

# The Schultze Granite, the Tea Cup Granodiorite, and the Granite Basin Porphyry: A Geochemical Comparison of Mineralized and Unmineralized Stocks in Southern Arizona

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U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1303



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*By* S. C. CREASEY

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# THE SCHULTZE GRANITE, THE TEA CUP GRANODIORITE, AND THE GRANITE BASIN PORPHYRY: A GEOCHEMICAL COMPARISON OF MINERALIZED AND UNMINERALIZED STOCKS IN SOUTHERN ARIZONA

By S. C. CREASEY

## ABSTRACT

The petrography, geochemistry, and intrusive history of three Laramide stocks—the Schultze Granite, the Tea Cup Granodiorite, and the Granite Basin Porphyry (new)—in southern Arizona were studied in detail to determine whether a distinctive geochemistry or petrology is characteristic of intrusive rocks associated with porphyry copper deposits.

The Schultze Granite, which is spatially and temporally related to porphyry copper deposits, comprises multiple intrusions, including more than one porphyry phase. The crystallization history of the Schultze Granite is distinct from that of the other two stocks, particularly in the development of the multiple-porphyry phase, whose texture may have resulted from the ore-forming process. The Tea Cup Granodiorite comprises two phases, porphyritic and equigranular. Crosscutting relations indicate that the porphyritic phase is the younger; it is cut by quartz-sericite-sulfide veins but has not been the locus of a commercial copper deposit. The Granite Basin Porphyry is a single intrusion with no indications of mineralization.

The abundances of major chemical elements in these three stocks and the stocks in the Ray porphyry copper district of Arizona were compared on the basis of the number of cations per standard cell of 160 anions. The resulting data indicate that porphyry copper deposits are associated with rocks that are relatively enriched in silica and potassium and are impoverished in iron, magnesium, and calcium (femic elements). A plot of  $\text{Si}/(\text{femic elements} + \text{Si})$  against  $\text{K}/(\text{femic elements} + \text{K})$  is a smooth curve on which the data points for the mineralized stocks are separate from those for the unmineralized stocks.

These data, though limited, suggest that the major-element content of an intrusive body provides a criterion useful in the evaluation of its porphyry copper mineral potential. All the data obtained suggest that whatever may be involved in the ore-forming process, the magmas associated with such porphyry copper deposits as the Schultze Granite do not form by some mechanism that is unique or distinctive relative to magmas not associated with porphyry copper deposits, such as the Tea Cup Granodiorite and the Granite Basin Porphyry; rather, the intrusion and crystallization histories of intrusive bodies that are associated with porphyry copper deposits may differ significantly from the histories of those that are not, and so the ratios of Si, K, and femic elements in mineralized stocks may differ significantly from those in unmineralized stocks. It is also entirely possible that none of the minor elements considered are useful in the recognition of unaltered intrusives associated with porphyry copper deposits.

## INTRODUCTION

Within an area extending from Silver City, N. Mex., 28 km east of the Arizona border, to Ajo, Ariz., on the west and from Kingman, Ariz., on the north to some unknown point in Sonora, Mexico, on the south, copper occurs in an abundance that is equaled by few other areas in the world. This area constitutes the Arizona porphyry copper province. Copper production from only the part of the province that lies within Arizona exceeds that of all the other States combined. So far as is known, most of the copper resources of the United States lie within this province.

All the porphyry copper deposits in the copper province—with the notable exception of the deposit at Bisbee—formed during the Laramide orogeny, from about 75 to 50 m.y. ago (Creasey and Kistler, 1962; Mauger and others, 1965; Damon and Mauger, 1966; Livingston and others, 1968). They are all temporally and spatially associated with intrusive bodies, commonly mineralized stocks, that range in composition from granodiorite to quartz monzonite. About half the copper occurs in the stocks and the other half in the contiguous country rocks; it follows that a search for porphyry copper deposits usually involves a search for mineralized stocks. However, only a small percentage of the Laramide stocks contain porphyry copper deposits.

The purpose of this study is to compare mineralized and unmineralized Laramide stocks in order to determine whether a distinctive geochemistry and petrology characterizes each category. My intention was to compare Laramide stocks within only the Globe-Miami district (fig. 1) of the Arizona porphyry copper province; however, the unmineralized presumed Laramide stock in the district was found to be Precambrian (Creasey, 1980). Therefore, two Laramide stocks were chosen: a barren stock, the Granite Basin Porphyry (herein

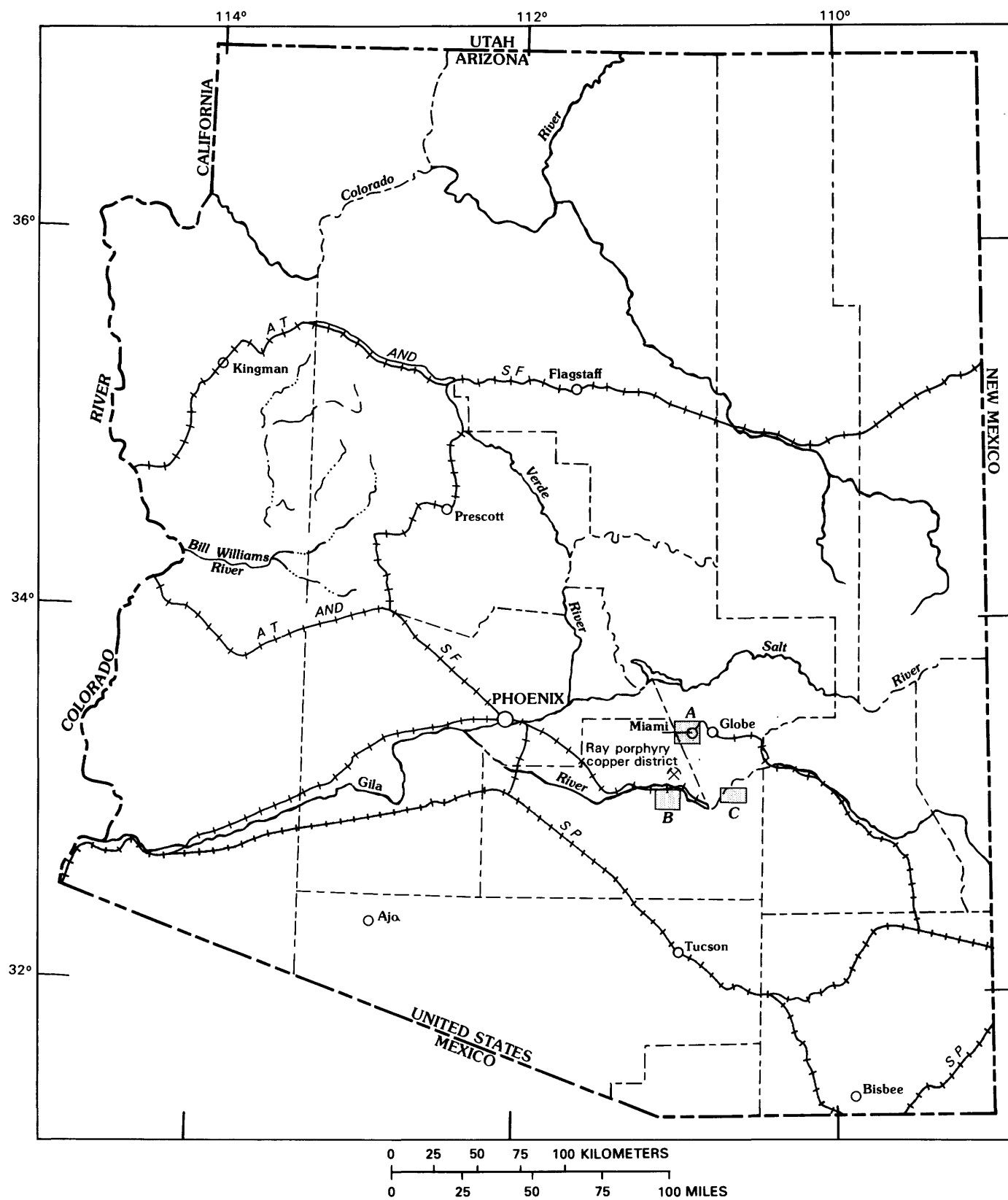


FIGURE 1.—Locations of areas where rocks studied occur. A, Schultze Granite. B, Tea Cup Granodiorite. C, Granite Basin Porphyry.

named), and a weakly mineralized stock, the Tea Cup Granodiorite, which are located about 40 km southeast and southwest, respectively, of the Globe-Miami district (fig. 1).

The Ray porphyry copper district lies about 30 km south of the stocks in the Globe-Miami district. The Laramide intrusive rocks in the Ray district have been extensively analyzed for major elements and to a lesser extent for minor elements (H. R. Cornwall and N. G. Banks, unpub. data, 1980; Banks and others, 1972). Wherever appropriate, the geochemistry of the Laramide intrusive rocks at Ray are compared and contrasted with the Granite Basin Porphyry, the Tea Cup Granodiorite, and the Schultze Granite.

The geology of the Globe-Miami district has been well documented. Comprehensive geologic studies were begun in about 1901 and have continued to the present. Major publications include those by Ransome (1903, 1919), Peterson (1954, 1962), Peterson and others (1951), Olmstead and Johnson (1966), Simmons and Fowells (1966), and Creasey (1980); of these, Peterson (1962) is the most comprehensive.

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## GEOLOGY AND PETROLOGY

### SCHULTZE GRANITE

The Schultze Granite occurs in the western part of the Globe-Miami district (pl. 1). It covers about 44 km<sup>2</sup>, of which only about 5 km<sup>2</sup> are covered by younger rocks. On the basis of texture and mineral composition, the Schultze was divided into five primary phases: early, main, transitional, porphyry, and dike. The early phase occurs in five separate masses, the largest in the southeastern corner of the Schultze and the four smaller masses entirely surrounded by the main phase in and about the center of the Schultze (pl. 1). The transitional phase comprises rocks that grade from the main phase to the porphyry. The porphyry phase comprises several texturally and mineralogically distinct rock types that probably were intruded at slightly different times; this report includes all of them in one unit. The porphyry phase occurs in two larger masses that are contiguous to the main phase at the northeast and southeast corners of the Schultze, and in small isolated masses in and near the Copper Cities pit and near the Pinto Valley pit (pl. 1). The porphyry at the northeastern corner of the

Schultze, hereafter called the Miami-Inspiration porphyry mass, grades southwestward into the main phase through a transitional phase. No such transitional phase was recognized in association with the southeastern porphyry mass, hereafter called the Copper Springs porphyry mass. The dike phase is represented by a single dike about 10.7 m thick that cuts into the main phase of the Schultze well away from any indication of mineralization.

The K-Ar ages of hornblende, biotite, and muscovite in granitic rock located north of the Schultze in the area between the main phase and the isolated porphyry masses near the Copper Cities and Pinto Valley pits have been reset; the new dates strongly suggest that the top of the Schultze lies at a shallow depth in this area (Creasey, 1980). If so, the horizontal extent of the stock is appreciably larger than is indicated by the outcrop. If this interpretation is correct, the northern contact of the stock dips gently northward. All other observed contacts of the stock appear to dip steeply.

The main mass of the Schultze intrudes the Pinal Schist, the granite of Manitou Hill, the Willow Spring Granodiorite, the Solitude Granite, the Lost Gulch Quartz Monzonite, and the diabase, all of Proterozoic age. In addition, a small porphyry mass intrudes Paleozoic limestone east of the Pinto Valley pit. The Schultze Granite is overlain unconformably by the Whitetail Conglomerate and Apache Leap Tuff of Oligocene and Miocene age, respectively, and by younger Tertiary and Quaternary sand, gravel, and conglomerate (fig. 2).

Dikes of the main phase of the Schultze cut the early phase; locally within the Miami-Inspiration porphyry mass, sharp contacts between the porphyry and the main-phase Schultze indicate local intrusive relations. In general, however, the Miami-Inspiration porphyry mass grades into the main phase through the transitional phase. The Copper Springs porphyry mass does not have sharp contacts with the main phase, although no mappable transition zone was recognized. Peterson (1962, p. 33-35) described in detail the gradational contact of the porphyry and main phases, but he did not recognize the early phase.

The early phase of the Schultze is a granodiorite composed of 23 percent quartz, 54.3 percent plagioclase, 14.1 percent K-feldspar, and 7 percent biotite (modal composition). The mesonorm (table 1) agrees well with the mode. The mesonormative composition of the plagioclase is An<sub>18</sub>. The chief accessory minerals are magnetite and, in lesser amounts, hematite, apatite, sphene, and zircon.

The texture of the early phase ranges from porphyritic with a medium-grained, hypidiomorphic granular groundmass to medium grained, hypidiomorphic seriate. Where phenocrysts are present, they are com-



TABLE 1.—Chemical analyses, mesonorms, and cations per standard cell of 160 anions of 11 rock phases

[New chemical analyses by T. Artis, S. Botts, P. M. Bushman, M. Cremer, P. Elmore, L. Espos, J. Glenn, B. King, and J. H. Tillman]											
	Early phase, Schultze Granite	Main phase, Schultze Granite	Porphyry phase, Schultze Granite	Altered porphyry phase, Schultze Granite	Equigranular phase, Tea Cup Granodiorite	Porphyritic phase, Tea Cup Granodiorite	Granite Basin Porphyry	Granite Mountain Porphyry	Teapot Mountain Porphyry	Rattler Granodiorite	Tortilla Quartz Diorite
Mean -----	2	4	4	3	3	2	4	6	2	13	4
Chemical analyses											
SiO <sub>2</sub> -----	70.16	70.89	70.24	74.27	69.40	67.66	61.90	70.12	67.00	67.10	56.61
Al <sub>2</sub> O <sub>3</sub> -----	16.12	16.10	15.77	13.92	15.87	15.85	16.96	15.53	15.45	16.43	17.38
Fe <sub>2</sub> O <sub>3</sub> -----	1.28	1.12	1.15	.44	1.33	1.27	3.02	1.06	1.25	1.71	3.88
FeO -----	.76	.46	.48	.37	.88	1.08	1.84	1.27	1.03	1.73	3.75
MgO -----	.64	.55	.36	.50	.80	1.16	2.43	.92	.75	1.43	3.20
CaO -----	2.40	2.01	1.98	1.03	2.50	1.30	3.98	2.42	2.75	3.95	6.70
Na <sub>2</sub> O -----	4.74	4.67	4.65	3.07	3.93	2.40	4.34	3.88	2.80	3.68	3.23
K <sub>2</sub> O -----	3.10	3.58	3.59	5.69	2.80	3.45	2.31	3.32	4.10	2.55	2.08
H <sub>2</sub> O -----	.41	.35	.69	.42	.63	.84	1.63	.79	1.30	.64	.91
TiO <sub>2</sub> -----	.30	.25	.22	.18	.26	.44	.53	.31	.35	.45	.54
P <sub>2</sub> O <sub>5</sub> -----	.12	.12	.08	.11	.08	.10	.21	.16	.15	.24	.30
MnO -----	.04	.03	.03	.02	.05	.04	.18	.04	.05	.06	.14
CO <sub>2</sub> -----	.05	.09	.03	.08	.06	.03	.09	.06	.19	---	.06
F -----	.08	.07	.06	.05	---	---	---	---	---	---	---
Mesonorms											
Quartz -----	24.58	21.34	24.08	30.95	29.45	29.95	20.30	28.58	29.62	26.35	15.60
Orthoclase ---	12.25	15.48	17.37	28.31	7.70	11.45	5.45	11.01	15.43	6.86	4.03
Albite -----	42.60	41.70	42.32	27.73	36.22	31.84	39.89	35.36	26.52	33.61	29.60
Anorthite ---	9.24	7.80	8.46	3.20	10.89	9.86	15.82	9.75	10.84	16.88	26.59
Muscovite ---	6.04	6.20	4.45	6.01	9.72	7.78	2.91	7.86	10.64	5.93	.44
Biotite -----	2.85	1.76	1.44	1.99	3.74	6.33	10.36	5.20	4.03	6.71	13.13
Sphene -----	.63	.53	.46	.39	.57	.94	1.43	.75	.78	.88	1.01
Magnetite ---	1.35	1.11	1.06	.42	1.44	1.62	2.83	1.13	1.39	1.90	4.16
Apatite -----	.27	.35	.18	.16	.17	.21	.45	.27	.33	.36	.64
Fluorite ---	.30	.28	.21	.20	---	---	.19	---	---	(Andalusite)	.32
Calcite -----	.13	.09	.07	.21	.15	.09	.23	.16	.51	---	.13
Other -----	(Hematite)	.04	.11	---	---	(Hematite)	.06	---	(Actinolite)	.48	3.90
Cations per standard cell of 160 anions											
Si -----	61.17+ .18	61.87+ .92	61.60+ .66	64.73+ 1.57	61.19+ 2.07	61.07+ .30	55.89+ .56	61.17+ .82	59.97+ .77	59.15+ 1.22	52.60+ 1.54
Al -----	16.55+ .02	16.56+ .64	16.30+ .24	14.31+ 1.05	16.51+ 1.04	16.00+ .32	16.87+ .16	15.98+ .49	16.31+ .17	17.13+ .56	18.84+ 1.14
Fe <sub>3</sub> -----	.85+ .06	.74+ .17	.76+ .09	.29+ .29	.89+ .40	1.00+ .20	2.02+ .67	.70+ .13	.85+ .34	1.19+ .37	2.69+ .88
Fe <sub>2</sub> -----	.56+ .04	.35+ .09	.36+ .07	.25+ .21	.65+ .38	.96+ .10	1.37+ .09	.93+ .06	.78+ .07	1.26+ .41	2.89+ .30
Mg -----	.84+ .10	.57+ .20	.47+ .10	.65+ .13	1.06+ .40	1.71+ .18	3.23+ .39	1.20+ .27	1.00+ .40	1.81+ .45	2.89+ 1.05
Ca -----	2.24+ .01	1.88+ .10	1.86+ .16	.96+ .52	2.37+ .70	2.28+ .26	3.81+ .44	2.26+ .14	2.65+ .37	3.75+ .65	6.61+ .55
Na -----	8.01+ .02	7.91+ .59	7.92+ .20	5.19+ 1.60	6.73+ .48	5.91+ .11	7.51+ .30	6.57+ .41	4.87+ .23	6.37+ .49	5.76+ .97
K -----	3.45+ .16	4.14+ .47	4.02+ .26	6.32+ 1.18	3.15+ .20	3.89+ .41	2.64+ .21	3.69+ .30	4.69+ .19	2.87+ .29	2.44+ .19
Ti -----	.20+ 0	.17+ .02	.15+ .01	.13+ .06	.18+ .06	.29+ .14	.46+ .08	.24+ .03	.24+ .09	.30+ .07	.50+ .27
P -----	.10+ .01	.12+ .08	.07+ 0	.08+ .03	.07+ .03	.08+ .01	.16+ .04	.10+ .02	.12+ .02	.13+ .06	.24+ .06
Mn -----	.04	.02	.03	.01	.05	.04	.05	.04	.05	.06	.12
C -----	.06	.11	.03	.10	.07	.05	.11	.08	.24	---	.07
H -----	2.42+ .86	1.38+ .67	4.05+ 2.38	1.92+ .26	3.72+ 1.25	4.91+ .91	9.68+ .76	4.61+ .59	7.77+ .81	3.87+ 1.39	---
F -----	.22	.20	.11	.10	---	---	---	---	---	---	---

Sample numbers and references to published analyses:

Early phase, Schultze Granite: 11, 68 (this report)  
 Main phase, Schultze Granite: A4, 10, A21, NPP-1 (Peterson, 1962; this report)  
 Porphyry phase, Schultze Granite: 16, 23 and NPP-2, NPP-3 (Peterson, 1962; this report)  
 Potentially altered porphyry phase, Schultze Granite: A32, 54, 56 (this report)  
 Equigranular phase, Tea Cup Granodiorite: 121-1, 130-2, 145-5 (H. R. Cornwall and N. G. Banks, unpub. data, 1980)  
 Porphyritic phase, Tea Cup Granodiorite: 148-5, 148-7 (H. R. Cornwall and N. G. Banks, unpub. data, 1980)  
 Granite Basin Porphyry: 165, and 64-73, 83-75, and GB-1 (Koski, 1978)  
 Granite Mountain Porphyry: (Ransome, 1919; Banks and others, 1972; H. R. Cornwall and N. G. Banks, unpub. data, 1980)  
 Teapot Mountain Porphyry: (Banks and others, 1972; H. R. Cornwall and N. G. Banks, unpub. data, 1980)  
 Rattler Granodiorite: (Ransome, 1919; Banks and others, 1972; H. R. Cornwall and N. G. Banks, unpub. data, 1980)  
 Tortilla Quartz Diorite: (Ransome, 1919; Banks and others, 1972; H. R. Cornwall and N. G. Banks, unpub. data, 1980)

posed of K-feldspar, plagioclase, and quartz. The early phase, noticeably finer grained than the main phase, contains fewer and smaller phenocrysts and contains more biotite. The early phase contains miarolitic cavities.

Thin sections and stained slabs suggest that either the plagioclase crystallized first or it was present in the original melt as xenocrysts. It is strongly zoned. Quartz followed the plagioclase, and K-feldspar crystallized late; it largely fills the interstices between plagioclase and quartz.

The main phase of the Schultze is a porphyritic quartz monzonite; it consists of 25 percent quartz, 47 percent plagioclase, 23 percent K-feldspar, and 4 percent biotite. Common accessory minerals are magnetite and apatite and, in lesser amounts, sphene. The texture is porphyritic, with a coarse- to medium-grained hypidiomorphic seriate groundmass. The phenocrysts are large (1-5 cm) subhedral to anhedral K-feldspar; the groundmass comprises quartz, plagioclase, K-feldspar, and biotite.

Over most of the time they were growing, the K-feldspar, plagioclase, and quartz crystallized together; K-feldspar formed the larger crystals (phenocrysts) because it had fewer centers of crystallization. Biotite appears to have crystallized both early and late. The larger crystals in the groundmass consist of quartz, plagioclase, and K-feldspar. At one stage these crystals were floating in a melt that later crystallized into a medium-grained, hypidiomorphic granular aggregate. During the final stage of crystallization, quartz and K-feldspar filled interstices between the larger crystals. Perhaps this tag-end crystallization took place at the time the porphyry phase formed. Miarolitic cavities occur here and there, and in one outcrop round, 4-cm aggregates of quartz-muscovite occur randomly through the rock. It seems likely that a vapor phase separated from the melt.

Although K-feldspar forms phenocrysts as long as 5 cm, there is no indication that these preceded the plagioclase. Apparently during the early stages of crystallization, plagioclase nucleated at many more sites than the K-feldspar did. All during their period of growth, K-feldspar phenocrysts included small, zonally arranged plagioclase crystals.

The most common porphyry consists of phenocrysts of K-feldspar, bipyramidal quartz, plagioclase, and biotite set in a groundmass whose components range from very fine grained phanocrystalline aplitic to aphanitic microcrystalline aplitic. The groundmass is predominantly K-feldspar and quartz, but it includes a few percent plagioclase, and—uncommonly—biotite.

Phenocryst size differs according to mineralogy. In general, K-feldspar phenocrysts are 10-15 mm along their maximum dimension, quartz 5-10 mm, plagioclase

2-8 mm, and biotite about 2 mm. Originally the quartz was all bipyramidal, but some has been partly resorbed.

Among the Miami-Inspiration and Copper Cities porphyry masses is one variant characterized by the absence of K-feldspar phenocrysts and the prominent presence of quartz; it is a typical quartz porphyry. In the Diamond H pit there is a nonporphyritic fine-grained phanocrystalline dike that is considered to be a variant of that porphyry because it is coeval and has a similar mineral composition.

The dike phase of the Schultze Granite has a central nonporphyritic zone that grades outward into porphyritic borders. The central zone is aplitic; it is made up of idiomorphic quartz, K-feldspar, plagioclase, and sparse biotite. The grain size of its felsic minerals is about 1/10 mm. The groundmass of the porphyritic border zones is also aplitic, like the central zone. The phenocrysts (which are sparse) are composed of K-feldspar and quartz. The length of the K-feldspar phenocrysts is about 15 mm and that of the quartz is about 5 mm.

The weighted mean K-Ar age of five samples of the main phase of the Schultze Granite is  $61.2 \pm 0.4$  m.y., that of six samples of the mineralized porphyry phase of the Schultze from the Miami-Inspiration area is  $59.5 \pm 0.3$ , and that of two samples of the mineralized porphyry phase of the Schultze from the Copper Cities area is  $63.3 \pm 0.5$  m.y. (Creasey, 1980). Ages of the unaltered or slightly altered porphyry phase of the Schultze are  $59.2 \pm 0.7$ ,  $64.4 \pm 0.7$ , and  $61.9 \pm 0.7$  m.y. (Creasey, 1980). From these three dates alone, we cannot determine whether the age of the unaltered porphyry phase unequivocally in contact with the main phase of the Schultze differs significantly from that of the main phase. However, the mineralized Copper Cities mass is 3.8 m.y. older than is the mineralized porphyry from the Miami-Inspiration mass. This difference is significant at the 95-percent level of confidence. Similarly, the mineralized Copper Cities porphyry mass is 2.1 m.y. older than the main phase of the Schultze, and this difference also proves to be significant at the 95-percent level of confidence. These data indicate that the Copper Cities porphyry mass is both older than the main phase of the Schultze and older than the porphyry phases contiguous to the main phase.

The geochronology does not indicate any age difference between the Copper Springs and Miami-Inspiration porphyry masses, which are contiguous to the main phase of the Schultze (Creasey, 1980).

#### TEA CUP GRANODIORITE

The Tea Cup Granodiorite crops out over about 41 km<sup>2</sup>, about 40 km and 13 km southwest of the Globe-Miami and Ray districts, respectively, in the Grayback quadrangle (a quadrangle mapped in detail by Cornwall

and Krieger, 1975). The stock extends an unknown distance into the adjoining quadrangles on the south and west, so the total extent of the pluton is unknown. The part of the stock within the Grayback quadrangle comprises two distinct intrusive phases: an early equigranular phase and a later porphyritic one (fig. 2).

The equigranular phase is a holocrystalline, phanerocrystalline, medium-grained, hypidiomorphic rock composed of about 43 percent plagioclase, 30 percent quartz, and 16½ percent K-feldspar; and 10½ percent biotite. Magnetite, apatite, zircon, and sphene are the common accessory minerals. Epidote group minerals are alteration products of plagioclase and biotite; chlorite is an alteration of biotite, and sericite of plagioclase.

Textural relations indicate that plagioclase crystallized early, followed by quartz. K-feldspar crystallized late, filling interstices between the plagioclase and quartz. Locally, late-crystallizing K-feldspar encloses small anhedral quartz crystals poikilitically. Biotite appears to have crystallized throughout the period in which the rock was consolidating. Myrmekite is common in all our thin sections.

The porphyritic phase of the Tea Cup Granodiorite is porphyritic with a phanerocrystalline, medium-grained, hypidiomorphic granular groundmass composed of 44 percent plagioclase, 26 percent quartz, 20 percent K-feldspar, and 10 percent biotite and hornblende. The most conspicuous phenocrysts are anhedral K-feldspar as much as 3 cm in longest dimension, but in some outcrops either quartz or plagioclase may also be phenocrystic. The K-feldspar phenocrysts always include plagioclase, quartz, biotite, and hornblende.

The groundmass minerals are plagioclase, quartz, K-feldspar, biotite, and hornblende. In some specimens, very little K-feldspar occurs in the groundmass. A direct correlation between the large size of K-feldspar phenocrysts and a paucity of K-feldspar in the groundmass suggests that the K-feldspar phenocrysts continued to grow during the entire period of crystallization.

The accessory minerals are magnetite, ilmenite, apatite, zircon, and sphene; sphene is abundant in some samples.

The amount of alteration ranges from weak to a trace. Plagioclase altered to clay, sericite, and carbonate; biotite to celadonite and chlorite; and hornblende to chlorite.

Textures indicate that K-feldspar, plagioclase, quartz, and mafic minerals were all crystallizing simultaneously. The large size of the K-feldspar resulted from its having fewer nucleation sites. The difference in texture between the equigranular and porphyritic phases resulted from differences in crystallization sequences.

When K-feldspar crystallized early, a porphyritic texture resulted; when it crystallized late, an equigranular texture developed. The porphyritic phase contains 3.45 percent K<sub>2</sub>O; the equigranular phase, 2.80 percent.

Within the equigranular phase, areas of two-mica granodiorite occur; they were not mapped separately, and they are not distinguished in figure 3. These rocks are texturally like the equigranular phase and are composed of 43 percent plagioclase, 30½ percent quartz, 19 percent K-feldspar, 3 percent biotite, and 4½ percent white mica. The total mica content is about the same as that of the normal equigranular phase. In thin section the white mica appears to have crystallized late and to have replaced K-feldspar but not plagioclase or biotite. The crystallization of the white mica is interpreted to be a late magmatic event. Both phases of the Tea Cup are corundum normative, and both contain muscovite in the mesonorm (table 1). However, the ratio of muscovite to biotite in the mesonorm for the equigranular phase is 2.6:1:1.2, and for the porphyritic phase, 1:26.

Table 2 gives the radiometric ages of the Tea Cup Granodiorite. Geologic relations indicate that the porphyritic phase cuts the equigranular phase. The two K-Ar ages of the equigranular phase ( $62.9 \pm 1.3$  and  $62.5 \pm 0.5$ ) are within the range of analytical uncertainty and are accepted as the isotopic age of the rock. The two samples from the porphyritic phase (table 2) are a biotite-hornblende mineral pair whose ages of  $68.6 \pm 0.5$  and  $61.8 \pm 0.5$  m.y., respectively, are discordant. An independent fission-track age of  $61.4 \pm 3.2$  m.y. for an apatite that cuts the porphyritic phase confirms the hornblende age of 61.8 m.y. Two ages were determined independently for the biotite sample, with the same results (within analytical uncertainty), so that the high age of the biotite apparently is not due to error in analysis; the rock from which the biotite was obtained does not appear to be disturbed structurally, chemically, or thermally. I have no reason to discard the age determined. Nevertheless, considering the geologic relations and the ages on the equigranular phase, I judge that the younger of these ages is likely the true isotopic age of the porphyritic phase and that the age difference between the two phases may be about 1 m.y. These ages (63 and 61 m.y.) are very close to those of the Granite Mountain Porphyry in the Ray district and of the main phase of the Schultze Granite in the Globe-Miami district.

#### GRANITE BASIN PORPHYRY

The Granite Basin Porphyry, here named for the good exposures at its type locality in Granite Basin (fig. 3) in the Christmas 15' quadrangle, crops out over about 16 km<sup>2</sup> about 35 km south-southeast of Globe, Ariz.

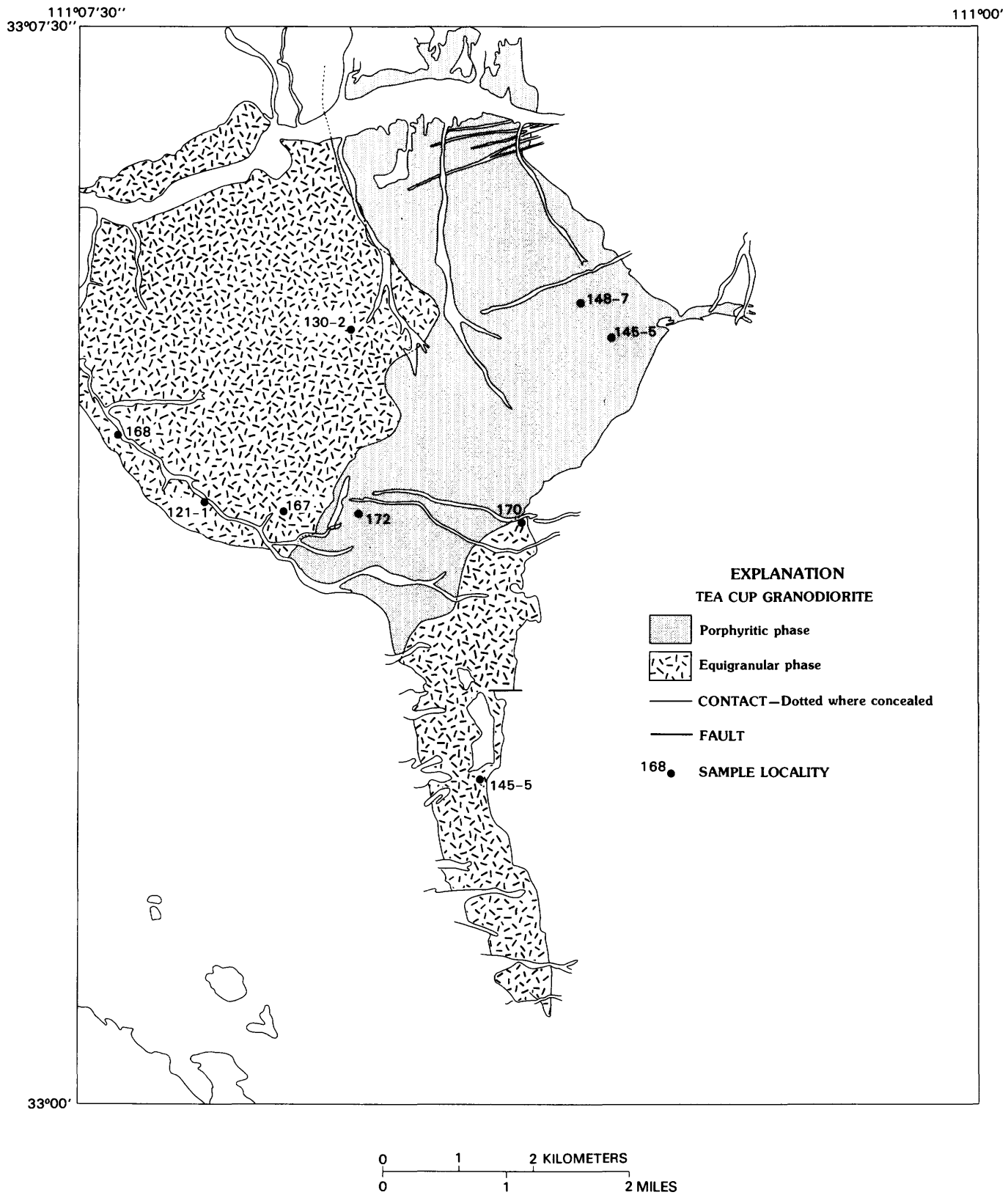


FIGURE 2.—Distribution of the equigranular and porphyritic phases of the Tea Cup Granodiorite and the location of analyzed samples, Grayback quadrangle, Arizona. Modified from Cornwall and Krieger (1975).

These rocks were mapped as part of a feldspar-mica porphyry unit by Willden (1964). The porphyry is a sill-like mass occurring in Paleozoic carbonate rocks (Escabrosa and Naco Limestones). Its dominant characteristics are its uniformity of chemical composition, texture, and mineralogy, and the evenness in degree and extent of its secondary alteration. Contact metamorphism of the carbonate rocks contiguous to the stock is surprisingly weak; the width of the contact zone is at most a few feet. Presumably the porphyry melt was low in volatiles, particularly water. The porphyry is devoid of any indications of mineralization; this is why it was selected for comparison with the Schultze Granite.

The Granite Basin Porphyry consists of euhedral phenocrysts of plagioclase, hornblende, and biotite set into a holocrystalline, phanerocrystalline, fine-grained, aplitic groundmass of K-feldspar, quartz, plagioclase, and hornblende. The modal composition is 37 percent plagioclase, 13 percent hornblende and biotite, and 49 percent groundmass. Plagioclase phenocrysts range in length from 1 to 10 mm; those of hornblende, from 1 to 5 mm; and those of biotite, from 1 to 4 mm; the groundmass grain size is 0.10 mm or less. All the K-feldspar is in the groundmass. During the phenocrystic stage of crystallization, the melt was never saturated in quartz and K-feldspar. This petrology is in marked contrast to the petrologies of the Schultze Granite and the Granite Mountain Porphyry, whose units are associated with porphyry copper deposits in the Globe-Miami and Ray districts, respectively.

The plagioclase is dusted with a low birefringent alteration, presumed to be a clay mineral. The biotite—but not the hornblende—is altered to chlorite, to colorless prehnite in lenses that lie parallel to the folia, and to granular, microcrystalline aggregates of rutile. A minor amount of the hornblende includes irregular patches of biotite. These patches are judged to be due to magmatic reaction. In such occurrences, the biotite part of the grain is altered but the hornblende is not. Common accessory minerals are magnetite, apatite, and sphene; zircon is rare.

Two K-Ar ages have been determined for hornblende from the Granite Basin Porphyry (table 2). Koski (1978) obtained an age of  $72.3 \pm 1.6$  m.y.; a new age from this study is  $60.7 \pm 0.6$  m.y. The reason for the age discrepancy is uncertain. The plagioclase and biotite in the porphyry have been altered, the biotite to such an extent that I judge it to be unfit for K-Ar dating. In thin section the hornblende appears fresh, however, and so it appears to be suitable for isotopic age determination. The best guess to explain this age discrepancy is that somehow the alteration has affected the radiogenic-argon content of the hornblende. Which age is closer to the crystallization age of the porphyry is uncertain, but

TABLE 2.—Radiometric ages of the Granite Basin Porphyry and of equigranular and porphyritic phases in the Tea Cup Granodiorite

Rock	Mineral	Method	K <sub>2</sub> O (wt pct)	$\frac{^{40}\text{Ar}}{^{40}\text{Ar} + ^{39}\text{Ar}}$ ( $10^{-10}$ mol/g)	$\frac{^{40}\text{Ar}}{^{40}\text{Ar} + ^{39}\text{Ar}}$	Age (m.y.)	References
Aplite in porphyritic phase, Tea Cup Granodiorite.	Garnet	Fission-track	---	---	---	61.4+3.2	Banks and Stuckless (1973).
Porphyritic phase, Tea Cup Granodiorite.	Biotite	K-Ar	8.47, 8.42	8.4966	90	68.6+0.5	This report.
"	Hornblende	K-Ar	.651, .654	.59063	60	61.8+0.5	"
Equigranular phase, Tea Cup Granodiorite.	Biotite	K-Ar	---	---	---	62.9+1.3	Damon (1970).
"	Biotite	K-Ar	8.99, 8.98	8.2270	78	62.5+0.5	This report.
Granite Basin Porphyry	Hornblende	K-Ar	---	---	---	72.3+1.6	Koski (1978).
"	Hornblende	K-Ar	.570, .582	.51225	44	60.7+0.6	This report.

$$\lambda_e = 0.572 \times 10^{-10} \text{ yr}^{-1}, \lambda_g = 4.963 \times 10^{-10} \text{ yr}^{-1}, \frac{^{40}\text{Ar}}{^{39}\text{Ar}} / K_{\text{total}} = 1.167 \times 10^{-4} \text{ mol/mol}$$

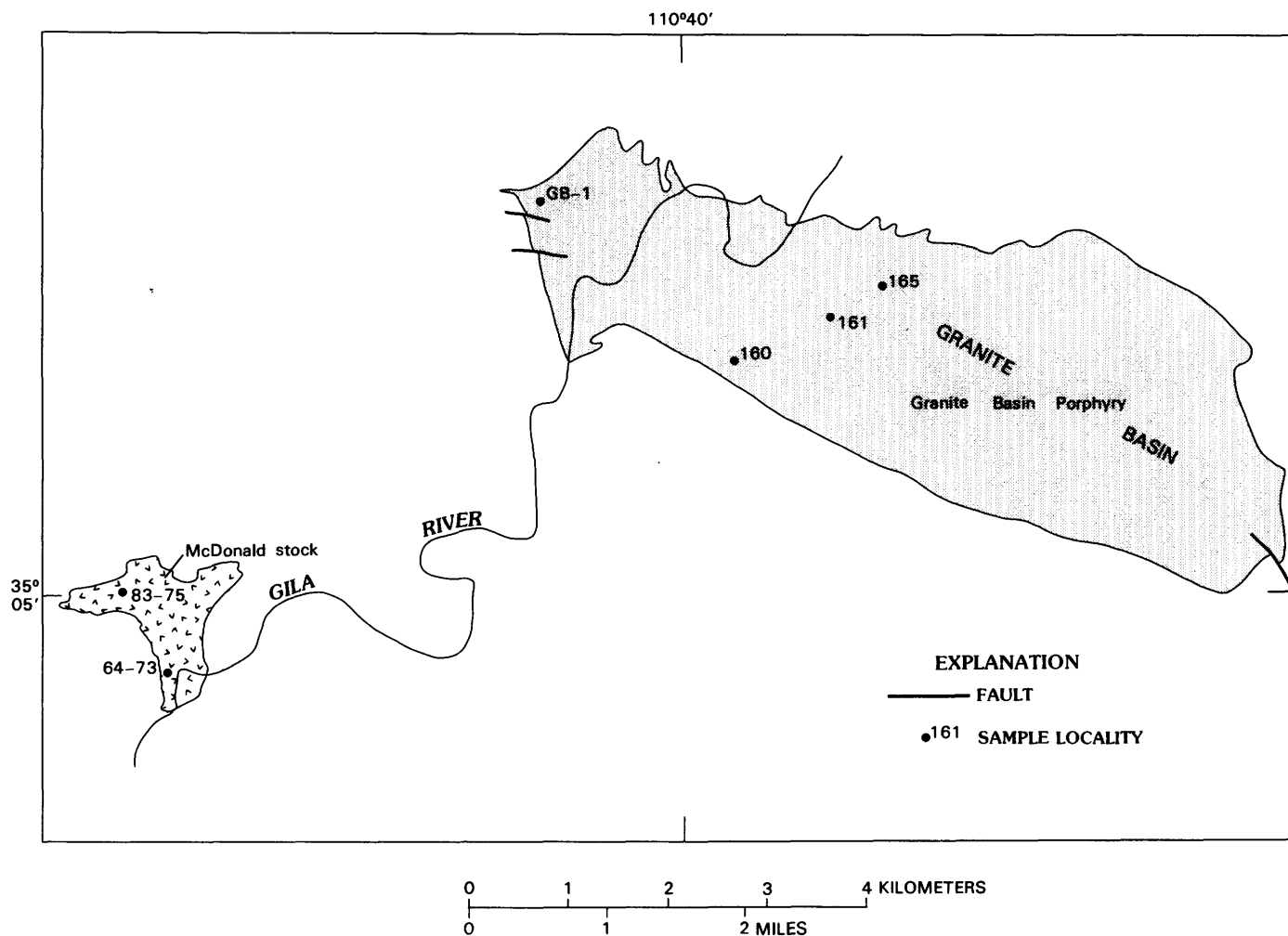


FIGURE 3.—Location of samples from the Granite Basin Porphyry and the McDonald stock (after Willden, 1964).

the greater age is the more consistent with other K-Ar ages in the area.

Koski (1978) also obtained a K-Ar age of  $69.8 \pm 0.9$  m.y. for hornblende from the McDonald stock, which lies about 5 km southwest of the Granite Basin Porphyry (fig. 3). The McDonald stock is similar in texture and in mineral and chemical composition to the Granite Basin Porphyry, and Koski suggests on the basis of water-well and diamond-drill records that the two may connect at depth. Koski (1978) obtained an age of  $62.5 \pm 1.0$  for hydrothermal sericite associated with the Christmas copper deposit, which is about 8 km southwest of the porphyry, and a K-Ar age of  $81.7 \pm 1.8$  m.y. for hornblende from a hornblende andesite porphyry dike there. The intrusive and thermal history of the area is complex, and with the available data the most likely age of the Granite Basin Porphyry is about 70 m.y., although it may be as young as 60 m.y. The uncertainty of the dating restricts the age designation of the

Granite Basin Porphyry to Cretaceous and (or) Tertiary.

#### SUMMARY

Petrographic studies indicate that the texture of porphyritic quartz monzonites and granodiorites with phanerocrystalline, medium-grained, hypidiomorphic granular groundmasses is a function of the abundance and order of crystallization of the plagioclase, K-feldspar, and quartz; this type of porphyritic texture is not the one frequently found in the porphyries related to porphyry copper deposits. If K-feldspar starts to crystallize before the plagioclase or simultaneously with it, the K-feldspar nucleates at fewer points than the plagioclase. It then forms large euhedral crystals that commonly poikilitically enclose plagioclase, quartz, and mafic minerals. In the later stages of crystallization, plagioclase, quartz, and K-feldspar crystallize together in the interstices between the phenocrysts to form the

medium-grained hypidiomorphic granular groundmass. This texture appears to be a function of the chemical composition. The porphyritic phase of the Tea Cup Granodiorite and the early and main phases of the Schultze Granite followed this pattern of crystallization.

If the K-feldspar starts to crystallize after plagioclase and quartz, it tends to fill the interstices between the earlier minerals and to be anhedral. The rock thus formed is equigranular, as is, for example, the equigranular phase of the Tea Cup Granodiorite.

The porphyry phase of the Schultze Granite had an entirely different crystallization history. Apparently, phenocrysts of bipyramidal quartz, K-feldspar, and plagioclase were floating in a melt that was suddenly quenched. A sudden drop to hydrostatic or atmospheric pressure would induce rapid crystallization and result in a groundmass with a fine-grained aplitic texture. This venting origin for the porphyry texture is consistent with the origin of breccia pipes associated with these porphyries, with the geologic reconstruction of cover rocks indicating shallow intrusion of porphyries, and with the common occurrence of coeval porphyry stocks and extrusive volcanism. The fact that this is the type of porphyritic texture most commonly associated with porphyry copper deposits suggests that the process that formed the porphyries is related to the ore-forming process.

## GEOCHEMISTRY

### MAJOR ELEMENTS

The major-element compositions of Schultze Granite, Tea Cup Granodiorite, and Granite Basin Porphyry were compared with each other and with the Laramide intrusive rocks in the nearby Ray district—the Granite Mountain Porphyry, Teapot Mountain Porphyry, Tortilla Quartz Diorite, and Rattler Granodiorite. Element-by-element differences in composition are simple to obtain, but when the intrusions are of similar composition it is not easy to determine whether these elemental differences are significant. To determine a level of significance, one needs to know the normal variations in chemical composition within a one-phase pluton and between phases of a composite or zoned pluton. This can be accomplished by taking multiple samples of individual rock types and determining standard deviations for each element. Where variations occur, the number of samples and their distribution influence the accuracy of both means and standard deviations. In this study, the units selected for comparison by means of detailed geologic mapping appeared to be uniform in mineral composition and texture, and detailed field relations indicated a single intrusive episode.

Table 1 gives the arithmetic means of chemical analyses, of mesonorms, and of number of cations per standard cell of 160 anions for 11 rock types. The chemical analyses used include some from Ransome (1903, 1919), Peterson (1962), and H. R. Cornwall and N. G. Banks (unpub. data, 1980) as well as new analyses made for this study. The locations of the samples analyzed are indicated on figures 2, 3, and 4. A total of 47 chemical analyses was used. To evaluate chemical similarities and differences, Barth's (1962) number of cations for a standard cell of 160 anions was calculated. For a first approximation, the cations per standard cell (psc) allows comparison of numbers of cations on an equal-volume basis. Multiple analyses permit calculation of standard deviations and statistical analysis of cation differences. Table 3 indicates individual cation differences between the 11 rock types at the 80-percent confidence level (CL) according to the *t*-test.<sup>1</sup> Table 4 lists for each kind of cation the unaltered rock phases in descending order of mean cation content, and it indicates those rock phases whose mean cation contents cannot be distinguished at the 80-percent CL.

The potassically altered porphyry phase of the Schultze Granite is the only altered rock included in the study. Its relatively unaltered counterpart is the Copper Springs porphyry mass of the Schultze Granite. A comparison of these two units shows that the altered porphyry is enriched by 3.13 silicon and 2.80 potassium cations psc and is depleted by 1.99 aluminum, 0.47 ferric iron, 0.90 calcium, and 2.73 sodium cations psc. Similar differences exist between the altered porphyry and the main and early phases of the Schultze: the altered porphyry contains more silicon and potassium and less aluminum, ferrous and ferric iron, magnesium, sodium, and calcium.

The silicon contents of the three unaltered phases of the Schultze Granite are indistinguishable from each other and from both phases of the Tea Cup Granodiorite and the Granite Mountain Porphyry, which is the rock most closely associated in time and space with the porphyry copper deposits at Ray (tables 3, 4). The range of silicon psc for these six rock types is only 61.07 to 61.87.

<sup>1</sup>The *t*-test (Dixon and Massey, 1957) is used to evaluate whether differences in element amounts are significant, given the amount of available data; it considers the hypothesis that two populations have the same mean when the variation is unknown. Given a preselected level of confidence (CL), the *t*-test gives the range about the mean within which all determinations are part of a single population. A single analysis or a second mean that lies outside the range is likely to belong to a different population. The population is determined by the value of the mean and the standard deviation. Where both the number of analyses and the differences in value between analyses of a single element are small, the *t*-test will indicate significance at a low level of confidence, if at all—i.e., the results will suggest that the tendency indicated by the data should be considered tentatively and cautiously, because the calculated standard deviation may well not represent accurately the distribution of the population from which the samples were taken. On the other hand, if differences in the values from analyses of an element are large, a few analyses will suffice to establish a significant difference at a high level of confidence.

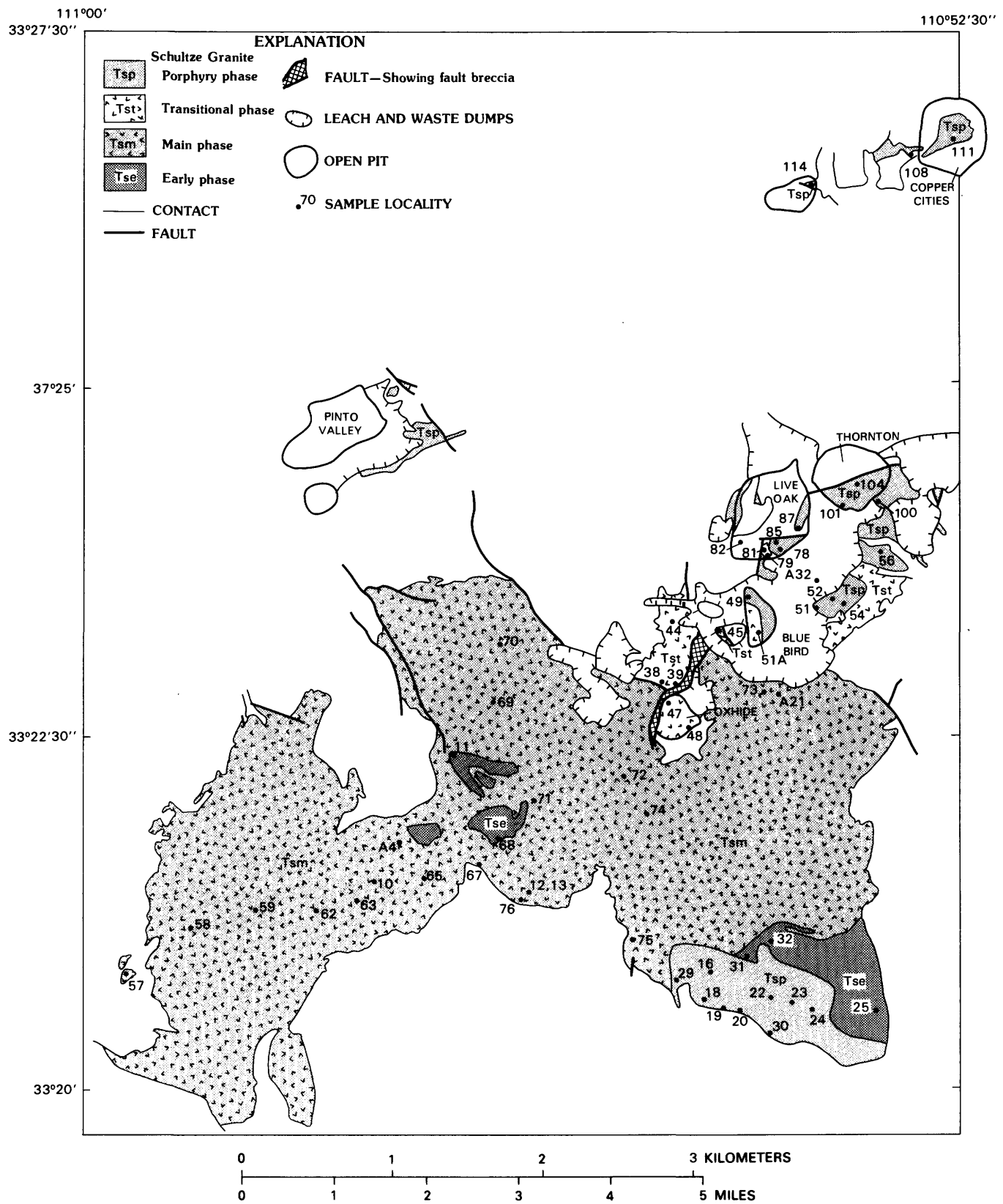


FIGURE 4.—Locations of samples from the Schultze Granite.



TABLE 3.—Significant differences for 11 rock phases in major element cations (92-97) per standard cell of 160 anions, at the 80-percent-confidence level of the t-test

[Unbracketed numbers, how many more cations per standard cell occur in rocks listed on left than occur in rock phases at the top; bracketed numbers, how many fewer cations per standard cell occur in rocks on left; 0, no significant difference]

Rock phase	Main phase, Schultze Granite	Early phase, Schultze Granite	Porphyry phase, Schultze Granite	Potassically altered porphyry phase, Schultze Granite	Porphyritic phase, Tea Cup Granodiorite	Equigranular phase, Tea Cup Granodiorite	Granite Basin Porphyry	Granite Mountain Porphyry	Teapot Mountain Porphyry	Rattler Granodiorite	Tortilla Quartz Diorite
Aluminum on lower left; silicon on upper right											
Main phase, Schultze Granite -----		0	0	(2.86)	0	0	5.98	0	1.90	2.72	9.27
Early phase, Schultze Granite -----	0		0	(3.56)	0	0	5.28	0	1.20	2.02	8.57
Porphyry phase, Schultze Granite -----	0	0		(3.13)	0	0	5.71	0	1.63	2.45	9.0
Potassically altered porphyry phase, Schultze Granite -----	(2.25)	(2.24)	(1.99)		2.63	3.54	8.84	3.56	4.76	5.58	12.23
Porphyritic phase, Tea Cup Granodiorite --	0	(0.55)	0	1.69		0	5.18	0	1.10	1.92	8.47
Equigranular phase, Tea Cup Granodiorite --	0	0	0	2.20	0		5.30	0	0	2.04	8.59
Granite Basin Porphyry ---	0	0.32	0.57	2.56	0.87	0		(5.28)	(4.08)	(3.26)	3.29
Granite Mountain Porphyry -----	(0.58)	(0.57)	0	1.67	0	0	(0.89)		1.2	2.02	8.57
Teapot Mountain Porphyry -----	0	(0.24)	0	2.0	0	0	(0.56)	0		0	7.37
Rattler Granodiorite -----	0.75	0.58	0.83	2.82	1.92	0.62	0	1.15	0.82		6.55
Tortilla Quartz Diorite -----	2.28	2.29	2.54	4.53	2.84	2.33	1.97	2.86	2.53	1.71	
Ferric iron (Fe <sup>2+</sup> ) on lower left; ferric iron (Fe <sup>3+</sup> ) on upper right											
Main phase, Schultze Granite -----		0	0	0.45	(0.26)	0	(1.28)	0	0	(0.45)	(1.95)
Early phase, Schultze Granite -----	0.21		0	0.56	0	0	1.17	0.15	0	0	(1.84)
Porphyry phase, Schultze Granite -----	0	(0.20)		0.47	(0.24)	0	(1.26)	0	0	(0.43)	(1.93)
Potassically altered porphyry phase, Schultze Granite -----	0	(0.31)	0		(0.71)	(0.60)	(1.73)	(0.41)	(0.60)	(0.90)	(2.40)
Porphyritic phase, Tea Cup Granodiorite --	0.61	0.40	0.50	0.71		0	(1.02)	0.30	0	0	(1.69)
Equigranular phase, Tea Cup Granodiorite --	0.30	0	0.29	0.40	0		(1.13)	0	0	0	(1.80)
Granite Basin Porphyry ---	1.02	0.81	1.01	1.12	0.41	0.72		1.32	1.17	0.83	0
Granite Mountain Porphyry -----	0.58	0.37	0.57	0.68	0	0.28	(0.44)		0	(0.33)	(1.99)
Teapot Mountain Porphyry -----	0.43	0.22	0.42	0.53	0	0	(0.59)	(0.15)		0	(1.84)
Rattler Granodiorite -----	0.91	0.70	0.90	1.01	0	0.61	0	0.33	0.48		(1.5)
Tortilla Quartz Diorite --	2.54	2.33	2.53	2.64	1.93	2.24	1.52	1.96	2.11	1.63	

TABLE 3.—Significant differences for 11 rock phases in major element cations (92-97) per standard cell of 160 anions, at the 80-percent-confidence level of the t-test—Continued.

Rock phase	Main phase, Schultze Granite	Early phase, Schultze Granite	Porphyry phase, Schultze Granite	Potassically altered porphyry phase, Schultze Granite	Porphyritic phase, Tea Cup Granodiorite	Equigranular phase, Tea Cup Granodiorite	Granite Basin Porphyry	Granite Mountain Porphyry	Teapot Mountain Porphyry	Rattler Granodiorite	Tortilla Quartz Diorite
Calcium on lower left; magnesium on upper right											
Main phase, Schultze Granite -----		0	0	0	(1.14)	0	(2.66)	(0.63)	0	(1.24)	(2.32)
Early phase, Schultze Granite -----	0.36		0.37	0	(0.87)	0	(2.39)	0	0	(0.97)	(2.02)
Porphyry phase, Schultze Granite -----	0	(0.38)		(0.18)	(1.24)	(0.59)	(2.76)	(0.73)	(0.53)	(1.34)	(2.42)
Potassically altered porphyry phase, Schultze Granite -----	(0.92)	(1.28)	(0.96)		(1.06)	(0.41)	(2.58)	(0.55)	0	(1.16)	(2.24)
Porphyritic phase, Tea Cup Granodiorite --	0.40	0	0.42	1.32		0.65	(1.52)	0.51	0.71	0	0
Equigranular phase, Tea Cup Granodiorite --	0	0	0	1.41	0		(2.17)	0	0	(0.75)	(1.83)
Granite Basin Porphyry -----	1.93	1.57	1.95	2.85	1.53	1.44		2.03	2.23	1.42	0
Granite Mountain Porphyry -----	0	0	0.40	1.30	0	0	(1.55)		0	(0.61)	(1.69)
Teapot Mountain Porphyry -----	0.77	0	0.79	1.69	0	0	(1.16)	0.39		(0.81)	(1.89)
Rattler Granodiorite -----	1.87	1.51	1.89	2.79	1.47	1.38	0	1.49	1.10		(1.08)
Tortilla Quartz Diorite --	4.73	4.37	4.75	5.65	4.33	4.24	2.80	4.35	3.96	2.86	
Potassium on lower left; sodium on upper right											
Main phase, Schultze Granite -----		0	0	2.72	2.00	1.18	0	1.34	3.04	1.59	2.15
Early phase, Schultze Granite -----	(0.69)		0	2.82	2.10	1.28	0.50	1.44	3.14	1.69	2.25
Porphyry phase, Schultze Granite -----	0	0.57		2.73	2.01	1.19	0.41	1.35	3.05	1.60	2.10
Potassically altered porphyritic phase, Schultze Granite -----	2.18	2.87	2.30		0	(1.54)	(2.32)	(1.38)	0	(1.18)	0
Porphyritic phase, Tea Cup Granodiorite --	0	0	0	(2.43)		(0.82)	(1.60)	(0.66)	1.03	0	0
Equigranular phase, Tea Cup Granodiorite --	(0.99)	0	(0.87)	(3.17)	(0.74)		(0.78)	0	1.86	0	0.97
Granite Basin Porphyry -----	(1.50)	(0.81)	(1.38)	(3.68)	(1.25)	(0.51)		0.94	2.64	1.19	1.75
Granite Mountain Porphyry -----	(0.45)	0	(0.33)	(2.63)	0	0.54	1.05		2.30	0	0.81
Teapot Mountain Porphyry -----	0	1.24	0.67	(1.63)	0.80	1.54	2.05	1.00		(1.45)	0
Rattler Granodiorite -----	(1.27)	(0.58)	(1.15)	(3.45)	(1.20)	(0.28)	0.23	(0.82)	(1.82)		0.61
Tortilla Quartz Diorite --	(1.70)	(1.01)	(1.58)	(3.88)	(1.45)	(0.71)	0	(1.25)	(2.25)	(0.43)	
Phosphorus on lower left; titanium on upper right											
Main phase, Schultze Granite -----		0	0	0	0	0	(0.29)	0	0	(0.13)	0
Early phase, Schultze Granite -----	0.03		0.05	0	0	0	(0.26)	0	0	0	0
Porphyry phase, Schultze Granite -----	0	(0.03)		0	(0.14)	0	(0.31)	(0.09)	(0.09)	(0.15)	(0.35)
Potassically altered porphyritic phase, Schultze Granite -----	0	0	0		(0.16)	0	(0.33)	(0.11)	(0.11)	(0.17)	(0.37)
Porphyritic phase, Tea Cup Granodiorite --	0	0	0	0		0	0	0	0	0	0
Equigranular phase, Tea Cup Granodiorite --	0	0	0	0	0		(0.28)	(0.06)	0	(0.12)	(0.32)
Granite Basin Porphyry -----	0.06	0	0.09	0	0.08	0.09		0.22	0.22	0.16	0
Granite Mountain Porphyry -----	0	0	0.03	0	0	0.03	0		0	(0.06)	(0.26)
Teapot Mountain Porphyry -----	0	0	0.05	0	0.04	0.05	0	0		0	0
Rattler Granodiorite -----	0	0	0.06	0.05	0	0.06	0	0	0		(0.20)
Tortilla Quartz Diorite --	0.14	0.12	0.17	0.16	0.16	0.17	0.08	0.14	0.12	0.11	

TABLE 4.—Unaltered rock phases listed in order of decreasing mean cations per standard cell of 160 anions for 8 elements

[Brackets enclose rock phases whose mean cation content does not differ significantly at the 80-percent-confidence level]

<u>Si</u>	<u>Al</u>
Main phase, Schultze Granite Porphyry phase, Schultze Granite Equigranular phase, Tea Cup Granodiorite Early phase, Schultze Granite Granite Mountain Porphyry Porphyritic phase, Tea Cup Granodiorite Teapot Mountain Porphyry Rattler Granodiorite Granite Basin Porphyry Tortilla Quartz Diorite	Tortilla Quartz Diorite Rattler Granodiorite Granite Basin Porphyry Main phase, Schultze Granite Early phase, Schultze Granite Equigranular phase, Tea Cup Granodiorite Porphyritic phase, Tea Cup Granodiorite Teapot Mountain Porphyry Porphyry phase, Schultze Granite Granite Mountain Porphyry
<u>Fe<sup>3+</sup></u>	<u>Ca</u>
Tortilla Quartz Diorite Granite Basin Porphyry Rattler Granodiorite Porphyritic phase, Tea Cup Granodiorite Equigranular phase, Tea Cup Granodiorite Teapot Mountain Porphyry Early phase, Schultze Granite Porphyry phase, Schultze Granite Main phase, Schultze Granite Granite Mountain Porphyry	Tortilla Quartz Diorite Granite Basin Porphyry Rattler Granodiorite Teapot Mountain Porphyry Equigranular phase, Tea Cup Granodiorite Porphyritic phase, Tea Cup Granodiorite Granite Mountain Porphyry Early phase, Schultze Granite Main phase, Schultze Granite Porphyry phase, Schultze Granite
<u>Fe<sup>2+</sup></u>	<u>Na</u>
Tortilla Quartz Diorite Granite Basin Porphyry Rattler Granodiorite Porphyritic phase, Tea Cup Granodiorite Granite Mountain Porphyry Teapot Mountain Porphyry Equigranular phase, Tea Cup Granodiorite Early phase, Schultze Granite Porphyry phase, Schultze Granite Main phase, Schultze Granite	Early phase, Schultze Granite Porphyry phase, Schultze Granite Main phase, Schultze Granite Granite Basin Porphyry Equigranular phase, Tea Cup Granodiorite Granite Mountain Porphyry Rattler Granodiorite Porphyritic phase, Tea Cup Granodiorite Tortilla Quartz Diorite Teapot Mountain Porphyry
<u>Mg</u>	<u>K</u>
Granite Basin Porphyry Tortilla Quartz Diorite Rattler Granodiorite Porphyritic phase, Tea Cup Granodiorite Granite Mountain Porphyry Equigranular phase, Tea Cup Granodiorite Teapot Mountain Porphyry Early phase, Schultze Granite Main phase, Schultze Granite Porphyry phase, Schultze Granite	Teapot Mountain Porphyry Main phase, Schultze Granite Porphyry phase, Schultze Granite Porphyritic phase, Tea Cup Granodiorite Granite Mountain Porphyry Early phase, Schultze Granite Equigranular phase, Tea Cup Granodiorite Rattler Granodiorite Granite Basin Porphyry Tortilla Quartz Diorite

Of this group, only the Tea Cup is not closely associated with commercial copper deposits, although the porphyritic phase of the Tea Cup contains common quartz-sericite-sulfide veins. The Teapot Mountain Porphyry is closely associated with the copper ores in the Ray district. It differs at the 80-percent CL from the main, early, and porphyry phases of the Schultze Granite, and from the porphyritic Tea Cup Granodiorite and Granite Mountain Porphyry. It contains about 1.5 fewer silicon cations psc than the mean of the six rock types.

In general, the number of aluminum cations psc is significantly higher in the more mafic rocks. Among the main and porphyry phases of the Schultze Granite and the Tea Cup Granodiorite, the Teapot Mountain Porphyry and the Granite Mountain Porphyry, there are no significant differences in aluminum cations psc at the 80-percent CL (tables 3, 4).

In general, the rocks may be divided into two groups on the basis of ferric iron content: (1) the Tortilla Quartz Diorite and Granite Basin Porphyry, which are high in ferric iron, and (2) the Rattler Granodiorite, the Granite Mountain and Teapot Mountain Porphyries, and all phases of the Schultze Granite and Tea Cup Granodiorite, which are low. The abundance distribution of ferrous iron, in contrast, is more like that of magnesium. Phases of the Schultze are depleted in ferrous iron and magnesium relative to the other rocks (see table 3). Potassically altered Schultze is significantly depleted in ferrous iron and calcium relative to all the other rocks, including other phases of the Schultze.

Except in the altered Schultze, calcium ranges from 1.86 cations psc in the porphyry phase of the Schultze to 6.61 in the Tortilla. The Granite Mountain Porphyry is more similar in calcium content to the phases of the Schultze than to any of the others. Clearly, rocks most closely related to porphyry copper deposits are relatively low in calcium, magnesium, and iron.

A few generalizations on ferric and ferrous iron, magnesium, and calcium contents (femic elements) can be affirmed confidently. The main and porphyry phases of the Schultze are the most depleted in femic elements, whereas the Tortilla Quartz Diorite and Granite Basin Porphyry are the most enriched. Intermediate rock phases—which include the early phase of the Schultze, both phases of the Tea Cup, and the Granite Mountain and Teapot Mountain Porphyries—do not differ significantly from each other in femic-element content. The Rattler Granodiorite appears to be transitional between the femic-rich and the intermediate phases.

Porphyry copper deposits in the Globe-Miami district are associated with the porphyry phase of the Schultze, and thus with femic-poor rocks. In the Ray district, however, the deposits are associated with the

Granite Mountain Porphyry, which has an intermediate content of femic elements; the Granite Mountain Porphyry cannot be distinguished by femic elements from the Tea Cup Granodiorite, which is not associated with a known commercial copper deposit.

Sodium content does not correlate well with either femic-element or potassium content. For example, in the rocks under study here, the Teapot Mountain Porphyry contains the least sodium and the most potassium, whereas the Granite Basin Porphyry is high in both sodium and femic elements. The phases of the Schultze Granite are all sodium rich, and although they are associated with copper deposits, one of those phases is not significantly different in sodium content from the Granite Basin Porphyry, which is remarkably barren of all indications of mineralization (table 4).

The pattern of significant differences in potassium cations psc is more like that of the femic elements than that of sodium, although rock types fall into reverse order for the two pairs of patterns. The porphyry and the main phases of the Schultze are high in potassium and low in femic elements, whereas the Tortilla, the Granite Basin, and the Rattler are just the reverse. The Teapot Mountain does not fit this pattern; it contains the most potassium but is intermediate in femic-element content. Although the porphyry phase of the Schultze Granite and Granite Mountain Porphyry are distinguishable on the basis of potassium cations psc at the 80-percent CL, the values are separated by only 0.36 psc; these are the two phases most commonly associated with porphyry copper deposits. Silicon has a relation to the femic elements much like that of potassium. Figure 5 shows that the inverse relations between silicon and femic elements and between potassium and femic elements are consistent, the values from the Teapot Mountain Porphyry being the most erratic. Data for the potassically altered porphyry phase of the Schultze is included in figure 5; its position on the extrapolation of the curve suggests a regular and consistent change from potassium enrichment in the magma to potassic metasomatism. The chemical similarity of porphyry and main phases of the Schultze for all elements is reflected by their close association on the curve. Rocks associated with porphyry copper deposits are clearly separated on the curve from those that are not so associated; rocks of economic interest have  $\text{Si}/(\text{femic} + \text{Si}) > 0.91$  and  $\text{K}/(\text{femic} + \text{K}) > 0.36$ . The two phases of the Tea Cup Granodiorite occupy a central position on the curve. The porphyritic phase is commonly associated with quartz-sericite-sulfide veins, but not with any known commercial sulfide deposit; the equigranular phase contains no indications of copper mineralization. Although the amount of data in figure 5 is limited, the data suggest

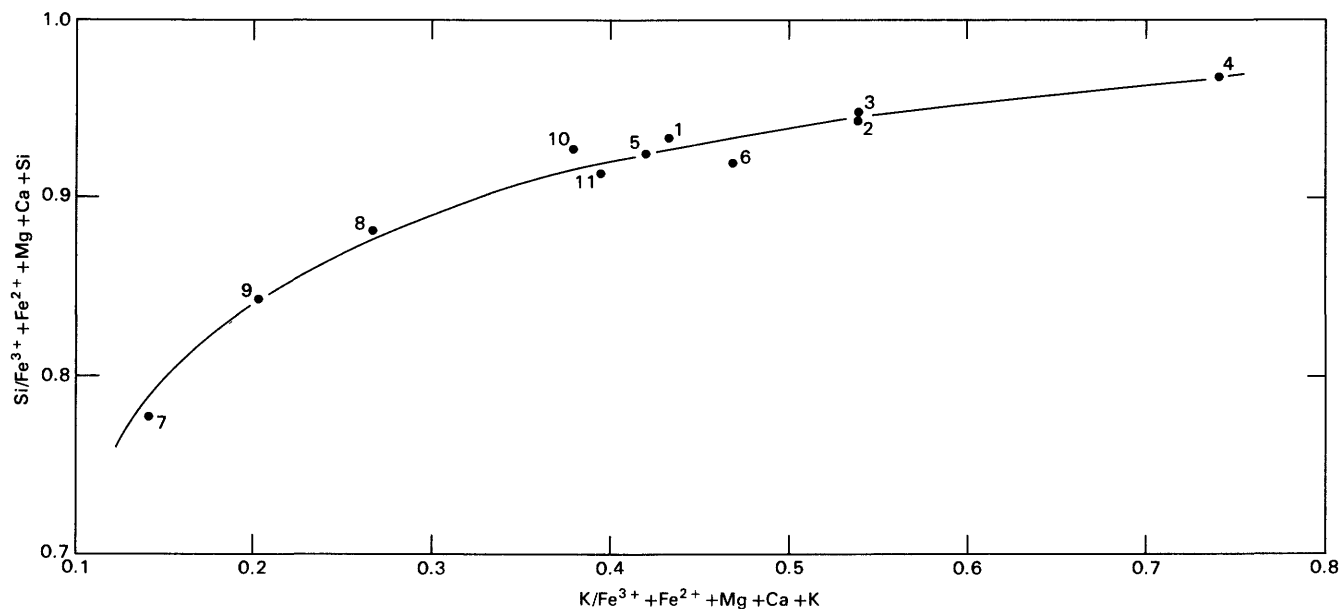


FIGURE 5.—Plot of Si/femic + Si versus K/femic + K ratios for ten rock phases. 1, early phase, Schultz Granite; 2, main phase, Schultz Granite; 3, porphyry phase, Schultz Granite; 4, potassically altered porphyry phase, Schultz Granite; 5, Granite Mountain Porphyry; 6, Teapot Mountain Porphyry; 7, Tortilla Quartz Diorite; 8, Rattler Granodiorite; 9, Granite Basin Porphyry; 10, equigranular phase, Tea Cup Granodiorite; 11, porphyritic phase, Tea Cup Granodiorite.

that the major-element content of intrusives in an area is a criterion useful for evaluation of the area's copper potential.

A comparison of cations psc among the three unaltered phases and the one altered phase of the Schultz Granite indicates some differences among the unaltered phases and substantial differences between the potassically altered and unaltered phases (table 5). Femic elements decrease progressively from the early phase through the main phase to the porphyry, but the difference between the main and porphyry phases is too small to be significant at the 80-percent CL. This suggests that the porphyry magma was a late-crystallizing part of the main phase that was subjected to physical conditions different from those of the main phase. One possible means of change is venting by hydrofracturing; and indeed, sudden reduction to hydrostatic or atmospheric pressures could explain the porphyritic textures, the breccia pipes, and possibly the mineralization.

The differences among the cation contents of the unaltered phases of the Schultz might result from a weak fractionation, but the rare-earth elements, discussed in a later part of this report, do not substantiate this. Either fractionation was too slight to be indicated by the rare earths or the differences have resulted from some other process. Consistent compositional differences between the potassically altered and unaltered phases of Schultz indicate that mineralization added

silica and potassium, and removed femic elements, by the amounts indicated on table 5.

#### MINOR ELEMENTS

Minor-element contents of intrusive rocks in the western half of the Globe-Miami district are listed in table 6, and the locations of samples analyzed are indicated on figures 3, 4, and 5. A summary consisting of logarithms of means and standard deviations of the Globe-Miami intrusive rocks is presented in table 7; table 8 indicates differences in minor elements between various rocks. In addition, the summary (table 7) presents for comparison the logarithms of means and standard deviation for minor elements in the Granite Mountain and Teapot Mountain Porphyries, Rattler Granodiorite, and Tortilla Quartz Diorite from the Ray district (H. R. Cornwall and N. G. Banks, unpub. data, 1980).

With the possible exception of the copper content in the Schultz Granite, the minor-element content as determined by quantitative spectrography did not include any element whose abundance serves to discriminate between barren stocks and unaltered parts of stocks associated with porphyry copper deposits. For some elements, such as arsenic, boron, molybdenum, lead, and zinc, analytical sensitivity of quantitative spectrography is inadequate to determine accurately the mean content of the element.

TABLE 5.—Significant differences in cations (93-94) per standard cell of 160 anions of the rock phases of the Schultze Granite at the 80-percent-confidence level of the t-test

[Unbracketed numbers, how many more cations per standard cell occur in the rock phases; bracketed numbers, how many fewer cations occur in rock phases; 0, no significant difference]

Rock phase	Si	Al	Fe <sup>3+</sup>	Fe <sup>2+</sup>	Mg	Ca	Na	K	Ti	P
Porphyry phase										
Main phase -----	0	0	0	0	0	0	0	0	0	0
Early phase -----	0	0	0	0.20	0.37	0.38	0	[0.57]	0.05	0.03
Potassically altered porphyry phase -----	3.13	[1.99]	[0.47]	0	0	[0.96]	[2.73]	2.30	0	0
Main phase										
Early phase -----	0	0	0	0.21	0	0.36	0	[0.69]	0	0.03
Potassically altered porphyry phase -----	2.86	[2.25]	[0.45]	0	0	[0.92]	[2.72]	[2.18]	0	0
Early phase										
Potassically altered porphyry phase -----	3.56	[2.24]	[0.56]	[0.31]	0	[1.28]	[2.82]	2.87	0	0

TABLE 6.—Quantitative spectrographic analyses of the Schultze Granite, the Tea Cup Granodiorite, and the Granite Basin Porphyry

[Analysts: C. Heropoulos, M. Leong, and V. F. McDaniel]

Locality	Mn	As	B	Ba	Cu	Mo	Co	Ni	Pb	Zn	Sr
Early phase, Schultze Granite											
25	---	<200	3	---	450	<1	---	2	9	<10	---
32	---	<200	<1	---	38	1	---	6	7	56	---
68	---	<200	1	---	1.5	<1	---	2	6	36	---
Main phase, Schultze Granite											
5	---	<200	3	---	47	1	---	1	56	<10	---
10	---	<200	5	---	4	1	---	2	12	<10	---
57	---	<200	4	---	20	1	---	2	9	<10	---
58	250	<200	17	530	3	<1	1.5	1	10	<10	330
59	---	<200	4	---	55	1	---	1	8	29	---
62	170	<200	15	660	4	1	1.5	1	9	<10	370
63	140	<200	2	780	14	1	1	1	9	<10	400
65	---	<200	3	---	4	<1	---	1	8	<10	---
67	---	<200	<1	---	4	1	---	1	8	<10	---
69	180	<200	4	710	9	<1	1	1	6	<10	360
70	---	<200	2	---	25	<1	---	1	7	<10	---
71	230	<200	5	850	2	<1	2	1	8	<10	440
72	---	<200	1	---	1	<1	---	1	7	17	---
73	---	<200	1	---	3	<1	---	4	6	<10	---
74	240	<200	<1	820	2	<1	2	1	6	<10	440
75	---	<200	<1	---	2	<1	---	1	5	<10	---
76	170	<200	<1	610	3	<1	2	1	6	<10	280
Porphyry phase, Schultze Granite											
16	---	<200	5	---	17	1	---	2	8	<10	---
18	440	<200	<1	680	42	<1	1	1	5	43	300
19	---	<200	2	---	9	1	---	2	7	<10	---
20	190	<200	10	700	34	<1	1	2	6	67	310
23	---	<200	4	---	210	1	---	1	9	78	---
24	46	<200	14	210	42	<1	<1	<1	12	<10	120
29	---	<200	5	---	5	1	---	2	8	<10	---
30	140	<200	14	650	180	<1	1	1	11	<10	260
Transitional phase, Schultze Granite											
38	---	<200	2	---	350	1	---	3	5	<10	---
39	100	<200	<1	600	200	<1	1.5	1.5	7	<10	280
44	---	<200	2	---	84	1	---	3	5	<10	---
48	83	<200	12	560	620	<1	4	4	6	<10	260
49	---	<200	2	---	320	<1	---	2	7	<10	---
79	66	<200	<4	2,200	410	<4	4	5	<14	34	700
81	51	<200	<4	1,100	710	<4	3	2	<14	<30	450
51A	---	<200	2	---	630	1	---	2	7	<10	---
Potassically altered porphyry phase, Schultze Granite											
45	---	<200	3	---	7	1	---	5	8	<10	---
47	---	<200	2	---	1,800	3	---	9	11	<10	---
51	130	<200	14	500	61	<1	<1	<1	10	<10	180
52	75	<200	11	740	31	<1	1	2	8	<10	320
54	---	<200	2	---	17	<1	---	3	6	<10	---
56	---	<200	<1	---	9	<1	---	1	6	<30	---
78	38	<200	<4	1,100	170	<4	2	3	<14	<30	550
82	42	<200	<4	1,200	3,400	26	<2	3	<14	<30	990
85	54	<200	<4	2,000	3,300	<4	8	4	<14	<30	670
87	---	<200	27	---	1,600	<4	---	7	<14	43	---
100	33	<200	<4	840	1,800	<4	3	3	<14	<30	570
101	48	<200	4	720	1,600	<4	4	3	<14	<30	650
104	---	<200	18	---	2,400	72	---	4	<14	<30	---
108	---	<200	24	---	360	<4	---	13	<14	<30	---
111	---	<200	20	---	1,400	<4	---	4	<14	<30	---
114	---	<200	130	---	520	<4	---	5	<14	<30	---
Equigranular phase, Tea Cup Granodiorite											
167	230	<200	<4	700	25	<4	6	7	<14	30	820
168	180	<200	<4	1,200	8	<4	2	<1.4	<14	30	920
171	400	<200	<4	1,800	20	<4	6	<1.4	<14	64	1,200
175	240	<200	<4	1,700	20	<4	6	4	<14	61	920
Porphyritic phase, Tea Cup Granodiorite											
169	370	<200	<4	920	69	4	9	11	<14	74	820
170	320	<200	<4	1,100	3	4	9	13	<14	57	1,100
172	330	<200	<4	1,000	2	<4	8	11	<14	67	760
174	320	<200	<4	1,400	28	<4	7	11	<14	43	730
Granite Basin Porphyry											
158	430	<200	<4	940	25	<4	24	44	<14	50	780
159	400	<200	<4	900	26	<4	22	48	<14	73	760
160	390	<200	<4	820	27	<4	22	47	<14	46	860
161	420	<200	<4	840	17	<4	26	49	<14	51	760
162	420	<200	<4	740	27	<4	22	43	<14	52	700
163	390	<200	<4	820	30	<4	21	38	<14	43	880
164	400	<200	<4	900	25	<4	24	47	<14	47	860
165	370	<200	<4	880	20	<4	24	50	<14	51	840

TABLE 7.—Summaries of quantitative spectrographic analyses: Means and standard deviations of logarithms

	Mn	B	Ba	Cu	Co	Ni	Pb	Zn	Sr
	[N.D., no data]								
Early phase, Schultze Granite (3)-----	N.D.	0.05870 $\sigma$ = .39238	N.D.	1.46970 $\sigma$ = 1.24404	N.D.	0.46007 $\sigma$ = .27546	0.85916 $\sigma$ = .08889	1.33449 $\sigma$ = .80430	N.D.
Main phase, Schultze Granite (7 or 17)-----	2.28600 $\sigma$ = .09966	.35076 $\sigma$ = .41443	2.84510 $\sigma$ = .07405	.76202 $\sigma$ = .47734	.17932 $\sigma$ = .25920	.07083 $\sigma$ = .16927	.92966 $\sigma$ = .23202	<1.47712 ---	2.56768 $\sigma$ = .07042
Porphyry phase, Schultze Granite (4 or 8)-----	2.18275 $\sigma$ = .40342	.66154 $\sigma$ = .34857	2.70319 $\sigma$ = .25432	1.52989 $\sigma$ = .57107	.0 $\sigma$ = 0	.11289 $\sigma$ = .22397	.90040 $\sigma$ = .12725	<1.47712 ---	2.36566 $\sigma$ = .19384
Transitional phase, Schultze Granite (4 or 8)-----	1.86154 $\sigma$ = .12643	.32303 $\sigma$ = .37112	2.97754 $\sigma$ = .27663	2.54129 $\sigma$ = .30951	.46433 $\sigma$ = .20099	.41606 $\sigma$ = .17703	.80002 $\sigma$ = .06666	<1.47712 ---	2.59011 $\sigma$ = .20009
Potassically altered porphyry phase, Schultze Granite (6, 7 or 16)-----	1.73202 $\sigma$ = .27631	.77297 $\sigma$ = .63579	2.96735 $\sigma$ = .19363	2.51902 $\sigma$ = .96300	.28318 $\sigma$ = .41344	.28433 $\sigma$ = .48624	.86593 $\sigma$ = .06894	<1.47712 ---	2.69875 $\sigma$ = .24371
Equigranular phase, Tea Cup Granodiorite (4)-----	2.39982 $\sigma$ = .19997	<.60206 $\sigma$ = N.D.	3.10250 $\sigma$ = .18842	1.22577 $\sigma$ = .21992	.65887 $\sigma$ = .23856	1.05953 $\sigma$ = .03628	<.60206 $\sigma$ = N.D.	1.63644 $\sigma$ = .18416	2.98014 $\sigma$ = .07012
Porphyritic phase, Tea Cup Granodiorite (4)-----	2.52425 $\sigma$ = .03972	<.60206 $\sigma$ = N.D.	3.03783 $\sigma$ = .07885	1.01604 $\sigma$ = .74488	.91417 $\sigma$ = .05198	1.65892 $\sigma$ = .03614	<.60206 $\sigma$ = N.D.	1.77166 $\sigma$ = .10290	2.92483 $\sigma$ = .08049
Granite Basin Porphyry (8) <sup>1</sup> -----	2.60430 $\sigma$ = .02153	<.60206 $\sigma$ = N.D.	2.93090 $\sigma$ = .03266	1.38527 $\sigma$ = .07902	1.36314 $\sigma$ = .03053	.53069 $\sigma$ = .33968	<.60206 $\sigma$ = N.D.	1.68522 $\sigma$ = .02802	2.90457 $\sigma$ = .03504
Granite Mountain Porphyry (5) <sup>2</sup> -----	2.60413 $\sigma$ = .12824	2.95168 $\sigma$ = .11334	2.95154 $\sigma$ = .06853	1.68594 $\sigma$ = .18848	.81337 $\sigma$ = .07875	1.02076 $\sigma$ = .011996			2.91937 $\sigma$ = .07064
Teapot Mountain Porphyry (2) <sup>2</sup> -----	2.56420 $\sigma$ = .16553				.60206 $\sigma$ = .42572	.53959 $\sigma$ = .76310			2.78645 $\sigma$ = .62798
Rattler Granodiorite (12) <sup>2</sup> -----	2.68939 $\sigma$ = .18276	2.92133 $\sigma$ = .15806	2.92133 $\sigma$ = .15806	1.37417 $\sigma$ = .65028	.86003 $\sigma$ = .15425	.73509 $\sigma$ = .38547			2.89303 $\sigma$ = .14136
Tortilla Quartz Diorite (3) <sup>2</sup> -----	2.77815 $\sigma$ = .01872	2.77815 $\sigma$ = .09675	2.77815 $\sigma$ = .09675	1.93153 $\sigma$ = .16617	1.36862 $\sigma$ = .08384	0.83138 $\sigma$ = .65529			3.02180 $\sigma$ = .24193

<sup>1</sup>Koski (1978).<sup>2</sup>H. R. Cornwall and N. G. Banks, unpub. data, 1980.



TABLE 8.—Differences in logarithms of minor elements at the 80-percent-confidence level of the t-test

[+, a significant difference; 0, nonsignificant; ND, no data]

	Main phase, Schultze Granite	Early phase, Schultze Granite	Porphyry phase, Schultze Granite	Potassically altered porphyry phase, Schultze Granite	Transition phase, Schultze Granite	Porphyritic phase, Tea Cup Granodiorite	Equigranular phase, Tea Cup Granodiorite	Granite Basin Porphyry
Manganese on lower left; boron on upper right								
Main phase, Schultze Granite -----		0	+	+	0	ND	ND	ND
Early phase, Schultze Granite -----	ND		+	+	0	ND	ND	ND
Porphyry phase, Schultze Granite -----	0	ND		0	0	ND	ND	ND
Potassically altered porphyry phase, Schultze Granite -----	+	ND	+		+	ND	ND	ND
Transition phase, Schultze Granite -----	+	ND	0	0		ND	ND	ND
Porphyritic phase, Tea Cup Granodiorite --	+	ND	+	+	+		ND	ND
Equigranular phase, Tea Cup Granodiorite --	0	ND	0	+	+	0		ND
Granite Basin Porphyry ---	+	ND	+	+	+	+	+	
Copper on lower left; barium on upper right								
Main phase, Schultze Granite -----		ND	+	+	0	+	+	+
Early phase, Schultze Granite -----	+		ND	ND	ND	ND	ND	ND
Porphyry phase, Schultze Granite -----	+	0		+	+	+	+	+
Potassically altered porphyry phase, Schultze Granite -----	+	+	+		0	0	0	0
Transition phase, Schultze Granite -----	+	+	+	0		0	0	0
Porphyritic phase, Tea Cup Granodiorite ---	0	0	0	+	+		0	0
Equigranular phase, Tea Cup Granodiorite ---	+	0	0	+	+	0		+
Granite Basin Porphyry ---	+	0	0	+	+	+	+	

TABLE 8.—Differences in logarithms of minor elements at the 80-percent-confidence level of the t-test—Continued.

	Main phase, Schultze Granite	Early phase, Schultze Granite	Porphyry phase, Schultze Granite	Potassically altered porphyry phase, Schultze Granite	Transition phase, Schultze Granite	Porphyritic phase Tea Cup Granodiorite	Equigranular phase, Tea Cup Granodiorite	Granite Basin Porphyry
Nickel on lower left; cobalt on upper right								
Main phase, Schultze Granite -----		ND	0	0	+	+	+	+
Early phase, Schultze Granite -----	+		ND	ND	ND	ND	ND	ND
Porphyry phase, Schultze Granite -----	0	+		0	+	+	+	+
Potassically altered porphyritic phase, Schultze Granite -----	+	0	+		0	0	0	+
Transition phase, Schultze Granite -----	+	0	+	0		+	0	+
Porphyritic phase, Tea Cup Granodiorite ----	+	+	+	+	+		+	+
Equigranular phase, Tea Cup Granodiorite ----	+	0	0	0	0	+		+
Granite Basin Porphyry ----	+	+	+	0	+	+	+	
Zinc on lower left; lead on upper right								
Main phase, Schultze Granite -----		0	0	0	0	ND	ND	ND
Early phase, Schultze Granite -----	ND		0	0	0	ND	ND	ND
Porphyry phase, Schultze Granite -----	ND	ND		0	0	ND	ND	ND
Potassically altered porphyritic phase, Schultze Granite -----	ND	ND	ND		+	ND	ND	ND
Transition phase, Schultze Granite -----	ND	ND	ND	ND		ND	ND	ND
Porphyritic phase, Schultze Granite -----	ND	0	ND	ND	ND		ND	ND
Equigranular phase, Tea Cup Granodiorite ----	ND	0	ND	ND	ND	0		ND
Granite Basin Porphyry ----	ND	0	ND	ND	ND	0	ND	

## MANGANESE

The relative concentrations of manganese are similar to those of magnesium and iron. The phases of the Schultze Granite are relatively low in these elements, and the Granite Basin Porphyry are high. Potassically altered porphyry and transitional phases of Schultze appear to be leached of manganese as they are of femic elements.

The porphyritic Tea Cup contains significantly more manganese than does the Schultze; the equigranular Tea Cup does not. There is no significant difference between the two phases of the Tea Cup. Although there is a suggestion that the Tea Cup is higher in manganese than the Schultze, the difference is not striking.

Except in the altered rocks, there is a direct correlation between manganese and femic content. These data do not suggest that manganese would be useful in distinguishing intrusions associated with porphyry copper deposits.

Although the Granite Mountain and Teapot Mountain Porphyries, which are the rocks most closely associated with the Ray porphyry copper deposit, are higher in manganese than is the porphyry phase of the Schultze Granite, which is most closely associated with copper deposits in the Globe-Miami district, the difference is not significant at the 80-percent CL. These unaltered rocks associated with copper deposits are neither depleted nor enriched in manganese.

## BORON, ARSENIC, ZINC, AND LEAD

Data on boron is limited because the amount of boron in all of the samples from the two phases of the Tea Cup Granodiorite and from the Granite Mountain Porphyry is below the detection limit. Boron in some of the samples of the phases of the Schultze Granite is also below the detection limit, but in others it is not. The relative amounts of boron between the phases of the Schultze were obtained by assuming that the boron content of those samples of the Schultze below the detection limit is half that of the detection limit. On this basis, potassically altered and unaltered porphyry phases were found to be enriched in boron relative to other phases. However, the difference between the two phases was not significant at the 80-percent CL. Although the data are unsatisfactory, they suggest that the porphyry phase of the Schultze is enriched in boron.

For all rocks analyzed, the arsenic content of all samples is below the detection limit, which is 200 ppm. A more sensitive analytical method is required before differences in arsenic content can be used to establish differences among rocks.

Data in table 6 show that the mean value for zinc in all of the different phases is less than 30 ppm. If one as-

sumes a zinc value of 30 ppm for each phase of the Schultze, all those phases are significantly lower in zinc than are the porphyritic and equigranular phases of the Tea Cup Granodiorite and Granite Basin Porphyry, which do not differ significantly from each other. Unfortunately, the phases of the Schultze Granite cannot be compared with one another because the zinc content is below the detection limit. From the limited data, the most conservative interpretation correlates zinc content directly with femic content.

Lead is similar to zinc in that the lead content of some rocks is below the detection limit. The lead content of the porphyritic and equigranular phases of the Tea Cup Granodiorite and Granite Basin Porphyry is below 14 ppm. If one assumes a lead content of 14 ppm for these low-lead rocks, they appear to be significantly lower in lead than are any of the phases of the Schultze, which (with one exception) are not significantly different from each other. Given the data at hand, the increase in lead in the Schultze can be explained by lead substitution for potassium.

## COPPER AND MOLYBDENUM

The main phase of the Schultze is significantly lower in copper than are all the other rocks except the porphyry phase of the Tea Cup Granodiorite, and this exception is due to the unusually high standard deviation of the Tea Cup. In contrast, potassically altered porphyry and the transitional phases of the Schultze are significantly higher in copper than are the other rocks, but the two phases of the Schultze do not differ from each other. Higher copper content in the two phases of the Schultze is due to introduction of hydrothermal copper, but the reason for the low copper content of the main phase of the Schultze is not certain. The suggestion that somehow copper was removed from the main phase to produce porphyry copper deposits elsewhere is so important that additional studies should be undertaken to further test this possibility.

Neither the early phase or the unaltered porphyry phase of the Schultze are significantly different in copper content from the two phases of the Tea Cup Granodiorite and Granite Basin Porphyry. This similarity implies that stocks associated with porphyry copper deposits are not abnormally high in copper except where they have been mineralized by hydrothermal solutions.

Only 31 percent of the analyses show molybdenum above the detection limits, which are either 1 or 4 ppm depending on the analytical laboratory. These data were deemed unsatisfactory for a meaningful comparison between rocks. The potassically altered porphyry phase of the Schultze contained two samples which contained 26 and 72 ppm molybdenum respectively. These samples clearly indicate introduction of molybdenum.

## COBALT AND NICKEL

In general, cobalt and nickel contents are directly proportional to femic content, with the exception of abnormally low nickel in the equigranular phase of the Tea Cup and abnormally high nickel in the potassically altered porphyry phase of the Schultze. The standard deviation of nickel content in the equigranular Tea Cup is large; inadequate sampling may be responsible for that value. In the potassically altered porphyry phase of the Schultze, hydrothermal alteration apparently leached femics but added nickel, probably as part of the copper mineralization. Possibly a little cobalt also accompanied the copper, but not in quantities large enough to be indicated at the 80-percent CL.

## BARIUM, STRONTIUM, AND RUBIDIUM

Barium, strontium, and rubidium contents were determined more precisely by neutron activation. They are evaluated under the section "Other Elements."

## RARE-EARTH ELEMENTS

The rare-earth elements (REE's) are uniquely helpful in the attempt to determine the source and origin of igneous rocks and to determine whether two igneous rocks differ in evolution. REE's vary systematically as a group in ways amenable to petrologic interpretations, and REE abundances are less affected by the concentration of the elements in the system, by changes in mineral composition, and by concentrations of other elements (Schnetzler and Philpotts, 1968).

Levels of the rare-earth elements were determined for the five phases of the Schultze Granite (the porphyry phase was subdivided into three separate masses), for the two phases of the Tea Cup Granodiorite, and for the Granite Basin Porphyry by neutron activation performed in the analytical laboratories of the U.S. Geological Survey. A total of 38 analyses were made: 31 on the different phases of the Schultze Granite, four on the Tea Cup Granodiorite, and three on the Granite Basin Porphyry (table 9). Locations of the samples analyzed are indicated on figures 3, 4, and 5.

The granitic rocks analyzed were divided into lithologically distinct units that, with the exception of the porphyry dike in the Schultze Granite, cropped out over an area of at least one square mile. The units selected for comparison are map units. Their outcrop areas are indicated on plate 1 and figures 2, 3, and 4.

The extent to which alteration has modified the REE content obscures comparison of initial REE content. Neither the early nor the main phases of the Schultze is altered. However, the separate masses of the porphyry phase of the Schultze Granite are altered,

although to differing degrees. The Copper Spring porphyry mass is only slightly altered, and samples selected for analysis appear in stained slab and thin sections to be completely unaltered. They are regarded as unaltered in comparison to other rocks. The Copper Cities porphyry mass has undergone a weak potassic alteration; the Miami-Inspiration porphyry mass has undergone a moderately strong potassic alteration, with sericitic alteration probably superimposed. The transition phase of the Schultze Granite exhibits a weak potassic alteration, but the least altered samples were selected for analysis. These rocks therefore permit comparisons of REE content between altered main and early phases of the Schultze and altered and unaltered parts of the porphyry phase, and between altered and unaltered parts of the porphyry phase.

Multiple analyses of individual rock units permitted calculation of the mean values and standard deviations for each unit (fig. 6). Additional REE analyses for some of the units would have reduced some standard deviations, and would thereby have increased the sensitivity to significant differences. For example, abundances of heavy rare-earth elements (HREE) for the Copper Cities porphyry mass of the Schultze are appreciably higher than are those of any other phase of the Schultze Granite, but the standard deviations of HREE's for the Copper Cities porphyry mass are so large that one cannot assert that a meaningful difference exists.

The similarities and differences between rock units are based on comparisons of individual numerical values of REE's normalized to concentrations in chondrodites, on the comparison of normalized abundance curves for all REE's, and on a combination of the two. Shapes of the normalized abundance curves will be considered first, followed by consideration of differences among individual elements. Figure 7 shows normalized abundance curves for 10 rock units and the standard deviation for each element. Because the curves are plotted on semilogarithmic paper, standard deviations for light rare-earth elements (LREE) appear to be less than those for HREE's, whereas the reverse is true (cf. fig. 7).

All of the abundance curves for the Schultze Granite, except that for the dike phase, have the same general shape, but there are slight differences that may be significant; additional sampling would be necessary to statistically establish the validity of the differences. Comparison of the unaltered and slightly altered phases of the Schultze—the main, early, and transition phases, and the Copper Springs porphyry mass—show a remarkable similarity (fig. 7). Comparison of the potassically altered Miami-Inspiration porphyry mass with unaltered phases shows that the altered Miami-Inspiration porphyry mass is slightly higher in LREE's than are

TABLE 9.—Mean values and standard deviations of rare-earth and other elements from the Schultze Granite, the Tea Cup Granodiorite, and the Granite Basin Porphyry

[Instrumental neutron-activation analyses; analysts: R. J. Knight, R. T. Millard, Jr., L. J. Schwarz, C. M. Ellis, V. C. Smith, and J. Kent. All values in parts per million except for K, which is in weight percent. Rare-earth elements normalized using the composite of nine chondrites from Haskins and others (1968, table 1)]

Elements	Early phase, Schultze Granite	Main phase, Schultze Granite	Porphyry phase, Schultze Granite, Miami-Inspiration	Transition phase, Schultze Granite	Porphyry phase, Schultze Granite, Copper Cities mass	Porphyry phase, Schultze Granite, Copper Springs Canyon	Porphyry dikes in main phase, Schultze Granite	Equigranular phase, Tea Cup Granodiorite	Porphyritic phase, Tea Cup Granodiorite	Granite Basin Porphyry
Mean	3	10	6	3	3	4	2	2	2	3
Cs	1.15 ±0.17	1.68 ±0.82	0.71±0.2	1.57 ±0.29	2.75 ±1.73	0.92 ±0.26	1.91 ±0.31	2.7±0.46	1.68 ±0.25	0.82 ±0.03
Rb	89.6±4	105.9±12.9	88.0±7.0	110.±13.	115.±25	76.3±29	143.±15	84.5±16.	94. ±4.2	47.7±8.3
Ba	1037.±127.	1010.±170.	1302.±197	1018.±52.	1108.±33.5	979.±280	383. ±150.	624. ±206.	634.±24.	755.±18.
Sr	771.±92.	635.±53.	624. ±125.	615.±36.	—	659. ±121.	292. ±107.	—	—	—
K	2.50±.36	2.75±.29	4.00±1.2	3.36±.42	—	2.40±.58	3.31±.25	2.32±.17	2.87±.29	1.92±.17
Th	3.74±1.0	4.4±.5	4.6±.5	4.24±.52	4.43±.78	4.56±.8	3.3 ±.40	6.63±5.2	10.2±1.9	4.0 ±.18
U	3.0 ±.3.7	1.18±.37	1.03±.38	1.18±.4	7.43±9.8	1.24±.13	1.71±.56	1.83±1.24	2.23±.18	.80 ±.05
La <sub>N</sub>	74.9 ±1.8.	83.3±7.7	98.7±1.1.	77.5±6.	80.4±15.	74.7±3.5	40.5 ±1.7	57.2±23.	97.5±13.	64.7±1.9
Ce <sub>N</sub>	59.0 ±10.4	63.3±5.1	74.1±9.	63.2±5.5	67.0±9.	59.7±4.3	35.1±8.8	41.1±1.6.	65.1±9.3	44.5±1.3
Nd <sub>N</sub>	39.4±6.7	40.5±3.0	46.5±5.4	40.7±2.8	42.6±5.	39.7±4.2	18.9±6.8	28.1±9.1	34.8±3.4	29.8±1.0
Sm <sub>N</sub>	21.2±2.0	21.7±1.3	24.6±4.2	21.0±1.3	25.6±1.4	20.2±2.5	14.2±2.6	17.8±4.7	20.7±2.3	18.6±1.1
Eu <sub>N</sub>	12.9±1.4	13.2±.8	14.9 ±1.7	13.0±5	17.4±2.0	12.8±1.3	7.5 ±1.0	9.9±2.5	11.1±.42	12.6±.3
Gd <sub>N</sub>	9.1±.6	10.5±.9	11.9±1.0	9.4 ±2.2	14.9±4.9	11.2±1.9	9.0 ±.34	—	—	—
Th <sub>N</sub>	8.0 ±1.6	9.3±.7	9.3 ±1.4	8.6±.7	12.9±6.5	7.9 ±2.0	9.2 ±.33	8.9±2.4	8.5 ±1.4	5.8±.6
Ho <sub>N</sub>	—	—	—	—	—	—	—	4.8±1.1	4.4±.8	—
Dy <sub>N</sub>	7.3 ±1.0	7.4 ±1.6	6.8 ±1.6	7.4 ±1.1	—	7.3 ±2.4	6.7	—	—	—
Tm <sub>N</sub>	4.8 ±1.9	5.8 ±1.3	6.0 ±1.3	6.3±.5	9.3 ±4.4	5.3 ±1.4	—	—	—	—
Th <sub>N</sub>	4.7±.1	5.6 ±1.2	5.3 ±.9	5.0±.1	7.3 ±2.4	4.4±.3	6.8	6.7±2.3	8.1 ±1.1	3.4±.2
La <sub>N</sub>	3.6 ±1.5	5.1 ±1.3	4.9±.7	4.5±.4	6.9 ±3.0	3.8 ±1.1	6.2 ±.30	5.8±2.3	7.6 ±1.6	2.9 ±.16
Ta	.51 ±.14	.89 ±.17	.69 ±.14	.80 ±.07	.71 ±.25	.58 ±.10	2.27±.16	.7 ±.18	.94 ±.20	.44 ±.01
Zr	134.±8.5	120.±8.6	143.±25.	122.±2.0	189.±7.	116.±9.2	74. ±24.	111.±37.5	158.±26	108.±15
Hf	3.76±.38	3.75±.36	4.16±.58	3.84±.18	4.08±.38	3.63±.12	2.28±.22	2.75±.71	3.75±.64	2.82±.08
Sb	—	.22±.4	.08 ±.02	1.47±2.0	<3.	.06 ±.05	.04 ±.03	—	<3.	<3.
Sc	3.14±.35	2.81±.25	2.98±.55	2.89±.33	3.15±.33	2.26±.75	2.40±.01	3.61±1.72	6.39±.03	6.1 ±.13
Cr	3.99±1.1	2.75±.54	3.51±.93	3.41 ±1.07	<17.±	3.82 ±1.34	2.05±.54	4.6±4.3	14.3±1.1	22.8±.06
Co	3.73±1.6	2.38±.34	4.1 ±4.5	2.10±.43	3.73 ±1.42	1.71±1.0	1.28±.46	3.9±2.4	6.6±.5	13.±.2
Zn	—	—	—	—	30.3±3.5	—	—	42.±13.	43.±6.	61.3±2.1
Th/U	3.06±2.6	4.06±1.2	5.0 ±1.7	3.78±.88	2.67±3.0	3.90±.9	2.12±1.1	3.51±.34	4.49±.56	5.12±.67
K/Rb	279.	259.	453.	305.	—	315.	231.	275.	305.	403.
Rb/Sr	.12	.17	.14	.18	—	.12	.49	—	—	—
K/Ba	24.08	27.18	30.65	33.00	—	24.51	86.29	37.18	45.19	25.43
Ce <sub>N</sub> /Nd <sub>N</sub>	1.50	1.56	1.59	1.55	1.58	1.50	1.86	1.46	1.87	1.49
Be/Ce <sub>N</sub>	17.58	15.96	17.57	16.11	16.54	16.40	10.91	15.18	9.74	16.97
Ce <sub>N</sub> /Yb <sub>N</sub>	12.55	11.30	13.98	12.64	9.18	13.57	5.16	6.13	8.57	13.09

Samples (see figs. 3, 4, and 5):

Early phase, Schultze Granite: 25, 32, 68  
Main phase, Schultze Granite: 5, 10, 57, 59, 65, 67, 70, 72, 73, 75  
Porphyry phase, Schultze Granite, Miami-Inspiration area: 47, 49, 51, 54, 56, 104  
Transition phase, Schultze Granite: 38, 44, 45  
Porphyry phase, Schultze Granite, Copper Cities area: 108, 111, 114  
Porphyry phase, Schultze Granite, Copper Springs Canyon area: 16, 419, 23, 29  
Porphyry dikes in main phase, Schultze Granite: 12, 13  
Equigranular phase, Tea Cup Granodiorite: 167, 168  
Porphyritic phase, Tea Cup Granodiorite: 170, 172  
Granite Basin Porphyry: 160, 161, 165

any of the unaltered phases of the Schultze but that the HREE contents are similar; comparison of the altered Copper Cities porphyry mass with the unaltered phases shows similarity of LREE contents, but differences in HREE contents, those of the Copper Cities porphyry mass being slightly higher. Comparison of the two altered porphyry phases shows a close similarity in LREE content, but the Copper Cities porphyry mass is slightly richer in HREE's. On the basis of K-Ar ages, the Copper Cities porphyry mass is probably about 2 m.y. older than the main phase of the Schultze Granite

(Creasey 1980); possibly its origin differed sufficiently from that of the other masses of the Schultze, which are all of the same isotopic age, to explain the differences in HREE concentrations. The Copper Cities samples were slightly altered, but not as extensively as the Miami-Inspiration samples, whose HREE contents are similar to those of the main phase of the Schultze; the differences probably do not result from alteration. Fractionation of plagioclase will increase the HREE concentrations in the melt, but fractionation of plagioclase sufficient to produce a significant increase in HREE will also pro-

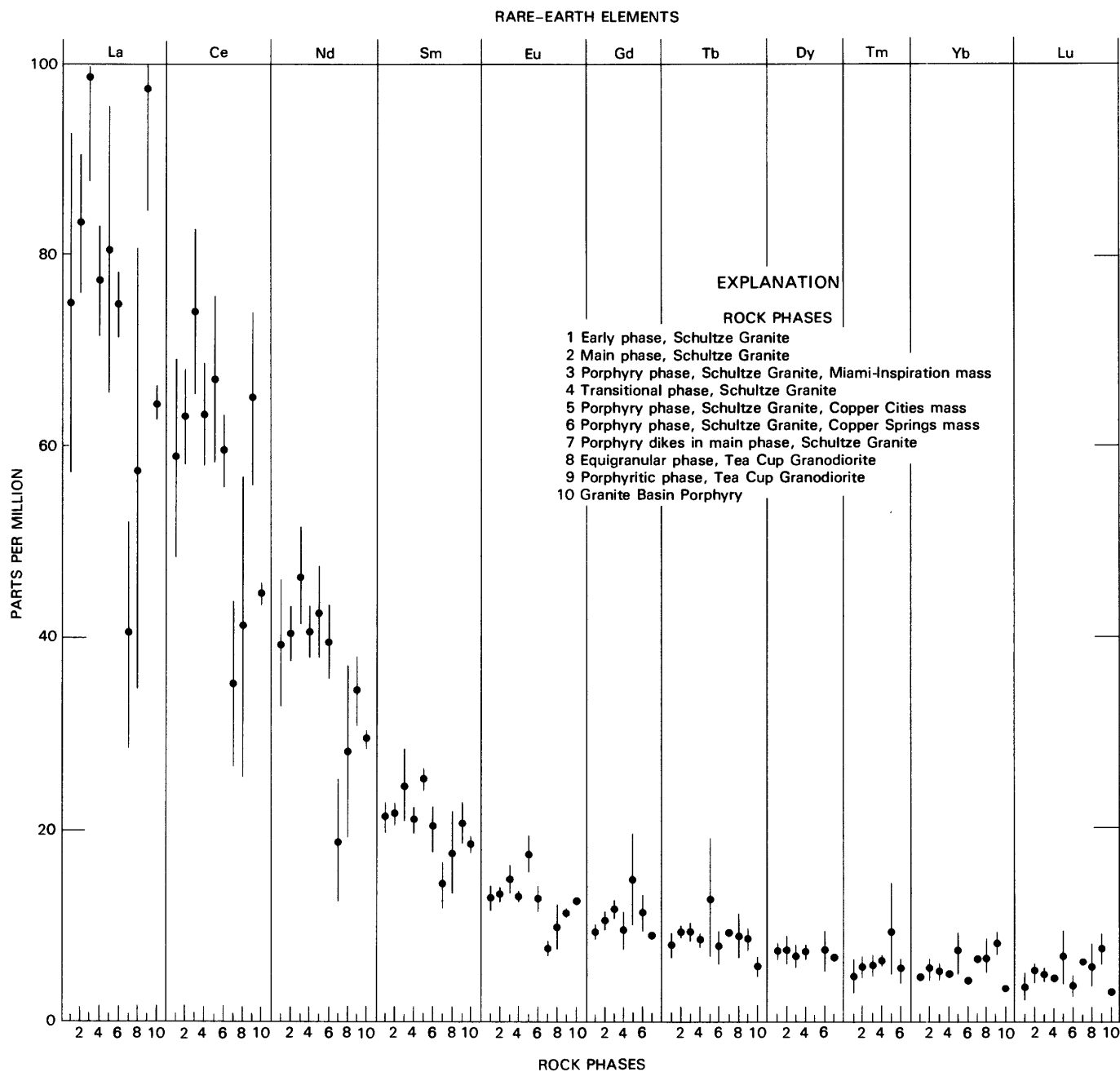


FIGURE 6.—Comparison of the mean values of normalized rare-earth elements and their standard deviations for the Schultze Granite, the Tea Cup Granodiorite, and the Granite Basin Porphyry. Analysis by neutron activation. Analysts: C. M. Ellis, S. S. Fine, R. S. Knight, H. T. Millard, Jr., L. J. Schwarz, and V. C. Smith.

duce a negative Eu anomaly, which does not occur in the Copper Cities porphyry mass.

A comparison of the normalized abundance curve for the dike phase and the other phases shows that the dike is consistently lower in LREE's, and that it is the only phase with a distinct negative Eu anomaly. As it moves toward HREE's, the abundance curve for the

dike flattens and crosses over the other abundance curves near  $Ho_n$ . The differences in HREE abundances are not large, although the difference in curve slope is quite apparent. Fractionation of plagioclase will produce a negative Eu anomaly and an increase in HREE content; it will also tend to increase LREE's, although not to the same extent as HREE's (Arth and Hanson, 1975).

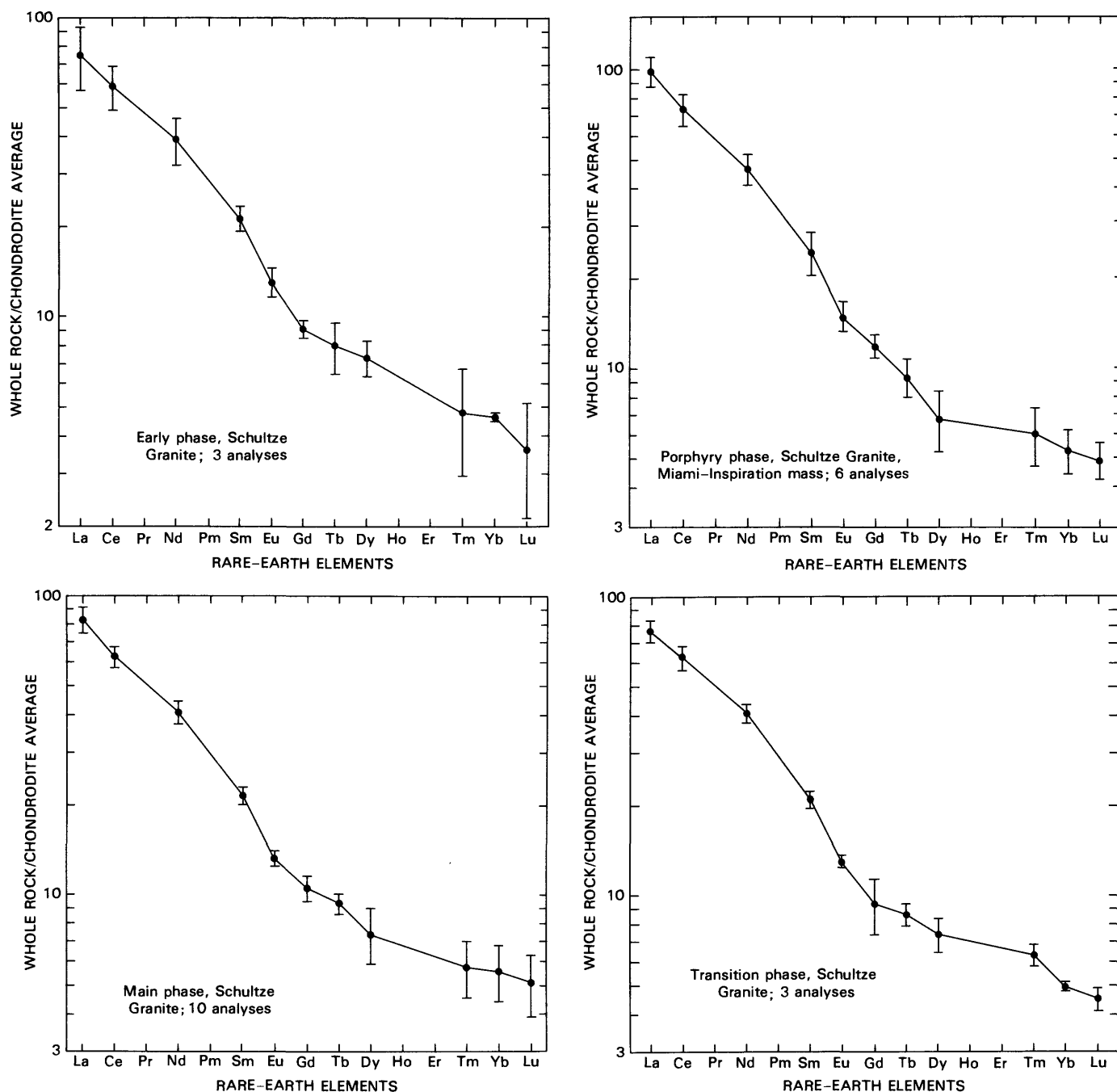


FIGURE 7.—Normalized rare-earth-element abundance curves and the standard deviation for each element for the 10 rock phases that constitute the Schultz Granite, the Tea Cup Granodiorite, and the Granite Basin Porphyry.

Surprisingly, LREE contents for the dike phase are significantly lower than for any of the other phases of the Schultz; this anomaly is inexplicable, if the dike is a fractionate of the Schultz melt. The dike phase may be unrelated to Schultz Granite. Tertiary volcanic rocks do occur in the district, and the dike could be related to that period of igneous activity.

To ascertain how much of the observed differences among individual REE values is significant and how much is due to natural variations in the rock units indicated by standard deviations, the *t*-test was used (Dixon and Massey, 1957). As we have said, the *t*-test determines the validity, at a predetermined level of confidence, of the hypothesis that two populations have the

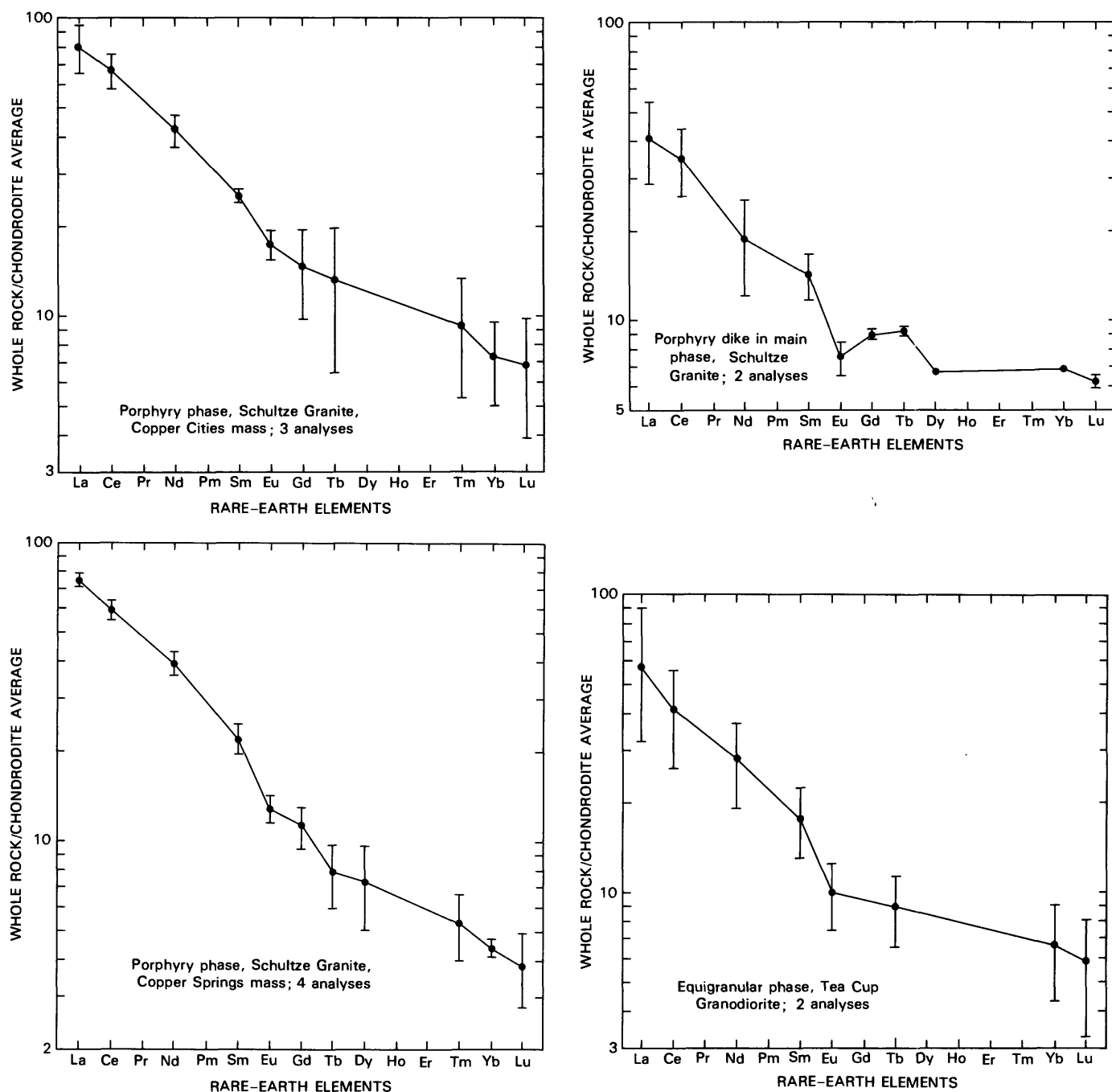


FIGURE 7.—Continued.

same mean when the variance is not known. In this case, each population is a set of REE analyses for a rock unit. For this report, the 80-percent confidence level (CL) was selected because for some rock units we have only two rare-earth analyses. A larger number of analyses would permit more precise determinations of means and standard deviations, which would justify testing at a higher confidence level.

Table 10 shows a summary of the *t*-tests for comparisons of REE contents of some of the rock units. The main phase of the Schultze differs from the porphyry phase for about half of the REE's, but the differences are inconsistent. Only for the Miami-Inspiration mass are LREE contents higher than those for the main phase, whereas HREE contents for only the Copper Cities porphyry mass are higher than those for the main



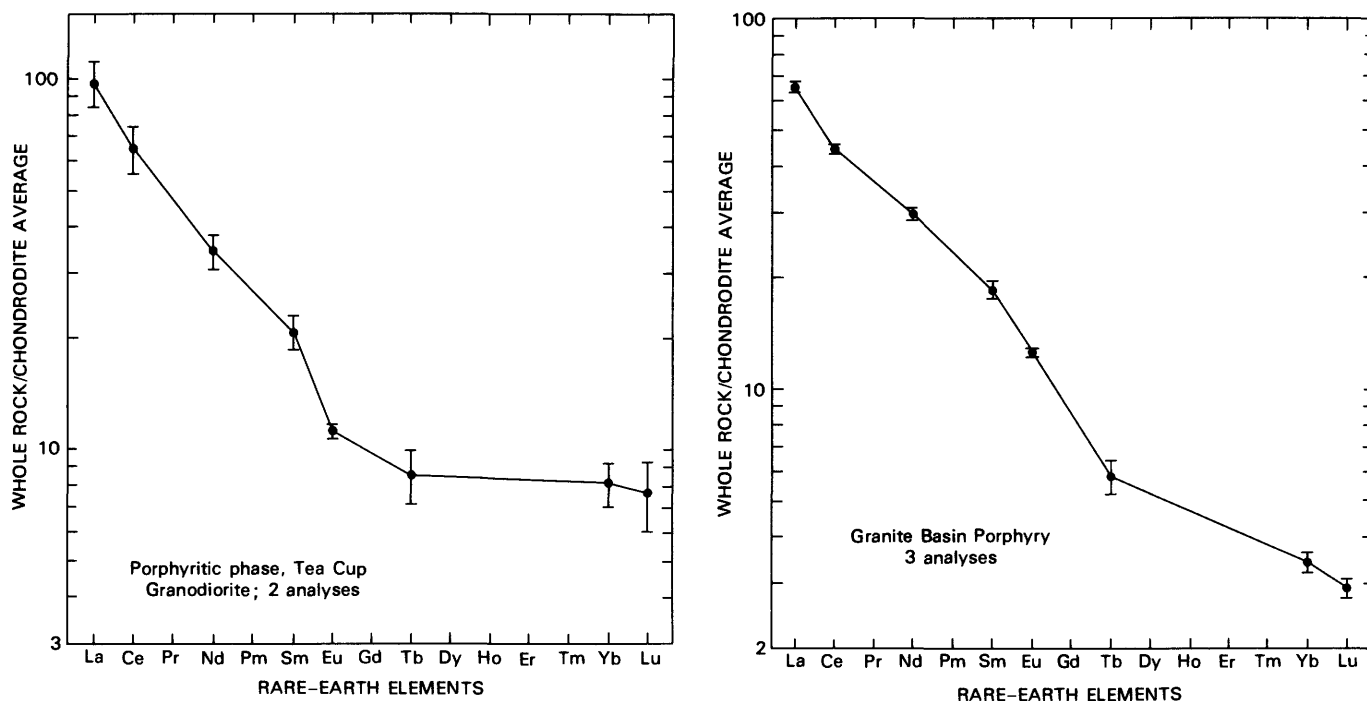


FIGURE 7.—Continued.

phase. The Copper Springs mass tends to be lower in both HREE's and LREE's, but only some of the REE values are significantly lower (fig. 7). The absence of a consistent pattern for the differences between the main and porphyry phases eliminates any simple explanation. An added complexity is the alteration, however slight, of the porphyries. It is unclear whether the differences are primary or are secondarily introduced by alteration, but in either case more consistency would be expected.

With the exception of  $Gd_n$  and  $Tb_n$  in the early phase, there is no difference in REE content between the main, early, and transitional phases of the Schultze. These phases are unaltered, or the least altered, and the groundmass textures of all are medium-grained hypidiomorphic granular, which similarity suggests that the differences in REE content between the nonporphyry and porphyry phases are related either to the origin of the porphyry texture or to the alteration or to both. A linkage seems likely between porphyry texture and alteration. If so, there is some hope that REE content may be useful for ascertaining the nature of the ore-forming process.

The abundance curves of all of the phases of the Schultze Granite consistently differ visibly from those of the Tea Cup Granodiorite. The LREE contents of the Schultze are similar to those of the porphyritic phase of the Tea Cup and higher than those for the equigranular phase. However, for HREE's the abundance curves for both phases of the Tea Cup flatten, so the values are

higher than for the phases of the Schultze; the cross-over occurs near  $Gd_n$ . For the porphyritic Tea Cup phase, about half of the LREE's and all of the HREE's differ significantly from those in the phases of the Schultze. Most of the LREE contents of the equigranular Tea Cup phase but only about a third of its HREE contents differ significantly from those in the phases of the Schultze. Clearly there are differences in REE contents between the Schultze and the Tea Cup, but there is no system to those differences other than the general shapes of the abundance curves.

All of the phases of the Schultze differ significantly in  $Ce_n$  from the equigranular phase of the Tea Cup, but not from the porphyritic phase. The two phases of the Tea Cup also differ in  $Ce_n$  from each other at the 80-percent CL. Because the common major rock-forming minerals other than hornblende have a partitioning coefficient (PC) for  $Ce_n$  between crystals and melt of less than 1, a direct relation exists between the numerical value for  $Ce_n$  and the amount of fractionation, or an inverse relation relative to partial melting.  $Ce_n$  values suggest that the porphyritic phase of the Tea Cup and all phases of Schultze, except the dike phase, are products of about the same amount of fractionation or partial melting at the source of the magma, but they all differ significantly from the equigranular phase of Tea Cup Granodiorite.

For the two phases of Tea Cup Granodiorite, the differences between the LREE data are incompatible with the HREE data, if those differences are due to

## MINOR ELEMENTS

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TABLE 10.—Summary of the significant differences in the indicated elements at the 80-percent-confidence level of the t-test

[+, significant difference; 0, no significant difference  
or too close to judge; X, no analysis]

	La	Ce	Nd	Sm	Eu	Gd	Tb	Dy	Tm	Yb	Lu
Main phase, Schultze Granite											
Granite Basin Porphyry -----	+	+	+	+	0	X	+	X	X	+	+
Transition phase, Schultze Granite -----	0	0	0	0	0	0	0	0	0	0	0
Porphyry phase, Schultze Granite, Miami-Inspiration mass -----	+	+	+	+	+	+	0	0	0	0	0
Porphyry phase, Schultze Granite, Copper Cities mass -----	0	0	0	+	+	+	+	X	+	+	+
Porphyry dikes in main phase, Schultze Granite -----	+	+	+	+	+	+	0	X	X	X	0
Equigranular phase, Tea Cup Granodiorite -----	+	+	+	+	+	X	0	X	X	0	0
Porphyritic phase, Tea Cup Granodiorite -----	+	0	+	0	+	X	0	X	X	+	+
Porphyry phase, Schultze Granite, Copper Springs Canyon mass ---	+	0	0	+	0	0	+	0	0	+	+
Early phase, Schultze Granite -----	0	0	0	0	0	+	+	0	0	0	0
Early phase, Schultze Granite											
Granite Basin Porphyry -----	0	+	+	+	0	X	+	X	X	+	0
Transition phase, Schultze Granite -----	0	0	0	0	0	0	0	0	0	+	0
Porphyry phase, Schultze Granite, Miami-Inspiration mass -----	+	+	+	0	0	+	0	0	0	0	+
Porphyry phase, Schultze Granite, Copper Cities mass -----	0	0	0	+	+	+	0	X	+	+	+
Porphyry dikes in main phase, Schultze Granite -----	+	+	+	+	+	0	0	X	X	X	+
Equigranular phase, Tea Cup Granodiorite -----	0	+	+	0	+	X	0	X	X	+	0
Porphyritic phase, Tea Cup Granodiorite -----	0	0	0	0	+	X	0	X	X	+	+
Porphyry phase, Schultze Granite, Copper Springs Canyon mass ---	0	0	0	0	0	+	0	0	0	+	0
Porphyry phase, Schultze Granite, Copper Springs area											
Granite Basin Porphyry -----	+	+	+	0	0	X	+	X	X	+	0
Transition phase, Schultze Granite -----	0	0	0	0	0	0	0	0	0	+	0
Porphyry phase, Schultze Granite, Miami-Inspiration mass -----	+	+	+	0	+	0	0	0	0	0	+
Porphyry phase, Schultze Granite, Copper Cities mass -----	0	0	0	+	+	0	0	X	+	+	+
Porphyry dikes in main phase, Schultze Granite -----	+	+	+	+	+	0	0	X	X	X	+
Equigranular phase, Tea Cup Granodiorite -----	+	+	+	0	+	X	0	X	X	+	+
Porphyritic phase, Tea Cup Granodiorite -----	+	0	0	0	+	X	0	X	X	+	+
Porphyritic phase, Tea Cup Granodiorite											
Granite Basin Porphyry -----	+	+	+	+	+	X	+	X	X	+	+
Transition phase, Schultze Granite -----	+	0	+	0	+	X	0	X	X	+	+
Porphyry phase, Schultze Granite, Miami-Inspiration mass -----	0	0	+	0	+	X	0	X	X	+	+
Porphyry phase, Schultze Granite, Copper Cities mass -----	0	0	+	+	+	X	0	X	X	0	0
Porphyry dikes in main phase, Schultze Granite -----	+	+	+	+	+	X	0	X	X	X	0
Equigranular phase, Tea Cup Granodiorite -----	+	+	0	0	0	X	0	X	X	0	0
Equigranular phase, Tea Cup Granodiorite											
Granite Basin Porphyry -----	0	0	0	0	+	X	+	X	X	+	0
Transition phase, Schultze Granite -----	0	+	+	0	+	X	0	X	X	0	0
Porphyry phase, Schultze Granite, Miami-Inspiration mass -----	+	+	+	+	+	X	0	X	X	0	0
Porphyry phase, Schultze Granite, Copper Cities mass -----	0	+	+	+	+	X	0	X	X	0	0
Porphyry dikes in main phase, Schultze Granite -----	0	0	0	0	0	X	0	X	X	X	0

fractionation or partial melting—i.e., if a fractionation model is assumed, the LREE data suggest that equigranular phase is younger, whereas the HREE data suggest that the porphyritic phase is younger. However, if a partial melting model is assumed, then the LREE data indicate that the porphyritic phase is younger, whereas the HREE data indicate the equigranular is younger. In fact, crosscutting relations indicate that the porphyritic phase is the younger. Possibly both phases formed from independent melts, although from the same source region, and with similar but not identical degrees of fractionation or partial melting, to judge from the similar shapes of the abundance curves (table 9).

The significant differences in HREE content between the phases of the Schultze and the porphyritic phase of the Tea Cup indicate a difference in origin. Because none of the phases have negative  $Eu_n$  anomalies, the differences are not due to fractionation (or lack of melting) of plagioclase. Crystallization of hornblende will increase the melt in HREE. Hornblende is a common mineral in the porphyritic phase of the Tea Cup (but not the equigranular), but it does not occur in any phase of Schultze; it may account for the differences in HREE content. Comparison of REE data between the Schultze Granite and Tea Cup Granodiorite clearly indicates different magmas, owing to differences in fractionation or partial melting, in source rocks, or in both.

In contrast to the Tea Cup Granodiorite, the Granite Basin Porphyry is characteristically lower in REE's than are any of the phases of the Schultze, although where standard deviations are particularly large, the differences are not statistically significant. Perhaps the most informative comparison is between the main phase of the Schultze, where 10 analyses have resulted in smaller standard deviations, and the Granite Basin Porphyry, which shows small standard deviations owing to little variation in REE content between samples. Table 10 indicates that only  $Eu_n$  does not differ significantly in the two rocks. The Granite Basin Porphyry contains a little hornblende into which all  $REE_n$  partition, particularly middle rare-earth elements and HREE's. At first consideration, this might seem to conflict with the lower total REE content of the Granite Basin Porphyry. However, if the hornblende present represents only a minor fraction of that which crystallized from the original melt, depletion of all REE's, and particularly of HREE's, would be significant. Abundance curves for the main phase of the Schultze Granite and Granite Basin Porphyry are compatible with this interpretation. Frey and others (1978) ascribed depletion of REE's in the youngest intrusive in the zoned Tuolumne Intrusive Suite (Cretaceous) of the Sierra Nevada batholith to hornblende fractionation. Differences in REE content

between the Schultze Granite and Granite Basin Porphyry suggest different magma chambers, different degrees of fractionation or partial melting, and possibly different source rocks.

A comparison of normalized abundance curves of the Granite Basin Porphyry shows striking differences from the porphyritic phase of the Tea Cup Granodiorite, but some similarity with the equigranular phase of the Tea Cup. Abundance curves for HREE's in the Tea Cup flatten to higher values (6-8), whereas for the Granite Basin, normalized values tend to continue to decrease to almost 3 (fig. 7). Similarity of LREE-normalized abundance curves for the equigranular phase of the Tea Cup and the Granite Basin is striking (fig. 7), and even most of the HREE's do not differ significantly (fig. 7). In contrast, all the REE contents of the porphyritic phase of the Tea Cup differ significantly from those of the Granite Basin Porphyry (fig. 7). The porphyritic phase is generally higher in REE's than is the Granite Basin Porphyry and in this respect, it is similar to the phases of the Schultze. It is noteworthy that the equigranular phase of the Tea Cup, where observed, contained no indications of silicate alteration or of copper metallization and neither does the Granite Basin, whereas indications of alteration and subeconomic metallization are common in the porphyritic phase of the Tea Cup.

REE abundances suggestive of fractionation from a parent magma located in upper crust occur in the dike phase of the Schultze Granite and possibly the Granite Basin Porphyry, but not in any other phase of the Schultze, nor in the Tea Cup Granodiorite. Mineralization is associated with those rock units or phases that show no indications of fractionation. Although minor fractionation is possible without leaving recognizable chemical indications, the intense fractionation postulated as a process that ultimately yields hydrothermal solutions responsible for mineralization should be apparent in rocks most closely associated with ore bodies. For the Schultze Granite, this would be the porphyry phase.

The strongest mineralized porphyry phase of the Schultze Granite (Miami-Inspiration porphyry mass) is slightly higher in LREE's than is the main phase, but similar in HREE's; LREE differences are not significant at the 80-percent CL. Thus, porphyry in the heart of the most pronounced mineralized area does not differ significantly in REE's from the main phase, and it does not appear to involve fractionation relative to the main phase.

#### OTHER ELEMENTS

Figure 8 plots the amounts of uranium, thorium, hafnium, scandium, tantalum, zirconium, cesium, rubidium, barium, and strontium in parts per million,

their standard deviations, and their average concentrations in granodiorite and granite (Taylor, 1968). Table 8 lists the analytical data and summarizes significant differences at the 80-percent CL for selected rocks. Results were determined by neutron activation; the samples analyzed were the same as those used for REE analyses.

## URANIUM AND THORIUM

The mean uranium contents of the seven phases of the Schultze Granite, two phases of Tea Cup Granodiorite, and the Granite Basin Porphyry range from  $0.8 \pm 0.05$  to  $7.43 \pm 9.8$  ppm; if the early phase of the Schultze and the Copper Cities porphyry mass are dis-

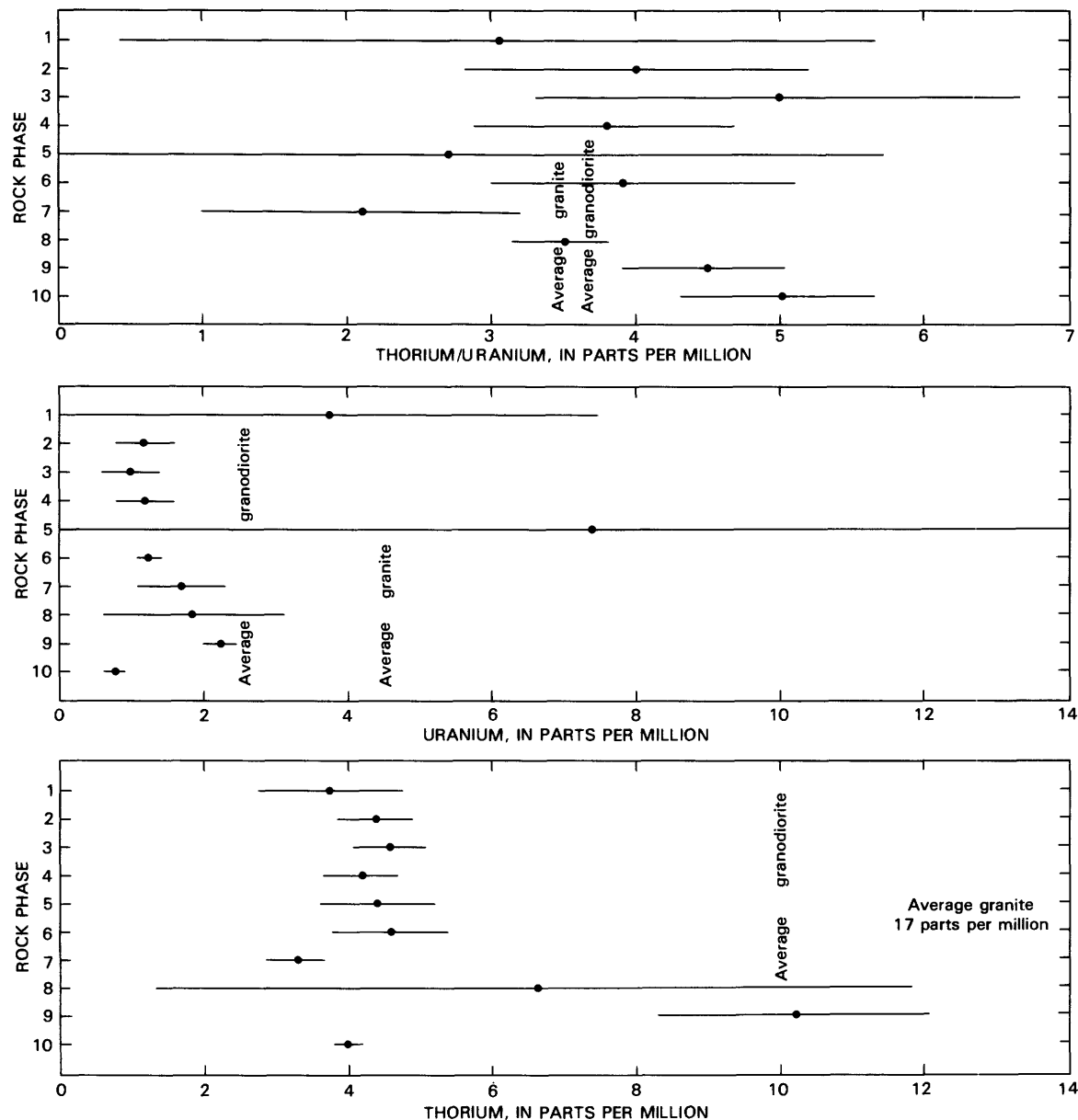


FIGURE 8.—Comparison of the mean values for cesium, rubidium, barium, strontium, hafnium, scandium, tantalum, zirconium, thorium, uranium, and the thorium/uranium ratio. Average values for granite and granodiorite from Taylor (1968). Analysis by neutron activation. Analysts: C. M. Ellis, S. S. Fine, R. J. Knight, H. T. Millard, Jr., L. J. Scharz, and V. C. Smith.

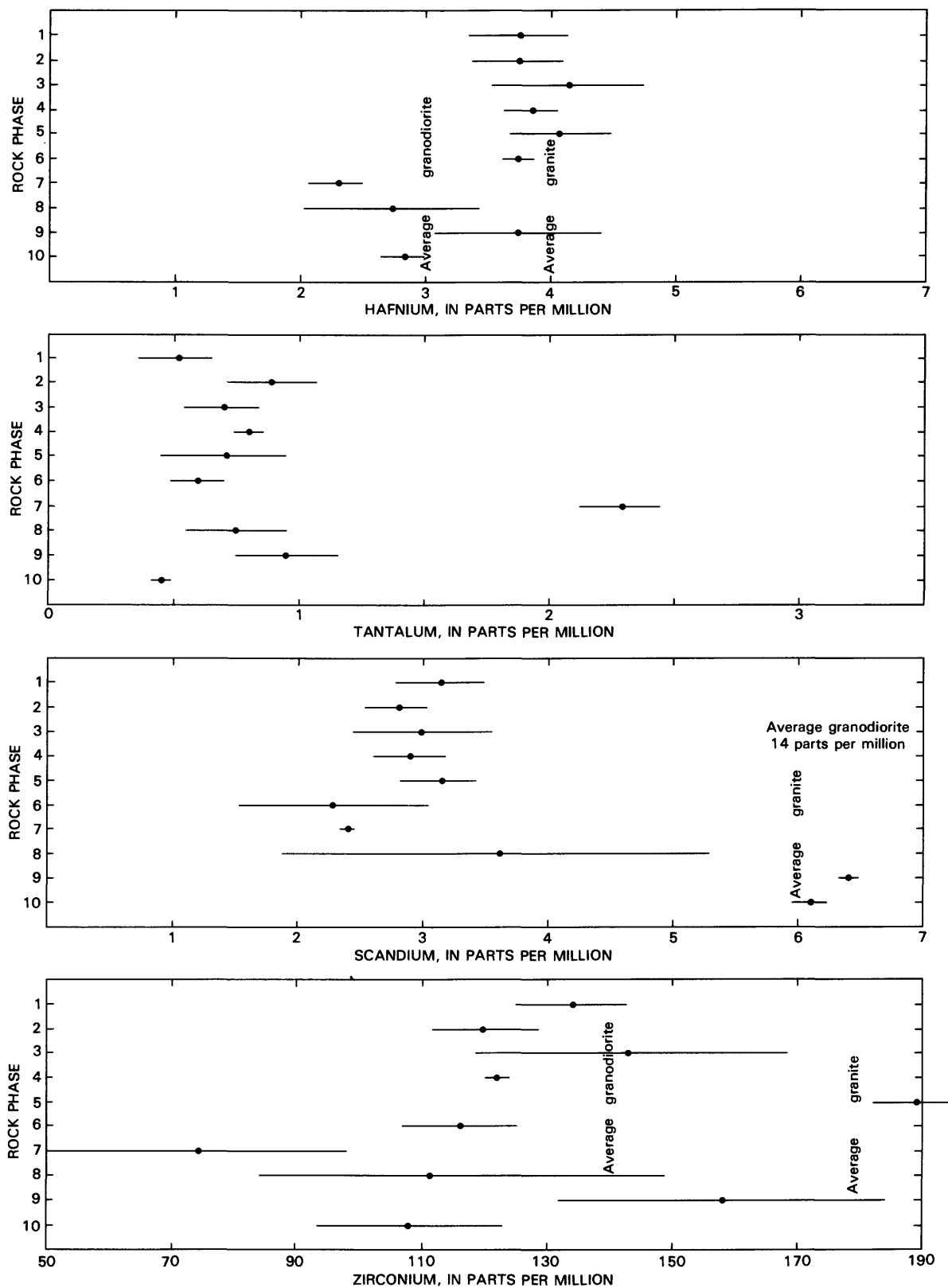


FIGURE 8.—Continued.

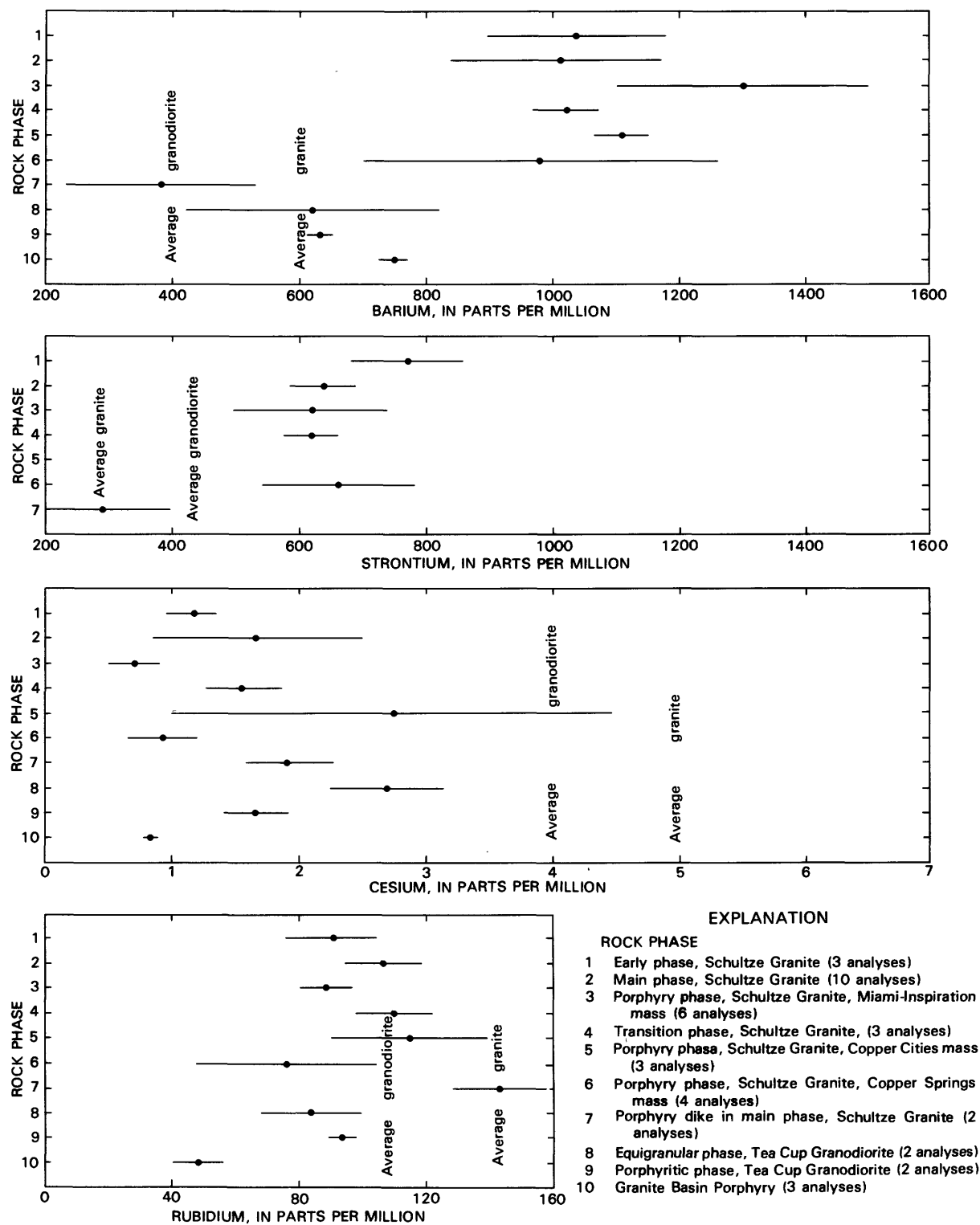


FIGURE 8.—Continued.

regarded on account of their large standard deviations, the mean range is from  $0.8 \pm 0.05$  to  $2.23 \pm 0.18$ . The early phases of the Schultze and the Copper Cities porphyry mass contain one abnormally high uranium analysis, and each resulted in a large standard deviation to the mean. These high analytical means resulted in differences at the 80-percent CL between these two phases and the main phase of the Schultze, but not for the others (table 11). However, there is no consistent significant difference in uranium content between the phases of the Schultze; neither the early phase nor the Copper Cities mass differed from the main phase at the 80-percent CL. Although the uranium content of the Copper Cities porphyry mass is high and the samples are mineralized, the suggestion that the mineralization introduced uranium is not supported by the uranium content of the more intensely mineralized Miami-Inspiration porphyry mass nor by the large standard deviation of the mean uranium content of the Copper Cities porphyry mass.

Although there are no consistent differences in uranium content among all of the phases of the Schultze Granite and either the Tea Cup Granodiorite or the Granite Basin Porphyry, the main phase of the Schultze is slightly lower in uranium content than the Tea Cup Granodiorite and slightly higher than the Granite Basin Porphyry. This pattern of slight differences in uranium content probably also holds among the largely unaltered Copper Springs porphyry mass of the Schultze Granite, the Tea Cup Granodiorite, and the Granite Basin Porphyry. The *t*-test indicates no significant difference in uranium content from the equigranular phase of Tea Cup, but the large standard deviation of the uranium content of the equigranular Tea Cup is thought to account for this exception. However, these differences are not large, and they do not indicate any correlation between uranium content and unaltered stocks associated with porphyry copper deposits.

With the exception of the porphyritic phase of the Tea Cup Granodiorite, the mean thorium contents of the different phases do not consistently differ significantly from each other at the 80-percent CL (table 11). However, the thorium content of the porphyritic phase of the Tea Cup Granodiorite differs from all the others except the equigranular phase of the Tea Cup at the 95-percent CL, and a sample of the equigranular phase of the Tea Cup is one of the two that contain 10.2 ppm Th. Data for the Tea Cup Granodiorite suggest that it might be richer in thorium than are the other phases, but additional sampling would be necessary to determine a representative thorium content. The thorium/uranium content shows no significant differences among any of the rock units (table 11). The Schultze Granite does not clearly differ from either the Tea Cup Granodiorite or

Granite Basin Porphyry in uranium or thorium content, except for the above-mentioned datum on thorium in the Tea Cup Granodiorite.

Comparison of average concentrations in granodiorite and granite indicate that the rocks studied are low in both uranium and thorium but that the thorium/uranium content is distributed around the average values. The thorium and uranium contents of the phases of the Schultze do not consistently and systematically differ enough from those of the other rocks to suggest that these elements would be useful in distinguishing rocks related to copper mineralization.

#### HAFNIUM, TANTALUM, SCANDIUM, AND ZIRCONIUM

The hafnium contents of the unaltered phases of the Schultze Granite are remarkably uniform and are similar to the average concentration in granites, except for the dike phase which is impoverished and which differs from the other phases at the 95-percent CL (table 11). Because other data indicate that the dike phase was strongly influenced by fractionation, the low hafnium content suggests that it is partitioned into crystals relative to melt.

The hafnium contents of the Copper Cities and Miami-Inspiration masses, which are the two strongly altered porphyry masses of the Schultze Granite, differ from the apparently unaltered Copper Springs porphyry mass at the 80-percent CL. The altered porphyries do not differ at the 80-percent CL from the other phases of the Schultze, although they contain more hafnium (fig. 8). Data from Hildreth (1977) on the Bishop Tuff show hafnium to be strongly partitioned into zircon. The two altered porphyries are also significantly enriched in zirconium. The data are not conclusive, but they suggest that hafnium and zirconium were added during mineralization.

The Granite Basin Porphyry is low in hafnium and distinct from the phases of the Schultze at the 90-percent CL. The mean hafnium content of the equigranular phase of the Tea Cup is less than that of the Granite Basin Porphyry, but the standard deviation is so large that it does not differ from some of the phases of the Schultze Granite at the 80-percent CL. Additional sampling would be required to determine any real difference. The atomic radius of hafnium is 0.079 nm (Whitaker and Mintus, 1970), and it carries a +4 charge; it does not commonly substitute for any of the major elements in the rock-forming minerals.

The tantalum content of the dike phase of the Schultze differs from that of all the others at the 99-percent CL (fig. 8). Tantalum apparently was concentrated in the melt phase during fractionation; such concentration of tantalum has also been reported by Hildreth (1977), although Hildreth does not support the

TABLE 11.—*Summary of significant differences in the indicated elements at the 80-percent-confidence level of the t-test*[+, significant difference; 0, no significant difference  
or too close to judge; X, no analysis]

	Th/U	U	Th	Hf	Sc	Ta	Zr	Cs	Rb	Ba	Sr
Main phase, Schultze Granite											
Granite Basin Porphyry -----	+	+	+	+	+	+	0	+	+	+	X
Transition phase, Schultze Granite -----	0	0	0	0	0	0	0	0	0	0	0
Porphyry phase, Schultze Granite, Miami-Inspiration mass -----	0	0	0	0	0	+	+	0	+	+	0
Porphyry phase, Schultze Granite, Copper Cities mass -----	0	+	0	0	+	+	0	+	0	0	X
Porphyry dikes in main phase, Schultze Granite -----	+	+	+	+	+	+	+	0	+	+	+
Equigranular phase, Tea Cup Granodiorite -----	0	+	+	+	+	0	0	+	0	+	X
Porphyritic phase, Tea Cup Granodiorite -----	0	+	+	0	+	0	0	0	0	+	X
Porphyry phase, Schultze Granite, Copper Springs Canyon mass -----	0	0	0	0	+	+	0	0	+	0	0
Early phase, Schultze Granite -----	0	+	+	+	+	+	+	0	+	0	0
Early phase, Schultze Granite											
Granite Basin Porphyry -----	0	0	0	+	+	0	+	+	+	+	X
Transition phase, Schultze Granite -----	0	0	0	0	0	+	+	+	0	0	+
Porphyry phase, Schultze Granite, Miami-Inspiration mass -----	0	0	+	0	0	+	0	+	0	+	+
Porphyry phase, Schultze Granite, Copper Cities mass -----	0	0	0	0	0	0	+	+	0	0	X
Porphyry dikes in main phase, Schultze Granite -----	0	0	0	+	+	+	+	+	+	+	+
Equigranular phase, Tea Cup Granodiorite -----	0	0	0	+	0	+	0	+	0	+	X
Porphyritic phase, Tea Cup Granodiorite -----	0	0	+	0	+	+	0	+	0	+	X
Porphyry phase, Schultze Granite, Copper Springs Canyon mass -----	0	0	+	0	+	0	+	0	0	0	0
Porphyry phase, Schultze Granite, Copper Springs mass											
Granite Basin Porphyry -----	+	+	0	+	+	+	0	0	+	+	X
Transition phase, Schultze Granite -----	0	0	0	0	0	0	0	+	+	0	0
Porphyry phase, Schultze Granite, Miami-Inspiration mass -----	0	0	0	+	+	0	+	+	0	+	0
Porphyry phase, Schultze Granite, Copper Cities mass -----	0	0	0	+	+	0	+	+	+	0	X
Porphyry dikes in main phase, Schultze Granite -----	+	0	+	+	0	+	+	+	+	+	+
Equigranular phase, Tea Cup Granodiorite -----	0	0	0	0	0	+	0	+	0	+	X
Porphyritic phase, Tea Cup Granodiorite -----	0	+	+	+	+	+	+	+	0	+	X
Porphyritic phase, Tea Cup Granodiorite											
Granite Basin Porphyry -----	0	+	+	+	+	+	+	+	+	+	X
Transition phase, Schultze Granite -----	0	+	+	0	+	0	+	0	+	+	X
Porphyry phase, Schultze Granite, Miami-Inspiration mass -----	0	+	+	0	+	+	0	+	0	+	X
Porphyry phase, Schultze Granite, Copper Cities mass -----	0	0	+	0	+	0	+	0	0	+	X
Porphyry dikes in main phase, Schultze Granite -----	+	0	+	+	+	+	+	0	+	+	X
Equigranular phase, Tea Cup Granodiorite -----	+	0	0	0	+	0	0	+	0	0	X
Equigranular phase, Tea Cup Granodiorite											
Granite Basin Porphyry -----	+	0	0	0	+	+	0	+	+	0	X
Transition phase, Schultze Granite -----	0	0	0	+	0	0	0	+	+	+	X
Porphyry phase, Schultze Granite, Miami-Inspiration mass -----	0	0	0	+	0	0	0	+	0	+	X
Porphyry phase, Schultze Granite, Copper Cities mass -----	0	0	0	+	0	0	+	0	0	+	X
Porphyry dikes in main phase, Schultze Granite -----	0	0	0	0	0	+	0	+	+	0	X



hypothesis of simple fractionation. For the other phases of the Schultze, the means range from 0.51 to 0.89 ppm and the standard deviations range from 0.07 to 0.25. Although table 11 shows a similarity in tantalum content for the phases, the *t*-test indicates that some phases differ from others at the 80-percent CL, whereas others do not; no systematic difference between the phases is apparent. For example, the main and porphyry phases are closer in space and time than the early and porphyry phases. Yet the latter two do not differ at the 80-percent CL, whereas the former two do. The reason for the scatter of tantalum among the phases of the Schultze is not apparent.

The tantalum in the Granite Basin Porphyry is lower at the 80-percent CL than in both phases of the Tea Cup and in most of the phases of the Schultze. However, the scatter in tantalum in the phases of the Schultze makes it difficult to be certain that the Granite Basin Porphyry truly contains less tantalum.

Similarly, the phases of the Tea Cup differ at the 80-percent CL from only some phases of the Schultze. In contrast to the Granite Basin Porphyry, the phases of the Tea Cup tend to be similar in tantalum content to the Schultze. The tantalum content of the two phases of the Tea Cup do not differ from each other at the 80-percent CL.

Means and standard deviations of scandium by rock units are illustrated in figure 8. Except for the Copper Springs porphyry mass and the dike phase, the phases of the Schultze are grouped around 3 ppm, but scatter separates the early phase and the Copper Cities porphyry mass from the main and transition phases and the Miami-Inspiration porphyry mass at the 80-percent CL (table 11). The Copper Springs porphyry mass and dike phase contain less scandium than all the others, at the 80-percent CL. All the phases of the Schultze are lower in tantalum than is the average granite, and the average granite is lower than the average granodiorite, all of which suggests that scandium partitions into the crystal phase during fractionation. Data on rare earths indicate that the dike phase is the product of fractionation; it and the Copper Springs porphyry mass contain the lowest scandium. In contrast to what we have said about the dike, no other data suggest that the Copper Springs porphyry was produced by fractionation different from that responsible for the other phases of the Schultze, so its low scandium content is unexplained. The general scatter of scandium in the Schultze is similar to that for other elements, such as tantalum. Perhaps in elements of such low concentration as scandium and tantalum, much larger samples are required in order to be representative.

The scandium contents of the two phases of the Tea Cup differ from each other radically. The scandium con-

tent of the equigranular phase is more like that of the phases of the Schultze, whereas the scandium content of the porphyry phase is similar to that in Granite Basin Porphyry. The reason for the difference in scandium between the two phases of the Tea Cup is uncertain, but it could be due to the hornblende in the porphyritic phase of the Tea Cup Granodiorite and Granite Basin Porphyry. Scandium is strongly concentrated in amphibole. Cesium is the only other element that differs in the two phases at the 80-percent CL; it is more abundant in the equigranular phase. If the difference in scandium between the two phases were due to a fractionation so slight that it is not reflected in REE contents at the 80-percent CL, it is unlikely that cesium and scandium would show strong fractionation effects. The data permit the interpretation that the two phases of the Tea Cup did not originate from the same magma.

The zirconium content of the phases of the Schultze is erratic. The main and transitional phases and the Copper Springs porphyry mass are indistinguishable at the 80-percent CL. The early phase and Miami-Inspiration and Copper Cities porphyry masses are all richer than the other phases of the Schultze at the 95-percent CL or better, whereas the dike phase is lower than all other phases at the 99-percent CL. High zirconium in the Miami-Inspiration and Copper Cities porphyry masses could be due to mineralization, but such an explanation is unacceptable for the early phase. Zirconium partitioning into crystals would result in low zirconium content of the dike phase. The two phases of the Tea Cup differ considerably in zirconium, but standard deviations are so large that the phases do not differ at the 80-percent CL. The Granite Basin Porphyry is lower in zirconium than are all phases of the Schultze (except the dike phase) and the porphyritic phase of the Tea Cup, but not the equigranular phase. The distribution of zirconium content in the stocks analyzed shows no pattern that would distinguish the unaltered phases of the Schultze from the Tea Cup Granodiorite or Granite Basin Porphyry. The suggestion that zirconium was introduced during mineralization is of scientific interest but is of no evident practical use in exploration. The zirconium content of all units or phases studied except the Copper Cities porphyry mass is below the average for granite, and most are below the average for granodiorite. There is, therefore, no suggestion of zirconium enrichment in stocks associated with porphyry copper deposits.

#### BARIUM, STRONTIUM, CESIUM, AND RUBIDIUM

The mean contents and standard deviations of barium, strontium, cesium, and rubidium are listed by rock units or phases in figure 8, and the differences in

abundances of these elements between the units at the 80-percent CL are tabulated on table 11. The barium content of the Miami-Inspiration porphyry mass of the Schultze is higher and the dike phase lower than all the others, at the 80-percent CL or better. The phases of the Tea Cup differ significantly from the Schultze Granite, but not from each other. The Granite Basin Porphyry differs from the Schultze and the porphyry phase of the Tea Cup at the 80-percent CL. The high barium in the Miami-Inspiration porphyry mass possibly resulted from mineralization. The Copper Cities porphyry mass is also weakly mineralized, and its value is a little higher than those for the other phases (except the Miami-Inspiration porphyry mass), but not at the 80-percent CL.

Strontium analyses exist only for the Schultze Granite. Strontium in the dike phase is significantly depleted, as is barium, and the early phase is inexplicably enriched in strontium at the 80-percent CL relative to the other phases, all of which do not differ from each other. Barium and strontium data in the phases of the Schultze suggest no significant differences in the geologic histories of the phases, with the possible exception of introduction of barium during mineralization. Barium and strontium partition into feldspar; therefore, during fractionation they should be increased in the crystal fraction and depleted in the melt. With the exception of the dike phase, all the other phases contain significantly more barium and strontium than does the average for granodiorite and granite. I have no explanation for this, other than the possibility that the source rocks were rich in these elements and, by inference, richer in feldspar. A lower crustal source is more compatible with the data than a subcrustal source.

In the dike phase, both barium and strontium are low; this is consistent with other data that indicate the dike is the only phase studied that is the product of fractionation. Barium and strontium contents in the dike phase differ from those in the main phase of the Schultze at the 90-percent CL. Barium contents of the equigranular and porphyritic phases of the Tea Cup Granodiorite and of the Granite Basin Porphyry differ from those of the phases of the Schultze at the 80-percent CL. I interpret these differences in barium to be due to initial differences in the magmas.

Distribution of cesium is so erratic that it appears to be random. Considering its ionic radius (0.178 nm) and its charge (+1), it should behave much like rubidium, and so substitute for potassium. However, there is no consistent correlation between cesium and either potassium or rubidium. The phases of the Schultze contain different amounts of cesium, and thus a reasonable connection is not known between cesium content and the known geological history of the

Schultze. Differences in cesium content among the phases of the Schultze appear to be distributed randomly.

Rubidium values are more consistent than those for cesium, but there are unexplained differences. The early phase and the Miami-Inspiration and Copper Springs porphyry masses of the Schultze are lower in rubidium at the 80-percent CL than are the main and transition phases and the Copper Cities porphyry mass. The dike phase is significantly higher in rubidium than are all other phases. This is consistent with fractionation being involved in the origin of the dike phase and with partitioning of rubidium into melt. Except for the dike phase, the differences in rubidium content among the other phases of the Schultze do not appear to indicate any different origins.

The phases of the Tea Cup do not differ from each other or from the early phase and Miami-Inspiration and Copper Springs porphyry masses of the Schultze. The Granite Basin Porphyry contains the lowest rubidium content of all the rocks; it differs in rubidium content from the main phase of the Schultze at the 99-percent CL. This difference is probably due to the source of the magma. The rubidium content of none of the phases studied is abnormally high (compare the average concentrations in granodiorite and granite), and consequently there is no indication of a buildup of rubidium in any of the rocks studied.

If felsic rocks have some common origin, then the processes that produce varying compositions in the rocks discriminate between Sr and Rb. Rb/Sr for melts with a common parentage, or formed by the same process from similar parents, will be affected mainly by plagioclase or K-feldspar in the residue during partial melting or by fractionation of feldspar. The presence of either mineral as a residual or a fractionate will increase Rb/Sr in the melt, because strontium is partitioned into crystalline feldspar and rubidium into the melt.

The similar Rb/Sr ratios for all phases of the Schultze Granite except the dike phase suggest a common degree of fractionation or partial melting (table 8). The Rb/Sr ratio in the dike phase is much higher; considering that this phase is high in potassium, this high ratio is probably due to fractionation of plagioclase, or to much residual plagioclase under partial melting. Because the dikes are younger than the main phase, fractionation would seem the most likely.

Sr analyses were not obtained for the Tea Cup Granodiorite and Granite Basin Porphyry. If Sr values from semiquantitative analyses are used, Rb/Sr ratios for the Tea Cup appear to be similar to those for the Schultze Granite, but significantly less feldspar would have been involved in the partial melting or fractionation that produced the Granite Basin Porphyry. With

the available data, the Rb/Sr ratios suggest that the processes that led to the evolution of the rocks associated with copper deposits were not distinct from those that produced barren stocks.

Because the common rock-forming minerals that are rich in potassium also have a high partitioning coefficient for barium, the K/Ba ratio will be changed little by fractionation or partial melting. Although the K/Ba ratios for the crystal and melt phases will be about the same, different rocks may have different ratios. With the exception of the dike phase, the K/Ba ratios are similar for all the phases of the Schultze, suggesting that all originated from the same source (table 8). The distinctly higher ratio in the dike phase is no surprise, and it further suggests that the dike is not related to the other phase of the Schultze. K/Ba ratios of the phases of the Tea Cup Granodiorite differ from those of the Schultze and possibly from each other, whereas the ratio for the Granite Basin Porphyry is similar to the Schultze. Thus, the K/Ba ratios suggest the same source for the Granite Basin Porphyry as for the Schultze Granite, the differences between the two being due to relative amounts of fractionation during partial melting.

#### SUMMARY

##### MAJOR ELEMENTS

Although more chemical analyses are needed for those rock phases that by detailed field mapping and geochronology have been clearly established to be spatially and temporally associated with porphyry copper deposits, my data for these rock units indicate that where the elements are expressed as cations per standard cell of 160 anions, copper deposits are associated with rocks whose ratios of  $\text{Si}/(\text{femic} + \text{Si})$  and  $\text{K}/(\text{femic} + \text{K})$  exceed 0.91 and 0.36, respectively. Thus, rocks associated with porphyry copper deposits are relatively enriched in silicon and potassium and impoverished in the femic elements. The data also suggest that when more chemical analyses become available for Laramide stocks, some associated with porphyry copper deposits and some not, chemical ratios may help distinguish mineralized from unmineralized stocks throughout the Arizona copper province.

##### MINOR ELEMENTS

With the possible exception of copper, minor-element data reveal no clear relation between minor-element content and rocks associated with porphyry copper deposits. This lack of apparent relation may result in part from inadequate analytical sensitivity and in part from too few analyses, considering that the standard de-

viations commonly nearly equal the mean concentrations. However, it is also entirely possible that none of the minor elements considered are indicators for unaltered intrusives associated with porphyry copper deposits.

The unaltered main phase of the Schultze has significantly lower copper content than do the other unaltered phases. Because the main phase constitutes the bulk of Schultze Granite, and because the porphyry phase is more closely related in space and time to copper mineralization, low copper content of the main phase may reflect loss of copper to mineralizing solutions. Although the data is inconclusive, it warrants additional sampling to confirm or deny these preliminary results.

The mineralized porphyry phases of the Schultze show addition of copper, nickel, and possibly cobalt.

#### RARE-EARTH ELEMENTS

The shapes of the normalized rare-earth abundance curves are distinct for many of the the rock phases, but abundances of individual REE's in different formations commonly do not differ from each other at the 80-percent CL. With the exception of the dike phase, REE concentrations in the other phases of the Schultze Granite resemble one another and strongly suggest a common origin from the same magma. The porphyry phase of the Schultze is most closely associated in time and space to the porphyry copper deposits in the Globe-Miami district, but there is nothing in the REE data for this phase to indicate that any process that acted on the porphyry phase did not also act on the other phases. A negative Eu anomaly, indicative of feldspar fractionation, occurs only in the dike phase of the Schultze. In addition, the  $\text{Ce}_n$  content and the K/Ba ratio for the dike phase are inconsistent with the judgment that the dike phase is part of the Schultze Granite. If the dike phase is a separate entity, the phases of the Schultze are devoid of any indications of fractionation from a parent magma in the upper crust; models for the origin of porphyry copper deposits should take this into account.

Differences in REE concentrations between the Schultze Granite, Tea Cup Granodiorite, and Granite Basin Porphyry indicate they probably came from different magma chambers, experienced slightly different histories of fractionation or partial melting, and possibly had somewhat different source rocks. These indications, however, are predictable from the regional geologic relations and from the major-element geochemistry.

REE abundances in the Granite Basin Porphyry suggest upper crustal fractionation of hornblende, but because the Granite Basin Porphyry is devoid of any signs of mineralization, no significance can be attached to this in regard to ore-forming processes.

Differences between the equigranular and porphyritic phases of the Tea Cup Granodiorite in the lanthanum, scandium, zirconium, and cerium contents, and in the K/Ba ratios, as well as in LREE concentrations, raise the possibility that these phases may not be time-separated fractions from a single magma chamber. Megascopic differences in the two phases also occur; the porphyritic phase has quartz-sericite sulfide veins, whereas the equigranular phase contains late-stage muscovite that locally produces a two-mica rock. However, general similarities in REE and a close spatial relation indicate a similar origin, if not a common source magma. Crosscutting relations indicate that the porphyritic phase is younger than the equigranular phase, but they give no clue to the magnitude of the age difference. K-Ar age determinations for each phase were ineffective in establishing age difference, because of discordant ages from a hornblende-biotite mineral pair from the porphyritic phase.

#### OTHER ELEMENTS

Differences between the unaltered phases of the Schultze Granite, exclusive of the dike phase, in concentrations of other elements, including uranium, thorium, hafnium, scandium, tantalum, zirconium, rubidium, barium, and strontium do not indicate any probable differences in magmatic history, such as fractionation, although there are random differences at the 80-percent CL. The reasons for the random scatter in some elements is not known; samples may have been nonrepresentative, or the distribution of elements in the different phases may be nonuniform.

Scandium and rubidium are enriched in the dike phase of the Schultze, and tantalum, zirconium, barium, and strontium are impoverished. Cesium here does not differ from the other phases of the Schultze. The dike phase is enriched in the elements partitioned into melt, and it is impoverished in the elements partitioned into crystal phases. The magma that formed the dike phase was profoundly affected by either fractionation or partial melting.

The altered phases of the Schultze may indicate some addition of other elements, but the patterns are not consistent. For example, the Copper Cities porphyry mass alone is—inexplicably—enriched in zirconium, and the Miami-Inspiration porphyry mass is significantly enriched in barium but not strontium.

Phases of the Tea Cup Granodiorite and Granite Basin Porphyry differ somewhat in other elements from the Schultze Granite. These differences support the data on the major and minor elements and REE's that suggest that these rocks came from different magma chambers, and probably from somewhat different source

rocks. However, the data do not indicate that these rocks formed by different processes.

#### CONCLUSIONS

The primary purpose of this investigation was to compare the geochemistries and petrologies of Laramide stocks associated, and unassociated, with porphyry copper deposits. I was particularly interested in searching for indications that fractionation in the middle or upper crust played a significant part in the copper mineralization; the results strongly suggest that it did not. The results of this study leave unanswered the questions of why the earliest Laramide stock in a district such as Ray, or the earliest phase of a composite stock in a district such as Globe-Miami, is the most mafic; why the copper mineralization is associated with the youngest intrusion; and why the intrusion associated with copper mineralization is the most salic; however, the work of others suggests possible explanations. Current theories that either fractional crystallization or partial melting produces calc-alkaline magmas are compatible with field relations of the rocks studied. For example, Green and Ringwood's (1969) experimental studies resulted in their proposal of two models for the origin of calc-alkaline magmas. The first is by the partial melting of quartz eclogite at 80-150-km depths, leaving a pyroxene-garnet residuum. The second is by either partial melting of a mafic lower crust (amphibolite) under hydrous conditions or fractionation of a hydrous basaltic melt, both at depths of 30-40 km, leaving amphibole as either the residuum or the liquidus phase. At depths of 80-150 km, under anhydrous conditions, diorite is a lower-melting fraction than granodiorite or quartz monzonite, and the fractionation of a basalt melt by separation of clinopyroxene and garnet will cause the melt composition to change toward andesite. Such a model would explain why early Laramide stocks in the Ray district were dioritic, whereas later stocks were quartz monzonitic, and why no indications of hydrous conditions were associated with the early intrusions.

For their second model, Green and Ringwood (1969) stated, "For  $P_{H_2O} > P_{Load}$  temperatures necessary to produce calc-alkaline liquids at 30-40-km depth would range from 900°C in the case of dacite and rhyodacite, to about 1000°C for basaltic andesite." The hydrous model is compatible with the field relations of stocks associated with porphyry copper deposits. The San Manuel deposit, for example, is not associated with earlier, more mafic stocks. However, if a heat source produced both the deep anhydrous and the shallower hydrous magma types, the early stocks would be dry and dioritic, and the later ones hydrous and quartz monzonitic, much as occurs in the Ray district.

Both models propose residual phases (garnet or amphibole) that selectively retain HREE's. Associated melts would be impoverished in HREE's and would produce rocks like the Granite Basin Porphyry and the phases of the Schultze Granite. In contrast, the two phases of the Tea Cup are enriched in HREE's, and in this respect they do not fit either model.

The data on trace elements do not distinguish stocks that may have formed by fractionation from those that may have resulted from partial melting. The Rb/Sr ratio could help in this distinction (see section above entitled "Other elements"), but Sr analyses were not available for some of the rocks. Available data suggest a common origin.

There is no suggestion in the REE data that any of the stocks underwent fractionation in the upper crust at, or near, the place of final consolidation, such as has been reported for the Tuolumne Intrusive Suite of the Sierra Nevada batholith (Bateman and Chappell, 1979). Theoretically, fractionation of a magma could concentrate water and other volatiles and metals expelled during the final stages of crystallization to form ore deposits. Such a model is compatible with early stocks being more mafic than latter ones, if both came from the same magma chamber, but the model is unsupported by REE data.

REE data do not indicate any major differences between the origin of barren stocks and those that produced mineralization. The data are compatible with the thesis that the mode of magma generation is not critical to the generation of a porphyry copper deposit. This thesis is further supported by fact that porphyry copper deposits are not associated with a unique type or suite of igneous rocks. They are found with rocks derived from both oceanic and continental crust (Creasey, 1977). This implies that other factors, such as water, metal, and sulfur contents, may be critical and that these pivotal factors may be unrelated to how the magma was generated. However, metal and volatile content are not the only differences between productive and barren stocks. The productive stocks show greater variation in texture and chemical composition than do the barren ones, and they commonly contain multiple phases (as does Schultze Granite). In part, at least, these differences are probably manifestations of volatile content, and as such, the physical and chemical differences are valuable in the evaluation of plutons for their mineral potential.

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