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AGE AND EXTENT OF POTASSIC VOLCANISM ON THE COLORADO PLATEAU

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Six K-Ar ages on phlogopite from minettes in and near the Buell Park diatreme establish that minette and coeval kimberlitic volcanism occurred 25 m.y. ago. Two altered phlogopites yield younger ages, while on phlogopite sample with an age of 34 m.y. may contain excess argon. Published apatite fission-track ages for inclusions in the kimberlitic tuff at Buell Park are too old, perhaps due to partial retention of pre-eruption tracks. Published ages for other minette localities on the Colorado Plateau are insufficient to precisely define the duration of volcanism, but some eruptions may be as old as 30 m.y.

Potassic volcanic rocks similar to the felsic minettes at Buell Park erupted at about the same time at Chino Valley, Arizona, in the transition zone of the Colorado Plateau. The correlation between the two localities of unusual potassic rocks is evidence that these rocks may reflect mantle conditions associated with the stability of the Plateau, and that these conditions contrasted with those in adjacent tectonic provinces at least as early as 25 m.y. ago.

1. Introduction

Potassic volcanic rocks ("minettes") and ultramafic microbreccias of kimberlitic affinity make up the Navajo field of the central Colorado Plateau [1]. These rocks occur as diatremes, flows, and shallow intrusions which crop out in an area of over 100,000 km^2. Published age data suggest that all igneous activity of the field took place in the middle Oligocene [2]. The ages reported here were determined to investigate in more detail the time interval of Navajo volcanism, primarily utilizing samples from the Zilditloi cluster in the south central part of the field, within and near the Buell Park diatreme. The new data, together with information on Cenozoic volcanism in the southwestern transition zone of the Colorado Plateau, indicate that similar potassic volcanic rocks were generated at about the same time beneath widely separated parts of the Plateau. The contrasts between these potassic rocks and the calc-alkalic rocks produced at the same time in adjacent tectonic provinces support the relationships between magmatic type and tectonic setting in the southwestern United States.

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2. The Zilditloi field and nearby minettes

The Zilditloi field encompasses an area of about 5 km X 24 km in the south-central part of the Navajo field (localities 8–10, Fig. 1). The area contains two major pipes of ultramafic microbreccia (Buell Park and Green Knobs) and one small pipe and a number of shallow intrusions or flows of minette. We call the ultramafic microbreccias "kimberlitic" in accordance with past usage, though it is unlikely that silicate melt was a component of the erupting systems [3,4]. The term "minette" [5] is used here for a variety of intrusive and extrusive volcanic rocks, high in K_2O; these minettes contain phenocrysts of diopside and phlogopite in a groundmass rich in sanidine and without plagioclase.

The Zilditloi area affords a particularly good opportunity to study actual and relative ages of kimberlitic breccia and minette, because only in this area do the two rock types occur in direct association. Buell Park, the largest kimberlitic diatreme in the Navajo field, includes a ring dike and a diatreme of minette [6,7]; detailed mapping by Roden and Smith [8] has shown that the eruptions of kimberlitic breccia and minette overlapped in time. A small, unnamed pipe of kimberlitic breccia to the east of Buell Park is cut by a minette dike, and two other minette necks include blocks of kimberlitic breccia. The only previous geochronologic study of volcanic rocks of the Zilditloi field was that of Naeser [2], who determined fission track ages of minerals from two granitic inclusions in the kimberlitic tuff at Buell Park.

3. Ages of Navajo volcanism

3.1. New K-Ar determinations

Using standard mineral separation techniques, virtually pure phlogopite separates were obtained readily from all samples. Potassium was analyzed in duplicate by flame photometry with sodium buffering and lithium as internal standard. Samples for argon analysis were fused by induction heating and measured by isotope dilution mass spectrometry, also in duplicate. Pooled replicate analyses indicate a precision of ±1.5% (1σ) for mica ages in which atmospheric argon corrections are not limiting factors.

The nine analyzed samples were collected and dated in two groups, the results of which are presented

TABLE 1

K-Ar determinations on phlogopite separates from minette

Sample and locality [a]	K (%)	$^{40}Ar^*$ (%)	$^{40}Ar^*$ ($\times10^{-6}$ cm^3/g)	Age (m.y.) ± 1σ
Buell Park (at 9, Fig. 1)				
BP34: felsic intrusion, south end Buell Mtn.	7.64	69	7.80	25.4 ± 0.4
	7.59	73	7.73	
BP37: bomb in tuff breccia, west side Buell Mtn.	7.79	71	7.88	25.2 ± 0.4
	7.83	75	7.88	
BP75: clast in dike of tuff breccia, east side, Buell Mtn.	8.15	82	11.2	33.9 ± 0.5 [b]
	8.16	82	11.0	
N255: southeast end of mafic ring dike	6.32	59	6.15	24.3 ± 0.4
	6.38	74	6.29	
The Beast (at 10, Fig. 1)				
TB7: dike	7.77	71	7.84	24.9 ± 0.4
	7.80	72	7.73	
N247: friable dike	7.07	72	6.09	20.7 ± 0.3 [c]
	7.15	58	5.68	
Outlet Neck (between 9 and 10, Fig. 1)				
N240: friable dike	5.87	24	4.48	19.4 ± 0.5 [c]
	5.88	23	4.65	
Fluted Rock (at 8, Fig. 1)				
FR3: western end	6.54	75	6.77	25.9 ± 0.4
	6.54	70	6.82	
Black Rock (at 11, Fig. 1)				
BR4: central region	7.26	74	7.59	25.8 ± 0.4
	7.34	76	7.52	

$\lambda_\beta = 4.72 \times 10^{-10}$ yr^{-1}; $\lambda_e = 0.584 \times 10^{-10}$ yr^{-1}; $^{40}K/K = 1.19 \times 10^{-4}$ atoms/atom.

[a] Localities are described generally by Gregory [1] and Allen and Balk [6] and in detail by Roden [25].

[b] Field relations indicate BP34, BP37, and BP75 are the same age (see text).

[c] X-ray diffraction spectra indicate alteration, and field relations indicate TB7 and N247 are the same age (see text).

together in Table 1. The first group contained three samples, one from Buell Park (N255) and two from nearby minette necks (N240 and N247, Table 1). The latter two samples were from friable, phlogopite-rich minette; the phlogopite appeared fresh in thin section. X-ray diffraction study of the phlogopite separates from these two rocks, however, revealed the presence of an additional hydrous sheet silicate in N240, defined by a non-phlogopite peak at 11.8 Å, and of mica alteration in N247, indicated by a broadened 10-Å peak for phlogopite. Sample N240 has a high atmospheric argon content (Table 1). The ages for these two rocks were thus considered suspect, and six more samples were collected. All the phlogopite separates from these six rocks had well-defined X-ray spectra without broad or extraneous peaks. One of the localities with a suspect age was resampled (rock TB7); based on the data in Table 1, we conclude that the two phlogopite separates with distinctive X-ray spectra have preferentially lost argon.

Six of the remaining seven phlogopite separates yield ages in the range 24.3–25.9 m.y. The seventh sample (BP75), which yields an age of 33.9 m.y., was separated from a glass-rich clast in a tuff-breccia from Buell Park; phlogopites from a different clast in another tuff-breccia (BP37) and from a shallow intrusion (BP34) in the same deposit appear to be 25.2 and 25.4 m.y. old, respectively. Detailed mapping by Roden and Smith [8] indicates that the three samples must be essentially the same age. The anomalous 33.9 m.y. age may reflect contamination by xenolithic mica or incorporation of excess argon by phlogopite phenocrysts in the glass-rich rock.

3.2. Other age determinations on the Navajo rocks

Fig. 1 shows our data along with other relevant geochronologic studies of Navajo rocks. The closest minette occurrence for which K-Ar data exist is the sill at Dineh bi Keyah (7, Fig. 1), 60 km north of the Zilditloi field. There, Pohlmann [9] reported a whole rock age of 31 m.y. *, and R.F. Marvin, Isotope Geology Branch, U.S. Geological Survey (personal communication, 1977) determined ages on another rock of 25.0 m.y. for biotite and 40.9 m.y. for sanidine. Because

* Ages recalculated with the decay constants reported in Table 1.

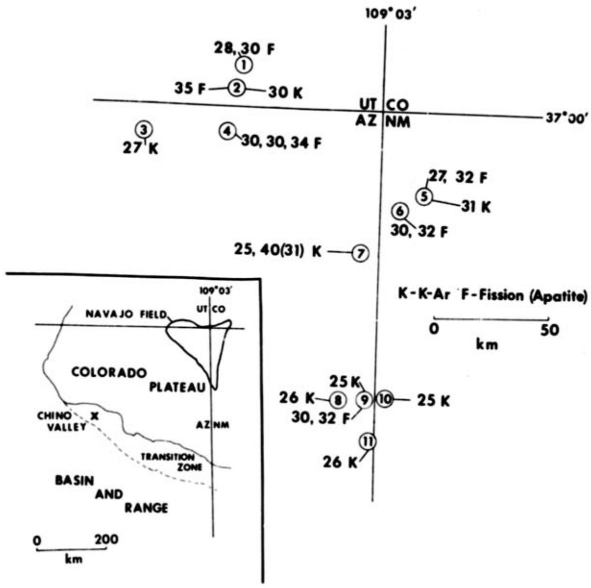

Fig. 1. Locations of the Navajo field and of Chino Valley, and age determinations for minette (m) and kimberlitic (kimb) volcanic rocks of the Navajo field. Data have been rounded to two figures. All fission-track results (F) are from Naeser [2]; sources of K-Ar results (K) are listed below with the locality names: 1 = Mule Ear (kimb); 2 = Moses Rock (kimb) [12]; 3 = Monument Valley (m) [10]; 4 = Garnet Ridge (kimb); 5 = Shiprock (m) [11]; 6 = Mitten Rock (m); 7 = Dineh bi Keyah (m) [9] and Marvin, 1977 – see text; 8 = Fluted Rock (m), Table 1; 9 = Buell Park (m, kimb), Table 1; 10 = The Beast (m), Table 1; 11 = Black Rock (m), Table 1.

important potassium-bearing phases give widely disparate ages, the whole-rock result is probably not meaningful. The sanidine result is older than any age reported for the Navajo field. The biotite age is identical to the Buell Park results, and we interpret it as the time of intrusion of the sill at Dineh bi Keyah. Excess argon or xenocrystic feldspar are possible explanations for the old feldspar age. It and the anomalous phlogopite age of 33 m.y. at Buell Park (Table 1) may be evidence that excess radiogenic argon was present during crystallization of at least some of the minettes. In view of this possibility we urge caution in accepting single K-Ar results from minettes as meaningful. Thus, a 27-m.y. age from a whole-rock minette sample from Monument Valley [10] and a 30.6-m.y. age on "pyroxene (1% biotite)" (total K = 1.27%) from a dike near Shiprock [11] are not firm evidence for Navajo volcanism older than 26 m.y. The 30.1-m.y. K-Ar age for phengite from an eclogite inclusion in the Moses Rock kimberlitic diatreme [12] may indicate older volcanism.

Ohter age data for the Navajo field are the extensive fission-track studies by Naeser [2]. His data include apatite, sphene, and zircon ages from inclusions in kimberlitic and minette diatremes and apatite ages from the groundmass of two minettes. Zircon and sphene results from inclusions were typically older than apatite ages because of incomplete annealing of fission tracks before and during emplacement of the low-temperature kimberlitic diatremes. Ages of apatite from both inclusions and groundmass were interpreted by Naeser as times of diatreme eruption. Only apatite ages are shown in Fig. 1.

Fission-track ages for apatite in two granite inclusions in the Buell Park kimberlitic tuff are 31.9 ± 3.2 and 29.7 ± 3 m.y. [2], distinctly older than the 25 m.y. phlogopite K-Ar ages reported here. Detailed mapping at Buell Park by Roden and Smith [8], however, has demonstrated that kimberlitic and minette eruptions overlapped in time. A similar age discrepancy occurs at the Moses Rock diatreme, where a fission-track age of 35 m.y. for apatite and a K-Ar age of 30 m.y. for phengite have been reported (Fig. 1). At Shiprock (5, Fig. 1) K-Ar and fission-track ages agree at 31 m.y. At Buell Park we suggest that the 25-m.y. phlogopite ages give the time of diatreme eruption and minette volcanism and that the apatite fission-track ages are too old, perhaps due to incomplete annealing of earlier-formed tracks. If so, both the eruption temperatures and the ambient temperatures at the source of the inclusions were below that required for complete annealing of fission tracks in apatite. Our interpretation cannot be applied to the ages on apatite crystallized from minette at localities 5 and 6, Fig. 1.

3.3. Summary of age data

Geochronology at Buell Park is complex, and our conclusion that the minette and kimberlitic diatremes erupted about 25 m.y. ago differs from that formed from more limited data. Other localities in the Navajo field are represented by comparatively few dates and conclusions from them must be considered as tentative. The recurrence of ages near 30 m.y. at various diatreme localities, however, is suggestive evidence that eruption of these unusual volcanic rocks occured over a time span of about 5 m.y., beginning in the northern part of the Navajo field about 30 m.y. ago.

4. Extent of coeval potassic rocks

Potassic volcanic rocks similar to the most felsic rocks of the minette field erupted during the same time interval in Chino Valley, over 300 km away in the transition zone of the Colorado Plateau (Fig. 1). The transition zone here is structurally part of the plateau [13]. These potassic rocks form part of the Sullivan Buttes Latite, which includes shallow intrusions, flows and pyroclastic breccias. It has yielded K-Ar ages of 23.4 (biotite) and 26.7 m.y. (hornblende) from separate localities [14]. Some of the rock types in the Sullivan Buttes Latite have phenocrysts of diopside and phlogopite in a felsic groundmass, like some of the rare felsic rocks in Buell Park and elsewhere in the Navajo field; plagioclase in an additional constituent in crystalline groundmass of these latites. The Sullivan Buttes Latite also includes less potassic latites, some of which have amphibole, plagioclase, sphene, and apatite as additional phenocryst minerals. The rocks with biotite and pyroxene phenocrusts are shoshonitic; they could be called "quartz banakites" in the terminology of Joplin [15], except for their low alumina contents.

A comparison of the compositions of selected rocks from the two regions (Table 2) shows high K_2O/Na_2O ratios and low Al_2O_3 for all analyses, with more extreme values for the Navajo rocks. Rare earth fractionations are likewise more extreme for the Navajo rocks, but the trend of strong enrichment of light relative to heavy REE is similar for both groups.

Felsic volcanic rocks are known from only a few areas in the Navajo field [8,16,17]; the more mafic minettes are much more common. The two magma types may be related by crystal fractionation and wall-rock assimilation in the uppermost mantle, or they may be direct partial melts of a heterogeneous source, initially with phlogopite and with residual garnet. The relative scarcity of potassic mafic rocks in Chino Valley supports the hypothesis that the felsic rocks in both regions are derived directly from mantle sources, not by differentiation of mafic magmas.

TABLE 2

Compositions of comparable potassic rocks on the Colorado Plateau (in wt.%)

	Navajo field		Chino Valley	
	1	2	3	4
SiO_2	57.8	59.50	58.58	61.61
TiO_2	0.8	0.89	0.78	0.76
Al_2O_3	12.4	12.93	14.47	13.89
Fe_2O_3		3.02		4.14
FeO	4.5	1.46	5.21	0.72
MnO	0.07	0.06	0.09	0.08
MgO	5.5	4.90	3.59	3.69
CaO	6.3	5.30	4.62	4.63
Na_2O	2.6	2.53	2.57	2.79
K_2O	7.3	7.21	5.15	5.49
P_2O_5	0.8	0.64	0.36	0.36
H_2O^+	1.7	0.54	1.46	0.73
H_2O^-		0.60	1.66	0.31
Total	99.8	99.68	98.54	99.20
La (ppm)	117	108.9	64.7	
Sm (ppm)	15	15.9	9.4	
Yb (ppm)	1.2	0.938	1.4	

1 = Mitten Rock (rock a 072MTR [17]). FeO is total iron; H_2O^+ is total loss on ignition.
2 = Buell Park (rock BP-35[8])(sum includes 0.10 CO_2). Rare earth data are from a different sample of the same unit [27].
3 = Chino Valley (rock PR42 [26]). FeO is total iron.
4 = Chino Valley, modified rapid method, G.K. Hoops analyst (rock PR155, from latite dome at 112° 19′W, 34° 47′ N).

Far greater volumes of more typical calc-alkalic rocks were erupted during the same time period in provinces adjacent to the Colorado Plateau. In the San Juan Mountains at the eastern edge of the plateau, about 130 km northeast of the Navajo field, intermediate-composition lavas and breccias followed by more silicic ash-flow tuffs were erupted from 35 to 26 m.y. ago [18]; at the same silica contents, these lavas are less potassic and more aluminous than the Colorado Plateau volcanics, and they have K_2O/Na_2O ratios less than 1. The summaries of Snyder et al. [19] and Cross and Pilger [20] show a surge of "arc" volcanism in much of southern Arizona and Nevada from 40 to 20 m.y. ago. In the Superstition Mountains, at the south edge of the plateau and about 150 km southeast of Chino Valley, dacites, quartz latites, and rhyolites were erupted from 29 to 15 m.y.; rocks of intermediate silica content are lacking for direct comparison, but none of the rocks is unusually potassic [21,22]. Ultrapotassic trachytes, about 20 m.y. old, have been described from southeastern Arizona [23], while high-potassium rhyolites, mid-Miocene or younger, have been reported from west-central Arizona [24]. Both locations are in the Basin and Range Province: these highly potassic compositions may reflect alteration, however, and in neither locality do the rocks resemble those described here.

The compositional differences between these volcanic rocks on the Colorado Plateau and the more voluminous, less potassic rocks typical of bordering tectonic provinces must be related to differences at the magma sources. The similarities in eruption time and composition of the Navajo and Chino Valley rocks demonstrate that conditions appropriate for generation of these unusual rocks occurred at the same time in two widely separated parts of the mantle beneath the Colorado Plateau. The correlation supports the hypothesis that the mantle conditions responsible for the generation of these unusual potassic magmas 25 m.y. ago were also responsible for the unusual stability of the Colorado Plateau.

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