

Alteration of Equigranular Monzonite, Bingham Mining District, Utah

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Abstract

Equigranular monzonite of the Bingham stock, the main host for the Bingham porphyry copper deposit, was an augite-actinolite-biotite monzonite before alteration, the same composition as the largely unaltered and unmineralized Last Chance stock adjacent to the mine. Mineralogy and chemistry of the alteration is quantified in a 31-sample traverse which illustrates changes in rock composition that occur over a distance of 7,000 feet outward from the center of the orebody. Plagioclase becomes more soda rich, orthoclase becomes richer in potassium, and trioctahedral mica becomes richer in magnesium toward the center of the deposit. Plagioclase is progressively replaced by K-feldspar and augite is replaced by actinolite which is in turn replaced by phlogopite. Trends in whole-rock chemical composition are congruous with these mineral trends. Based on mineral abundance, two main zones are recognized in pervasive hydrothermal alteration, a central quartz-orthoclase-phlogopite zone corresponding to potassium silicate alteration, and an outer actinolite-chlorite-(epidote) propylitic zone.

Introduction

MONZONITE, the most abundant intrusive igneous rock in the Bingham mining district, is dark gray, fine grained, subequigranular, and forms a major portion of two small, irregularly shaped stocks each about a square mile in area. The Bingham stock contains the Bingham porphyry copper deposit whereas the adjacent Last Chance stock contains only minor lead-zinc prospects. Geology and alteration of the Bingham mining district is described in several papers, including detailed maps in Bray and Wilson (1975).

Monzonite has been described as quartz monzonite, monzonite (Keith, 1905; Boutwell, 1905; Stringham, 1953; Bray, 1969; Moore, 1973; Lanier et al., 1975), dark porphyry (Butler, 1920), and granite (Stringham, 1953; James et al., 1961; Bray, 1969). The granite classification was mainly applied to what is now recognized as the potassically altered portion of the monzonite in the Bingham stock which is richer in hydrothermal orthoclase, phlogopite, and quartz. This report describes changes in the chemical composition of minerals and modal composition of the monzonite caused by hydrothermal alteration.

The megascopic similarities of granitoid rock in the Bingham and Last Chance stocks suggested to most of the above investigators that the rock was one intrusive phase. Stringham (1953) and Moore (1973) present evidence for two distinct intrusive phases. However, the single phase interpretation is supported by the inability to show separate intrusive phases during three field mapping programs by Kennecott geologists since 1959, and by more recent drilling through biotitized granitoid rock which

grades into rock that is mineralogically identical to the Last Chance stock. Additional evidence presented here in the form of mineralogical and chemical data shows gradations in plagioclase, biotite, and whole-rock compositions. Further, a sequential replacement of augite with hydrothermal minerals can be mapped between the two stocks. These relationships strongly suggest that all granitoid rock in the mine vicinity had essentially the same prealteration composition and may have been the same age. This conclusion assigns mineralogical and chemical variations within the relatively homogeneous monzonite to postcrystallization alteration. With this model in mind, the unaltered Last Chance stock is used as a chemical and mineralogical reference.

This investigation presents thin section observations and microprobe analyses from 31 samples collected in 1971. The sample traverse is 7,000 ft long with a 2,400-ft elevation difference from near the center of the porphyry copper deposit southwest through the southern lobe of the Bingham stock, the Phoenix dike, and into the Last Chance stock (Fig. 1). In discussing alteration, distances are measured from the probable heat source, quartz monzonite porphyry, along rays projected from the central point in the porphyry to sample locations and zone boundaries.

Only pervasive alteration of monzonite is considered. Care was taken when preparing thin sections to avoid veins and weathered surfaces; however, this was not always possible, especially in areas outside the mine. Several samples contained minor amounts of supergene clay and goethite.

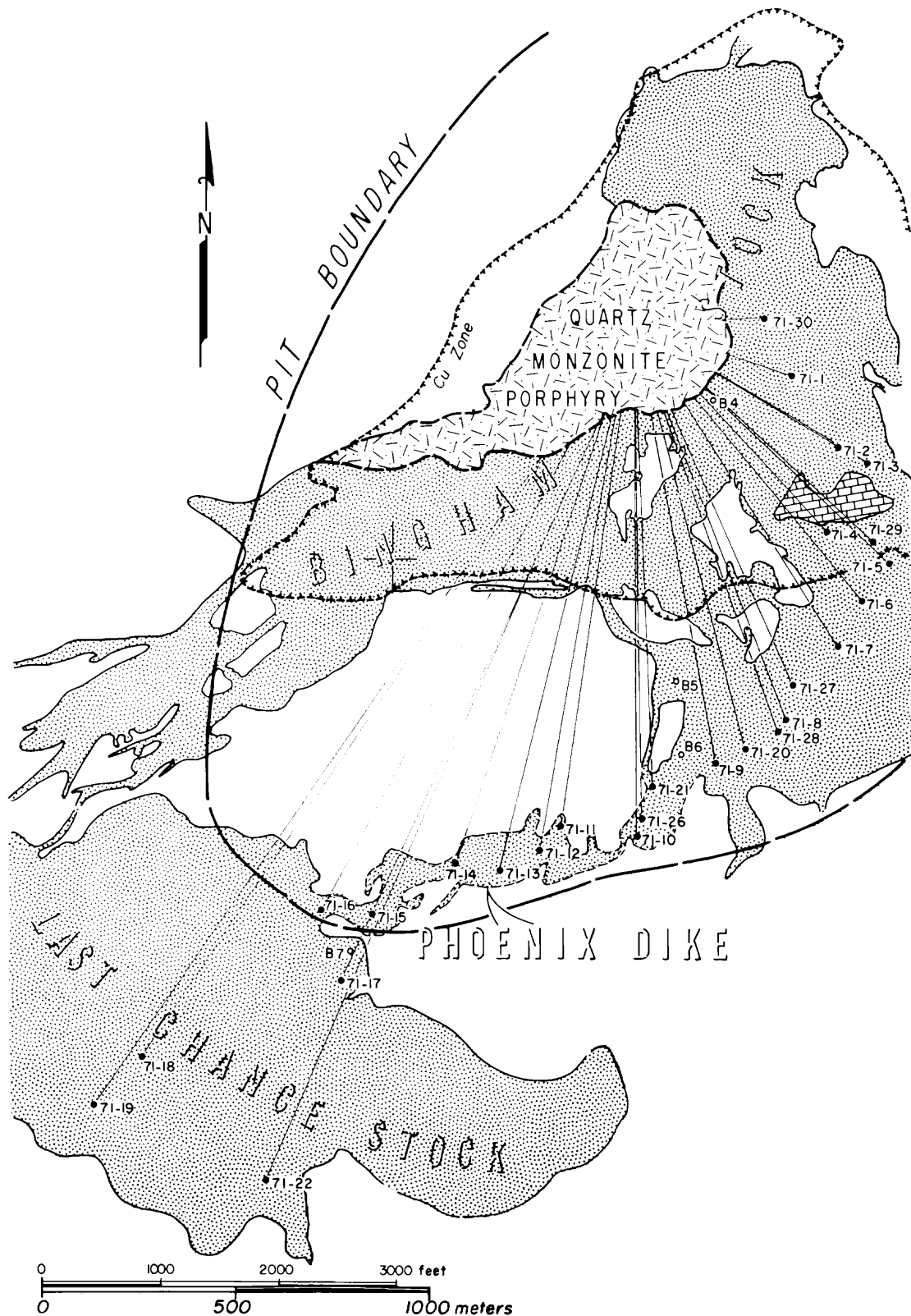


FIG. 1. Generalized geologic map showing sample locations in equigranular monzonite and relationship to quartz monzonite porphyry (QMP)

TABLE 1. Microprobe Analyses of Augite from the Last Chance Stock and Phoenix Dike

Sample	Grains analyzed	Weight percent oxides					Total
		SiO ₂	Al ₂ O ₃	FeO	MgO	CaO	
71-12	4	52.60	1.62	7.94	15.42	21.42	99.00
71-14	5	53.68	1.13	7.28	15.46	22.63	100.18
71-17	4	52.47	1.52	7.30	16.18	22.60	99.98
71-19	5	51.14	1.94	8.55	18.14	19.88	99.66

Structural formulas for augite based on 6(O)									
Sample	x Ca	y			z		O	Σ x + y	Σ z
		Mg	Fe	Al	Al	Si			
71-12	0.86	0.86	0.25	0.03	0.04	1.96	6	2.00	2.00
71-14	0.89	0.85	0.22	0.03	0.02	1.98	6	1.99	2.00
71-17	0.90	0.89	0.23	0.01	0.06	1.94	6	2.03	2.00
71-19	0.79	1.01	0.27	—	0.09	1.90	6	2.07	1.99
Average	0.86	0.90	0.24	0.02	0.05	1.95	6	2.02	2.00

Analyzed with microprobe by R. B. Folsom, Electron Microprobe Laboratory, Kennecott Copper Corporation Research Center, Salt Lake City, Utah.

Because only pervasive alteration will be discussed, a few comments are necessary to describe the alteration which is essentially vein associated. Sericitic alteration is vein controlled on the south side of the open pit and is quantitatively much less significant than on the northwest side, where it is locally pervasive (Moore and Nash, 1974). Sericite envelopes on quartz-pyrite veins become common adjacent to the economic copper zone. Sericite selvages average less than one inch across but infrequently reach 5 ft across. Sulfides coat fractures in the Bingham stock and Phoenix dike. Quartz veins, up to 2 inches wide, containing minor calcite, orthoclase, phlogopite, and sulfides, are abundant in the lower levels of the mine and decrease in abundance and size south along the traverse. Epidote commonly coats fractures in propylitically altered monzonite on upper levels.

Methods

The investigation involved five major steps: (1) selection of samples to characterize the zoning sequence, (2) petrography aided by whole-rock X-ray diffraction, (3) electron microprobe and wet chemical analysis of minerals, (4) whole-rock chemical analyses, and (5) modal calculations.

Polished thin sections were carbon coated and analyzed with an ARL AMX electron microprobe at Kennecott Copper Corporation Research Center in Salt Lake City under the following conditions: an accelerating potential of 15 kV, a 0.05 μ -amp beam current, a beam diameter of 2 to 5 μ , and a 50-sec counting interval. Raw data are corrected for drift, background, absorption, fluorescence, and atomic number effect using a computer program based on a technique developed by Bence and Albee (1968) and

using later correction factors by Albee and Ray (1970).

Standards used for the above analyses are: a synthetic anorthite glass, an albite from Amelia County, Virginia, obtained from A. A. Chodos, California Institute of Technology, and biotite, orthoclase, and hornblende standards from R. Wittkopp, University of California at Davis. All iron analyses are reported as FeO. Although values for weight percent oxide are reported to two decimal places in all tables, accuracy of no more than three significant figures can be assumed. Typical analytical error is from 1 to 3 percent. The number of grains probed in each sample is stated in the tables.

Descriptive Mineralogy and Mineral Compositions

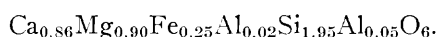
The definition of three terms, magmatic, relict magmatic, and hydrothermal, is required for the following discussion. Magmatic infers that the mineral crystallized from a magma and has undergone no appreciable alteration. Optical and textural properties of minerals from the relatively unaltered Last Chance stock are used as standards for the identification of magmatic minerals. Relict magmatic is used for a mineral of magmatic origin which has undergone exchange reactions with hydrothermal fluids but which closely retains its original crystal form. "Relict primary" is used by Moore and Czamanske (1973) to describe mica of this origin. The distinction between magmatic and relict magmatic grains is made for feldspars and trioctahedral mica where it is possible to show that original chemical compositions have been altered and/or where there is recognizable microscopic post-consolidation alteration. Hydrothermal means that

the mineral formed by direct precipitation or replacement of a preexisting mineral by the action of hydrothermal fluids. Stringham (1953) uses the term hydrothermal biotite for mica that replaces earlier ferromagnesian minerals.

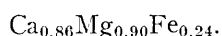
Augite

Dark green augite comprises 10 percent of the Phoenix dike and Last Chance stock. Augite also occurs as remnants in hydrothermal actinolite in the southern part of the Bingham stock. It forms pale green to colorless, subhedral to euhedral 0.7-mm crystals that are rimmed to varying degrees with deuteritic actinolite.

Eighteen microprobe analyses of augite from two localities in the Last Chance stock and two localities in the Phoenix dike are listed in Table 1. All samples have Ca-rich compositions and show no systematic chemical trends. The mean composition is



Moore (1973) reports a composition of augite in the Last Chance stock as



Actinolite

Amphibole occurs in monzonite as two genetic types: deuteritic amphibole, probably actinolite, formed through reaction of augite with a late-stage, postconsolidation, aqueous fluid; and actinolite of younger hydrothermal origin related to sulfide mineralization (hereafter designated hydrothermal actinolite). The two types are distinguished texturally; the hydrothermal type is more closely related spatially to sulfide mineralization. Deuteritic actinolite forms 7 percent of the Phoenix dike and Last Chance stock. It has yellowish-green to light green pleochroism, forms euhedral to anhedral pseudomorphs after augite (sometimes showing amphibole cleavage), and has an average grain size of 0.4 mm. Generally, smaller grains of augite are replaced by actinolite and larger grains are rimmed.

Hydrothermal actinolite makes up to 16 percent of the rock in a zone 2,200 to 3,600 ft from the porphyry contact in the southern edge of the Bingham stock and adjacent Phoenix dike. Megascopically it occurs as medium green, fibrous laths which alter to a tan smectite. Microscopically it forms cloudy pale green, fibrous, frayed, rectangular 0.6-mm laths partially or totally replacing augite. Small amounts of calcite and epidote are commonly associated with hydrothermal actinolite.

Boutwell (1905) describes the deuteritic amphibole reaction rims as uralitized augite. This term also applies to the actinolite formed by later hydro-

thermal fluids, because uralitization is ascribed to the action of hydrothermal solutions of both late-stage crystallization and postconsolidation metasomatic metamorphism (Deer et al., 1966). Bray (1967, 1969) describes a zone of actinolite replacing augite in monzonite and latite dikes in Carr Fork. The occurrence of actinolite zones in both the latite dikes and monzonite of the Bingham stock supports the conclusion that actinolite is a product of sulfide-associated hydrothermal alteration.

The origin of actinolite is somewhat complicated by the limited occurrence of actinolite syenite (Stringham, 1953) near some contacts with calcareous sediments. This actinolite syenite is a contaminated variety of monzonite. The actinolite may be orthotectic or a replacement product of augite. Actinolite in syenites is not completely replaced by phlogopite within the zone of pervasive hydrothermal phlogopitization.

The hydrothermal actinolite zone is marked by selective and multistage replacement, resulting in at least six textural combinations of rimmed and replaced ferromagnesian minerals. The paragenesis interpretation of these minerals is based on the deuteritic actinolite-rimmed augite texture common in the Last Chance stock.

1. Actinolite-rimmed augite (Fig. 2A): Hydrothermal actinolite incipiently replaces augite. Well-developed hydrothermal actinolite rims formed at the expense of both augite and probably earlier formed, less developed deuteritic actinolite rims.

2. Actinolite-rimmed actinolite (Fig. 2B): A magmatic augite core, rimmed with deuteritic actinolite, appears to have been replaced by hydrothermal actinolite. This rare textural feature shows the two generations of actinolite.

3. Phlogopite-rimmed actinolite (Fig. 2C): Hydrothermal phlogopite incipiently replaces hydrothermal actinolite after augite but is not observed directly replacing augite. This suggests a total replacement of augite by hydrothermal actinolite before phlogopitization.

4. Actinolite-rimmed chlorite (Fig. 2D): Light green, slightly pleochroic chlorite rimmed by actinolite is a common feature near the outer margins of the hydrothermal actinolite zone. It suggests an initial rimming of augite by deuteritic and/or hydrothermal actinolite with later selective replacement of the more reactive augite core by chlorite. Partial microprobe analyses of two chlorite cores give a composition of pycnochlorite



5. Chlorite-rimmed smectite (Fig. 2F): A rim of bent, rectangular laths of chlorite surrounds a core of tan to brown smectite. The chlorite rim may be

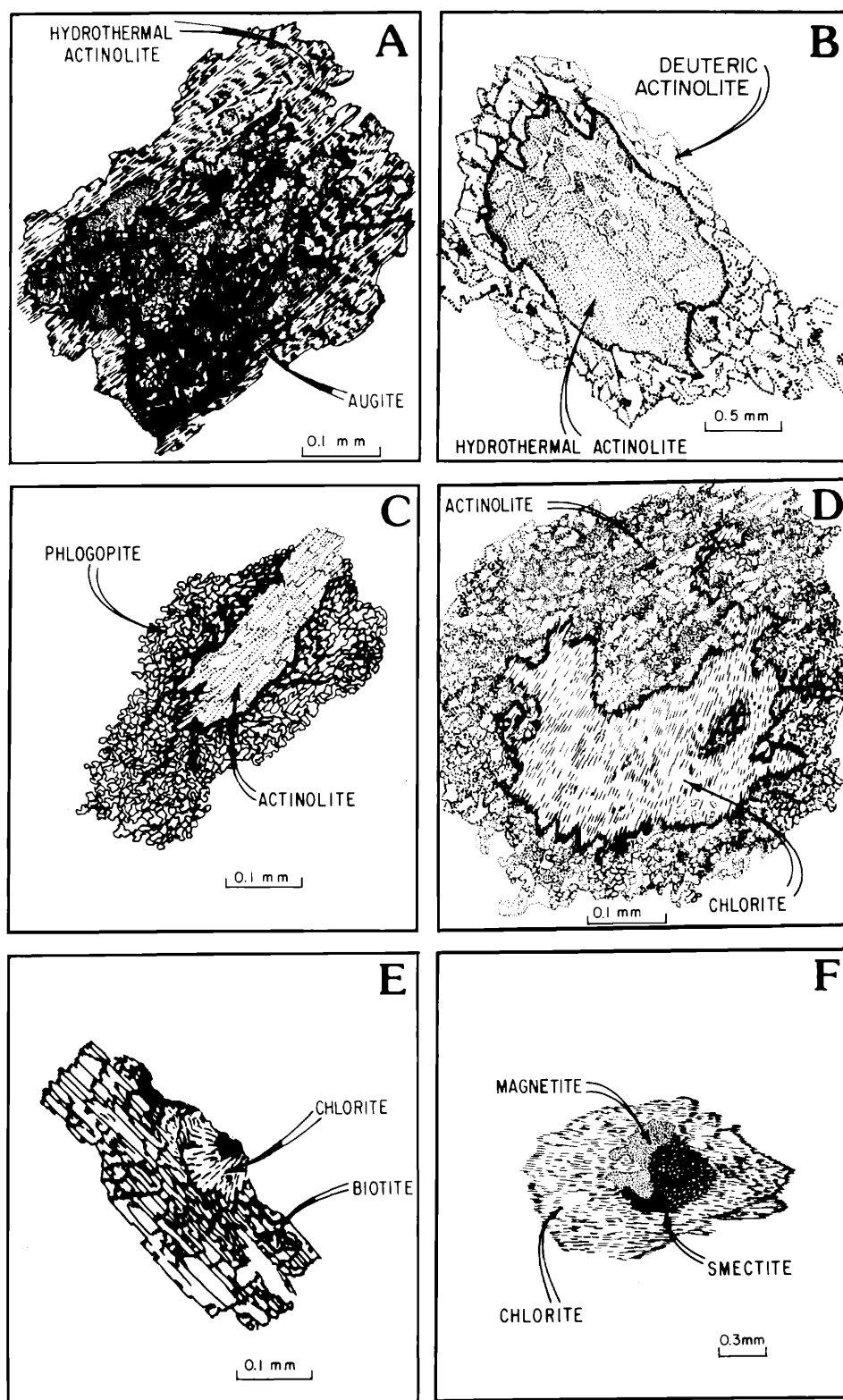


FIG. 2. Replacement of ferromagnesian minerals illustrated from photomicrographs: A, hydrothermal actinolite-rimmed augite; B, deuteric actinolite-rimmed hydrothermal actinolite; C, phlogopite-rimmed hydrothermal actinolite; D, hydrothermal actinolite-rimmed chlorite; E, chlorite replacing relict magmatic biotite; and F, chlorite-rimmed smectite.

TABLE 2. Microprobe Analyses of Actinolite from the Bingham Stock

Sample	Grains analyzed	Weight percent oxides								Total
		SiO ₂	Al ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	
71-1	2	54.67	2.22	11.20	16.85	11.24	0.49	0.20	0.13	97.00
71-7	3	54.87	2.45	9.52	16.47	14.19	0.21	0.08	0.15	97.95
71-9	5	52.73	2.83	12.36	16.61	11.70	NA	NA	NA	97.23
71-20	4	53.90	2.90	11.43	16.67	11.94	NA	NA	NA	96.84

Structural formulas for actinolite on anhydrous basis of 23(O)

Sample	x			y				z Σ = 8		Σ _x	Σ _y	100 Mg/ Mg + Fe
	Ca	Na	K	Mg	Fe	Ti	Al	Al	Si			
71-1	1.72	0.14	0.04	3.60	1.34	0.01	0.21	0.17	7.83	1.90	5.16	73
71-7	2.15	0.06	0.01	3.48	1.13	0.02	0.19	0.22	7.78	2.22	4.82	75
71-9	1.82	NA	NA	3.60	1.50	NA	0.16	0.33	7.67	1.82	5.26	71
71-20	1.84	NA	NA	3.57	1.37	NA	0.23	0.26	7.74	1.84	5.17	72
Average	1.88	0.10	0.02	3.56	1.34	0.02	0.20	0.24	7.76	2.00	5.12	73

NA-No analysis.

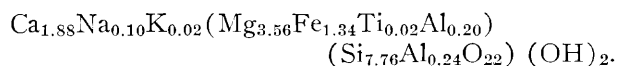
Analyzed with microprobe by R. B. Folsom, Electron Microprobe Laboratory, Kennecott Copper Corporation Research Center, Salt Lake City, Utah.

replacing actinolite and the smectite core is an alteration product of augite. Chlorite is commonly seen replacing actinolite in the inner portion of the hydrothermal actinolite zone.

6. Smectite after ferromagnesian minerals: Locally throughout the zone of actinolitization, a smectite (determined by X-ray diffraction) selectively replaces ferromagnesian minerals. Almost all of the pseudomorphs have a peripheral shrinkage crack filled with chalcedony. The absence of weathering features and association with chalcedony suggest that the clay is related to hydrothermal alteration.

The paragenetic sequence of ferromagnesian minerals is interpreted from these replacement textures. The initial metal-associated hydrothermal alteration caused the replacement of augite by hydrothermal actinolite. Earlier formed reaction rims of deuteric actinolite are locally preserved showing two generations of actinolite. Hydrothermal actinolite was then replaced by hydrothermal phlogopite. Chloritic alteration was superimposed on all earlier formed ferromagnesian minerals (Fig. 2E).

The average composition of hydrothermal actinolite determined from microprobe analysis of 14 grains (Table 2) is



Hydrothermal actinolite is magnesium rich with a Mg:(Fe + Mg) mole ratio of 0.73. No significant variation in composition is evident.

Phlogopite and biotite

Two textural forms of trioctahedral mica occur in monzonite: (1) magmatic and relict magmatic and (2) hydrothermal. Magmatic and relict magmatic occur as subhedral to euhedral grains, 0.05 to 1 mm across with pale red-brown pleochroism, and comprises 6 percent of the monzonite. Relict magmatic mica is mainly restricted to the Bingham stock.

Well-developed sagenetic rutile occurs exclusively in relict magmatic grains and is noted by Stringham (1953) and Moore (1973). These needlelike, intersecting crystals of rutile exsolved from titaniferous magmatic mica and precipitated within the crystal structure under the influence of hydrothermal fluids. The abundance of sagenetic rutile in phlogopite is zoned with peak development 1,500 ft from the porphyry contact. Relative abundance of exsolved rutile in relict magmatic mica is noted by asterisks in Table 6.

Hydrothermal mica replacing actinolite occurs as small, frayed, yellow-brown and green pleochroic grains which generally form aggregates with quartz and sulfides. Some scattered grains replace feldspar. Green mica occurs with chlorite and may result from incipient chloritization. Hydrothermal mica makes up 28 percent of the monzonite in the Bingham stock out to 2,200 ft from the porphyry contact and beyond that is vein controlled into the Phoenix dike.

Mica was analyzed in 13 samples, nine by microprobe and four by wet chemical analysis (Table 3). Both hydrothermal and relict magmatic grains from the altered Bingham stock are mostly phlogopite with an average Mg:Fe mole ratio of 3.1. Relict magmatic and hydrothermal grains in the same

TABLE 3. Microprobe and Chemical Analyses of Biotite from Equigranular Rock

	Weight percent oxides														Total
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	MnO	TiO ₂	CaO	Na ₂ O	K ₂ O	BaO	Cl	F	H ₂ O	
B4 C	41.00	16.00	1.44	5.09	19.00	na	3.40	0.20	0.29	9.90	na	na	1.91	2.50	100.73
71-30 RM	39.42	12.85	*	13.34	18.16	0.06	2.76	nd	0.16	9.43	0.24	0.02	0.64	2.92	97.08
71-30 H	39.54	12.80	*	12.83	18.26	0.06	2.42	0.01	0.16	9.34	0.16	0.02	1.09	3.31	96.69
71-2 RM	38.56	13.06	*	15.39	15.73	0.04	3.06	0.01	0.24	8.48	0.40	0.12	0.44	4.47	95.53
71-2 H	38.66	13.47	*	15.21	16.00	0.03	2.70	nd	0.21	8.82	0.13	0.11	0.42	4.24	95.76
71-29 RM	39.99	12.99	*	12.84	16.68	0.04	3.24	0.01	0.20	9.53	0.35	0.40	1.16	3.37	96.63
71-29 H	41.28	12.79	*	11.16	18.47	0.03	1.57	0.01	0.13	9.54	0.19	0.14	1.47	3.60	96.40
B5 C	40.00	15.00	6.65	8.17	15.30	na	4.70	0.58	0.25	9.10	na	na	0.70	3.52	103.97
71-7 RM	39.26	12.79	*	17.04	14.28	0.07	4.36	0.02	0.11	9.22	0.40	0.53	0.60	1.32	98.68
71-28 RM	37.88	12.32	*	14.54	15.32	0.09	3.84	nd	0.18	8.86	0.36	0.08	0.63	5.90	94.10
B6 RM	39.40	14.60	7.25	6.99	16.40	na	4.63	0.87	0.30	8.42	na	na	0.84	3.83	103.53
71-11	38.86	12.27	*	14.84	15.78	0.18	4.84	0.04	0.26	8.72	0.79	0.08	0.97	2.37	97.63
71-14	39.04	12.04	*	13.82	16.20	0.18	5.08	0.12	0.34	8.76	0.55	0.06	0.92	2.89	97.11
71-16	38.00	12.72	*	10.64	18.22	0.08	4.64	0.01	0.40	8.92	0.50	0.03	1.67	4.17	95.83
B7 M	38.10	12.20	2.18	10.50	15.60	0.14	5.30	1.75	0.46	8.53	na	na	3.40	1.98	100.14
71-19 M	38.14	12.06	*	15.37	14.91	0.16	4.22	0.17	0.23	9.28	0.42	0.11	0.44	4.49	95.51

	Atomic proportion calculated to 24 (O + F)															
	Z		Y						X				Cl	F	OH	Mg:Fe
	Si	Al	Al	Fe ⁺³	Fe ⁺²	Mg	Mn	Ti	Ca	Na	K	Ba				
B4 C	5.86	2.14	0.56	0.16	0.61	4.05	na	0.37	0.030	0.08	1.81	na	na	0.86	2.39	5.2
71-30 RM	5.88	2.12	0.13	*	1.66	4.04	0.007	0.31	nd	0.05	1.79	0.014	tr	0.30	2.89	2.4
71-30 H	5.85	2.15	0.08	*	1.58	4.02	0.008	0.27	0.001	0.04	1.76	0.010	tr	0.51	3.24	2.5
71-2 RM	5.69	2.27	—	*	1.90	3.46	0.005	0.34	0.001	0.07	1.60	0.023	0.03	0.21	4.39	1.8
71-2 H	5.71	2.29	0.05	*	1.88	3.52	0.004	0.30	nd	0.06	1.66	0.007	0.03	0.20	4.18	1.9
71-29 RM	5.88	2.12	0.13	*	1.58	3.65	0.005	0.36	0.002	0.06	1.79	0.020	0.10	0.54	3.30	2.3
71-29 H	6.00	2.00	0.19	*	1.36	4.00	0.003	0.17	0.002	0.04	1.77	0.010	0.03	0.68	3.49	2.9
B5 C	5.64	2.36	0.13	0.71	0.96	3.22	na	0.50	0.090	0.07	1.64	na	na	0.31	3.31	1.9
71-7 RM	5.94	2.06	0.22	*	2.16	3.22	0.009	0.50	0.003	0.04	1.78	0.024	0.14	0.28	2.40	1.5
71-28 RM	5.51	2.11	—	*	1.76	3.32	0.012	0.42	nd	0.05	1.64	0.020	0.02	0.29	5.74	1.9
B6 RM	5.54	2.42	—	0.77	0.82	3.44	na	0.49	0.131	0.08	1.51	na	na	0.37	3.59	2.2
71-11	5.88	2.12	0.08	*	1.88	3.56	0.024	0.55	0.006	0.08	1.68	0.047	0.02	0.46	2.40	1.9
71-14	5.85	2.12	—	*	1.73	3.61	0.022	0.57	0.018	0.10	1.68	0.032	0.02	0.44	2.90	2.1
71-16	5.55	2.19	—	*	1.30	3.96	0.010	0.51	0.001	0.12	1.66	0.028	0.01	0.77	4.05	3.0
B7 M	5.71	2.16	—	0.25	1.32	3.49	0.018	0.60	0.281	0.13	1.63	na	na	1.61	1.98	2.2
71-19 M	5.67	2.11	—	*	1.91	3.30	0.020	0.47	0.026	0.06	1.76	0.024	0.03	0.21	4.44	1.7

*—Total Fe calculated as FeO, nd—not detected, na—no analysis, tr—trace, M—magmatic, RM—relict magmatic, H—hydrothermal, C—composite of relict magmatic and hydrothermal determined by chemical analysis.

Samples B5 and B6—H₂O analyses high due to fluorine interference. H₂O for probe analyses by difference.

Samples 71-2 through 71-28 analyzed with microprobe by R. B. Folsom, Electron Microprobe Laboratory, Kennecott Copper Corporation Research Center, Salt Lake City, Utah.

Samples B4 through B7 chemical analyses by Kennecott Exploration, Inc., Salt Lake City, Utah.

samples have similar Mg:Fe ratios. Relict magmatic grains from the southern portion of the Bingham stock and magmatic grains from the Phoenix dike and Last Chance stock are mainly biotite with Mg:Fe ratios less than or equal to 2. Moore and Czamanske (1973) found that the "Mg content increases progressively with the extent of alteration or reaction." This study generally confirms their observations (Fig. 3).

The abundance of Ca, Mn, Ba, and Ti in mica decreases toward the alteration center. Calcium abundance is considerably higher in wet chemical analyses than in probe analyses because of contamination by calcite intergrown with mica. Barium concentrations are higher in relict magmatic grains than in hydrothermal grains. The decline of Ti toward the altera-

tion center correlates with the increase in exsolved rutile. This correlation establishes titaniferous magmatic mica as the source of Ti in rutile.

Orthoclase

Magmatic orthoclase occurs in the Last Chance stock and Phoenix dike as anhedral grains interstitial to plagioclase and ferromagnesian grains and as large phenocrysts that locally make up to 2 percent of the rock. Slemmons and Swinderman (1962) and Moore (1973) suggest that this orthoclase has a cryptoperthitic texture. Relict magmatic orthoclase may be present in altered monzonite of the Bingham stock; however, grains of magmatic origin could not be texturally identified and compositionally compared to orthoclase from the Last Chance stock. The large

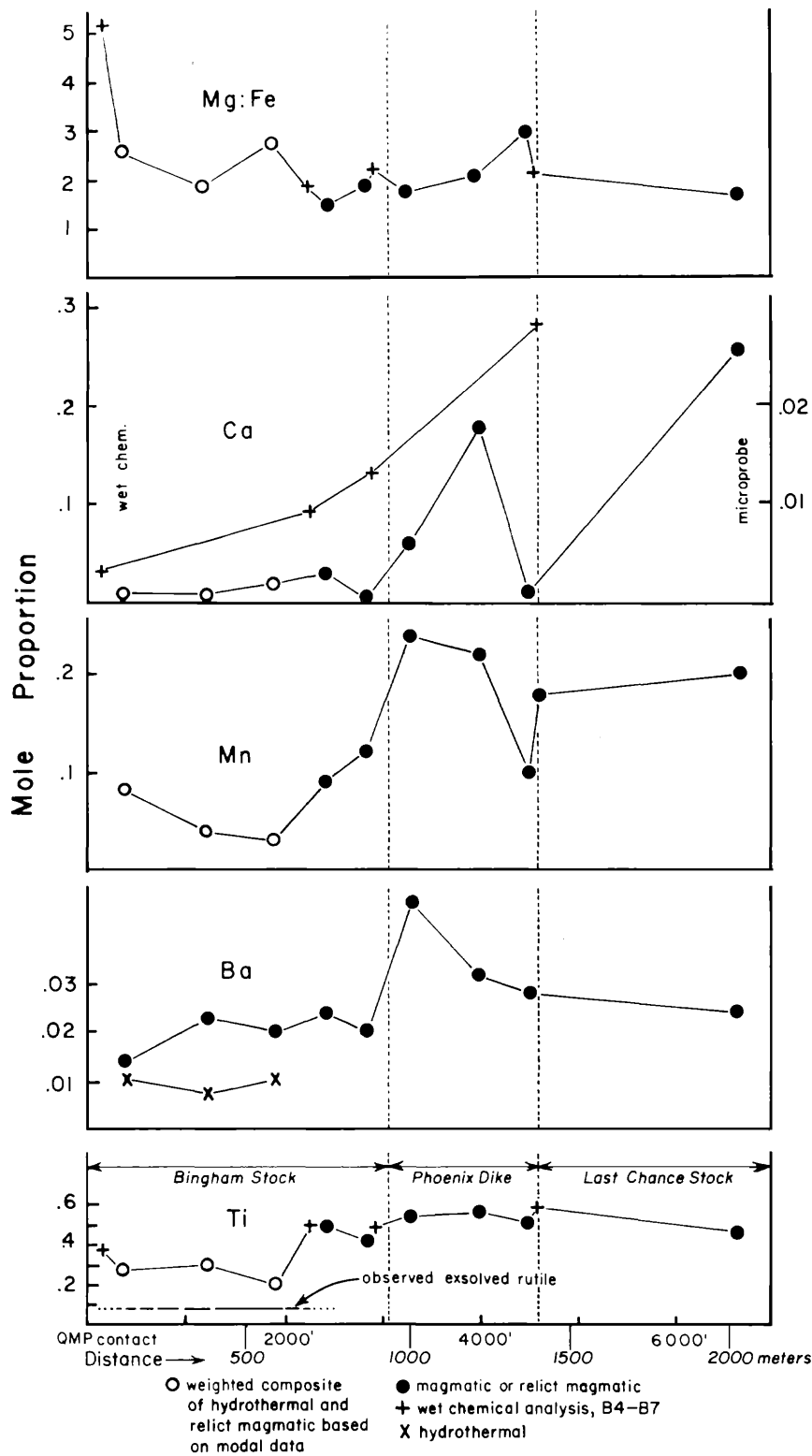


FIG. 3. Compositional trends of trioctahedral mica. Dot-dash line with Ti trend indicates relative abundance of exsolved rutile and the geographic extent of its occurrence; no mole proportion is implied.

TABLE 4. Microprobe Analyses of Orthoclase from Equigranular Rock

Sample	Grains analyzed	Weight percent oxides					KAlSi ₃ O ₈	NaAlSi ₃ O ₈	CaAl ₂ Si ₂ O ₈ *
		SiO ₂	Al ₂ O ₃	K ₂ O	Na ₂ O	Total			
71-1	4	63.69	19.10	13.28	2.25	98.32	78.5	19.0	2.5
71-29	10	65.57	19.17	13.61	1.86	100.21	79.5	16.5	4.0
71-7	10	62.28	19.82	13.90	1.77	97.77	79.4	15.3	5.3
71-19	10	65.21	19.61	12.52	2.84	100.18	74.0	24.0	2.0

*—By difference.

Analyzed with microprobe by R. B. Folsom, Electron Microprobe Laboratory, Kennecott Copper Corporation Research Center, Salt Lake City, Utah.

orthoclase phenocrysts in altered monzonite described as Type II by Stringham (1953) are most likely the result of normal magmatic crystallization processes.

Hydrothermal orthoclase is found in the Bingham stock and Phoenix dike. This type occurs as rims around plagioclase, as patch perthites with orthoclase enveloping small islands of Na-rich plagioclase, and as a minor constituent in quartz-phlogopite aggregates replacing actinolite. The perthitic texture formed by hydrothermal replacement of plagioclase by orthoclase is distinctive and can be classed as a replacement perthite of hydrothermal origin.

Magmatic orthoclase from the Last Chance stock has a composition of Or₇₅ (Table 4, 71-19) determined by microprobe, and agrees with X-ray determined compositions of Moore (1973). The average composition of orthoclase from the altered Bingham stock is K-enriched, Or₈₂ (Table 4, 71-1, -29, -7). The reader is referred to Moore (1970a) and Lanier et al. (1975) for discussions of alkali feldspar alteration.

Plagioclase

Magmatic plagioclase forms 30 percent of the Last Chance stock as subhedral to euhedral, elongate 0.5-mm laths which show well-developed albite twinning, common Carlsbad twinning, and weak normal zoning.

Relict magmatic plagioclase occurs in the Bingham stock and Phoenix dike as anhedral to euhedral crystals commonly having a sutured crystal boundary with orthoclase. In areas of strong replacement perthite development, albite twinning is obscured or absent in relict magmatic plagioclase, and the crystal boundary between orthoclase and plagioclase is poorly defined.

Microprobe analyses show that plagioclase in the Last Chance stock and adjoining Phoenix dike is andesine, An₃₄ to An₃₇ (Table 5, 71-16 and 71-19). Relict magmatic plagioclase in the Bingham stock and Phoenix dike has a gradational composition from andesine to oligoclase (An₁₈) near the alteration center (Fig. 4). Albite, with a composition of An₆ to An₇, is found near the alteration center as small anhedral to subhedral grains and as crystallographically continuous portions of relict magmatic oligoclase.

Modal Data

Modal analyses of the Last Chance stock, Phoenix dike, and southern edge of the Bingham stock give a monzonite composition (less than 10 percent quartz) with augite, actinolite, and biotite as the dominant ferromagnesian minerals (Table 6). The composition of the northern portion of the Bingham stock is highly variable because of hydrothermal alteration and endomorphic zones associated with

TABLE 5. Microprobe Analyses of Plagioclase from Equigranular Rock

Sample	Grains analyzed	Wt % oxides			CaAl ₂ Si ₂ O ₈ (An)	NaAlSi ₃ O ₈ (Ab)	KAlSi ₃ O ₈ (Or)	Wt % An + Ab + Or
		CaO	Na ₂ O	K ₂ O				
71-1	4	3.63	9.72	0.23	18.0	82.3	1.4	101.7
71-2	2	3.99	9.14	0.13	19.8	77.3	0.8	97.9
71-2 (Ab)	2	1.48	10.84	0.09	7.3	92.0	0.5	99.8
71-4	2	5.31	8.52	0.15	26.3	72.1	0.9	99.3
71-4 (Ab)	3	1.24	11.13	0.33	6.2	94.2	2.0	102.4
71-7	4	5.35	8.64	0.12	26.6	73.1	0.7	100.3
71-9	2	6.10	8.14	0.19	30.2	68.8	1.1	100.2
71-26	9	6.24	8.07	0.23	31.0	68.3	1.4	100.6
71-14	10	6.44	7.71	0.34	31.9	65.2	2.0	99.1
71-16	10	7.52	7.36	0.24	37.3	62.3	1.5	101.0
71-19	7	6.90	7.75	0.22	34.2	65.6	1.4	101.1

Analyzed with microprobe by R. B. Folsom, Electron Microprobe Laboratory, Kennecott Copper Corporation Research Center, Salt Lake City, Utah.

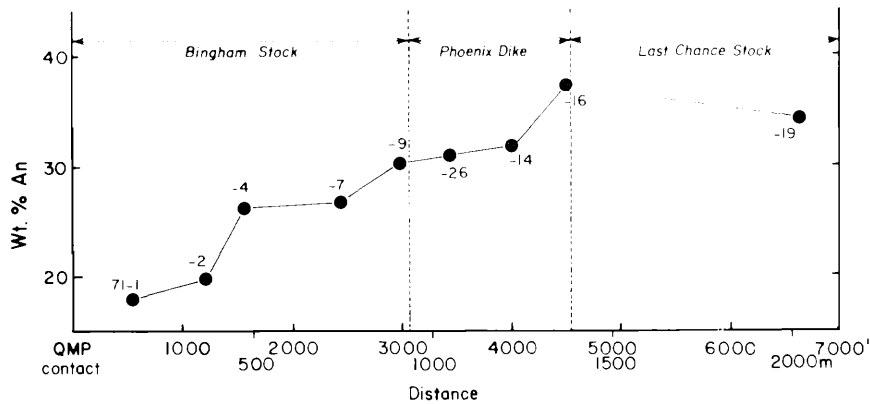


FIG. 4. Compositional trend of plagioclase in equigranular rock.

metallimestone and metaquartzite inclusions. Hydrothermal alteration results in rock with either a phlogopite quartz monzonite or phlogopite granite composition. Alteration of quartz-deficient rock results in syenite (sample 71-1).

Quartz-rich orthoclase-poor hybrid rock forms a narrow endomorphic zone around Commercial limestone inclusions in the monzonite on the south side of the mine. Three samples from this zone (71-2, -3, -4) have the mineral proportions of quartz diorite and quartz monzonite. The composition of plagioclase (Fig. 4) is normal for this location in the zoning sequence, and the abundances of both relict magmatic and hydrothermal biotite are typical. Equigranular samples classed as quartz diorite by Stringham (1953) and Peters et al. (1966) may have been collected from this or similar endomorphic zones.

Bulk Composition Gradients

Twenty-seven wet chemical analyses from the sample traverse are reported in Table 7. Mineral abundances calculated from chemical data agree fairly well with petrographic modes (Table 6, 29c and 30c).

Field, petrographic, and chemical relations indicate that the mineralogy of equigranular rocks of the Bingham stock could have been derived through hydrothermal alteration of monzonite very similar to that of the Last Chance stock. Mobility of elements during hydrothermal alteration is calculated as gains and losses using the average bulk composition of the Last Chance stock as the reference composition. To make these comparisons the analyses in Table 7 are converted to g/cc using bulk specific gravity assuming no postmineral porosity changes.

Chemical gains and losses along the sample traverse are plotted in Figure 6 as a function of distance from the quartz monzonite porphyry contact. The Hanning smoothing procedure (Blackman and Tukey, 1958) is applied to the data shown in Figure 6.

The Bingham stock shows losses in Al_2O_3 , Fe_2O_3 , CaO , and Na_2O and gains in FeO , MgO , K_2O , H_2O , S_{total} , and Cu . Along the traverse, the monzonite of the Bingham stock as a whole has lost in excess of 15 g/100 cc.

In general, iron has been removed from the altered rock in the Bingham stock. Mine assays document this low total-iron zone in greater detail. Samples in the vicinity of the pyritic halo have gained sulfide iron. Of particular interest is the coincidence of gains in MgO with the rather sudden and significant increase in hydrothermal phlogopite content toward the alteration center. In addition, losses in CaO can be related in a general sense to the sharp decrease in the sum of modal augite + actinolite + Ca-plagioclase. The relation of CaO loss to alteration is strongly supported by the general pattern in Figure 5. The most dramatic change in CaO losses occurs in the area where the Phoenix dike first becomes recognizable as a mappable geologic unit next to the Bingham stock. Closer to the Last Chance stock, the Phoenix dike shows essentially no change in CaO content.

It is concluded that changes in bulk composition from the quartz monzonite porphyry contact toward the Last Chance stock are due to hydrothermal alteration of a rock which had the composition of the Last Chance stock prior to alteration. This conclusion is supported by the fact that the average porosity of the altered rock is approximately twice that of the Last Chance stock and that changes in whole-rock composition are systematic and related to alteration mineral assemblages.

Alteration Trends and Mineral Zones

Modal data are plotted in Figure 5 with dashed lines showing the general mineral trends. The average mafic content of the least altered Last Chance stock, Phoenix dike, and southern edge of the Bingham stock is 26 percent. Augite is the principal

TABLE 6. Modes in Volume Percent of the Last

	Sample 71-	Distance (feet)	Quartz	Orthoclase	Plagioclase (Ca)	Albite	Magmatic biotite	Magmatic + hydrothermal mica	Hydrothermal phlogopite	Sagenitic rutile	Augite	Actinolite
Bingham stock	30	350	9	33	20	tr	5		26	*	—	—
	30c	350	17	26	24			27				
	1	540	4	41	19	tr	6		2	*	—	7
	2	1200	11	11	41	1	5		30	*	—	—
	3	1460	15	20	20	tr	7		34	**	—	—
	4	1560	21	8	32	2	7		25	****	—	—
	29	1900	12	38	19	tr	5		25	***	—	—
	29c	1900	13	33	17			30				
	5	2120	6	27	20	tr	7		32	****	—	—
	Average ¹		9	33	20	tr	6		27		—	—
	6	2220	3	36	26	—	11		3	*	—	7
	7	2420	3	36	33	—	4		—	*	tr	14
	27	2500	8	36	26	—	5		2	—	—	—
	8	2780	4	30	32	—	7		tr	—	—	20
Phoenix dike	28	2840	6	34	31	—	6		5	—	—	—
	20	2900	5	38	24	—	9		1	—	tr	15
	9	2980	2	35	36	—	8		—	—	1	11
	21	3140	4	32	38	—	5		—	—	8	10
	Average		4	35	31	—	7		1		1	10
	11	3280	4	36	26	—	6		—	—	6	14
	26	3420	4	30	30	—	8		—	—	15	10
	12	3540	2	35	34	—	8		—	—	10	7
	10	3560	4	37	32	—	10		1	—	5	6
	13	3900	4	30	38	—	5		—	—	14	8
Last Chance stock	14	4000	10	38	34	—	5		—	—	8	2
	15	4360	4	38	34	—	6		—	—	10	6
	16	4500	9	22	33	—	6		—	—	16	9
	Average		5	33	33	—	7		—		10	8
	17	5000	3	38	39	—	4		—	—	3	10
Last Chance stock	18	6080	10	45	35	—	4		—	—	3	2
	19	6640	2	35	36	—	7		—	—	6	11
	22	6900	4	33	29	—	4		—	—	20	7
	Average		5	37	34	—	5		—		8	8

¹ Average of samples 30, 29, and 5.

29c and 30c are calculated modes.

* Number of asterisks indicates relative abundance.

mafic constituent in rock at distances greater than 3,000 ft from the porphyry contact. Hydrothermal actinolite replacing augite makes up 16 percent of the rock between 3,400 and 2,200 ft. Closer than 2,200 ft hydrothermal phlogopite is the principal mafic mineral and comprises 28 percent of the Bingham stock, replacing actinolite and some feldspar. Chlorite occurs with and replaces hydrothermal actinolite and augite and makes up as much as 11 percent of the rock about 2,500 ft from the porphyry contact. Magmatic biotite consistently constitutes 6 percent of the monzonite.

Plagioclase makes up 52 percent (Moore, 1973) of the feldspar in the Last Chance stock and decreases to 37 percent in the Bingham stock near the porphyry contact. An anomalously high plagioclase:

orthoclase ratio occurs in the endomorphous alteration zone around the limestone xenoliths and is excluded from the trends shown in Figure 5.

Altered Bingham stock is divisible into two mineralogical zones: an inner quartz-orthoclase-phlogopite zone and an outer actinolite-chlorite zone. The inner zone extends 2,200 ft from the porphyry contact. In addition to increases in phlogopite, orthoclase, and quartz, the zone contains disseminated sulfides replacing magnetite. Apatite is more abundant and coarser grained than in unaltered rock. Quartz is added with phlogopite, sulfide, and apatite in aggregates replacing actinolite.

The actinolite-chlorite zone occurs 2,200 to 3,400 ft from the porphyry contact. It contains 2 percent magnetite, small amounts of epidote, calcite, and

Chance Stock, Phoenix Dike, and Bingham Stock

Chlorite	Smectite	Sericite	Magnetite	Chalcopyrite	Total sulfide	Pyrite	Apatite rutile	Classification	Alteration zones
tr	5	—	—	2.0		—	tr	qtz monzonite	Quartz-orthoclase-phlogopite
7	5	tr	1	1.2		—	3	qtz monzonite	
tr	—	tr	—	1.0		—	tr	syenite	
3	—	—	—	0.5		tr	1	qtz diorite	
tr	—	—	—	1.5		tr	tr	qtz monzonite	
—	—	tr	—	0.5		3.5	tr	qtz diorite	
3	—	tr	—	1.0		1.0	tr	granite	
				1.1		1.4		granite	
3	—	tr	—	0.5		2.5	2	monzonite	
1	2	tr	—		2.0		tr		Actinolite-chlorite
1	11	—	2	—		tr	1	monzonite	
8	tr	—	2	—		—	tr	monzonite	
14	7	tr	2	—		—	tr	monzonite	
4	—	—	2	—		—	tr	monzonite	
5	12	tr	1	—		—	tr	monzonite	
3	2	—	3	—		—	tr	monzonite	
5	—	—	2	—		—	tr	monzonite	
—	1	—	2	—		—	tr	monzonite	
5	4	tr	2	—		—	tr		
6	1	—	2	—		—	tr	monzonite	
—	—	—	3	—		—	tr	monzonite	
tr	—	—	4	—		—	tr	monzonite	
1	—	—	3	—		—	1	monzonite	
—	—	—	1	—		—	tr	monzonite	
—	—	tr	2	—		—	tr	qtz monzonite	
—	—	—	2	—		—	tr	monzonite	
2	—	—	3	—		—	tr	monzonite	
1	tr	tr	3	—		—	tr		monzonite qtz monzonite monzonite monzonite
—	—	—	3	—		—	tr		
—	tr	—	1	—		—	tr		
—	—	—	3	—		—	tr		
—	—	—	3	—		—	tr		
—	tr	—	3	—		—	tr		

smectite in addition to actinolite and chlorite. Orthoclase is added in the zone as rims around plagioclase.

Discussion

Bingham generally shares porphyry copper zoning characteristics of both the Lowell and Guilbert (1970) model and the Hollister (1975) diorite model. Alteration of monzonite on the south side of the Bingham stock is more closely comparable to the diorite model, with a core potassic assemblage and an adjacent chlorite-rich propylitic zone. Phyllic and argillic zones are poorly developed.

Bingham has an unusually large orthoclase-phlogopite zone which is directly analogous to the potassic alteration zone of Hemley and Jones (1964). Pervasive hydrothermal phlogopite extends 2,200 ft from the quartz monzonite porphyry, which also shows a well-developed potassic assemblage. The

economically significant coincidence of phlogopite with copper sulfides replacing magnetite has long been recognized at Bingham (Boutwell, 1905; Beeson, 1917) and is well illustrated in Figure 5. Hydrothermal orthoclase is formed out to 3,000 ft, and as much as 15 percent orthoclase replaces plagioclase in monzonite (Fig. 5). Roedder (1971) and Moore and Nash (1974) show a correlation of high-salinity inclusions with the potassium-silicate alteration assemblages.

The mineral assemblage in the actinolite-chlorite zone is equivalent to propylitic alteration. Alteration in this zone is dominantly replacement of earlier formed hydrothermal actinolite and phlogopite, as well as magmatic augite and biotite, by chlorite. Epidote and calcite, mainly associated with actinolite, are of minor importance but are much more abundant in the southeast portion of the monzonite.

TABLE 7. Whole Rock Chemical Analyses

Sample no.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O	S	H ₂ O ⁺	CO ₂	Cu ppm	Total	Bulk sp. gr.	Grain sp. gr.	Porosity %
71-30	62.7	14.9	0.84	2.28	4.67	1.19	2.80	6.77	0.307	1.49	<0.2	5140	98.7	2.54	2.71	6.27
71-1	59.5	14.3	1.87	3.74	5.52	2.50	2.00	5.84	0.206	1.83	0.39	2500	97.9	2.54	2.75	7.64
71-2	59.9	15.7	1.63	3.67	5.19	1.82	3.11	4.29	0.304	1.87	<0.2	1980	97.7	2.48	2.76	10.15
71-3	60.2	15.5	1.77	2.88	6.05	1.49	2.63	5.55	0.622	1.58	<0.2	5850	99.0	2.59	2.82	5.82
71-4	60.2	14.9	3.09	2.83	4.58	1.44	3.26	4.63	1.69	1.74	<0.2	1680	98.7	2.52	2.82	10.64
71-29	59.2	14.9	2.17	3.13	5.20	1.13	2.12	7.64	1.40	1.19	<0.2	3860	98.7	2.75	2.75	—
71-5	56.5	14.1	5.19	3.56	5.42	1.20	2.14	6.26	2.53	1.70	<0.2	3250	99.1	2.59	2.84	8.80
Average ¹	59.5	14.6	2.73	2.99	5.10	1.17	2.35	6.89	1.41	1.46	<0.2	4083	98.8	2.56	2.77	7.53
71-6	57.5	14.8	4.43	3.12	3.98	2.22	2.20	6.04	1.08	2.07	0.28	2620	98.0	2.43	2.74	11.31
71-7	57.6	15.4	3.39	4.15	5.14	2.01	2.63	4.40	1.50	2.19	—	1000	98.5	2.60	2.80	7.14
71-27	61.4	14.9	3.23	2.67	4.46	1.27	2.46	6.98	1.67	1.35	<0.2	1130	100.7	—	2.75	—
71-8	61.4	14.7	2.82	2.74	3.43	2.56	3.77	5.02	0.625	1.34	0.8	650	99.3	2.50	2.73	8.42
71-28	62.7	14.7	3.17	2.30	3.19	1.36	2.76	6.19	1.33	1.35	<0.2	590	99.3	2.74	2.74	—
71-20	61.0	15.2	2.86	2.90	3.60	2.42	3.05	5.20	0.704	1.39	—	2350	98.6	2.51	2.73	8.06
71-9	58.3	15.2	2.83	3.17	3.96	4.03	3.32	5.07	0.384	1.04	—	240	97.3	2.58	2.78	7.19
71-21	58.0	14.3	3.97	2.16	3.48	2.28	1.93	7.36	3.20	1.36	—	395	98.0	2.59	2.73	5.13
Average	59.7	14.9	3.34	2.90	3.91	2.27	2.77	5.78	1.31	1.51	<0.2	1122	98.9	2.53	2.75	7.87
71-11	57.9	14.6	3.19	2.96	4.06	4.70	3.30	5.20	0.932	1.01	—	90	97.9	2.66	2.82	5.67
71-26	59.2	14.7	2.90	3.02	3.96	4.41	2.79	5.36	0.274	0.81	—	115	97.4	2.58	2.75	6.18
71-12	58.4	15.3	2.58	3.11	3.98	4.83	3.53	4.81	0.055	0.68	<0.2	110	97.5	2.58	2.80	7.86
71-10	59.7	15.0	3.15	2.92	3.66	4.24	3.56	5.05	0.005	0.76	—	85	98.0	2.48	2.77	10.47
71-13	58.7	15.4	2.92	2.97	4.01	4.79	3.50	4.95	0.002	0.79	—	110	98.0	2.62	2.82	7.09
71-14	60.3	15.1	3.05	2.85	3.48	4.37	3.55	4.75	0.002	0.57	—	85	98.0	2.56	2.77	7.58
71-15	58.7	15.7	3.47	3.12	4.10	5.12	3.44	4.88	0.017	0.79	—	100	99.3	2.60	2.81	7.47
71-16	60.1	15.8	3.43	2.60	4.13	4.06	3.95	4.60	0.003	1.07	—	50	99.7	2.49	2.76	9.78
Average	59.1	15.2	3.09	2.94	3.92	4.57	3.45	4.95	0.161	0.81	—	93	98.2	2.57	2.79	7.88
71-17	59.8	16.2	3.57	2.55	3.47	4.67	3.61	4.26	0.005	0.85	—	120	99.0	2.68	2.77	3.25
71-18	63.8	15.6	2.20	1.93	2.80	3.34	3.56	4.54	0.010	0.94	—	55	98.7	2.53	2.73	6.59
71-19	59.0	15.8	2.46	3.11	4.41	5.28	3.59	4.22	0.031	0.77	—	60	98.6	2.71	2.80	3.21
71-22	57.0	15.4	3.33	3.32	4.78	5.89	3.40	4.66	0.004	0.66	—	35	98.4	2.70	2.82	4.26
Average	59.9	15.7	2.89	2.73	3.87	4.79	3.54	4.42	0.005	0.81	—	67	98.7	2.66	2.78	4.33

¹Average of samples 30, 29 and 5.Iron in sulfides reported as Fe₂O₃.

Chemically analyzed by Ron Bianchi, Kennecott Exploration, Inc., Salt Lake City, Utah.

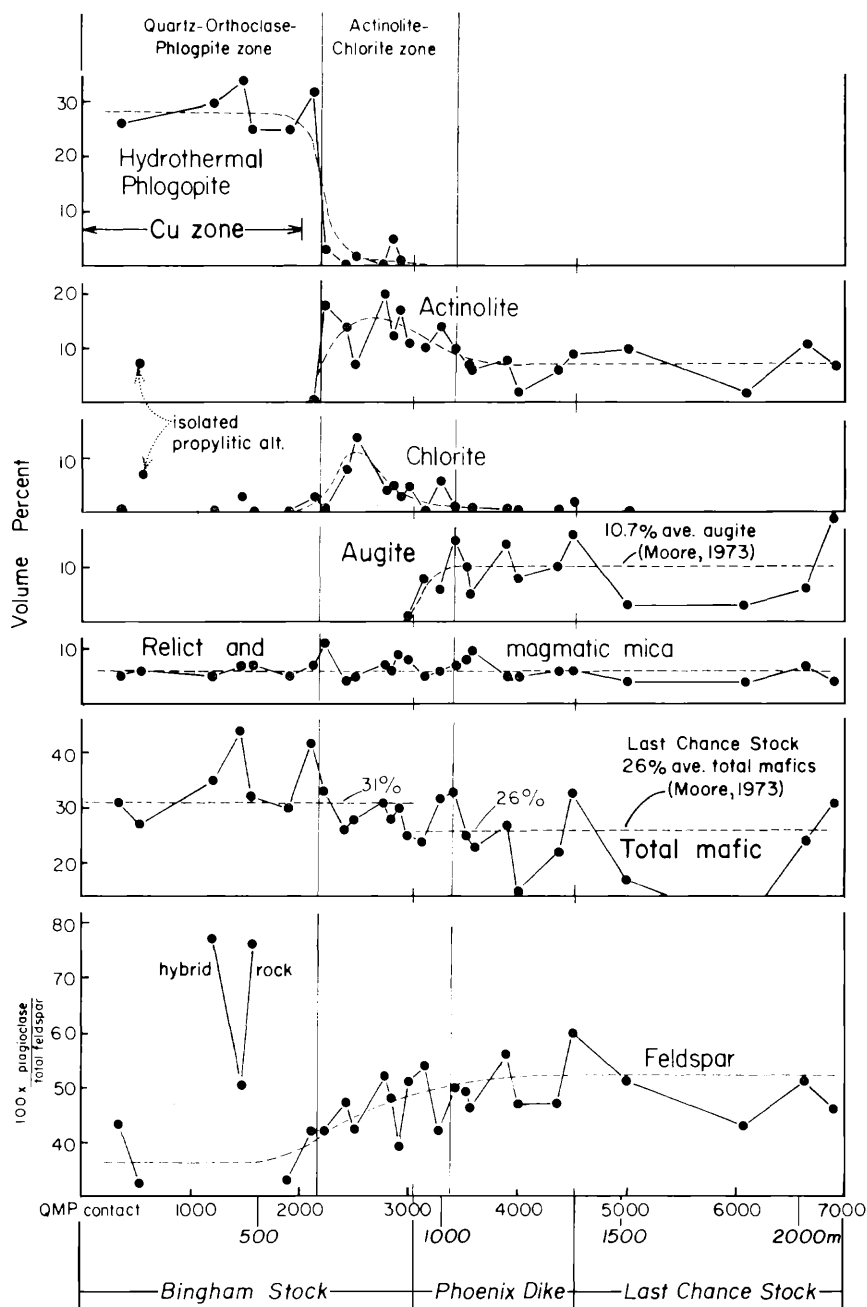


FIG. 5. Mineralogic trends in equigranular rock.

The occurrence of what is considered to be hydrothermal actinolite associated with sulfide mineralization is emphasized. Paragenetically it is probably earlier than the phlogopite in the potassic zone and also earlier than chlorite and epidote in the actinolite-chlorite zone.

Well-developed argillic and phyllic alteration zones are notably absent on the south side of the mine. A tan smectite replaces actinolite locally in the actino-

lite-chlorite zone. Although the clay has an erratic distribution, its association with quartz suggests a hypogene origin. Sericite replaces mainly plagioclase in envelopes around quartz-sulfide veins. The sericite selvages are generally small and mainly occur outside the copper orebody but are quantitatively insignificant in the study area.

Mineral and chemical trends suggest that the Last Chance stock represents rock of the same composi-

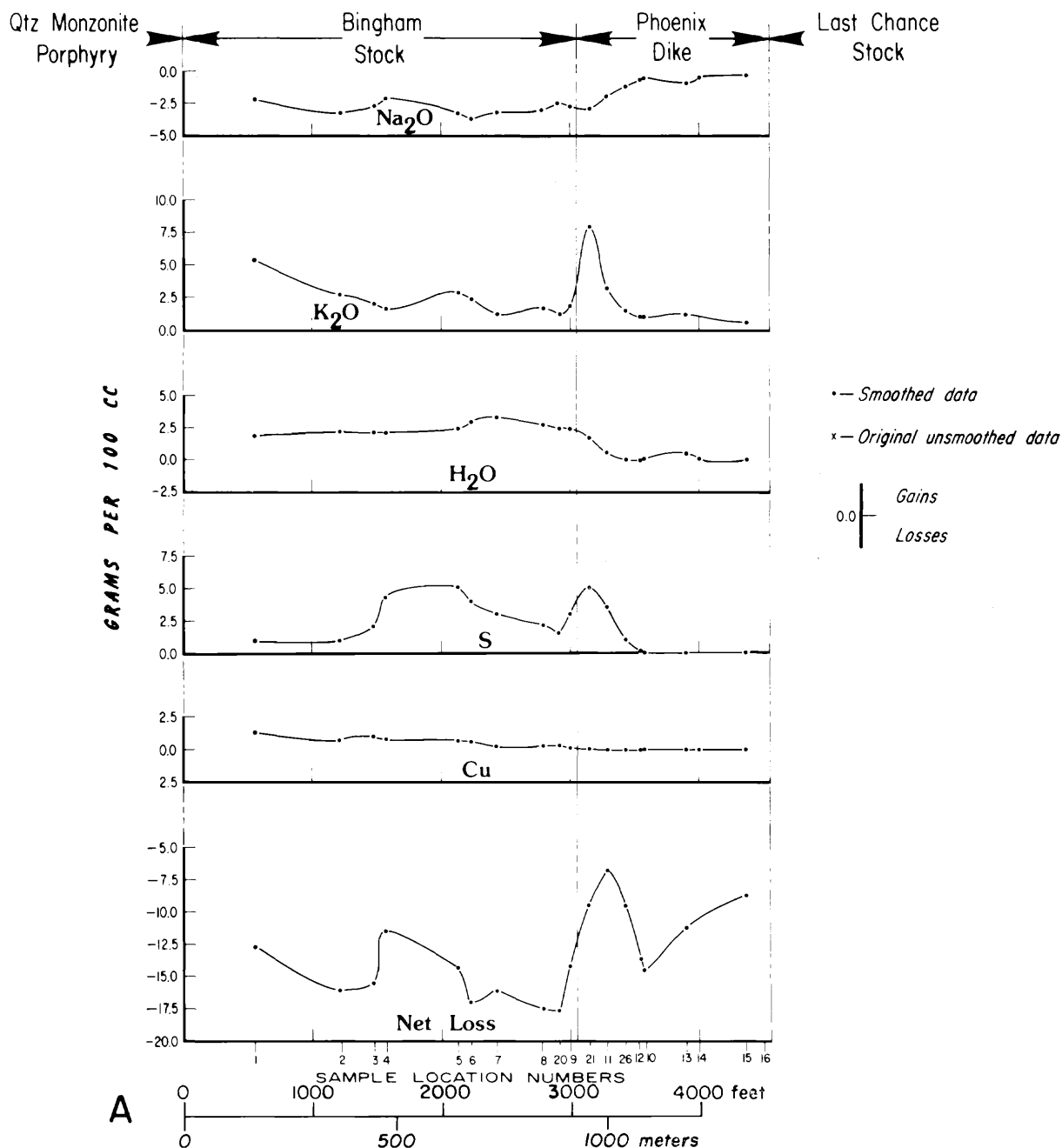


FIG. 6. A. Chemical gains and losses in equigranular rock.

tion as the prealteration equigranular rock in the Bingham stock and that granitoid rock in the two stocks represents one intrusive phase. Augite is replaced by hydrothermal actinolite, which in turn is replaced by phlogopite, and all three minerals are replaced by chlorite. Mineral trends are: (1) andesine of the Last Chance stock grades into oligoclase of the altered Bingham stock, (2) orthoclase of the Last Chance stock becomes more K rich in the Bingham stock, and (3) the Mg content of biotite

increases inward toward the alteration center (Moore and Czamanske, 1973). Chemical trends complement mineral trends and both are explained as a result of hydrothermal alteration of augite-actinolite-biotite monzonite.

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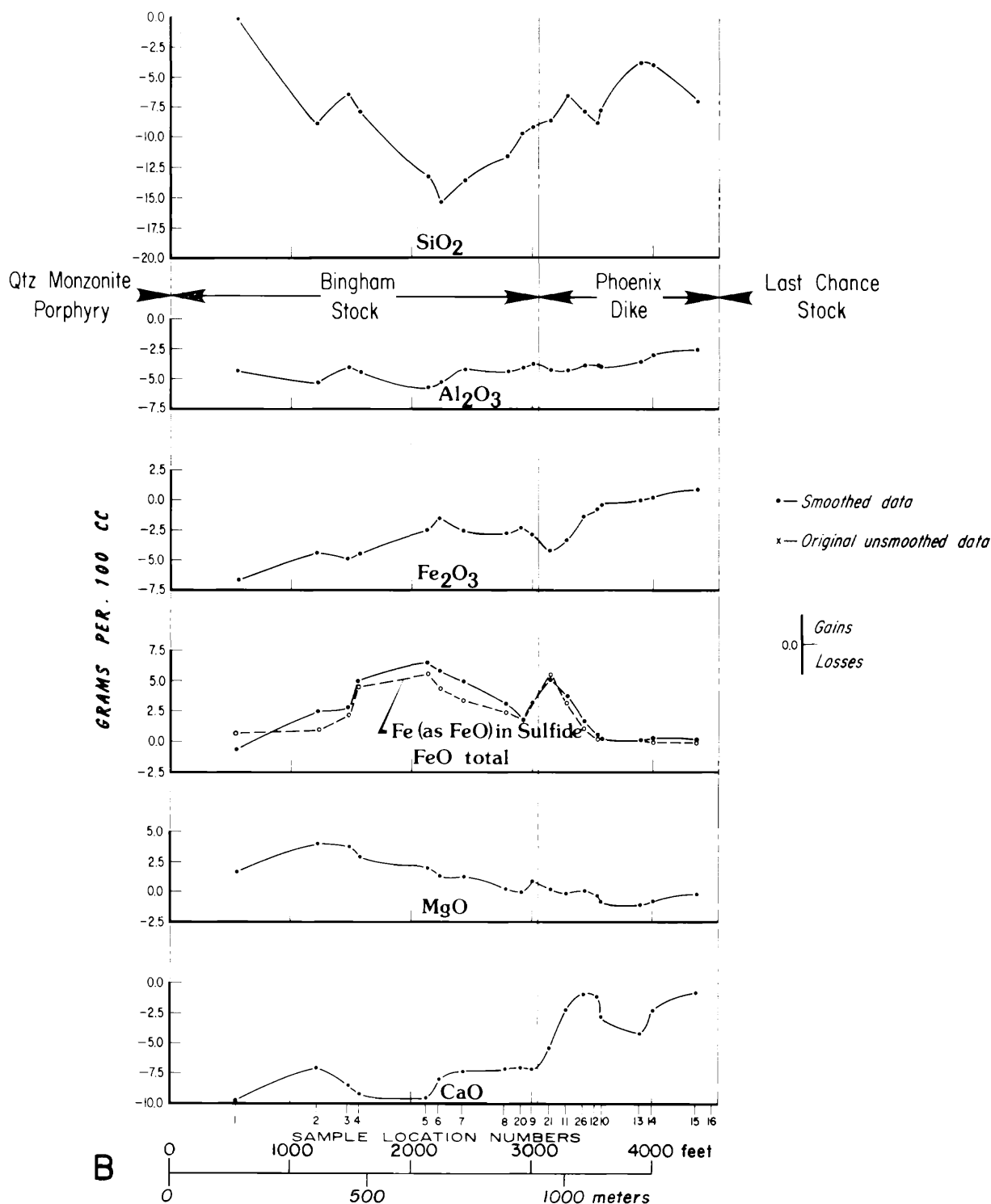


FIG. 6. B. Chemical gains and losses in equigranular rock (cont'd).

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