Economic Geology
Vol. 63, 1968, pp. 612–621

Chronology of Intrusion, Volcanism, and Ore Deposition at Bingham, Utah[1]

W. J. Moore, M. A. Lanphere, and J. D. Obradovich

Abstract

Potassium-argon dates for major igneous rock types in the Bingham mining district, Utah, range from 39 to 32 m.y. and suggest that:

(1) Plutonism, volcanism, and hydrothermal activity were sequential stages in a magmatic history of about 7 m.y. duration.

(2) Latitic volcanic rocks, in part, postdate emplacement of the Last Chance and Bingham stocks.

(3) Sulfide mineralization and hydrothermal alteration followed emplacement of the monzonitic stocks and extrusion of at least the earliest units in the volcanic sequence; the time interval between intrusion and alteration was probably less than 1 m.y.

(4) The rhyolites of Shaggy Peak, which may represent terminal differentiation products in a comagmatic series, are the youngest igneous rocks in the area.

Contents

Introduction

Porphyry copper deposits provide one of the best cases for a genetic relationship between hydrothermal ores and igneous rocks spatially associated with them. Perhaps the most compelling geologic evidence supporting this view is the common zonation of ore and alteration mineral assemblages with respect to a hypothetical point-source located within a particular intrusive rock mass. Isotope dating methods should further clarify the time relations between the igneous rocks and ores. This study provides necessary data for delineating the chronology of intrusion, volcanism, and ore deposition at Bingham, Utah.

Related Studies

Schwartz (1959) reported biotite K-Ar dates of 63 and 121 m.y., respectively, for altered intrusive rocks at the Chino, New Mexico, and Ely, Nevada, copper deposits; he considered the dates to represent apparent ages of mineralization.

Creasey and Kistler (1962) used K-Ar methods to study age relations of copper deposits in southeastern Arizona. They report biotite dates ranging from 56 to 72 m.y. for unaltered intrusive rocks in six mining districts. These dates are thought to provide "apparent maximum ages of ore deposition" and, collectively, "suggest a major Laramide period of copper mineralization."

Damon and Mauger (1966) present additional data supporting the concept of Laramide copper mineralization. They show that the K-Ar ages of plutonic rocks associated with porphyry copper deposits in the southwestern Basin and Range province are generally coincident with unmineralized plutonic rocks in the region and conclude that "during the Laramide, porphyry copper mineralization was time-congruent with magmatism."

Bingham was included with the "Laramide" copper deposits on the basis of a K-Ar date reported by Armstrong (1966) for biotite from a biotite-augite quartz monzonite on the southeastern margin of the Bingham stock. Armstrong determined replicate dates of 40 and 49 m.y. using neutron activation techniques for argon analyses. He states that the argon yields may be slightly low in some cases and that the highest values obtained should be considered the best. The dates we present in this paper, including two from the area sampled by Armstrong, are significantly younger than his preferred age of 49 m.y. and are at least 10 m.y. younger than any of the porphyry copper deposits studied thus far. We believe that Bingham should not be considered an element of the Laramide metallogenetic period proposed for the southwestern Basin and Range province.

[1] Publication authorized by the Director, U. S. Geological Survey.

In a study of the Providencia-Concepcion del Oro district, Mexico, Ohmoto and others (1966) used K-Ar and Rb-Sr methods to investigate the chronology of certain granodiorite stocks and spatially related hydrothermal minerals. They report a date of 40 m.y. for the granodiorites as compared to 38 m.y. for adularia from hydrothermal veins and conclude that the most probable time interval between intrusion and ore mineralization was between 1 and 3 m.y. Similarly, potassium-argon dates presented by McDowell and Kulp (1967) suggest a maximum interval of about 2 m.y. between intrusion and copper sulfide mineralization in the Robinson (Ely) mining district, Nevada. Thus, a growing number of studies indicate that ore deposition and hydrothermal alteration may occur within the cooling history of spatially associated intrusive rocks in certain mineralized areas.

Summary of District Geology

The Bingham mining district is in the central Oquirrh Mountains about 20 miles southwest of Salt Lake City, Utah. The first comprehensive geologic study of the district was by Boutwell (1905); his report provides the only descriptive record of many small properties developed in the 1800's but was completed before the inception of open-pit mining methods. Subsequent studies, including the work of Hunt (1924), James, Smith, and Bray (1961), Peters and others (1966), Bray (1967), and Rubright and Hart (1968) have added detailed information concerning the geology and ore deposits.

Sedimentary rocks exposed in the central and northern Oquirrh Mountains are of Pennsylvanian and Permian age and belong largely to the Oquirrh Group of Welsh and James (1961). The upper Paleozoic section is about 15,000 feet thick and is composed of limestone with minor quartzite in the lower part; cyclically bedded quartzite and lenticular limestone in the middle; and quartzite with subordinate dolomite, limestone, and shale in the upper part (Tooker and Roberts, 1961; Roberts and others, 1965).

Tertiary igneous rocks of the Last Chance and Bingham stocks (Fig. 1) have a combined outcrop area of about 2 square miles. These intrusive bodies are modal monzonites or quartz monzonites except where modified by contamination or hydrothermal alteration. A conspicuously porphyritic and highly altered phase makes up the northern third of the Bingham stock; less-altered porphyritic monzonites are found underground on the southern and eastern margins of the stock. The composite Bingham stock and northwestern part of the Last Chance stock are intruded by narrow quartz latite porphyry dikes (Stringham, 1953; Bray, 1967). The sill-like intrusives on the northern slopes of Butterfield Canyon are porphyritic aphanites, also latitic in composition.

Latitic flows and breccias cover the lower east-central slopes of the Oquirrh Mountains and are overlain by Quaternary alluvium and lake sediments in Utah Valley several miles east and south of the district. A domed mass of banded rhyolite, rhyolite vitrophyre, and intrusive rhyolite porphyry forms the Shaggy Peak topographic high south of Butterfield Canyon; narrow rhyolite dikes have also been reported in mines west of the Bingham stock (Hunt, 1924).

The major folded structure in the district is the asymmetrical, northwest- to west-trending Bingham syncline; its westward-plunging axial zone is the locus of important lead-silver-zinc ore deposits in the Lark mine (Rubright and Hart, 1968). Other folds with similar trend and plunge characterize the southern Oquirrh Mountains (Gilluly, 1932). It is thought that folding and related bedding plane fault adjustment accompanied northeast movement on the Midas thrust fault (Fig. 1) during late Mesozoic and early Tertiary orogeny (Roberts and Tooker, 1961).

Numerous northeast-trending faults and fractures of probable early Tertiary age have been a major factor in the localization of lead-silver-zinc ores and are discussed thoroughly by Rubright and Hart (1968). Some have locally controlled the emplacement of monzonitic dikes; others cut the igneous rocks and contain extensive fissure ore deposits. Northwest-trending normal faults are fewer in number and older than the northeast set (Farmin, 1933; Rubright and Hart, 1968). Intermittent adjustment on major high-angle faults probably continued into late Tertiary time when range front faulting accompanied uplift and eastward tilting of the Oquirrh Mountain block (Gilluly, 1932).

Ore Deposits

Following movement on the Midas thrust fault and emplacement of the monzonitic stocks, the rocks were cut by northeast- and northwest-trending high-angle faults and fractures. Disseminated copper-molybdenum ores formed in the intricately fractured Bingham stock and enclosing sedimentary rocks. Copper-lead-silver-zinc replacement and bedding fissure ores were deposited in the steeply dipping southwest limb and axial zone of the Bingham syncline. Bedding plane faults and certain crosscutting fissures of the northeast set were important factors in the transport and localization of the metal-bearing fluids.

The resulting distribution of metamorphic mineral assemblages and ores is crudely zonal (Hunt, 1924; Peters and others, 1966). Calcareous sedimentary rocks between and at the margins of the stocks are

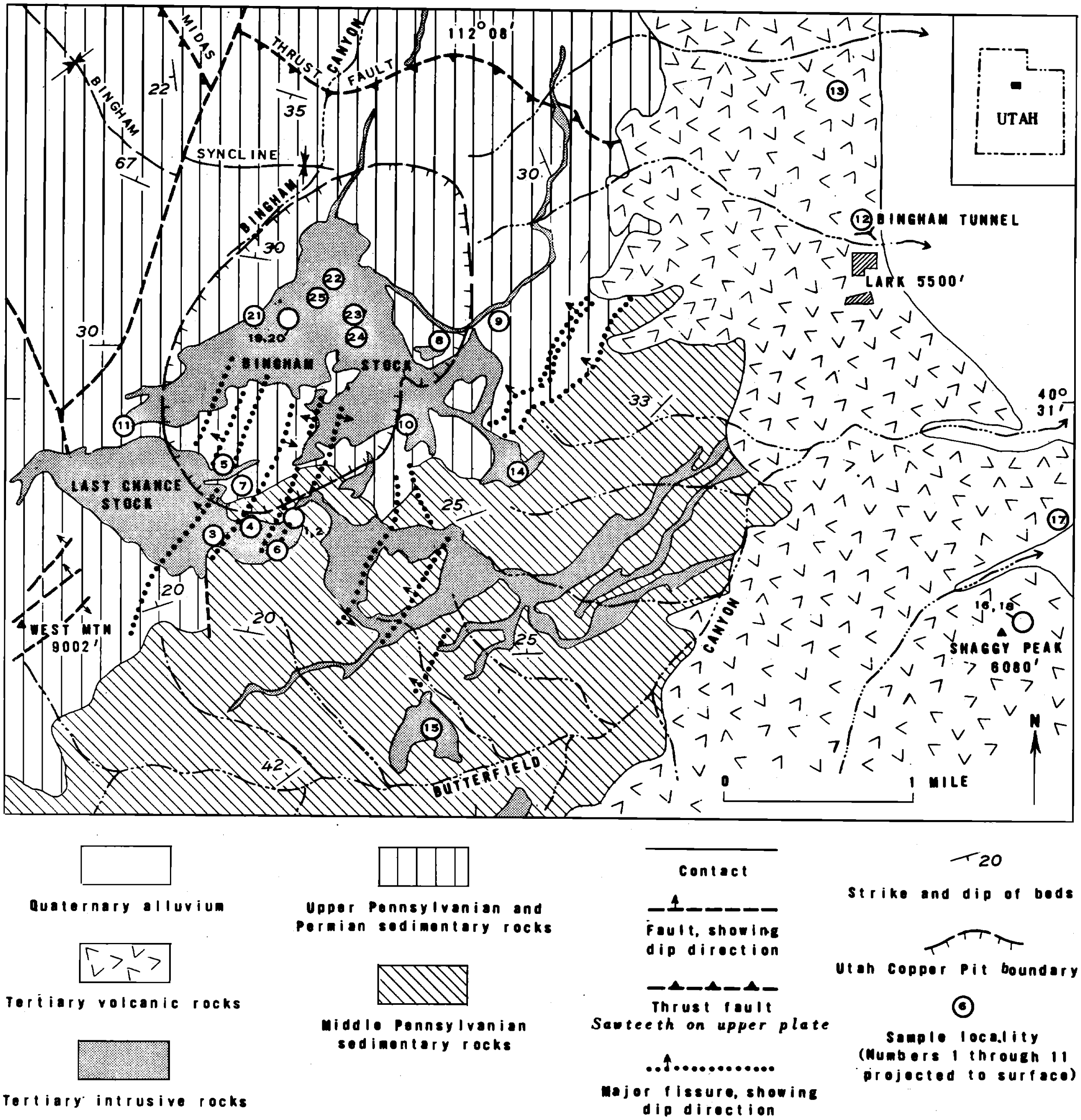

FIG. 1. Sketch map of the Bingham district, Utah (modified after James, Smith, and Welsh, 1961).

now composed largely of diopside, wollastonite, calcium garnets, and quartz in variable proportions. A white or mottled zone of recrystallization separates the silicated rocks from unmetamorphosed sediments. The metamorphic aureole seldom extends more than 1,000 feet from intrusive contacts.

Replacement copper ores west of the Bingham stock and lead-silver-zinc ores to the south occur in intensely silicated rocks. The outermost lead-zinc and gold-silver ores extend beyond the limits of bleaching and recrystallization (Hunt and Peacock, 1950; Rubright and Hart, 1968).

Outline of Igneous Petrology

Lithologic and Chemical Relations.—Various petrologic features of unaltered intrusive and extrusive rocks in the Bingham district have been discussed by Butler and others (1920), Gilluly (1932), Smith

(1961), Peters and others (1966), and Bray (1967). Hydrothermal alteration of igneous rocks in the disseminated copper ore zone is emphasized in a number of published reports (Stringham, 1953; Creasey, 1959; Burnham, 1962; Peters and others, 1966; Bray, 1967).

Intrusive rocks in the productive part of the district are, or apparently were, monzonitic in composition. We fully agree with Peters and others (1966) who state that "the part of the Bingham stock outside the porphyry copper body is monzonitic, suggesting that the composition of the Bingham stock prior to hydrothermal alteration was closer to that of the Last Chance stock," and "although the principal intrusive units of the Bingham stock are classified as granite, porphyritic granite, and granite porphyry, . . . the classification may have been biased as a result of hydrothermal effects."

The most abundant unaltered intrusive rock is medium- to dark-gray fine-grained monzonite or quartz monzonite typified by the main mass of the Last Chance stock and southeastern margins of the Bingham stock. This rock is composed of 25–40 percent euhedral to subhedral plagioclase (An_{30-47}), 20–40 percent cryptoperthitic orthoclase (Or_{72-77}) and 5–15 percent quartz, all with average grain diameters of less than 0.5 mm. The major mafic constituents—biotite, augite, and pale green amphibole—comprise 15–30 percent of the rock and have average grain diameters of about 1.5 mm.

Conspicuously porphyritic intrusive phases are found in the northern half of the Bingham stock and in satellitic, dikelike bodies marginal to the stock. Underground workings of the U. S. Smelting Refining and Mining Company on the eastern margins of the Bingham stock expose an extensive mass of porphyritic quartz monzonite; groundmass textures and modal compositions are similar to the Last Chance stock but 10–20 percent of the total orthoclase and plagioclase occur as unevenly distributed euhedral phenocrysts up to several centimeters in length. This rock is thought to be a relatively unaltered equivalent of the "granite porphyry" described in previous reports (Stringham, 1953; James, Smith, and Bray, 1961; Bray, 1967).

The latitic intrusives of lower Bingham Canyon and Butterfield Canyon contain phenocrysts of complexly zoned plagioclase, biotite, and hornblende in a dark-gray cryptocrystalline groundmass. Bray (1967) recently has described other porphyritic dikes ("types A, B, and C porphyries") which intrude the stocks and extend several miles southwest of the open pit.

Latites or quartz latites cover the lower east-central slopes of the Oquirrh Mountains. These rocks are closely related to the monzonites of the district in mineralogy, bulk chemical composition, and age. Breccias predominate in the lower half of the volcanic section, but are subordinate to flows in the upper half (Gilluly, 1932). The volcanic rocks are generally dark to medium gray on fresh surfaces and contain euhedral phenocrysts of andesine, hornblende, and biotite, subordinate in volume to the cryptocrystalline groundmass. In hand specimen the rocks appear to be andesitic, but stained thin sections show quartz and potash feldspar to be major groundmass constituents; and chemical analyses confirm the latitic classification (Gilluly, 1932).

The silicic rocks of Shaggy Peak comprise a distinct compositional unit. Steeply dipping flow structures and sheeting indicate that the porphyritic rhyolites form a volcanic neck that has intruded the surrounding latitic flows.

Accurate modal comparison of certain igneous rocks at Bingham is complicated by fine grain size and textural variability. Chemical analyses and normative compositions (Tables 1 and 2) have been useful in establishing compositional characteristics and trends not fully detectable by petrographic methods.

Gilluly (1932) has used silica variation diagrams to demonstrate "the consanguinity of latitic lavas and the monzonites of Bingham." Our data are consistent with this interpretation and suggest a sequential derivation of the igneous rocks through fractional crystallization of a monzonitic parent magma.

Age relations.—Hunt (1924) and Gilluly (1932) have noted that sharp contacts between the larger intrusive bodies are rarely observed, suggesting a single, extended period of emplacement. Clear field evidence regarding relative intrusive age in the productive part of the district is found in the Utah Copper pit, where latite or quartz latite dikes cut both equigranular and porphyritic phases of the Bingham stock (Bray, 1967; Stringham, 1953). The same dikes intrude the Last Chance stock in underground workings southwest of the pit (Bray, 1967). Evidence presented by Gilluly (1932) and Smith (1961) suggests that latitic dikes were intruded at various stages of the magmatic history; such episodic intrusion may be the result of repeated structural adjustment accompanying emplacement of the larger stocks.

Fragmentary stratigraphic evidence places post-Permian to pre-Pleistocene limits on the age of igneous activity in the Bingham district. Through a succession of analogies with structural and stratigraphic features in other areas in eastern Utah, Gilluly (1932) concluded that the most probable age of volcanism was late Eocene or early Oligocene. The

TABLE 1

Igneous rock types and locations, Bingham district, Utah

	Sample No.[1]	Rock type	Location
Unaltered igneous rocks			
Last Chance stock	1*	Biotite-augite monzonite	U.S. mine, 1400 level, 1875 S - 4185 W
	2*	Biotite-augite monzonite	U.S. mine, 1400 level, 1900 S - 4160 W
	3*	Biotite-augite quartz monzonite	U.S. mine, N. level, 2430 S - 6200 W
	4*	Pegmatitic biotite pods	U.S. mine, 200 level, 2280 S - 5340 W
	5	Biotite-augite monzonite	U.S. mine, 800 level, 350 S - 6250 W
	6	Biotite-augite monzonite	U.S. mine, 1400 level, 2760 S - 4620 W
	7	Biotite-augite monzonite	U.S. mine, 1200 level, 950 S - 5450 W
Bingham stock	8*	Biotite-augite monzonite	Lark mine, Masc. tunnel, 2900 N - 250 W
	9*	Biotite-augite monzonite	Lark mine, Masc. tunnel, 3500 N - 1500 E
	10*	Porphyritic biotite-amphibole monzonite	U.S. mine, N. level, 600 N - 1000 W
	11*	Porphyritic actinolite syenite	Utah Metals tunnel, station 110+35
Latitic dikes and volcanic rocks	12*	Biotite quartz latite	Portal of Bingham haulage tunnel
	13	Hornblende-biotite latite fragments from agglomerate	SW 1/4 sec. 20, T. 3 S., R. 2 W.
	14	Porphyritic hornblende-biotite latite dike	St. Joe adit, SW 1/4 sec. 36, T. 3 S., R. 3 W.
	15	Biotite-hornblende latite dike	NW 1/4 sec. 6, T. 3 S., R. 2 W.
Rhyolites of Shaggy Peak	16*	Rhyolite vitrophyre	NE 1/4 sec. 4, T. 3 S., R. 2 W.
	17*	Porphyritic biotite rhyolite	SW 1/4 sec. 4, T. 3 S., R. 2 W., 5750' elev.
	18	Flow-banded rhyolite	NE 1/4 sec. 4, T. 3 S., R. 2 W.
Igneous rocks from Utah Copper pit			
Latitic dikes	19*	Quartz latite porphyry dike, chilled border facies	5940 level, southwest side
	20*	Quartz latite porphyry dike	5940 level, southwest side
	21*	Quartz latite porphyry dike	H level, northwest side
	22*	Biotitized quartz latite dike	5740 level, northwest side
Monzonitic phases	23*	Biotitized equigranular monzonite	5740 level, southwest side
	24*	Biotitized equigranular monzonite	5590 level, south side
	25*	Orthoclasized porphyritic monzonite	5590-5640 switchback, southwest side

[1] Asterisk denotes sample which has been dated.

TABLE 2

Chemical analyses and norms of some unaltered igneous rocks, Bingham district, Utah

Sample No.[1]	1*	2*	3*	5	6	7	12*	13	14	15	16*	17*	18
Chemical analyses[2]													
SiO_2	55.7	57.6	60.1	59.1	58.9	63.4	64.5	62.7	61.8	64.5	73.7	73.2	74.9
Al_2O_3	14.5	14.7	14.8	15.0	14.8	15.6	15.7	14.9	14.6	15.2	12.9	14.3	13.0
Fe_2O_3	2.8	2.3	2.5	2.0	2.1	1.9	3.1	2.7	2.8	2.7	0.77	0.89	0.35
FeO	3.5	3.5	2.9	3.7	3.8	2.4	1.4	2.3	2.1	0.82	0.48	0.28	0.20
MgO	5.3	6.2	4.0	4.2	4.8	2.6	1.6	1.2	3.7	2.0	0.25	0.3	0.1
CaO	6.7	6.2	4.8	5.7	6.2	3.3	3.8	4.8	4.1	3.5	1.3	1.8	1.1
Na_2O	3.4	3.7	3.9	3.5	3.5	3.8	3.8	3.2	3.3	3.7	3.5	3.6	3.7
K_2O	4.1	3.1	4.2	4.6	3.8	4.3	3.3	3.8	3.5	3.5	4.3	4.2	4.4
H_2O-	0.31	0.30	0.20	0.25	0.09	0.53	0.80	0.33	0.94	1.2	0.06	0.15	0.18
H_2O+	1.1	0.64	0.58	0.49	0.38	0.77	0.70	2.6	1.4	1.1	2.4	0.48	0.77
TiO_2	0.87	0.87	0.81	0.86	0.86	0.69	0.60	0.67	0.63	0.45	0.17	0.16	0.05
P_2O_5	0.63	0.52	0.46	0.49	0.49	0.32	0.42	0.39	0.67	0.59	0.06	0.29	0.29
MnO	0.12	0.15	0.15	0.15	0.11	0.04	0.15	0.14	0.11	0.03	0.04	0.07	0.07
CO_2	0.55	0.12	0.15	<0.05	<0.05	0.10	<0.05	<0.05	0.11	0.32	<0.05	0.15	0.14
Total	100	100	100	100	100	100	100	100	100	100	100	100	99
Bulk Sp. Gr.	---	---	---	2.77	2.79	2.71	2.63	2.59	2.59	2.47	2.44	2.27	2.24
Norms													
Q	2.9	4.6	7.9	5.1	6.2	14.7	20.8	20.0	17.4	22.2	34.8	33.4	35.8
Or	24.7	18.5	25.1	27.4	22.6	25.8	19.8	23.2	21.2	21.3	26.1	25.0	26.5
Ab	29.3	31.6	33.4	29.8	29.8	32.7	32.7	28.0	28.7	32.2	30.4	30.7	31.9
An	12.4	14.5	10.6	11.7	13.5	13.0	16.3	13.9	15.1	11.8	6.2	6.1	2.7
Other	30.7	30.8	32.0	26.0	27.9	13.8	10.4	14.9	17.6	12.5	2.5	4.8	3.1

1/ Asterisk denotes sample which has been dated.

2/ Rapid rock analyses by P. L. D. Elmore, S. D. Botts, Lowell Artis, and J. L. Glen.

isotope dates presented here fully support this conclusion.

Potassium-Argon Isotope Studies

In 1963, samples of major igneous rock types, including altered phases of the Bingham stock, were collected for isotope studies. With the participation of geologists from operating companies in the district, 20 bulk samples were obtained and 13 of these have been dated. Additional samples have been collected in the course of subsequent underground studies. Sample locations are given in Figure 1 and Table 1; analytical results are summarized in Table 3.

A biotite-hornblende pair and 21 biotite separates have been analyzed; in several instances, two size fractions from the same bulk sample were analyzed. Biotite was separated from the 35–60 mesh fraction of each sample unless noted otherwise in Table 3.

Argon analyses were made using isotope dilution techniques, and potassium analyses were made by flame photometry using lithium as an internal standard. Mass analyses were made on Nier-type, 6-inch radius, direction-focusing mass spectrometers in the Denver and Menlo Park laboratories of the U. S. Geological Survey. The uncertainty assigned to each date (see Table 3) is the estimated standard deviation of analytical precision. This estimate includes un-

TABLE 3

Potassium-argon dates and analytical data, Bingham district, Utah

Rock unit	Sample no.	Mineral and size fraction analyzed	K_2O analyses (percent)	Avg. K_2O (percent)	Ar^{40}_{rad} (10^{-10} moles per gm)	Ar^{40}_{rad} / Ar^{40}_{total}	Apparent age (m.y.)
Last Chance stock	1	Biotite, 35-60 mesh	7.36, 7.44	7.40	4.29	0.90	38.9±1.2
	2	Biotite, 35-60 mesh	7.89, 7.96	7.92	4.55	0.83	38.5±1.3
	3	Biotite, 35-60 mesh	8.77, 8.88	8.82	5.03	0.77	38.3±1.3
	4	Biotite, 20-60 mesh	9.20, 9.24	9.22	5.216	0.77	37.9±1.0
Margins of Bingham stock	8	Biotite, 35-80 mesh	8.72, 8.78	8.75	4.922	0.83	37.7±1.2
	9	Biotite, 35-60 mesh	8.53, 8.53	8.53	4.794	0.85	37.7±1.2
	10	Biotite, 35-80 mesh	8.91, 8.95	8.93	4.997	0.74	37.5±1.2
	11A	Phlogopite, 20-60 mesh	9.15, 9.21	9.18	5.109	0.82	37.3±1.2
	11B	Biotite, 35-80 mesh	8.60, 8.70	8.65	4.807	0.73	37.2 1.2
Quartz latite dike	12A	Biotite, 35-60 mesh	---	8.10	4.461	0.64	36.9±1.0
	12B	Hornblende, 35-80 mesh	1.07, 1.07	1.07	0.5587	0.54	36.9±0.9
Rhyolites of Shaggy Peak	16	Biotite, 35-80 mesh	---	8.77	4.459	0.73	34.1±1.0
	17	Biotite, 35-60 mesh	---	7.25	3.459	0.57	32.0±0.9
Latitic dikes, in pit	19A	Biotite, 35-60 mesh	8.67, 8.71	8.69	4.96	0.74	38.3±1.4
	19B	Biotite, 80-120 mesh	7.86, 8.00	7.93	4.51	0.74	38.2 1.4
	20A	Biotite, 35-60 mesh	8.77, 8.91	8.84	5.02	0.79	38.1±1.3
	20B	Biotite, 80-120 mesh	8.41, 8.43	8.42	4.63	0.80	36.9±1.3
	21	Biotite, 35-80 mesh	---	8.74	4.916	0.80	37.7±1.0
	22	Biotite, 35-80 mesh	---	9.08	4.857	0.36	35.9±1.6
Monzonitic phases, in pit	23A	Biotite, 80-120 mesh	---	8.48	4.71	0.92	37.3±1.4
	23B	Biotite, 35-60 mesh	8.61, 8.87	8.74	4.81	0.68	37.0±1.4
	24	Biotite, 35-60 mesh	8.72, 8.73	8.725	4.757	0.85	36.5±1.2
	25	Biotite, 35-80 mesh	10.10, 10.00	10.05	5.39	0.60	36.0±1.5

Potassium analyses: Wayne Mountjoy, L. B. Schlocker, and H. C. Whitehead.

Argon analyses: J. C. Engels, M. A. Lanphere, J. D. Obradovich, and J. D. Luetscher.

Decay constants for K^{40}: $\lambda_e = 0.585 \times 10^{-10}$ year^{-1}; $\lambda_\beta = 4.72 \times 10^{-10}$ year^{-1}

Atomic abundance of $K^{40} = 1.19 \times 10^{-4}$

certainties in the isotopic composition and concentration of the Ar^{38} tracers and the concentrations of the flame photometer standards. For dates obtained in this study the total analytical uncertainty is equivalent to a plus-or-minus value of approximately 1.2 m.y.

Dates referred to in the following discussion are summarized in Figure 2. The order was established on the basis of field and petrographic relationships. We consider the sequential trend, indicated by the results, to be of critical significance in understanding the magmatic and hydrothermal history of the district.

Three dates for monzonite of the Last Chance stock are in excellent agreement and give an average apparent age of 38.6 m.y. Pegmatitic biotite segregations occur locally along the margins of a major fissure cutting this stock; the podlike segregations are about 5 cm in length and are composed of intergrown books and hexagonal plates of light-brown, Mg-rich mica with maximum diameters of 1 cm. The pods may have formed in low pressure zones resulting from incipient deformation along the trace of the fissure. The 37.9 m.y. date (No. 4 of Table 3) is consistent with such speculation, but the 0.7 m.y. difference between this date and the most probable age of the Last Chance stock is not significant within analytical error.

Identical dates of 37.7 m.y. were obtained for two samples of equigranular biotite-augite monzonite on the eastern margins of the Bingham stock (Nos. 8 and 9 of Table 3). The samples were collected on the Mascotte Tunnel level of the Lark mine (5,500 ft elev.); projected to the surface (about 7,000 ft elev.), the sample localities bracket the area where Armstrong (1966) reports replicate ages of 40 and 49 m.y. for a biotite separate from a biotite-augite monzonite porphyry. Analytical difficulties experienced by Armstrong were discussed earlier in this paper and may account for the apparent discrepancy.

A dikelike mass of porphyritic actinolite syenite was sampled in the Utah Metals tunnel near the western margin of the Bingham stock. This unusual rock type is also found near large limestone blocks in the Utah Copper pit (Stringham, 1953; Pl. 1) and may be a hybrid phase resulting from assimilation of calcareous sediments. The rock contains hexagonal plates of dark-brown biotite and pale-green phlogopite which yielded dates of 37.3 and 37.2 m.y., respectively (Nos. 11A and 11B of Table 3).

Porphyritic biotite-amphibole quartz monzonite from the southern margin of the Bingham stock gave a date of 37.5 m.y. The rock is the least altered porphyritic phase encountered thus far and occurs as a 50-foot dike cutting banded quartzite and siliceous metalimestone.

In summary, five dates from the margins of the Bingham stock range from 37.7 to 37.2 m.y. compared with an average of 38.6 m.y. for the Last Chance stock. Based on this evidence, we consider the composite Bingham stock to be slightly younger than the Last Chance, although crosscutting relations between the two have not been found.

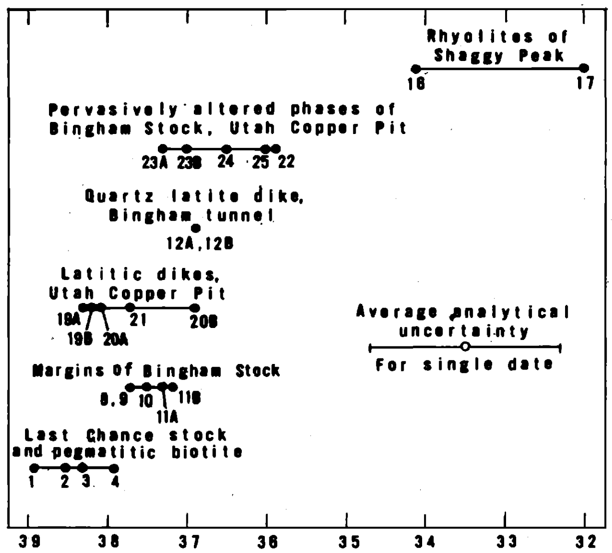

FIG. 2. Potassium-argon dates from the Bingham district, Utah, arranged according to field and petrographic relations. Sample numbers refer to Table 3.

All analyzed samples from the Utah Copper pit have been altered. The nature and extent of alteration varies with rock type as well as location. In general, K-metasomatism evidenced by orthoclase replacing plagioclase phenocrysts (Peters and others, 1966) is most pronounced in the porphyritic monzonite of the disseminated copper ore zone. Fine-grained Mg-rich biotite occurs in all phases of the stock and commonly comprises more than 20 percent of the rock by volume. The dates for altered rocks provide minimum ages of intrusion or apparent ages of alteration depending, in part, on the extent of argon reequilibration in the magmatic biotite.

Dates for five biotite samples from latite or quartz latite porphyry dikes in the pit range from 38.3 to 36.9 m.y. (Nos. 19 to 21 of Table 3) and thus overlap the apparent ages for equigranular and porphyritic monzonite phases which the dikes cut. These results suggest near time-equivalence for three intrusive rock types of the Bingham stock.

Altered rocks in the pit contain recrystallized biotite, biotite in fine-grained light-brown felted aggregates apparently pseudomorphous after preexisting mafic minerals (Bray, 1967; Stringham, 1953) and in single flakes pervasively distributed throughout the altered mass. Five biotites of this type from within the assay limits of the disseminated copper ore zone were analyzed and yielded dates ranging from 37.3 to 35.9 m.y. (Nos. 22 to 25 of Table 3). The average apparent age of alteration (36.5 m.y.) is significantly younger than most of the dates for unaltered monzonitic rocks.

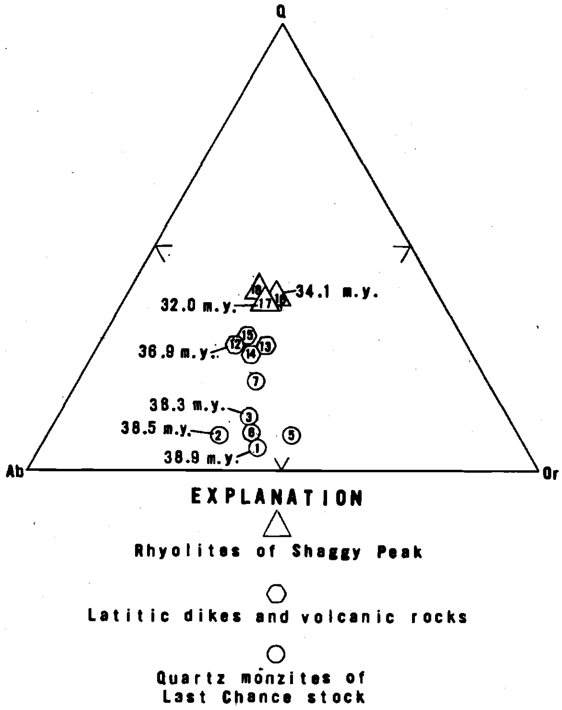

FIG. 3. Normative Q-Ab-Or plot for unaltered igneous rocks, Bingham district, Utah. Trend is toward more silicic compositions with decreasing apparent age. Data from Tables 2 and 3.

A northwest-trending body of biotite quartz latite exposed in the first 3,500 feet of the Bingham haulage tunnel gave identical biotite and hornblende dates of 36.9 m.y. (Nos. 12A and 12B of Table 3). The quartz latite intrudes latitic flows and agglomerates (W. H. Smith, Kennecott Copper Corporation, pers. commun., 1967) probably not more than 1,000 feet above the faulted basal contact of the volcanic sequence at the range front. Volcanic rocks which overlap the biotite quartz latite sills in Butterfield Canyon (Fig. 1) are considered to be younger than 36.9 m.y. and, thus, apparently postdate emplacement of the major stocks.

The isotope data do not show unequivocally that sulfide mineralization postdated volcanism. However, in the Bingham tunnel, northeast-trending pyritized fracture zones were found in a latitic agglomerate near the base of the volcanic sequence. We infer from this that certain hydrothermal events followed at least the early stages of volcanism.

The youngest igneous rocks at Bingham are found in the Shaggy Peak plug, which intrudes latitic volcanic rocks mineralogically similar to those exposed in the Bingham tunnel. A date of 34.1 m.y. was obtained for a basal rhyolite vitrophyre and 32.0 m.y. for rhyolite porphyry of almost identical bulk composition.

Summary

The isotopic data indicate that plutonism, volcanism, and hydrothermal activity at Bingham were sequential events closely related in time. Crystallization of monzonitic intrusive rocks and early volcanic equivalents was followed by hydrothermal alteration and sulfide mineralization; the time interval between intrusion and alteration was apparently less than 1 m.y. Continued volcanism and emplacement of rhyolitic rocks concluded the igneous history in middle Oligocene time.

Our inferences regarding the unaltered igneous rocks are summarized graphically in Figure 3. The trend toward more silicic compositions with decreasing apparent age suggests a sequential derivation of the igneous rocks through fractional crystallization of a monzonitic parent magma. This interpretation provides a model that will be tested in the course of future petrologic studies in the district.

Acknowledgments

We gratefully acknowledge the full support and encouragement provided by officials of the U. S. Smelting Refining and Mining Company and offer especial thanks to R. D. Rubright, resident geologist, O. J. Hart, geologist, and R. N. Hunt, former chief geologist, for their seasoned counsel. We also thank A. H. James, R. E. Bray, and W. H. Smith, geologists of the Kennecott Copper Corporation, for informative and spirited discussions of geologic problems in the district. R. J. McLaughlin and L. P. James provided capable assistance in the course of underground studies. The manuscript has profited by the comments and criticisms offered by our colleagues, C. A. Anderson, G. K. Czamanske, R. J. Roberts, and E. W. Tooker.

U. S. GEOLOGICAL SURVEY, MENLO PARK, CALIF.,
WASHINGTON, D.C.,
DENVER, COLO.,
February 9; April 29, 1968

REFERENCES

Armstrong, R. L., 1966, K-Ar dating using neutron activation for Ar analysis: Granitic plutons of the eastern Great Basin, Nevada and Utah: Geochim. et Cosmochim. Acta, v. 30, p. 565–600.

Boutwell, J. M., 1905, Economic geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, 413 p.

Bray. R. E., 1967, Igneous rocks and alteration in the Carr Fork area of Bingham Canyon, Utah: Salt Lake City, Utah Univ., M.S. thesis, 116 p.

Burnham, C. W., 1962, Facies and types of hydrothermal alteration: ECON. GEOL., v. 57, p. 768–784.

Butler, B. S., Loughlin, G. F., Heikes, V. C., and others, 1920, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, 672 p.

Creasey, S. C., 1959, Some phase relations in the hydrothermally altered rocks of porphyry copper deposits: Econ. Geol., v. 54, p. 351–373.

Creasey, S. C., and Kistler, R. W., 1962, Age of some copper-bearing porphyries and other igneous rocks in southeastern Arizona, *in* Geological Survey research 1962: U. S. Geol. Survey Prof. Paper 450-D, p. D1–D5.

Damon, P. E., and Mauger, R. L., 1966, Epeirogeny-orogeny viewed from the Basin and Range province: Soc. Mining Engineers Trans., v. 235, p. 99–112.

Farmin, Rollin, 1933, Influence of Basin Range faulting in mines at Bingham, Utah: Econ. Geol., v. 28, p. 601–606.

Gilluly, James, 1932, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U. S. Geol. Survey Prof. Paper 173, 171 p.

Hammond, E. D., 1961, History of mining in the Bingham district, Utah: p. 120–129 *in* Cook, D. R., *Editor,* Geology of the Bingham mining district and Northern Oquirrh Mountains: Utah Geol. Soc. Guidebook to the Geology of Utah No. 16, 145 p.

Hunt, R. N., 1924, The ores in the limestones at Bingham [Utah]: Am. Inst. Mining Metall. Engineers Trans., v. 70, p. 856–883.

Hunt, R. N., and Peacock, H. G., 1950, Lead and lead-zinc ores of the Bingham district, Utah, *in* Dunham, K. C., ed., Symposium on . . . lead and zinc: Internat. Geol. Cong., 18th, Great Britain 1948, Rept., pt. 7, p. 92–96.

James, Allan, Smith, Wilbur, and Bray, Eldon, 1961, Bingham district—a zoned porphyry ore deposit, p. 81–100 *in* Cook, D. R., *Editor,* Geology of the Bingham mining district and Northern Oquirrh Mountains: Utah Geol. Soc. Guidebook to the Geology of Utah No. 16, 145 p.

James, Allan, Smith, Wilbur, and Welsh, John, 1961, General geology and structure of the Bingham district, Utah, p. 49–69 *in* Cook, D. R., *Editor,* Geology of the Bingham mining district and Northern Oquirrh Mountains: Utah Geol. Soc. Guidebook to the Geology of Utah No. 16, 145 p.

McDowell, F. W., and Kulp, J. L., 1967, Age of intrusion and ore deposition in the Robinson mining district of Nevada: Econ. Geol., v. 62, p. 905–909.

Ohmoto, H., Hart, S. R., and Holland, H. D., 1966, K-Ar and Rb-Sr ages of intrusive rocks and hydrothermal minerals, II *of* Studies in the Providencia area, Mexico: Econ. Geol., v. 61, p. 1205–1213.

Peters, W. C., James, A. H., and Field, C. W., 1966, Geology of the Bingham Canyon porphyry copper deposit, Utah, p. 165–175 *in* Titley, S. R., and Hicks, C. L., editors, Geology of the porphyry copper deposits, southwestern North America: Tucson, Ariz., Univ. Arizona Press, 287 p.

Roberts, R. J., Crittenden, M. D., Jr., Tooker, E. W., Morris, H. T., Hose, R. K., and Cheney, T. M., 1965, Pennsylvanian and Permian basins in northwestern Utah, northeastern Nevada, and south-central Idaho: Am. Assoc. Petroleum Geologists Bull., v. 49, p. 1926–1956.

Roberts, R. J., and Tooker, E. W., 1961, Structural geology of the north end of the Oquirrh Mountains, Utah, p. 36–48 *in* Cook, D. R., *Editor,* Geology of the Bingham mining district and Northern Oquirrh Mountains: Utah Geol. Soc. Guidebook to the Geology of Utah No. 16, 145 p.

Rubright, R. D., and Hart, O. J., 1968, Non-porphyry ores of the Bingham district, Utah, p. —— *in* Ridge, J. D., *Editor,* Ore deposits of the United States, 1933–1965: Soc. Mining Engineers of AIME, Graton-Sales Volume, (In press.)

Schwartz, G. M., 1959, Hydrothermal alteration: Econ. Geol., v. 54, p. 161–183.

Smith, Wilbur, 1961, The volcanics of the eastern slopes of the Bingham district, Utah, p. 101–119 *in* Cook, D. R., *Editor,* Geology of the Bingham mining district and Northern Oquirrh Mountains: Utah Geol. Soc. Guidebook to the Geology of Utah No. 16, 145 p.

Stringham, B. F., 1953, Granitization and hydrothermal alteration at Bingham, Utah: Geol. Soc. America Bull., v. 64, p. 945–991.

Tooker, E. W., and Roberts, R. J., 1961, Stratigraphy of the north end of the Oquirrh Mountains, Utah, p. 17–35 *in* Cook, D. R., *Editor,* Geology of the Bingham mining district and Northern Oquirrh Mountains: Utah Geol. Soc. Guidebook to the Geology of Utah No. 16, 145 p.

Welsh, J. E., and James, A. H., 1961, Pennsylvanian and Permian stratigraphy of the central Oquirrh Mountains, Utah, p. 1–16 *in* Cook, D. R., *Editor,* Geology of the Bingham mining district and Northern Oquirrh Mountains: Utah Geol. Soc. Guidebook to the Geology of Utah No. 16, 145 p.