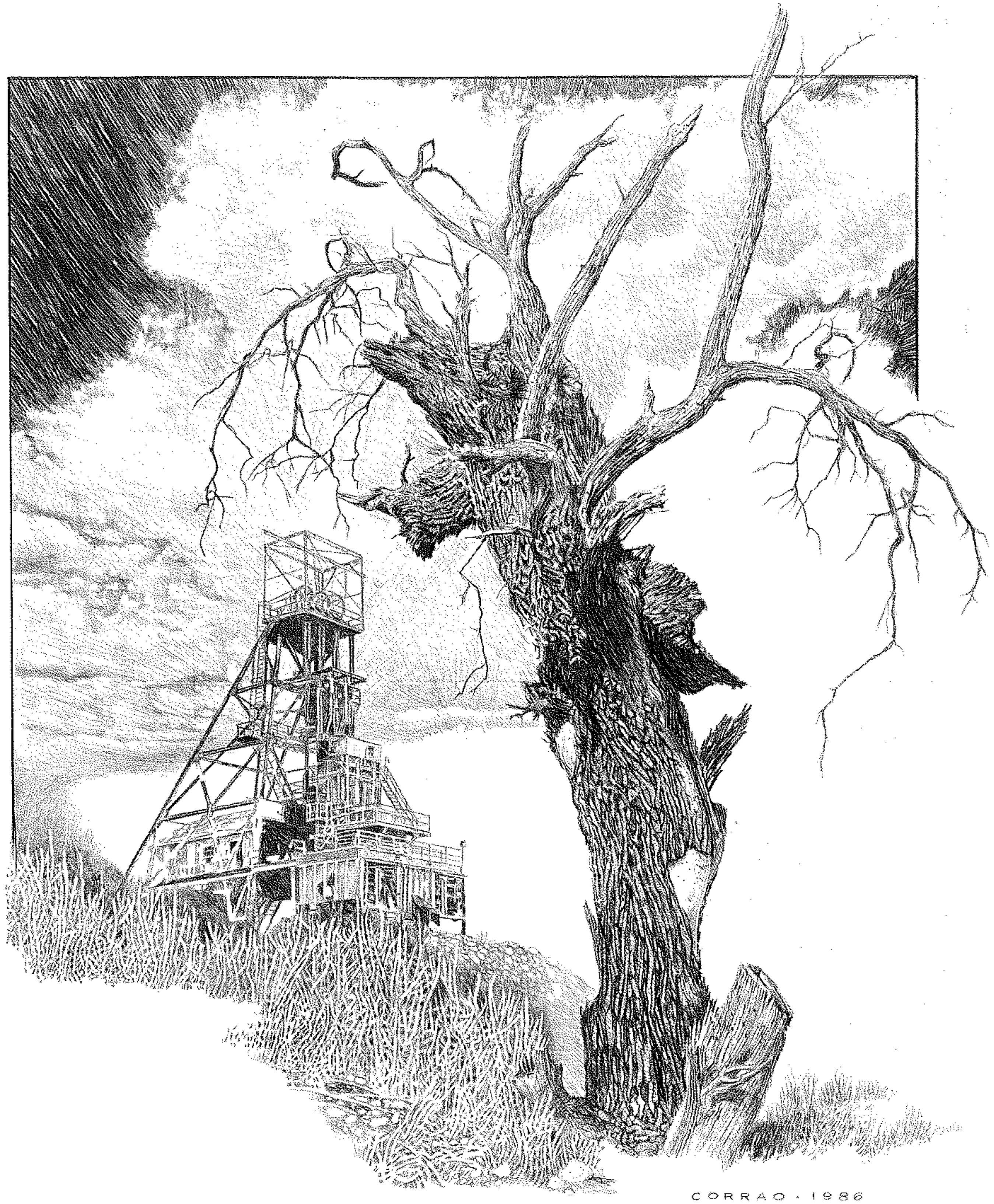

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GEOCHEMISTRY AND TECTONIC POLARITY OF EARLY PROTEROZOIC (1700-1750-Ma) PLUTONIC ROCKS, NORTH-CENTRAL ARIZONA

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ABSTRACT

The Early Proterozoic terrane surrounding Prescott, Arizona, contains abundant 1700-1750-Ma pre-, syn-, and posttectonic granitic to tonalitic plutons that intrude 1720-1780-Ma metavolcanic rocks and minor metasedimentary rocks. Seventeen major plutonic bodies sampled during this study can be grouped into four distinct and genetically related suites defined by differences in major- and minor-element concentrations.

1. Suite one consists of pretectonic, equigranular, medium-grained biotite granodiorite and leucocratic granodiorite and granite plutons including the 1750 ± 10-Ma Brady Butte Granodiorite, the granodiorite of Minnehaha, the granodiorite of Big Bug Creek, the Crooks Canyon Granodiorite, the granodiorite of Lane Mountain, and the granite of Rich Hill. The plutons are moderately peraluminous, have very low magnetite concentrations and low to average Sr, and crop out in the central part of the area.
2. Suite two consists of pre- to syntectonic, equigranular, medium-grained hornblende-biotite tonalite and granodiorite plutons including the 1740 ± 15-Ma tonalite of Cherry and the 1750 ± 15-Ma Government Canyon Granodiorite, the granodiorite of Wilhoit, and the Prescott Granodiorite. The plutons are metaluminous, have high magnetite and Sr concentrations, and are located both northwest and southeast of suite 1.
3. Suite three consists of pre- to late-tectonic, equigranular to porphyritic, medium- to coarse-grained biotite-hornblende granodiorite plutons including the 1720-Ma quartz diorite of Bland, the Bumblebee Granodiorite, and the Badger Spring Granodiorite. The plutons are metaluminous, have low magnetite concentrations, low Rb, Zr, La, and Ce, and very low Sr, and are restricted to the southeastern part of the area.
4. Suite four consists of syn- to posttectonic, moderately to coarsely porphyritic, coarse-grained biotite granodiorite to granite plutons including the 1700 ± 5-Ma Crazy Basin Quartz Monzonite, the granite of Iron Springs, the granodiorite of Yarnell, and the granodiorite of Hozoni Ranch. All except Crazy Basin are metaluminous and have moderate to high magnetite concentrations and high Ba, Rb, Zr, La, and Ce. All except Crazy Basin are restricted to the northwestern part of the area.

At constant SiO_2 or FeO_t, plutons within any one suite have increasingly greater alkalinity and higher concentrations of incompatible minor elements to the northwest. Most modern oceanic and Andean arc granitoid rocks possess similar polarities with regard to the same elements, i.e., K, Rb, Zr, Y, La, Ce, U, and Th increase in concentration across strike of the arc and toward the back-arc region or continent. Although a discrete subduction or collision zone cannot be recognized southeast of the Prescott area, compositions of the 1700-1750-Ma plutons indicate that processes leading to the formation of the plutons were consistent with northwestward subduction of oceanic crust beneath the Prescott area from 1750 to 1700 Ma. Such a subduction zone and trench would have been at least 60 to 100 km to the southeast, in the vicinity of Globe or Superior, Arizona. Any evidence of such a trench has since been obliterated by later tectonic events, including emplacement of the 1400-Ma Ruin Granite.

INTRODUCTION

Central Arizona contains the largest exposure of Proterozoic plutonic and metamorphic rocks south of the Canadian Shield. Although plutonic rocks are more voluminous here than metamorphic rocks, the plutons have been studied only cursorily. This paper presents major- and minor-element data for a variety of plutonic bodies in the region near Prescott, Arizona (fig. 1), and relates the evolution of those bodies to subduction processes that may have operated during the Early Proterozoic as originally suggested by DeWitt (1986) and Anderson (1986b).

BACKGROUND AND TECTONIC SETTING

The plutonic rocks of this study intrude and deform a predominantly metavolcanic suite of rocks ranging from basalt to rhyolite, which was first recognized by Jaggar and Palache (1905) and later described in detail by Lindgren (1926), Anderson and Creasey (1958), Anderson and Blacet (1972b), Anderson and Nash (1972), and DeWitt (1979). Most recently, Anderson and Silver (1976) and Phillip Anderson (1978, 1986a, 1986b) have proposed that the volcanic rocks were formed in Proterozoic island arcs. Refer to Phillip Anderson (this volume) for some current

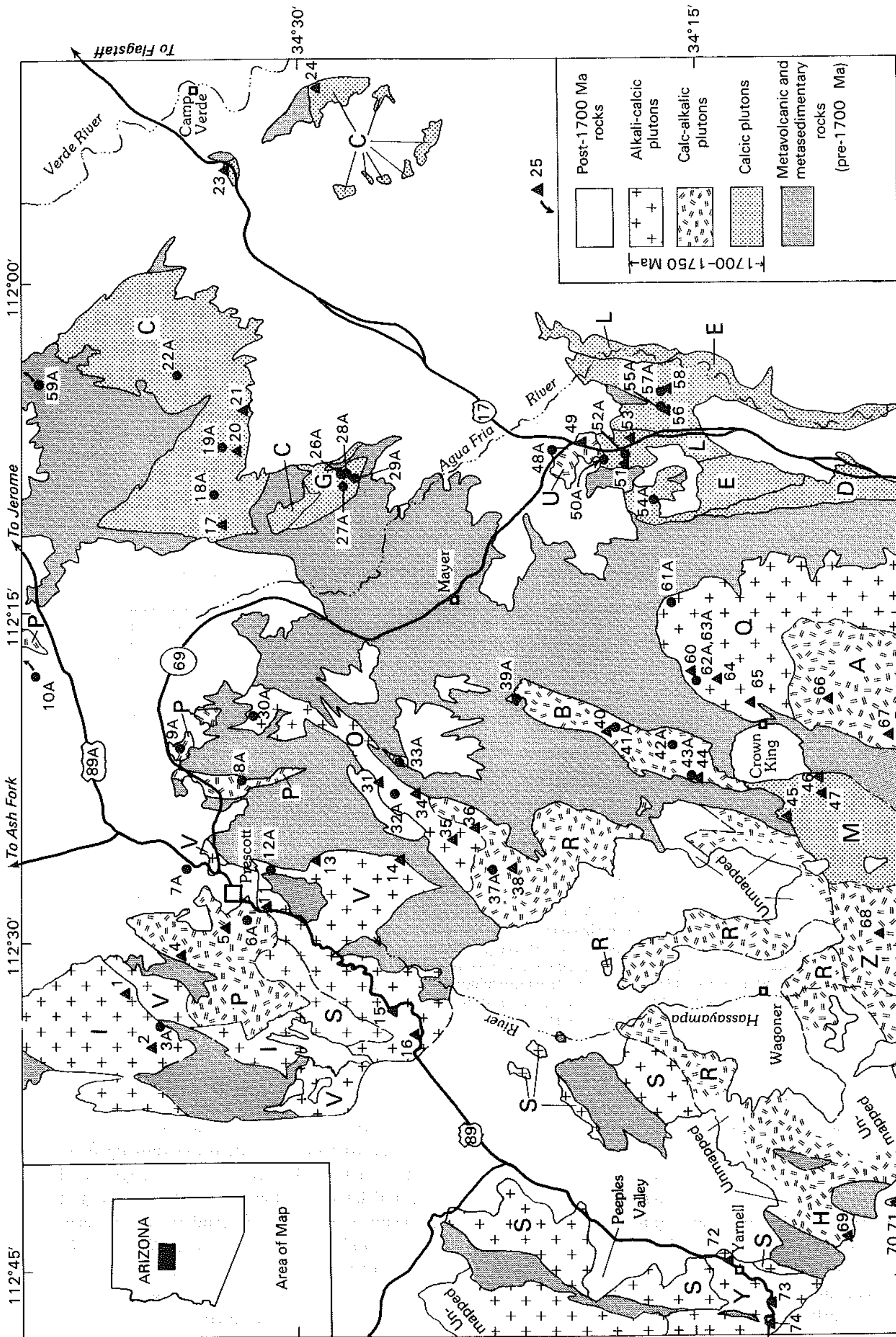


Figure 1. Simplified geologic map of the Prescott area, north-central Arizona, showing Early Proterozoic and post-Early Proterozoic rock units. Data from Krieger (1965, 1967), Anderson (1972), Anderson and Creasey (1958, 1967), Anderson and Blacet (1972a, 1972b, 1972c), DeWitt (1976, 1979), Jerome (1956), Light (1975), Hook (1956), Pflafker (1956), Wolfe (1983), and unpublished reconnaissance mapping by the author. All contacts, whether depositional, intrusive, or fault-related, are shown by the same kind of line. The Early Proterozoic metamorphic units (both pre- and postplutonic) consist of volcanic and sedimentary protoliths intruded by gabbroic masses. Sample numbers without an A are from this study. Sample numbers with an A are published and are from: Lee, 1984 (3A and 7A); Anderson and Blacet, 1972b (12A, 18A, 19A, 22A, 26A, 27A, 28A, 29A, 32A, 33A, and 37A); Anderson, 1972 (48A, 50A, 52A, 54A, 55A, and 57A); Krieger, 1965 (6A, 8A, 9A, 10A, and 30A); Anderson and Creasey, 1958 (59A); Blacet, 1968 (39A, 41A, 42A, 43A, and 62A), and Vrba, 1980 (61A and 63A). A, granodiorite of Lane Mountain; B, Brady Butte Granodiorite; C, tonalite of Cherry; D, quartz diorite of Bland; E, Badger Spring Granodiorite; G, granophyre of Cherry; H, granite of Rich Hill; I, granite of Iron Springs; L, Bumblebee Granodiorite; M, granodiorite of Minnehaha; O, Crooks Canyon Granodiorite [north]; P, Prescott Granodiorite; Q, Crazy Basin Quartz Monzonite; R, Crooks Canyon Granodiorite [south]; S, granodiorite of Wilhoit; U, granodiorite of Big Bug Creek; V, Government Canyon Granodiorite; Y, granodiorite of Yarnell; Z, granodiorite of Hozoni Ranch.

ideas concerning evolution of the metavolcanic terrane. Metasedimentary rocks are a minor part of the preplutonic bedrock in the northern and central parts of the region (fig. 1), but are approximately 25 percent in the southern part. All the preplutonic rocks have been metamorphosed to greenschist or higher metamorphic grade, possess a tectonic foliation that trends northeast in the western two-thirds of figure 1 and north in the eastern one-third, and have been mildly to isoclinally folded throughout.

Plutonic rocks in the Prescott area range in chemical and modal composition from tonalite to granite and in texture and structure from highly foliated, highly deformed to completely unfoliated and undeformed bodies. Some of the sampled plutons have been isotopically dated (Anderson and others, 1971; Bowring and others, 1986), but many have not. All of the plutons are believed to be 1700-1750 Ma because they have structural and chemical similarities to rocks of that age range dated elsewhere in Arizona (Silver, 1968; Conway, 1976; Ludwig, 1973; Silver and others, 1986; Bryant and Wooden, 1986). Numerous gabbroic plutons genetically associated with the mafic metavolcanic rocks are not discussed in this geochemical summary, but their approximate location is shown for reference on some minor-element plots. Gabbroic rocks are included with the metavolcanic and metasedimentary rocks on figure 1.

The formally named plutonic bodies discussed in this paper have been mapped and some of their major-element chemistry published by Anderson and Creasey (1958, 1967), Krieger (1965), Blacet (1966, 1968, 1985), Anderson (1972), and Anderson and Blacet (1972a, 1972b, 1972c). The bodies that are given informal names in this paper have been mapped in reconnaissance by the author. Diagnostic features, including names, isotopic age determinations, modal averages, mineralogy, magnetic susceptibility, and classifications according to major- and minor-element chemistry, are listed in table 1.

ANALYTICAL PROCEDURES

Samples for major- and minor-element analyses were collected from blasted roadcuts or fresh outcrops. Rocks for major-element analyses were ground in ceramic pulverizers to less than 200 mesh. Major elements were determined by X-ray fluorescence of fused disks. For minor-element determinations the rocks were ground in a jaw crusher, split, and pulverized to less than 200 mesh in a tungsten carbide ball mill. Approximately 5-6 grams of powder were pressed into pellets and analyzed by X-ray fluorescence using a Kevex energy-dispersive detector. Rb, Sr, Y, Nb, Zr, and total iron as FeO were analyzed with a ^{109}Cd source, and Ba, La, and Ce were analyzed with an ^{241}Am source. Detection limits for various elements are listed in table 2; the accuracy of the measurements is approximately ± 2 percent.

Samples for magnetic susceptibility measurements were those used for major- and minor-element geochemistry. A JH-8 susceptibility meter, manufactured by Geoinstruments Ky, Helsinki, Finland, was used for the measurements. The JH-8 meter has a sensitivity of 5×10^{-5} SI and can measure magnetic susceptibilities in the range 5×10^{-5} to 1×10^{-1} SI from natural specimens without the specimen having been drilled or cored. For purposes of this study, magnetite was assumed to be the only magnetic substance in the rocks. The percentage of magnetite was calculated from the measured magnetic susceptibility using a logarithmic Balsley-Buddington chart.

MAJOR- AND MINOR-ELEMENT GEOCHEMISTRY

The various plutonic bodies will be summarized in chronological order, from presumed oldest to youngest, and within each of four suites that have geochemical affinities. Because many of the plutons have not been dated, errors may exist in this sequential listing; I hope that the summary will indicate areas for future research, both geochemical and geochronologic.

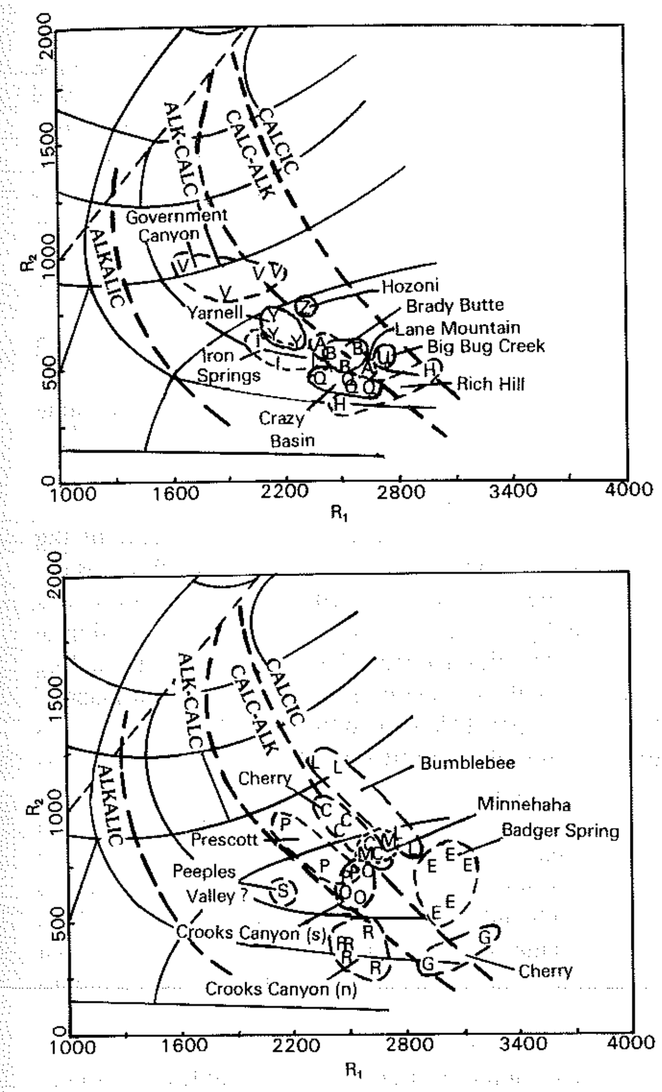
Rock names used in this paper are based on the chemical classification of De la Roche and others (1980). Modifiers include those based on Na_2O + K_2O concentration, i.e., calcic, calc-alkalic, and alkali-calcic (Peacock, 1931; Keith, 1978), degree of iron or magnesium enrichment (Miyashiro, 1974), K_2O concentration (Peccerillo and Taylor, 1976), and molar alumina saturation, i.e., metaluminous, mildly peraluminous, or strongly peraluminous (Shand, 1927; Keith, 1986). All dates have been recalculated using the decay constants recommended by Steiger and Jaeger (1977).

Suite 1: Pre-tectonic biotite granodiorite and granite plutons (moderately peraluminous, low to average Sr, very low magnetite).

Brady Butte Granodiorite (Blacet, 1966). This 1750 ± 10-Ma equigranular, calc-alkalic biotite granodiorite (figs. 2 and 3), the oldest dated pluton in north-central Arizona (Anderson and others, 1971), discordantly intrudes the metavolcanic terrane and is unconformably overlain by the metamorphosed and deformed Texas Gulch Formation (Blacet, 1968; O'Hara and others, 1978; Karlstrom and O'Hara, 1984). The pluton is foliated to gneissic throughout and is cut by numerous mylonitic zones that parallel the northeast-trending, high-angle foliation found in the metavolcanic terrane. The granodiorite exhibits marked iron and magnesium enrichment (fig. 4), an unusual feature for any 1700-1750-Ma pluton in the area. Brady Butte, somewhat surprisingly, is moderately to strongly peraluminous. Deformation of the pluton and growth of minor muscovite during regional metamorphism may account for the peraluminous nature of the body, as minor loss of alkali elements may have taken place during deformation. Brady Butte has the lowest percentage of magnetite (0.2 percent) of any of the granodioritic plutons studied. The granodiorite stands out as a 200-gamma magnetic low on the aeromagnetic

Table 1. Characteristics of 1700-1750-Ma plutonic rocks, north-central Arizona. [References for rock units: 1, Krieger (1965); 2, Blacet (1966, 1968); 3, Anderson and Blacet (1972b, 1972c); 4, Anderson and Creasey (1958); 5, Jerome (1956); 6, Vrba (1980); 7, Anderson and others (1971); 8, Karlstrom and Conway (1986); 9, Bowering and others (1986); 10, this study. Within groups, rock units listed in order of increasing alkalinity. Mode based on I.U.G.S. classification—gd, granodiorite; ton, tonalite; mzdi, monzodiorite; mzgr, monzogranite. Mineralogy—plag, plagioclase; qtz, quartz; mic, microcline; or, orthoclase; per, perthite; hb, hornblende; bt, biotite; ep, epidote; mt, magnetite; zr, zircon; ap, apatite; all, allanite; sph, sphene; ms, muscovite; kf, potassium feldspar. Rock names based on classification of De la Roche and others (1980); gd, granodiorite; ton, tonalite; gr, granite—see fig. 2 for explanation. Alkalinity based on both figs. 2 and 3—first entry is classification of fig. 2; entry in parentheses is classification of fig. 3—C, calcic; CA, calc-alkalic; AC, alkali-calcic. K_2O index based on classification of fig. 4—L, low; M, medium; H, high. Fe, Mg index based on classification of fig. 5—Mg, magnesium-rich; Fe, iron-rich; ~Mg, slightly magnesium-rich; ~Fe, slightly iron-rich; >Mg, strongly; magnesium-rich; >Fe, strongly iron-rich; ≥Fe, slightly to strongly iron-rich; Mg=Fe, neither iron- nor magnesium-rich. Al index based on molar ratio of Al/Ca+Na+K—M, metaluminous, <1; <1; ~P moderately peraluminous, >1, but <1.1; >P, strongly peraluminous, >1.1. Suites are those discussed in the text. --, characteristic not determined. *, unusual characteristic that is discussed in text]

Rock Unit (reference)	Age (Ma)	Mode (IUGS)	Mineralogy	Magnetite (%)	Rock name	Alkalinity	K_2O index	Fe, Mg index	Al index	Suite
Calcic Rocks										
Badger Spring Granodiorite (3)	<1720	--	Plag-qtz-bt-kf-sph-zr-ap	1.5	Gd	C (C)	L-M	~Mg	M	3
Bumblebee Granodiorite (3)	~1720	--	Plag-hb-qtz-kf-sph-ap-zr-mt	1.6	Gd-ton	C (C)	M	Fe*-Mg	M	3
Granodiorite of Minnehaha (10)	--	--	--	0.9	Gd	C (CA)	M	Mg	M	1
Tonalite of Cherry (4,7)	1740 ± 15	Ton-gd	Plag-or,mic-qtz-hb-bt-mt-ap-sph	7.0	Ton	CA-C (CA)	M	Mg	M	2
Granophyre of Cherry (4)	~1740	--	--	--	Gr	CA-C (C)	M-L	Fe	>P*	2
Quartz Diorite of Bland (5,9)	1720	--	Plag-hb-bt-qtz	0.2	--	--	--	--	--	3
Calc-Alkalic Rocks										
Crooks Canyon Granodiorite [South] (10)	<1750	--	--	1.5	Gd	CA (CA)	M	Mg	~P	1
Prescott Granodiorite (1)	<1750	Gd	Plag-qtz-mic,or-bt-ep-sph-mt-zr-ap	4.2	Gd	CA (CA-AC)	M	>Mg	~P*	2
Granodiorite of Big Bug Creek (10)	--	--	--	0.2	Gd	CA (C*)	L*	~Mg	>P*	1
Granite of Rich Hill (10)	--	--	--	0.8	Gr	CA-AC (CA-AC)	M-H	Mg=Fe	~P	1
Brady Butte Granodiorite (2,7)	1750 ± 10	Gd	Plag-qtz-mic-bt-ep-sph-mt-ms	0.2	Gd	CA-AC (CA)	M-H	>Mg->Fe*	~P->P	1
Granodiorite of Lane Mountain (10)	--	--	--	0.7	Gd	CA-AC (CA)	M	~Mg	M	1
Granodiorite of Hozoni Ranch (10)	--	--	--	2.8	Gd	CA (CA-AC)	H	~Mg	M	4
Alkali-Calcic Rocks										
Government Canyon Granodiorite (1)	1750 ± 15	Gd-mzdi	Plag-qtz-or-hb-bt-ep-sph	4.5	Ton	AC (AC)	M*-H	>Mg	M	2
Granodiorite of Wilhoit (10)	~1750	--	--	3.5	Gd	AC (AC)	--	--	--	2
Granodiorite of Yarnell (10)	--	--	--	8.0	Gd	AC (AC)	H	~Fe	M	4
Granite of Iron Springs (10)	--	--	--	5.3	Gr-gd	AC (AC)	H	~Mg	M	4
Crazy Basin Quartz Monzonite (2,6,8)	1700 ± 5	--	Mic-plag-qtz-bt-ms-sph-mt-zr	0.5	Gr	AC (AC)	H	≥Fe	~P	4
Crooks Canyon Granodiorite [North] (3,10)	<1750	Gd-mzgr	Mic,per-plag-bt-qtz-zr-all	1.5	Gr	AC (AC)	H	≥Fe	~P	1



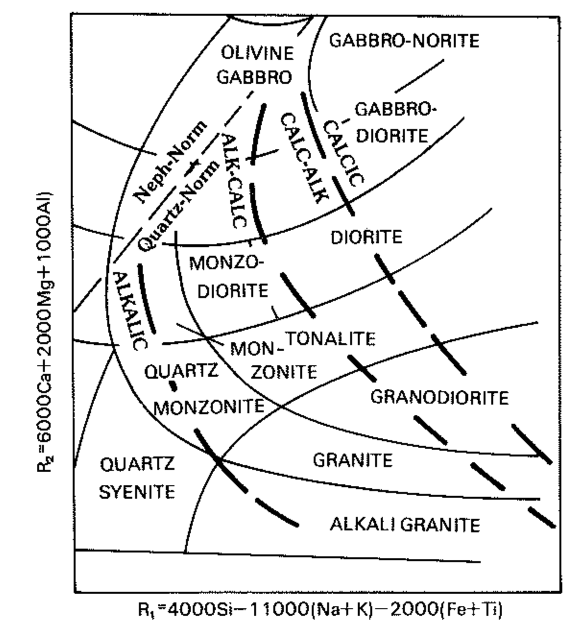


Figure 2. R_1-R_2 classification (De la Roche and others, 1980) for 1700-1750-Ma plutonic rocks, north-central Arizona. Data from Anderson (1972), Anderson and Blacet (1972b), Anderson and Creasey (1958), Blacet (1968), Krieger, (1965), Lee (1984), Vrba (1980), and this study. A, granodiorite of Lane Mountain; B, Brady Butte Granodiorite; C, tonalite of Cherry; E, Badger Spring Granodiorite; G, granophyre of Cherry; H, granite of Rich Hill; I, granite of Iron Springs; L, Bumblebee Granodiorite; M, granodiorite of Minnehaha; O, Crooks Canyon Granodiorite [north]; P, Prescott Granodiorite; Q, Crazy Basin Quartz Monzonite; R, Crooks Canyon Granodiorite [south]; S, granodiorite of Wilhoit; U, granodiorite of Big Bug Creek; V, Government Canyon Granodiorite; Y, granodiorite of Yarnell; Z, granodiorite of Hozoni Ranch. Names of rock types shown in inset. Calcic, calc-alkalic, alkali-calcic, and alkalic field boundaries from DeWitt (unpub. data, 1986) and from the boundaries on figure 3.

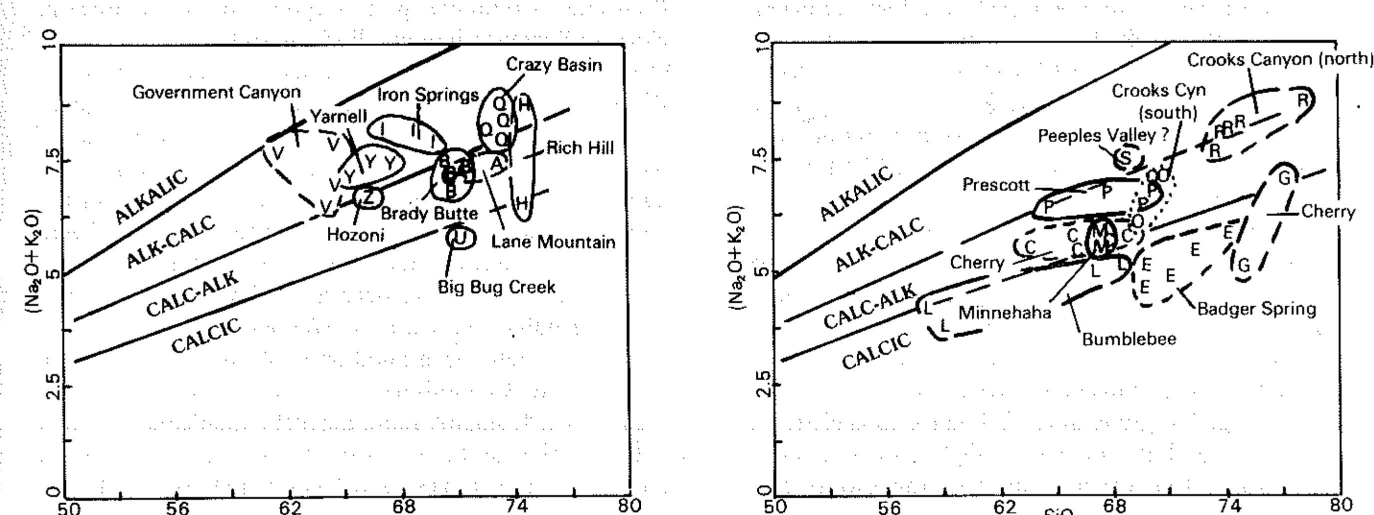


Figure 3. $Na_2O + K_2O$ versus SiO_2 diagrams for 1700-1750-Ma plutonic rocks, north-central Arizona. Calcic, calc-alkalic, alkali-calcic, and alkalic field boundaries from Anderson (1983) and DeWitt (unpub. data, 1986). Plotting symbols as in figure 2.

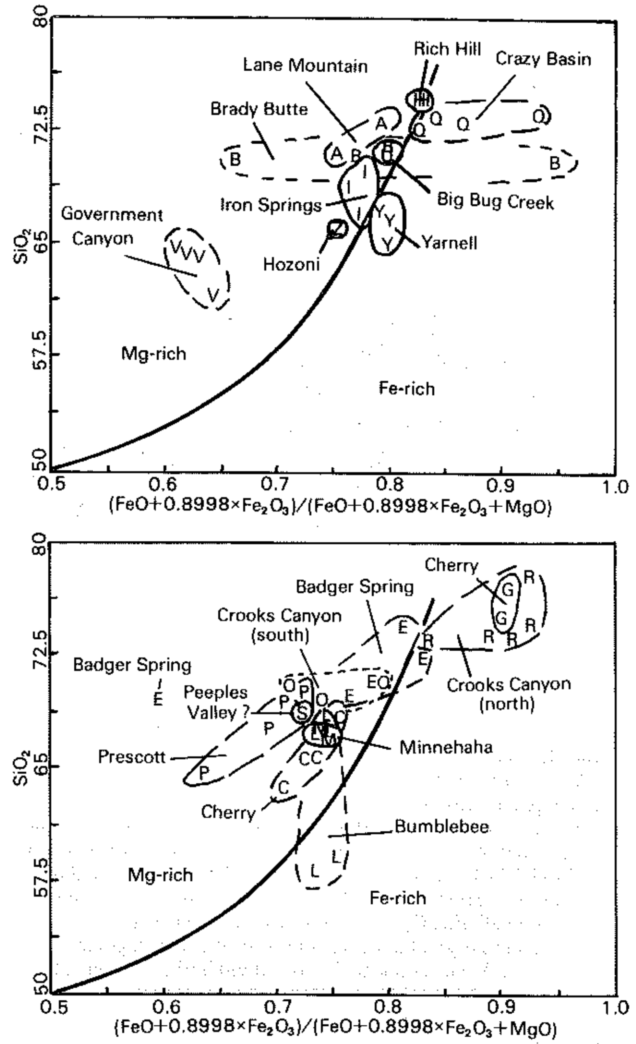


Figure 4. SiO_2 versus $(FeO + 0.90Fe_2O_3)/(FeO + 0.90Fe_2O_3 + MgO)$ diagram for plutonic rocks, north-central Arizona. Mg-rich and Fe-rich field boundary from Miyashiro (1974) as modified by Anderson (1983). Fields originally called calc-alkaline (Mg-rich) and tholeiitic (Fe-rich) by Miyashiro (1974). Plotting symbols as in figure 2.

map of the Bradshaw Mountains (U.S. Geological Survey, 1972) and on the residual intensity anomaly map of the Prescott 1° by 2° quadrangle (Aero Services, 1983). Brady Butte has average Ba, Rb, Sr, Zr, Nb, La, and Ce concentrations relative to the other studied plutons but could be considered a trondhjemite (Barker, 1979) on the basis of its relatively low Rb concentration.

Granodiorite of Minnehaha (new informal name). This equigranular, calcic biotite-hornblende granodiorite is the southwestern extension of the Brady Butte Granodiorite but is given an informal new name because of its more calcic nature and more mafic composition. The pluton is named for exposures along Minnehaha Creek, 3 miles southwest of Crown King. The granodiorite is foliated to gneissic on its western margin but is massive to slightly foliated on its eastern margin. Relative ages of this granodiorite and Brady Butte are unknown. Magnetite concentration of the pluton is low (0.9 percent), especially for a relatively hornblende-rich granodiorite. The aeromagnetic low defined by the Brady Butte Granodiorite is interrupted by the Cretaceous stock at Crown King (DeWitt, 1976), but a low of lesser magnitude continues southwest along this granodiorite (U.S. Geological Survey, 1972). The pluton exhibits moderate magnesium enrichment (fig. 4) similar to most of the 1700-1750-Ma plutons. The granodiorite has identical minor-element chemistry to Brady Butte except that it contains slightly less Sr. The Brady Butte Granodiorite and this pluton probably were derived from a very similar parent magma.

The granodiorite of Minnehaha could belong to suite 2 and be related to the tonalite of Cherry. However, the granodiorite is very depleted in Sr and magnetite for a suite 2 pluton. Additional study may be necessary to determine in which suite the granodiorite belongs.

Granodiorite of Big Bug Creek (new informal name). The equigranular, calc-alkalic biotite granodiorite of Big Bug Creek is megascopically identical to the Brady Butte Granodiorite. Previously, much of the granodiorite was described by Anderson and Blacet (1972c) as a diorite porphyry. The pluton is named for exposures along Big Bug Creek, about 9 miles southeast of Mayer. Size and shape of the body are poorly known at present. The granodiorite is highly foliated, contains very little magnetite, has anomalously low total alkalis (fig. 3) and K_2O (fig. 5), and is strongly peraluminous. Quite likely the granodiorite has been depleted in alkali elements during deformation and metamorphism. The one analysis of the pluton indicates very low Rb and low Ba compared to either Brady Butte or Minnehaha. The granodiorite may belong to suite 3 but would be unusual for that group because of its peraluminous nature.

Crooks Canyon Granodiorite (Anderson and Blacet, 1972a). The southern part of this granodiorite is a medium-grained, equigranular, leucocratic, calc-alkalic biotite granodiorite and is one of the largest plutonic bodies in the Prescott area. The granodiorite extends southwest from the Bradshaw Mountains past Wagoner to the southwest. North of Wagoner the granodiorite intrudes the granodiorite of Wilhoit. Some of the body southwest of the Hassayampa River is unmapped. Northwest and southwest of Wagoner the -400 gamma-contour on the magnetic anomaly map of the Prescott 1° by 2° quadrangle (Aero Services, 1983) appears to approximately delineate the boundaries of the pluton. The equigranular part of the body is mildly foliated in most exposures, but its late felsic differentiates are undeformed. These felsic rocks cut the foliated granodiorite of Minnehaha southeast of Wagoner. Although more leucocratic than the granodiorite of Minnehaha or the Brady Butte Granodiorite, the southern part of this granodiorite is slightly more magnetic than either of them (table 2). The southern part of this body is low in Rb, Y, La, and Ce (fig. 6; tables 2 and 3) compared to other plutons in the area. The minor-element concentrations of the southern part of Crooks Canyon strongly resemble those of the granodiorite of Lane Mountain described below.

The northern part of Crooks Canyon, a medium- to fine-grained, leucocratic, alkali-calcic biotite granite, differs from the southern part by having higher SiO_2, total alkalis, and K_2O and by being moderately to strongly iron rich. The granite is variably foliated to strongly mylonitic, indicating a pretectonic age of the body. Most of what Anderson and Blacet (1972a) described as Crooks Canyon has the same texture as this fine-grained northern part of the body. Magnetite concentration in the northern part is the same as the southern part. Minor-element concentrations, particularly higher than average Ba, Y, La, and Ce, and lower than average Sr, indicate that the northern part of the body is

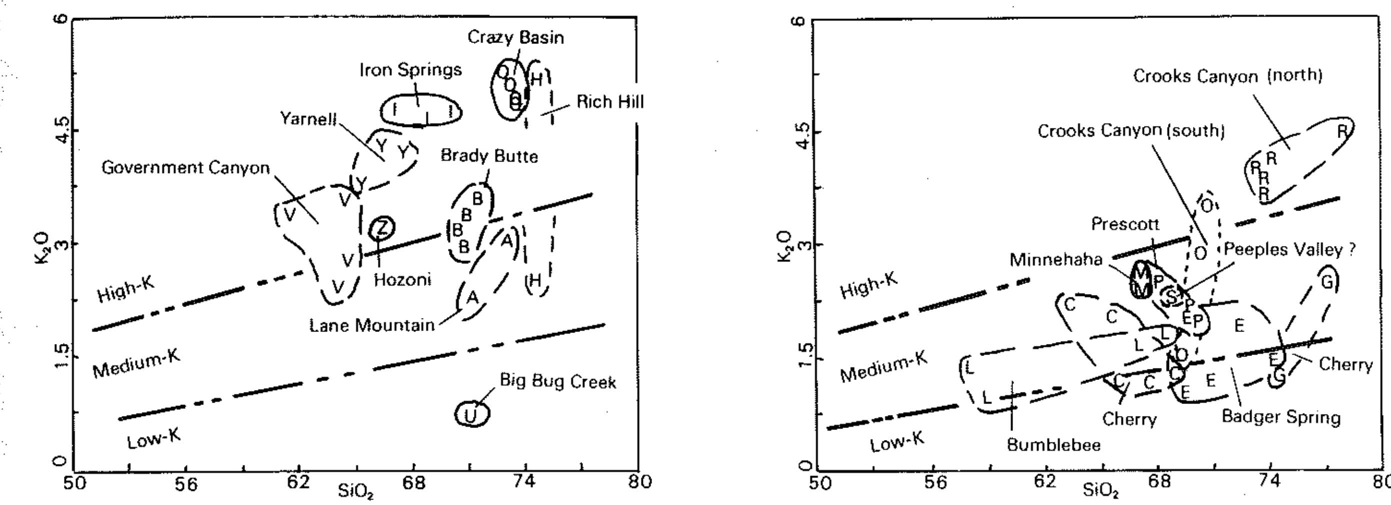


Figure 5. K_2O versus SiO_2 diagrams for 1700-1750-Ma plutonic rocks, north-central Arizona. Low-K, medium-K, and high-K field boundaries from Peccerillo and Taylor (1976). Plotting symbols as in figure 2.

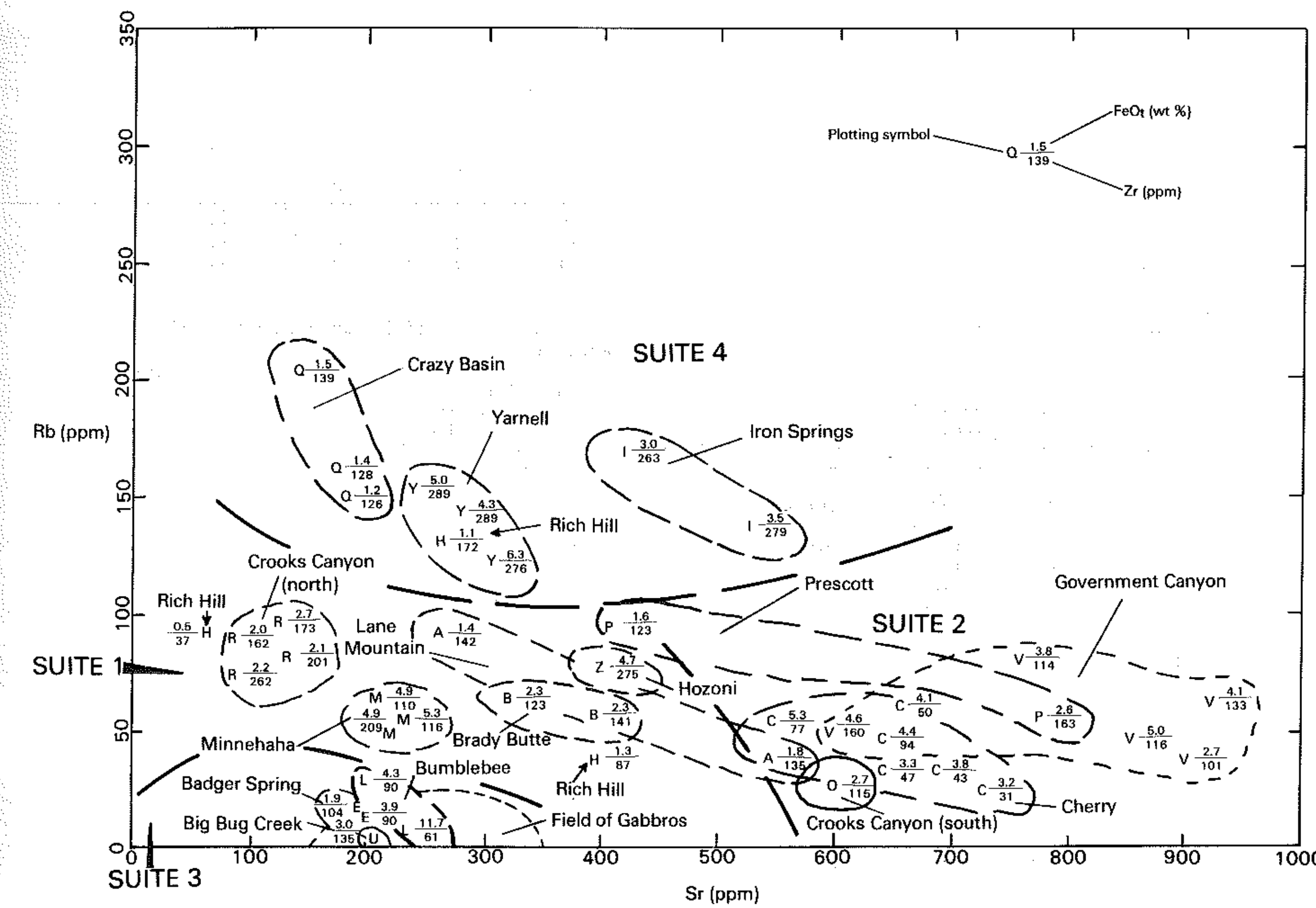


Figure 6. Rb versus Sr diagram for 1700-1750-Ma plutonic rocks, north-central Arizona. Fields of suites 1-4 (discussed in text) are shown. Plotting symbols as in figure 2.

much more evolved than the southern part. A 200-gamma, northeast-trending magnetic low (U.S. Geological Survey, 1972) delineates the body. The high La, Ce, and Y concentrations in the body probably account for abundant allanite in the granite, a mineral that strongly partitions Ce and light rare-earth elements (Arth and Hanson, 1975; Dodge and others, 1982). Except for the much higher Zr concentration in the northern part of the pluton, the two phases could be related to one another by simple fractional crystallization, which would also explain the strong iron enrichment trend for the northern part of the body.

Granodiorite of Lane Mountain (new informal name). This equigranular to slightly porphyritic calc-alkalic to alkali-calcic biotite granodiorite was mistakenly assumed to be part of the Crazy Basin Quartz Monzonite by DeWitt (1976, 1979) but is now known to be a foliated pluton older

Table 2. Major- and minor-element chemistry of 1700-1750-Ma plutonic rocks, north-central Arizona. [Number, i.e. 2, refers to sample location on fig. 1; letter in parentheses (M) is plotting symbol on figs. 2-8; major-element oxides (in weight percent) determined by X-ray fluorescence by J.E. Taggart, A.J. Bartel, and K.C. Stewart; Fe_tO_3, total iron as Fe_2O_3; LOI, loss on ignite minor elements (in parts per million) determined by X-ray fluorescence by Ed DeWitt and Ross Yeoman on Kevex detector; [6] detection limit for element listed; --, below detection limit for element listed]

Rock Unit, Field Sample Number

	Granite of Iron Springs		Government Canyon Granodiorite			Tonalite of Cherry		Crooks Canyon Granodiorite (north)		
	12-1-84-4	11-30-84-9	11-30-84-6	11-30-84-4	11-26-84-2	11-27-84-1	11-27-84-3	11-30-84-2	12-1-84-2	12-1-84-1
	1 (I)	2 (I)	11 (V)	14 (V)	15 (V)	17 (C)	21 (C)	31 (R)	35 (R)	36 (R)
SiO_2	70.0	67.0	64.5	64.5	64.0	63.3	67.5	74.0	73.3	73.6
Al_2O_3	13.9	15.0	15.2	15.2	15.1	15.8	16.2	13.0	13.3	13.2
Fe_tO_3	3.78	4.06	4.67	4.32	5.07	5.74	3.69	2.41	2.50	2.63
MgO	0.98	1.05	2.62	2.47	2.67	2.15	1.12	0.18	0.45	0.24
CaO	2.02	2.53	4.44	3.73	4.54	5.23	4.38	0.97	1.55	1.15
Na_2O	3.01	3.30	4.12	4.09	3.96	3.29	4.21	4.02	3.59	4.10
K_2O	4.77	4.72	2.73	3.61	2.36	2.20	1.23	4.06	3.98	3.86
TiO_2	0.61	0.72	0.51	0.45	0.71	0.45	0.31	0.15	0.21	0.18
P_2O_5	0.22	0.25	0.32	0.23	0.28	0.18	0.15	0.05	0.06	<0.05
MnO	0.08	0.09	0.06	0.05	0.06	0.09	0.06	0.06	0.06	0.06
LOI	0.52	0.60	0.60	0.79	0.98	1.14	1.71	0.61	0.53	0.35
Total	99.89	99.32	99.77	99.44	99.73	99.57	100.56	99.51	99.53	~99.39
Ba [6]	1557	1782	802	1085	831	710	598	1315	1166	1438
Rb [6]	168	134	60	80	46	48	24	84	96	73
Sr [6]	415	524	924	761	598	544	725	84	124	93
Y [5]	31	33	13	6	12	10	--	49	36	51
Zr [4]	263	279	133	119	160	77	31	262	173	262
Nb [3]	25	29	16	15	22	12	12	23	19	24
La [6]	96	92	39	49	51	27	23	93	54	80
Ce [7]	196	162	91	91	100	38	30	169	96	144

Table 2. (cont.)

Rock Unit, Field Sample Number

	Crooks Canyon Granodiorite (south)	Granodiorite of Minnehaha		Bumblebee Granodiorite		Badger Spring Gd	Crazy Basin Quartz Monzonite	Granodiorite of Lane Mountain		Granodiorite of Hozoni Ranch
	12-1-84-3	11-29-84-4	11-28-84-11	11-27-84-12	11-27-84-7	11-27-84-11	11-28-84-1	11-28-84-5	11-28-84-9	11-29-84-5
	38 (O)	45 (M)	47 (M)	51 (L)	53 (L)	56 (E)	60 (O)	66 (A)	67 (A)	68 (Z)
SiO_2	69.1	67.2	67.1	58.9	68.5	70.8	72.8	73.0	70.8	66.2
Al_2O_3	16.0	14.8	15.0	14.5	14.0	14.0	14.2	14.8	15.3	14.7
Fe_tO_3	3.10	5.43	4.73	10.2	4.80	4.21	1.78	1.80	2.18	5.41
MgO	1.00	1.73	1.44	3.00	1.49	0.98	0.34	0.42	0.65	1.58
CaO	3.53	4.38	4.11	6.90	4.20	4.02	1.33	1.76	2.39	3.76
Na_2O	4.46	3.02	3.18	2.68	3.23	3.39	2.92	4.15	4.91	3.39
K_2O	1.46	2.38	2.59	0.98	1.85	1.16	5.25	3.07	2.15	3.20
LOI	0.92	0.45	1.00	1.80	1.18	1.19	0.54	0.45	0.88	0.39
TiO_2	0.29	0.43	0.36	0.90	0.41	0.32	0.15	0.22	0.29	0.72
P_2O_5	0.12	0.14	0.64	0.33	0.13	0.10	0.08	0.07	0.10	0.28
MnO	0.06	0.09	0.08	0.18	0.08	0.08	0.04	0.02	<0.02	0.09
Total	100.04	100.05	100.23	100.44	99.87	100.25	99.43	99.76	~99.66	99.72
Ba	723	779	759	391	686	533	917	829	547	1438
Rb	34	49	49	7	24	9	202	89	45	73
Sr	598	231	209	253	207	202	139	261	543	393
Y	--	19	16	20	13	11	9	--	--	27
Zr	115	116	109	61	90	90	139	142	135	275
Nb	17	14	16	14	13	11	24	15	12	23
La	33	42	28	21	25	25	62	29	29	81
Ce	63	68	56	36	45	43	107	59	56	139

Table 2. (cont.)

Rock Unit, Sample Number

	Granite of Rich Hill		Granodiorite of Yarnell		
	11-25-84-2	11-25-84-3A	11-26-84-1	11-24-84-2	11-24-84-1
	69 (H)	70 (H)	72 (Y)	73 (Y)	74 (Y)
SiO_2	74.5	74.5	67.4	66.3	65.1
Al_2O_3	13.1	13.8	14.5	14.1	14.3
Fe_tO_3	1.50	1.64	4.98	5.45	6.65
MgO	0.28	0.31	1.17	1.22	1.52
CaO	0.66	1.85	2.57	2.84	3.43
Na_2O	3.43	3.85	3.08	3.10	3.14
K_2O	5.12	2.47	4.18	4.33	3.78
LOI	0.48	0.86	0.55	0.76	0.65
TiO_2	0.19	0.12	0.80	0.79	1.02
P_2O_5	0.05	0.02	0.27	0.34	0.39
MnO	0.04	0.06	0.12	0.11	0.13
Total	99.36	99.49	99.62	99.34	100.11
Ba	1167	1257	1129	1084	1034
Rb	141	39	143	145	117
Sr	276	394	276	248	296
Y	14	9	56	35	53
Zr	172	87	289	289	276
Nb	34	17	31	28	30
La	94	34	71	80	69
Ce	148	49	157	166	142

Table 3. Minor-element concentrations of 1700-1750-Ma plutonic rocks, north-central Arizona. [Sample numbers as in fig. 1; [0.02], detection limits for elements listed; --, element not detected; analyzed by X-ray fluorescence on Kevex detector by Ed DeWitt and Ross Yeoman; plotting symbols are those in figs. 2-8]

Rock Unit	Plotting symbol	Sample No.	FeO (%) [0.02]	Ba (ppm) [6]	Rb (ppm) [6]	Sr (ppm) [6]	Y (ppm) [5]	Zr (ppm) [4]	Nb (ppm) [3]	La (ppm) [6]	Ce (ppm) [7]
Prescott Granodiorite	P	4	2.6	1320	53	785	10	163	17	49	80
Prescott Granodiorite	P	5	1.6	1107	95	417	6	123	16	40	67
Government Cyn. Gd.	V	13	5.0	869	43	846	11	116	14	52	99
Government Cyn. Gd.	V	16	2.7	971	37	893	8	101	14	48	74
Tonalite of Cherry	C	20	3.8	630	31	676	6	43	6	22	32
Tonalite of Cherry	C	23	3.3	540	29	649	5	47	9	21	29
Tonalite of Cherry	C	24	4.1	661	56	651	--	50	9	24	33
Tonalite of Cherry	C	25	4.4	545	50	637	9	94	15	30	66
Crooks Cyn. Granodiorite	R	34	2.1	1087	77	134	36	201	24	75	151
Brady Butte Granodiorite	B	40	2.3	1289	52	399	11	141	20	52	80
Brady Butte Granodiorite	B	44	2.3	1041	61	316	21	123	16	49	84
Granodiorite of Minnehaha	M	46	4.9	1024	49	214	19	110	16	30	54
Gd. of Big Bug Creek	U	49	3.0	385	4	201	42	135	13	29	53
Badger Spring Gd.	E	58	1.9	799	13	185	18	104	18	28	46
Crazy Basin Qtz. Monz.	Q	64	1.4	879	157	174	11	128	20	75	135
Crazy Basin Qtz. Monz.	Q	65	1.2	1065	153	186	6	126	20	58	111
Granite of Rich Hill	H	71	0.5	577	87	63	19	37	21	22	40

than Crazy Basin. The pluton is named for exposures on Lane Mountain, about 4 miles south of Crown King. The granodiorite is poorly exposed in the southern Crown King area. Contacts of the granodiorite with Crazy Basin are approximate but correspond closely to the 2600-gamma contour on the aeromagnetic map of the Bradshaw Mountains (U.S. Geological Survey, 1972). The body is very similar in major-element chemistry to the southern part of the Crooks Canyon Granodiorite (figs. 2, 4, and 5). Minor-element concentrations, especially very low Y and relatively low Rb, La, and Ce, also are very similar to the southern part of Crooks Canyon.

Granite of Rich Hill (new informal name). This equigranular, calc-alkalic to alkali-calcic muscovite-biotite granite southeast of Yarnell is the most leucocratic rock in the region. The pluton is named for Rich Hill, about 4 miles southeast of Yarnell. The northeastern extension of the body has not been mapped, but may be gradational into the southern part of the Crooks Canyon Granodiorite southwest of Wagoner. The western part of the granite is situated over a 300-gamma magnetic high (U.S. Geological Survey, 1972) believed to be caused by magnetic lithologies in the older metavolcanic terrane, not by the weakly magnetic granite. The granite also is on the southeast shoulder of a 400-gamma magnetic high caused by the granodiorite of Yarnell and could be underlain by that highly magnetic granodiorite. The granite is mildly foliated, but late felsic differentiates do not appear to be as foliated as the medium-grained granite. Minor-element concentrations of the granite are variable (tables 2 and 3) but similar to those in the granodiorite of Lane Mountain and the southern part of Crooks Canyon. Quite possibly more than one leucocratic pluton may be present in the area southeast of Yarnell. The most leucocratic units of Rich Hill are depleted in Zr, Y, Ce, and La compared to the main granite and appear to be aplitic phases of the granite.

Suite 2: Pre- to syntectonic hornblende-biotite tonalite and granodiorite plutons (metaluminous, high Sr, high magnetite).

Tonalite of Cherry (new informal name). This equigranular, calc-alkalic to calcic hornblende-biotite tonalite to granodiorite (quartz diorite of Anderson and Creasey, 1958) is undeformed in the center and east, but tectonically foliated in the west. Granophyre associated with the tonalite is also calc-alkalic to calcic (figs. 2 and 3). However, this granophyre is also strongly peraluminous (table 1), which raises questions about deuteric alteration of the granophyre during late-stage crystallization. The tonalite is magnesium rich, but the granophyre is iron rich, a possible consequence of fractional crystallization of the granophyre from a tonalitic magma. The informal name is taken from Cherry, about 12 miles south of Jerome and 10 miles east of Camp Verde. The pluton was intruded 1740 ± 15 Ma (Anderson and others, 1971) and cooled rapidly to <250° C by 1685 to 1690 Ma (Lanphere, 1968, Dalrymple and Lanphere, 1974). Other 1700-Ma plutons to the west such as Brady Butte and the Prescott Granodiorite either were deeply buried or were reheated at or prior to 1300 Ma (Marvin and Cole, 1978). A swarm of north-trending granodiorite porphyry dikes cuts the tonalite of Cherry; these dikes may be genetically related to the Badger Spring Granodiorite as suggested below. The tonalite averages 7.0 percent magnetite, second in abundance only to the granodiorite of Yarnell. Much of the outcrop area of the tonalite, however, is not an aeromagnetic high as might be expected, but is magnetically similar to the metavolcanic terrane it intrudes (Dempsey and others, 1963; U.S. Geological Survey, 1972). Either the tonalite is a thin, sheetlike body, or it is reversely polarized to account for the lack of an associated magnetic high. The tonalite of Cherry is distinguished from other plutons of this group by its low concentrations of Rb, Zr, La, and Ce. Y is low in all plutons of this group. A peculiar feature of the tonalite is that rocks that contain the most Sr contain the least Fe, a trend not found in most 1700-1750-Ma plutons studied.

Government Canyon Granodiorite (Krieger, 1965). This equigranular, alkali-calcic hornblende-biotite tonalite is megascopically similar to the tonalite of Cherry, is predominantly massive, but in places possesses a mild tectonic foliation. The tonalite is 1750 ± 15 Ma (Anderson and others, 1971), an age indistinguishable from that of the tonalite of Cherry. Government Canyon is one of the most magnesium-rich plutons studied (fig. 4), comparable only to the Prescott Granodiorite discussed below. Magnetite concentration averages 4.5 percent, similar to the Prescott Granodiorite, but much of the outcrop area of Government Canyon is not a pronounced aeromagnetic high (Aero Services, 1983). This feature of Government Canyon is similar to the magnetic signature of the tonalite of Cherry. Government Canyon has the highest Sr concentration of any studied pluton (fig. 6) and is characterized by low Rb and Y, a distinctive feature of all plutons of this group. Both Government Canyon and the tonalite of Cherry could be interpreted as the tonalite part of the "trondhjemite-tonalite" suite of Barker (1979).

Granodiorite of Wilhoit (Anderson, 1986a, this volume). A large body of equigranular biotite-hornblende granodiorite containing distinctive, hexagonal plates of biotite extends from south of Yarnell to west of Prescott and underlies much of Peeples Valley (fig. 1). The granodiorite is mildly foliated in most exposures but appears more massive in isolated outcrops. West of Prescott the granodiorite intrudes the Government Canyon Granodiorite, but north of U.S. Highway 89 the granodiorite may be a leucocratic core phase of Government Canyon. The granodiorite is named for exposures near Wilhoit and in Peeples Valley, north of Yarnell, where the western edge of the pluton is a north-trending belt of metavolcanic rocks. North of Wagoner the Crooks Canyon Granodiorite intrudes the granodiorite as a massive swarm of leucocratic dikes and aplite bodies. The granodiorite, as used here, is a single

intrusive body, not a composite of a number of plutonic units as used by Anderson (1986a).

Chemical data are largely lacking for the granodiorite of Wilhoit. Sample 7A (fig. 1) may be from a rock of similar composition, an alkali-calcic granodiorite. Leucocratic varieties of the pluton are somewhat unusual for suite 2 rocks because of their low concentration of magnetite (~0.8 percent), but normal to mafic varieties of the pluton average 3.5-5 percent magnetite. The pluton is shown as an alkali-calcic body on figure 1 because of its megascopic similarity to leucocratic phases of the Government Canyon Granodiorite.

Prescott Granodiorite (Krieger, 1965). This equigranular to slightly porphyritic, calc-alkalic biotite granodiorite intrudes the Government Canyon Granodiorite and is undeformed. Some of the covered area northeast of Prescott may be underlain by this granodiorite (fig. 1), but northwest-trending magnetic highs and lows (Dempsey and others, 1963) that appear to represent buried metavolcanic lithologies indicate that not all the covered area is Prescott Granodiorite. The granodiorite has a relatively high percentage of magnetite (4.2 percent), is strongly magnesium rich, and is moderately peraluminous (table 3), an unusual feature for a rock of this nature. The moderately peraluminous nature appears to be due to slightly elevated alumina concentration, not a loss of alkali elements. The Prescott Granodiorite has relatively high Ba (highest in this suite) and Sr and low Y, characteristic features for plutons of this group. The granodiorite could have been derived from a magma similar to that of the Government Canyon Granodiorite by fractional crystallization.

Suite 3: Pre- to late-tectonic biotite-hornblende granodiorite plutons (metaluminous, low Rb, Zr, La, and Ce, very low Sr, and low magnetite).

Bumblebee Granodiorite (Anderson and Blacet, 1972c). This equigranular, calcic hornblende granodiorite intrudes metavolcanic units along and west of the Agua Fria River (fig. 1). Most of the Bumblebee is undeformed, but its western margin is tectonically foliated, indicating that the granodiorite is pretectonic to late tectonic. The border phase of the granodiorite, as mapped by Anderson and Blacet (1972b), is a diorite (fig. 2) that is iron rich (fig. 4), compared to the magnesium-rich main phase of the granodiorite. This reverse zoning of iron and magnesium may indicate that two separate plutons may be present instead of one. Also, dioritic to gabbroic sills and hypabyssal intrusive bodies related to the metavolcanic terrane are typically iron rich (DeWitt, unpub. data, 1986), indicating that the border phase of the Bumblebee may be older than the main granodiorite and not related to it. The granodiorite has low concentrations of Rb, La, and Ce, and is representative of this group of rather primitive plutons that have trace-element concentrations very similar to gabbro bodies that intrude the metavolcanic terrane (fig. 6).

Quartz Diorite of Bland (Jerome, 1956). A large body of equigranular hornblende-biotite quartz diorite, most of which is southeast of figure 1, intrudes metavolcanic rocks along Interstate highway 17. Jerome (1956) and Winn (1982) noted the highly foliated nature of much of the body, which has a U-Pb zircon age of 1720 Ma (Bowring and others, 1986). All textural and compositional phases of the body have very low magnetite concentrations averaging 0.2 percent. Major- and minor-element chemistry is lacking for the quartz diorite, but the pluton is shown as a calcic body on figure 1 because of its mineralogic similarity to the Bumblebee Granodiorite. The Badger Spring Granodiorite intrudes the quartz diorite but may be genetically related to it.

Badger Spring Granodiorite (Anderson and Blacet, 1972c). This porphyritic (quartz phenocrysts), calcic granodiorite intrudes the Bumblebee and is undeformed except locally along its western margin. Much of its plagioclase is altered to clinozoisite plus sericite, indicating that the pluton has been regionally metamorphosed or deuterically altered. The north-trending granodiorite porphyry dike swarm that cuts the tonalite of Cherry (Anderson and Creasey, 1967) is believed to be derived from this granodiorite because an analysis of one dike plots in the Badger Spring field in figure 2. For a pluton with a SiO_2 concentration of 70-72 percent, the Badger Spring has a very primitive minor element signature of low Rb, La, and Ce, and plots next to the Bumblebee in the field of gabbro bodies related to the metavolcanic terrane. The area along Interstate Highway 17 occupied by the Bumblebee and Badger Spring plutons coincides with a broad, low-amplitude magnetic low (U.S. Geological Survey, 1972). The 2400-gamma contour may approximately coincide with the buried contact of these plutons with the tonalite of Cherry.

Suite 4: Syn- to posttectonic biotite granodiorite to granite plutons (metaluminous, high Ba, Rb, Zr, La, and Ce, moderate to high magnetite).

Granodiorite of Yarnell (new informal name). This equigranular to slightly porphyritic, alkali-calcic biotite granodiorite is the westernmost foliated pluton in the study area and is named for exposures near Yarnell. The extent of the pluton to the northwest is poorly known; some of what is shown as granodiorite of Yarnell on figure 1 may turn out to be an alkali-calcic granite that occupies much of the high country of the Weaver Mountains (DeWitt, unpub. data, 1986). The granodiorite is relatively massive in the east but is progressively more deformed and slightly more mafic to the west. The Yarnell intrudes metavolcanic and metasedimentary rocks and the granodiorite of Wilhoit. Although the pluton is undated, it is assumed to be 1700-1750 Ma because of its foliated nature. L.T. Silver (personal commun., 1986) suggested on the basis of unpublished U-Pb zircon data that the granodiorite may be 1400 Ma; if so, it should be removed from suite 4. The granodiorite is the most magnetic rock in the region, averaging 8.0 percent magnetite, and coincides with a northeast-trending, 400-gamma magnetic high that extends from Yarnell to the southwest for 10 miles (Aero Services, 1983; Sauck and Sumner, 1970). Another distinguishing feature is the moderately iron-rich nature of the pluton (fig. 4), a characteristic restricted to this group of plutons. The granodiorite of Yarnell is more evolved than all previously described rocks even though it is a relatively mafic granodiorite. The trace-element signature of high Rb, Ba, and the highest Y (45 ppm), Zr (280 ppm), Nb (25 ppm), La (82 ppm), and Ce (164 ppm) of any pluton described so far distinguishes this granodiorite. Only the granite of Iron Springs, to be described later, has similar concentrations of incompatible minor elements. Apparently the granodiorite was derived from a magma much more enriched in incompatible minor elements than plutons of other suites. Although both the northern part of the Crooks Canyon Granodiorite and the granodiorite of Yarnell have high Y, Nb, Zr, La, and Ce, Crooks Canyon does not appear to be related to the latter because of the low Rb and Sr concentrations of Crooks Canyon.

Granite of Iron Springs (new informal name). This coarsely porphyritic (microcline phenocrysts), alkali-calcic biotite granite, named for exposures at Iron Springs, 8 miles northwest of Prescott, is typical of plutons thought to be the youngest in the 1700-1750-Ma group. Most of the granite is massive and undeformed, but northeast-trending mylonitic zones that cut the pluton on its western side attest to a late-tectonic (~1700 Ma) age for the body. Even though the coarsely porphyritic texture of the granite is similar to anorogenic 1400-Ma plutons in Arizona (Silver and others, 1977), the relatively high concentration of magnetite (5.3 percent), low radiometric signature, and deformed nature of the pluton indicate that the granite is not 1400 Ma. The granite contains the highest concentration of Ba, La, and Ce, and plots well away from any other pluton in figure 6. The minor-element signature of the granite is very similar to the granodiorite of Yarnell, and both could have crystallized from a magma of similar chemistry. Another feature that supports the late 1700-Ma age of the granite is its high Sr concentration (400-500 ppm). Anorogenic 1400-Ma plutons in the southwest having Sr concentrations greater than 350 ppm have not been recognized, with the exception of the unusually potassic granite of Hualapai Peak near Kingman, Arizona (Kesler, 1976; J.L. Anderson, this volume).

Granodiorite of Hozoni Ranch (new informal name). A moderately porphyritic (microcline phenocrysts), mildly foliated, calc-alkalic biotite-hornblende granodiorite appears to intrude the granodiorite of Minnehaha near Hozoni Ranch, southeast of Wagoner. The pluton forms a large body extending toward Wickenburg south of figure 1 (DeWitt, unpub. mapping, 1987) and is described in this section because it is representative of plutons of this suite. The granodiorite is similar in major-element chemistry to the granite of Iron Springs but contains less K_2O (fig. 5) and Rb (fig. 6). Trace-element concentrations of this granodiorite are very similar to the granite of Iron Springs and the granodiorite of Yarnell.

Crazy Basin Quartz Monzonite (Blacet, 1968; Anderson and Blacet, 1972b). This distinctive, equigranular to slightly porphyritic (microcline phenocrysts), undeformed, alkali-calcic biotite ± muscovite granite is the only pluton studied that intrudes predominantly metasedimentary rocks. Extensive cogenetic pegmatite swarms intrude both metasedimentary rocks and the granodiorite of Lane Mountain. Regional metamorphic grade of the wall rocks increases substantially adjacent to the pluton (Blacet, 1968; DeWitt, 1976; Blacet, 1985), indicating that the pluton was emplaced late during regional metamorphism and deformation. The granite has a Rb-Sr whole-rock model date of 1610 ± 90 Ma (Marvin and Cole, 1978) and a U-Pb zircon date of 1700 Ma (Bowring, Sam, unpub. data, 1986; discussed by Karlstrom and Conway, 1986). The granite is noteworthy because of its moderately peraluminous nature, its moderate to strong iron enrichment, and low (0.5 percent) magnetite concentration. Aeromagnetic lows coincide with the northern and eastern parts of the granite (U.S. Geological Survey, 1972). The granite is the most Rb-rich rock of any pluton studied but contains rather low Y, La, and Ce compared to other plutons of this suite. The pluton appears to have been derived from a magma slightly depleted in all the incompatible trace elements determined except Rb. Alternatively the granite could have been derived from a magma similar to that of the granite of Iron Springs by extensive plagioclase crystal fractionation.

DISCUSSION

The 1700-1750-Ma plutons of north-central Arizona show a great range in major- and minor-element geochemistry, from rocks characteristic of primitive magmas to those characteristic of evolved magmas. Because all the plutons (except Crazy Basin Quartz Monzonite) intrude 1720-1780-Ma mafic to felsic metavolcanic rocks (Anderson and others, 1971), the ultimate source of their parental magmas was either the volcanic rocks themselves or the presumed underlying oceanic mantle. Therefore, compositions of the plutons should be a reflection of their source, depth and degree of partial melting, and processes leading to their formation. Ideally, additional data such as initial Sr and Pb isotopic ratios and rare-earth element analyses should be employed in this discussion, but these data are not available. However, if plutons of a specific age and geochemical suite are considered, some very important tectonic features are noted.

In the Prescott region (fig. 1), a distinct alkalinity trend is noted for the 1700-1750-Ma plutons. Calcic rocks are restricted to the east and southeast areas, predominantly southeast of Mayer. Calc-alkalic rocks are present in a northeast-trending central belt, between Prescott and Mayer. Alkali-calcic rocks are present only in the west and

northwest parts of the region. The only major exception to this trend is the Crazy Basin Quartz Monzonite, which will be discussed below. The trend of increasing alkalinity to the northwest is also evident for K, Rb, and most of the incompatible minor elements. At constant SiO_2, K_2O increases to the northwest, from values as low as 0.8 percent for the tonalite of Cherry and the Badger Spring Granodiorite (SiO_2 = 66-70 percent) to greater than 4.5 percent for the granite of Iron Springs (fig. 5). At constant FeO_t (used instead of SiO_2 for minor-element plots because SiO_2 analyses are not available for all minor-element determinations), Rb increases from values as low as 10-30 ppm for the tonalite of Cherry and the Badger Spring Granodiorite to values as high as 160 ppm for the granite of Iron Springs (fig. 6). Although not shown in separate figures, Zr, Y, and Ce, at constant FeO_t, also increase to the northwest for the three plutons above as follows: Zr from between 60 and 90 ppm in the southeast to 280 ppm in the northwest; Y from 5-15 ppm in the southeast to 30-50 ppm in the northwest; Ce from 25-35 ppm in the southeast to 160 ppm in the northwest. Minor local reversals of this trend are noted for a few plutons in the calc-alkalic central belt, but those reversals do not invalidate the regional trend.

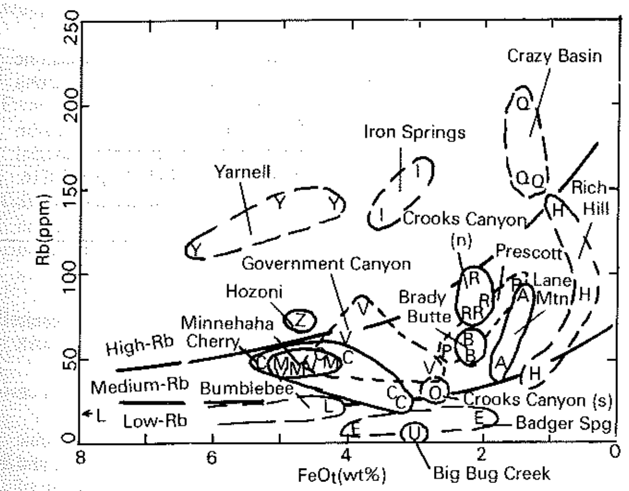


Figure 7. Rb versus FeO_t diagram for 1700-1750-Ma plutonic rocks, north-central Arizona. Low-Rb (low-K), medium-Rb (medium-K), and high-Rb (high-K) field boundaries constructed from those in figure 5. Plotting symbols as in figure 2.

The trend of increasing alkalinity and incompatible minor elements from southeast to northwest is strengthened if plutons of exactly the same age and similar major-element chemistry are considered. Examples from different suites are given below.

Suite 1 biotite granodiorite plutons. The Brady Butte Granodiorite (1750 ± 10 Ma, pretectonic), granodiorite of Minnehaha (pretectonic), and granodiorite of Big Bug Creek (pretectonic) have similar major-element compositions (fig. 2), are all highly foliated, and have very low magnetite concentrations (table 3). The granodiorite of Minnehaha is slightly more calcic than the other two bodies. Even though their major-element chemistry is similar, the plutons have different minor-element chemistry. The granodiorite of Big Bug Creek has the lowest total alkalis (fig. 3) and K_2O (fig. 5) and the lowest Rb (fig. 6) and Ba. Both Brady Butte and the granodiorite of Minnehaha are more alkali rich and have higher K_2O, Rb, Ba, La, and Ce concentrations. Therefore, at constant SiO_2, alkalinity and incompatible minor elements increase to the northwest.

Suite 1 leucocratic granodiorite-granite plutons. Leucocratic calc-alkalic granodiorite bodies similar in age to, or slightly younger than, the Brady Butte Granodiorite show the same trend. The southern part of the Crooks Canyon Granodiorite (pretectonic) and the granodiorite of Lane Mountain (pretectonic) have similar major- and minor-element compositions. Northwest of these bodies are the northern part of Crooks Canyon (pretectonic) and the granite of Rich Hill (pretectonic), which are more alkalic, have higher K_2O, Rb, Ba, Y, Zr, Nb, La, and Ce concentrations. Again, alkalinity and incompatible minor elements increase to the northwest.

Suite 2 hornblende tonalite plutons. The tonalite of Cherry (1740 ± 15 Ma) and the Government Canyon Granodiorite (1750 ± 15 Ma) are pre- to syntectonic, are both tonalitic, and have high concentrations of magnetite. At constant SiO_2, however, Government Canyon is much more alkalic, has higher K_2O, slightly higher Rb, and higher Zr, La, and Ce. Alkalinity and incompatible minor elements again increase to the northwest.

Suite 4 biotite-muscovite granite plutons. The only plutonic body that appears to violate the above trend is the Crazy Basin Quartz Monzonite, an alkali-calcic, high-K_2O, high-Rb pluton of suite 4 that crops out far to the southeast of other plutons in the suite. As noted above, Crazy Basin is the only pluton that intrudes predominantly metasedimentary rocks and is the only pluton in suite 4 that is peraluminous. Quite possibly the granite was derived from partial melting of a metasedimentary source (high K_2O, Rb; relatively low La, Ce, Zr) instead of a predominantly metavolcanic source inferred for all other plutons.

This trend of increasing incompatible minor elements to the northwest is also noted if the total of Ba, Rb, and Sr is plotted against FeO_t (fig. 8). These trace elements are combined because they are concentrated preferentially in the feldspars (microcline, orthoclase, plagioclase) in any oceanic arc or mantle source. Therefore, the amount of Ba + Rb + Sr in an arc-related magma will qualitatively reflect the amount and minor-element concentration of feldspar that was partially melted to form the magma. If the source material was relatively constant in composition (immature volcanic arc material or mantle wedge), and the amount of Ba, Rb, and Sr in plutons that intrude the arc increase to the northwest, the degree of partial melting may have increased to the northwest. If the source material varied in composition from southeast to northwest, an interpretation of increasing alkalinity and incompatible minor elements to the northwest would be more complex.

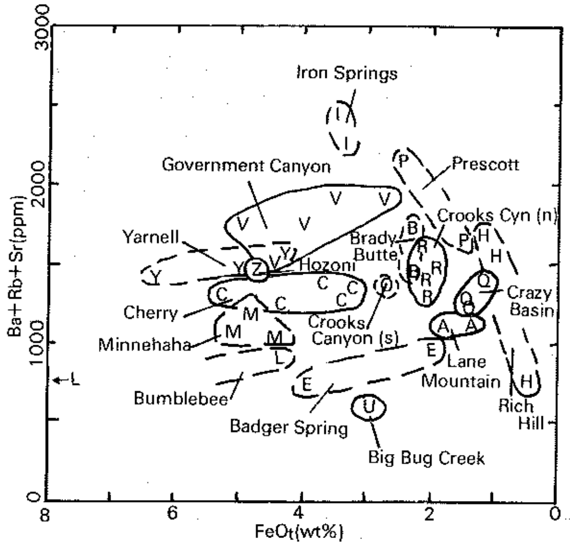


Figure 8. Ba+Rb+Sr versus FeO_t diagram for 1700-1750-Ma plutonic rocks, north-central Arizona. Plotting symbols as in figure 2.

In modern and Phanerozoic island arcs and Andean arcs, total alkalis ($Na_2O + K_2O$) and incompatible trace elements (Ba, Rb, Zr, U) increase in concentration across the strike of the arc and continentward away from the subduction zone (Dickinson, 1975; Keith, 1978; Ewart, 1979; Gill, 1981). Although the causes for this increase are varied (see discussion in Gill, 1981), the empirical relationship is valid, which enables the polarity of modern and Phanerozoic subduction zones and magmatic arcs to be determined. The 1700-1750-Ma plutons of this study have a pronounced increase of alkalinity and incompatible minor elements from southeast to northwest, and indicate a distinct polarity for the physical process that formed the magmas. That process may well have been subduction of oceanic crust from the southeast toward the northwest (northwest-dipping oceanic slab).

If the remains of a paleosubduction zone are to be found, they must lie to the southwest of figure 1, at least 60 km and up to 100 km away. The actual location of such a trench would depend on the dip of the subduction zone, but for an average dip of 45-60 degrees such a subduction zone would have been located near the present site of Globe or Superior, Arizona. Emplacement of the 1400-Ma Ruin Granite (see J.L. Anderson, this volume) has obliterated most evidence for such a subduction zone in that area. Farther south in the Johnny Lyon Hills and Little Dragoon Mountains, Swift (1986) recognized melange deformation in the Pinal Schist, a predominantly pelitic to quartzose metasedimentary unit. The Pinal Schist in that area is older than 1680-1700 Ma (Silver, 1978), and may be similar in age to the suite 4 plutonic rocks in the Prescott area. Conceivably, the melange character noted above may be an indication of an active continental margin between Globe and the Little Dragoon Mountains at about 1700 Ma. Condie and DeMalas (1985) did not note melange textures in Pinal Schist turbidite lithologies in southeast Arizona, but their suggestion of either marine rift-related or active basin settings could be accommodated in a passive continental margin being subducted to the northwest at about 1700 Ma.

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