	—	—	—	—	—
Bi	—	—	—	—	—
Cd	—	—	—	—	—
Co	5	10	10	7	7
Cr	5	10	10	7	7
Cu	2	7	150	150	7
La	—	50	30	—	—
Mn	700	700	300	200	500
Mo	—	—	—	5	—
Nb	10	10	10	7	—
Ni	—	5	10	5	—
Pb	15	10	10	—	—
Pd	—	—	—	—	—
Sb	—	—	—	—	—
Sc	10	15	10	7	10
Sr	1,000	1,500	1,000	700	300
V	70	100	70	50	70
W	—	—	—	—	—
Y	20	20	20	15	15
Zn	—	—	—	—	—
Zr	100	70	100	100	70

Semiquantiative spectrographic analyses; analyst: Chris Heroupolos. Results reported as midpoints of geometric brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, etc. The precision of a reported value is approximately plus or minus one bracket at 68 percent or two brackets at 95 percent confidence. Detectability limits: Ag 0.7, As 200, Au 15, B 7, Ba 2, Be 1, Bi 7, Cd 50, Co 2, Cr 1, Cu 1, La 30, Mo 2, Nb 7, Ni 1, Pb 7, Sb 100, Sc 2, Sr 5, V 3, W 30, Y 10, Zn 100, Zr 5.

phenocrysts were not destroyed during alteration; additional K-feldspar may have crystallized during alteration; however, no indication of this was found in the thin sections examined. Most of the K_2O that was added was fixed as sericite. Calcite and mixtures of calcite and dolomite form veins several centimeters to one-half millimeter in width and are developed pervasively throughout the altered granodiorite. Sulfides, particularly pyrite, realgar, and orpiment, occur within these carbonate veins and are disseminated throughout the altered rock.

Comparison of the major element chemistry of the altered granodiorite (GL-3, Table 1) from the South Extension Pit with unaltered granodiorite is difficult because the sample is pervasively veined with dolomite and calcite. It is clear, however, that potassium has been added to the rock, and petrographic examination indicates that the additional potassium has been fixed as sericite. Hornblende, biotite, and plagioclase have largely been destroyed or recrystallized to sericite. The Ca and Mg originally present in these phases is now probably in the carbonate. Joralemon (1951) suggests that some of the calcite in the veins was from solution of limestone beneath the ore deposit. An additional source outside the altered area for magnesium (now fixed in dolomite) may have been required.

That sericitic alteration accompanied the gold mineralization is demonstrated by sericitized cordierite crystals in gold-bearing hornfels. Away from the gold-bearing zones, the cordierite in this hornfels is not altered. On the basis of the petrographic examination, only one episode of sericite formation appears to be present.

TABLE 3. Quantitative Analyses for Selected Trace Elements and Potassium

Element	MB33B	MB34	MB32	GL3
K	2.17%	2.20%	2.50%	6.97%
Rb	69 ppm	62 ppm	59 ppm	192 ppm
Sr	602	670	623	182
Cu	3.8	9.2	160	NA
Pb	6.5	7.5	42	NA
Zn	50	43	24	NA
As	<10	<10	40	5,000[1]
Au	0.06	0.06	0.06	7.8[2]
Hg	0.03	0.02	0.03	19.5[3]
Sb	<1	<1	<1	10[3]
Ag	0.2	<0.2	0.4	NA

[1] As by modified Gutzeit method; analyst: E. J. Fenelly.
[2] Au by fire assay-atomic absorption method; analysts: D. Goss, R. Rahill.
[3] Hg and Sb by instrumental methods, analysts: R. L. Turner, J. B. McHugh.
K, Rb, Sr by X-ray fluorescence; analysts: B. P. Fabbi and L. F. Espos. Cu, Pb, Zn by atomic absorption spectroscopy; analyst: C. L. Burton. As by colorimetric spectroscopy; analyst: H. McBride. Au by atomic absorption; analyst: H. A. McBride. Hg by instrumental method; analyst: C. A. Curtis. Sb by colorimetric method; analysts: M. S. Rickard, S. I. Hoffman. Ag by atomic absorption; analyst: J. G. Viets. NA, not analyzed.

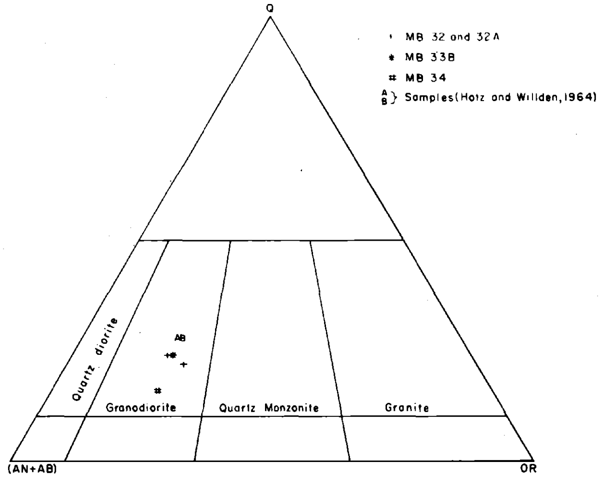

FIG. 3. Normative quartz, plagioclase, orthoclase diagram for samples from the Osgood Mountains pluton, calculated on a volatile-free basis.

Trace Elements

The trace element analyses (Table 3) show the addition of arsenic, gold, mercury, antimony, barium, and rubidium and the loss of strontium to the altered and veined granodiorite (sample GL-3) in the South Extension Pit. The arsenic is present as realgar and orpiment in the calcite-dolomite veins and disseminated throughout the rock. Erickson et al. (1964) show that arsenic, mercury, and tungsten have the greatest enrichment and are the most abundant metals in the zone of gold mineralization. Barium also increases in the ore zone. Of these metals, only tungsten was not detected in the altered granodiorite. The block of granodiorite that yielded sample GL-3 constitutes part of a mineralized pod, characteristic of the spotty sulfide mineralization in the South Extension Pit of the Getchell mine.

Rocks Dated by the K-Ar Method

K-Ar ages of two samples of granodiorite, one near the Alpine tungsten mine at the western margin of the stock and the other near the Valley View mine at the southeastern margin of the stock (Fig. 1), and of one sample of andesite porphyry from the east wall of the North Pit of the Getchell mine (Fig. 2), listed on Table 4, were published earlier by Silberman and McKee (1971).

Two samples of altered granodiorite (GL-3 and Section 4, Table 4) were collected for dating. Pervasive slickensides and kinked muscovite lamellae in replaced biotite phenocrysts at locality GL-3 indicate that fault movement affected this locality after alteration. Fine-grained sericite from the ground-

TABLE 4. K-Ar Ages of Altered and Unaltered Igneous Rocks from the Getchell Mine and Various Tungsten Mines, Northern Osgood Mountains

Sample number	Location	Rock type	Mineral	Apparent age	Reference
USGS(M)-MB33B	South-central sec. 6, T. 38 N., R. 42 E., near Alpine tungsten mine	Granodiorite	Biotite	89.9 ± 1.8	Silberman and McKee (1971)
USGS(M)-MB34	East-central sec. 29, T. 38 N., R. 42 E., near Valley View tungsten mine	Granodiorite	Biotite Hornblende	92.2 ± 1.8 89.5 ± 1.8	Silberman and McKee (1971)
USGS(M)-MB32	SE¼ sec. 29, T. 39 N., R. 42 E., east wall of north pit, Getchell mine	Andesite porphyry dike	Biotite	89.9 ± 1.8	Silberman and McKee (1971)
KIR-114	NW¼ sec. 17, T. 38 N., R. 42 E., Kirby tungsten mine	Sericite-bearing seam in tactite	Sericite[1]	87.6 ± 3.4	This report
MAR-103	East-central sec. 24, T. 38 N., R. 41 E, Marcus tungsten mine	Sericite-bearing seam in tactite	Sericite[1]	88.4 ± 3.3	This report
MB55	SE¼ sec. 31, T. 39 N., R. 42 E., Mountain King tungsten mine	Sericite-bearing seam in altered granodiorite	Sericite[1]	92.6 ± 2.8	This report
Sec. 4	Approx. center, sec. 4, T. 38 N., R. 42 E., Section 4 Pit	Altered granodiorite sill	Sericite[1]	92.2 ± 2.8	This report
GL-3A	SW¼ sec. 33, T. 39 N., R. 42 E., west wall of South Extension Pit, Getchell mine	Altered, mineralized granodiorite	Orthoclase Fine-grained sericite (<0.01 mm)	74.7 ± 2.2 67.0 ± 2.0	This report This report
			Coarse-grained sericite (0.1 to 0.6 mm)	80.9 ± 3.3	This report

[1] $2M_1$ muscovite.

mass of the GL-3 sample was obtained by crushing and grinding a specimen and letting the ground material settle in a water column. After 30 hours, the suspension was decanted and dried. A grainsize estimate of less than 0.001 mm was calculated on the basis of Stokes' law. Coarse-grained micaceous flakes were concentrated from another part of the specimen by using heavy liquids. These micaceous flakes consisted of muscovite lamellae, 0.2–0.6 mm in size, intergrown with leucoxene, pyrite, and some calcite. The low K_2O content of the mineral separate was caused by this intergrowth of potassium-free minerals. No attempt was made to regrind the sericite intergrowths for purification because of the possible loss of argon from deformation of the sample. An X-ray diffraction analysis of both the coarse- and fine-grained sericite showed it to have the $2M_1$ structure of muscovite.

A K-feldspar separate was obtained from the coarse-grained fraction by heavy liquids and a magnetic separator. X-ray analysis using Wright's (1968) method confirmed an orthoclase structure.

Another sample of sericitized granodiorite was collected from an altered sill in the Section 4 Pit (Section 4, Table 4), south of the main part of the Getchell mine (Fig. 1). The sill intrudes argillite of the Preble formation and both the sill and argillite show sericitic alteration. Coarse flakes of muscovite (up to 2 mm in size) occur in a grussy matrix of quartz and K-feldspar. Gold was not detected in the granodiorite, but the surrounding altered Preble argillite was strongly mineralized (B. R. Berger, unpub. data, 1972). About 36,000 tons of high-grade oxide gold ore was mined from the pit. A sericite concentrate was obtained from the altered granodiorite and this sericite, like the GL-3 sample, has the $2M_1$ muscovite structure but is not intergrown with potassium-free minerals. Mineral separates for sample GL-3 were prepared at the Nevada Bureau of Mines and Geology. The mineral separate from the Section 4 Pit sample was prepared at the U. S. Geological Survey.

Three samples from sericite-bearing seams were collected near tactite-granodiorite contacts (Fig. 1 and Table 4). Sample MAR-103 at the Marcus mine is from the quartz-calcite-sericite pods above a massive tungsten-bearing garnet tactite bed. KIR-114 at the Kirby mine is from a thin-bedded garnet-

TABLE 5. K-Ar Analytical Data for Previously Unpublished Age Determinations

Sample number	Mineral	K_2O (percent)	*Ar^{40}(RAD) moles/gm $\times 10^{-10}$	Ar^{40}(RAD) / Ar^{40}_{total}	Apparent age (m.y.)
G-K114	Sericite	4.82 4.92	6.538 6.403	0.627 0.571	87.6 ± 3.4
G-M103	Sericite	8.72 8.65	11.52 11.78	0.699 0.786	88.4 ± 3.3
(M) MB-55	Sericite	9.20 9.17	12.87	0.972	92.6 ± 2.8
(M) Sec. 4	Sericite	10.33 10.33	14.42	0.979	92.2 ± 2.8
(M) GL-3	Sericite (<0.01 mm)	9.17 9.17	9.242	0.859	67.0 ± 2.0
	Sericite (0.2–0.6 mm)	5.97 5.67 6.07 6.06	7.251	0.885	80.9 ± 3.2
	Orthoclase	14.38 14.40	16.19	0.959	74.7 ± 2.2
(M)[1] MB34	Hornblende	0.675 0.695 0.695 0.688 0.710 0.703 0.655 0.657	0.9272	0.621	89.5 ± 1.8
	Biotite	8.70 8.62 8.80 8.90	12.19	0.861	92.2 ± 1.8

[1] Age of hornblende revised from that reported in Silberman and McKee (1971) based on new K_2O analyses. No change in biotite age.

Argon analyses were made by standard isotope dilution techniques (Dalrymple and Lanphere, 1969). The samples were fused by RF induction heating and the extracted argon analyzed with a Neir-type, 6½-inch-radius, 60°-sector mass spectrometer (USGS-(M) samples) or an MS-10 mass spectrometer (geochron samples), both operated in the static mode. Analyst: M. L. Silberman ((M) samples). Potassium analysis ((M) samples) by differential flame photometry using lithium metaborate fusion technique; lithium serving as an internal standard. Analyst: Lois Schlocker. Potassium analysis (G samples) by differential flame photometry using a Beckman DU spectrophotometer. Constants used: $\lambda_e = 0.585 \times 10^{-10}$ yr^{-1}, $\lambda_\beta = 4.72 \times 10^{-10}$ yr^{-1}, $^{40}K/K_{total} = 1.22 \times 10^{-4}$ gm/gm. Plus/minus is estimated analytical uncertainty at one standard deviation. (M) analyses performed at U.S. Geological Survey Laboratory. G analyses performed at Krueger Enterprises, Geochron Laboratories Division, Isotope Laboratory, Cambridge, Mass.

diopside skarn with shaly hornfels breaks. The sericite is intergrown with quartz along the boundary between a tactite bed and unmineralized marble. Sample MB55 was collected from a cavity within the granodiorite along the contact of granodiorite with tactite at the Mountain King mine (Fig. 1), where sericite-bearing seams contain scheelite (Hotz and Willden, 1964).

The sericite in these samples was coarse grained, in flakes up to 1½ mm across. Mineral separations and all analytical work on the samples from the Marcus and Kirby mines were done by Geochron Labs, Inc. Mineral separation for the Mountain King mine sample was done at the Nevada Bureau of Mines and Geology. Analytical data are given for previously unpublished ages (Table 5).

K-Ar Ages

The age of the granodiorite based on averaging the three ages from the two specimens of unaltered granodiorite is 90 m.y. (Table 4). The concordance of the biotite and hornblende ages from sample MB-34 strengthens the validity of the 90-m.y. age. The andesite porphyry in the North Pit also gave a 90-m.y. age (sample MB-32, Table 4). On the basis of chemical similarity, proximity, and age, the andesite porphyry is most likely a phase of this magmatic episode. The agreement of the K-Ar ages of the granodiorite and andesite porphyry establishes a firm upper limit on the age of the ore deposit.

The muscovite samples from the tactite zones gave ages of 87.6, 88.4, and 92.6 m.y. These ages are broadly the same (within analytical uncertainty) as the age of the granodiorite. Both the geologic relations and K-Ar ages indicate a genetic relation between granodiorite and tungsten-bearing tactite deposits.

Altered granodiorite from the Section 4 Pit (Table 4), which contained the coarsest grained, purest muscovite, has an age of 92.2 m.y., the same within analytical uncertainty as the age determined for unaltered granodiorite. The South Extension Pit sample (GL-3, Table 4) gave three separate, discordant ages; all of these are significantly younger than the age of the pluton.

The 67-m.y. sericite date of sample GL-3 (Table 4) must be considered a minimum age because of the very fine grainsize of this groundmass sericite. Hanson and Gast (1967) and Hart (1964) showed that the retentivity of argon in micas is dependent on grainsize in a contact metamorphic environment. Where the grainsize of the sericite is very fine, a relatively large surface area is exposed, probably permitting increased argon loss at relatively low temperatures.

There are two probable interpretations of the orthoclase age and the coarse-grained sericite age of 75 and 81 m.y., respectively, from sample GL-3 (Table 4). The first is that mineralization in the South Extension Pit area occurred approximately 81 m.y. ago and that temperatures in the vicinity of the ore body remained high enough to prevent quantitative retention of argon in the feldspar until about 75 m.y. ago. Studies by Hart (1964) and Aldrich et al. (1965) have demonstrated that K-feldspar is less retentive of argon than micas when affected by a thermal event. Thus, the coarse-grained sericite age of 81 m.y. would more nearly reflect the age of mineralization than the feldspar age. If this is correct, the ages imply that temperatures remained relatively high for a period of at least several million years in the South Extension Pit and that hydrothermal mineralization in the Getchell area took place 10 m.y. after the deposition of tungsten and the Section 4 gold deposits which are all approximately 90 m.y. old (Table 4). The large thermal metamorphic halo to the east of the Getchell mine could indicate a long-term event. However, detailed studies of the age relations of vein and alteration minerals in epithermal ore deposits and modern hydrothermal systems (Silberman et al., 1972; Silberman and Ashley, unpub. data, 1972; Silberman and White, unpub. data) and in the Bingham Canyon porphyry copper deposit (Moore and Lanphere, 1971) have demonstrated that lifetimes of hydrothermal ore systems are of the order of 1 to 3 m.y. No system with a lifetime of more than 3 m.y. has yet been documented. We consider it unlikely that hydrothermal alteration and ore deposition at Getchell lasted for the 10-m.y. span.

An alternative interpretation, one that the writers favor, is that the age of 81 m.y. determined on coarse sericite (67 m.y. on fine-grained sericite) and the K-feldspar age of 75 m.y. from the South Extension Pit (sample GL-3, Table 3) resulted from argon loss due to deformation from postmineralization movement along the Getchell fault. Evidence for this movement has been discussed. Lee et al. (1970) have shown that the K-Ar age of a mica near a large fault can be reduced by fault movement.

Other interpretations of the data are possible, including the suggestion that the 67-m.y. fine-grained sericite age (GL-3) represents the true age of mineralization and that the coarse-grained sericite and K-feldspar ages were partially reset by the thermal effects of the mineralization. This would require the crystallization of two generations of sericite—the fine-grained sericite, during Au mineralization, and the coarse-grained sericite at some earlier time. Petrographic evidence for this is lacking. The fine-grained sericite is found replacing plagioclase, and K-feldspar, which in unaltered granodiorite tends to be interstitial to plagioclase, and quartz. The coarser sericite lamellae along with leucoxene and iron oxides are found replacing the biotite phenocrysts. These relations are exactly the same as are seen in epithermal deposits where K-silicate alteration has affected intermediate volcanic rocks and the process has occurred during a single stage. Another suggestion is that mineralization could have been still younger (e.g., Tertiary) and all of the GL-3 ages are hybrid, being reset to varying amounts. These possibilities cannot be entirely ruled out, however. The discordant ages occur in a highly deformed block of altered rock, whereas the K-Ar age of the sericite from the undeformed block of altered granodiorite (Section 4 Pit) shows no apparent argon loss. The physical effects of deformation extend down to the size range of individual crystals (kinking of muscovite lamellae) and we suggest that the deformation, or perhaps the frictional heat generated by it, caused the argon loss. The loss varies in amount relative to already established criteria on mineral retentivity of argon and on grainsize (Hanson and Gast, 1967; Hart, 1964). Hence, we suggest that the discordant GL-3 ages are best explained by postmineralization deformation. Using our favored interpretation, we believe that the tungsten ore bodies and the Getchell gold deposit formed shortly after the emplacement of the granodiorite and andesite porphyry at approximately 90 m.y. ago during a hydrothermal stage that overlapped and succeeded the magmatic activity. The entire process started with emplacement of the stock and contact metamorphism of the adjacent Paleozoic sedimentary rocks and continued with a hydrothermal stage that produced the tungsten in the tactites adjacent to the granodiorite. The Getchell gold mineralization was a last, lower temperature phase of the same hydrothermal activity. We view the entire process of emplacement of the granodiorite pluton, the andesite dikes, the tactite-tungsten deposits, and the hydrothermal gold deposits as all belonging to the same thermal episode. Because of the analytical uncertainties of ages (2 to 3 m.y.), the data do not permit an estimate of the length of time the entire thermal system operated, but previous and current studies on lifetimes of hydrothermal systems suggest that 2 to 3 m.y. is a reasonable estimate.

We wish to stress that our interpretation does not *require* a genetic relation between the pluton and gold deposits. Further geochemical and isotopic studies are necessary to clarify the genetic relations between the different episodes of the thermal system. [These studies of primary hydrothermal and alteration minerals in the igneous rocks as well as in the tungsten and gold deposits in the Getchell area are in progress at the U. S. Geological Survey. Experimental geochemical studies on the solubilities of tungsten and gold under varying conditions of temperature, pressure, and solution composition are in process at Stanford University. Comparison of the results of these studies should give new evidence as to the genetic relations between the mineral deposits of the Getchell area (A. S. Radtke, writ. commun., 1973).]

Ages of Mineralization of Other Disseminated Gold Deposits

Roberts et al. (1971) suggest that most of the disseminated gold deposits in north-central Nevada formed during an early Tertiary intrusive-metallogenic epoch, one of several defined by Silberman and McKee (1971). The basis for this suggestion is not clear from the data presented.

At Carlin, Cortez, Gold Acres, Northumberland, and Preble, altered igneous rocks, usually felsite dikes or sills, are present within the mineralized zones (Wrucke and Armbrustmacher, 1969; Wells et al., 1969; Hausen and Kerr, 1968; A. S. Radtke, oral commun., 1972; John Livermore, oral commun.). In at least three of the disseminated deposits, coarse-grained sericite formed in dikes or sills spatially associated with the ore.

At Gold Acres, felsite sills in the ore zone recrystallized to quartz, sericite, and iron oxide (C. T. Wrucke, unpub. data, 1972), an assemblage of minerals corresponding to sericitic alteration described by Meyer and Hemley (1967). High gold values occur in the fractured altered felsite (Wrucke and Armbrustmacher, 1969). Silberman and McKee (1971) report a K-Ar age of 94 m.y. from coarse-grained sericite ($2M_1$ muscovite) from a felsite sill at Gold Acres. Sericite ($2M_1$ muscovite) from a drill core of altered quartz monzonite which lies 500 feet below the Gold Acres Pit gave a similar age of 92 m.y., biotite from the same drill core gave a 99-m.y. age. Silberman and McKee (1971, p. 25) suggest sericitic alteration occurred during ore deposition. Roberts (Roberts et al., 1971, p. 27) believes that gold mineralization at Gold Acres may be related to intrusive rhyolite porphyry dikes of Oligocene age that are associated with gold-quartz veins at Tenabo, four miles to the northeast. No igneous rocks have been found in the vicinity of Gold Acres other than the altered sills and quartz monzonite mentioned above. The coarse-grained sericite dated at Gold Acres is similar to that of the Section 4 Pit sample at Getchell. Although the study has not been detailed enough to demonstrate conclusively that the Gold Acres mineralization is 92 to 94 m.y. old, the present data strongly suggest this conclusion.

At Carlin, thin felsic dikes have been altered to an assemblage of quartz, kaolinite, and sericite, indicative of an argillic alteration assemblage (Meyer and Hemley, 1967). Sericite has been identified in the main pit in altered mineralized limestones of the Roberts Mountains formation adjacent to the dikes as well as within the dikes themselves (A. S. Radtke, unpub. data, 1972). Altered dike material with coarse-grained sericite was collected during geochemical sampling (A. S. Radtke, unpub. data, 1972), but the sericite concentrate was inadequate for K-Ar dating.

The Cortez gold deposit may not be directly datable by the K-Ar method. The gold ore occurs in altered, brecciated limestone along the margin of a rhyolite porphyry dike which has undergone argillic alteration (Wells et al., 1969). Biotite and sanidine from an unaltered part of the dike are dated at 34 and 35 m.y., respectively (Wells et al., 1971). Many quartz porphyry dikes occur in the Cortez area and mineralization of the Cortez gold mine is believed to have been contemporaneous with, or later than, emplacement of these dikes (Wells et al., 1971).

In summary, Getchell has now been dated at approximately 90 m.y.; Gold Acres has a probable age of 92 to 94 m.y., Cortez is younger than 35 m.y., and the age of Carlin is uncertain. Careful study of the mineral assemblages in altered igneous rocks, which occur in the ore zones of all the disseminated gold deposits, may reveal datable sericite ($2M_1$ muscovite) and it may be possible to determine the age of mineralization of most of these deposits. Care must be taken, however, in sampling to see that areas of postmineralization deformation are avoided and that the sericite chosen for dating is as coarse-grained as possible.

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