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# COMENDITE (PERALKALINE RHYOLITE) AND BASALT IN THE MITU GROUP, PERU: EVIDENCE FOR PERMIAN-TRIASSIC LITHOSPHERIC EXTENSION IN THE CENTRAL ANDES

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*Abstract.*—The Mitu Group consists of generally coarse elastic strata and volcanic rock of Permian and (or) Triassic age filling elongate basins that parallel the general structural trend of the Peruvian Andes. Volcanic rocks of the Mitu Group include peralkaline and nonperalkaline rhyolite and subalkaline basalt. To our knowledge, the peralkaline rhyolites are the first of this rock type reported from South America. The presence of appreciable volumes of peralkaline rhyolite and basalt supports the interpretation that the Mitu Group was deposited in major graben structures that resulted from lithospheric extension produced by rifting or possible back-arc extension.

Redbeds, conglomerates, and volcanic rocks associated with the graben structures comprise the Mitu Group (fig. 1), which postdates Lower Permian marine strata of Late Triassic and locally Middle Triassic (Ladinian) age (Levin, 1974). Stewart, Evernden, and Snelling (1974) report a potassium-argon age of 251 million years obtained on a pluton that intrudes the Mitu Group in central Peru. A rubidium-strontium isochron age of  $238 \pm 16$  m.y. has been obtained for the batholith of La Merced in central Peru (François Mégard, unpub. data, 1976). This pluton intrudes

The central Andes have a long and involved tectonic history. Mesozoic tectonism is relatively well known, and the basic features of Cenozoic deformation and uplift presently are being worked out. Western South America also underwent major deformation prior to the Mesozoic, a fact long known but not generally appreciated.

Precambrian rocks are exposed in various places in Peru and northern Argentina (Dalmayrac and others, 1971). A major pulse of deformation affected virtually the entire central Andes at the close of the Devonian (Mégard and others, 1971; Helwig, 1972, 1973), and it is not unreasonable to suspect the presence of one or more early Paleozoic episodes. Minor vertical movement appears to have taken place in Peru during the Mississippian (Mégard and others, 1971).

Southern Peru appears to have undergone compressive deformation during the early Permian (Mégard and others, 1971; Audebaud and Laubacher, 1969). Elsewhere, late Paleozoic tectonism appears to have been largely extensional, with the apparent formation of major graben structures oriented parallel to the general structural grain of the region (Mégard, 1973; Newell and others, 1953).

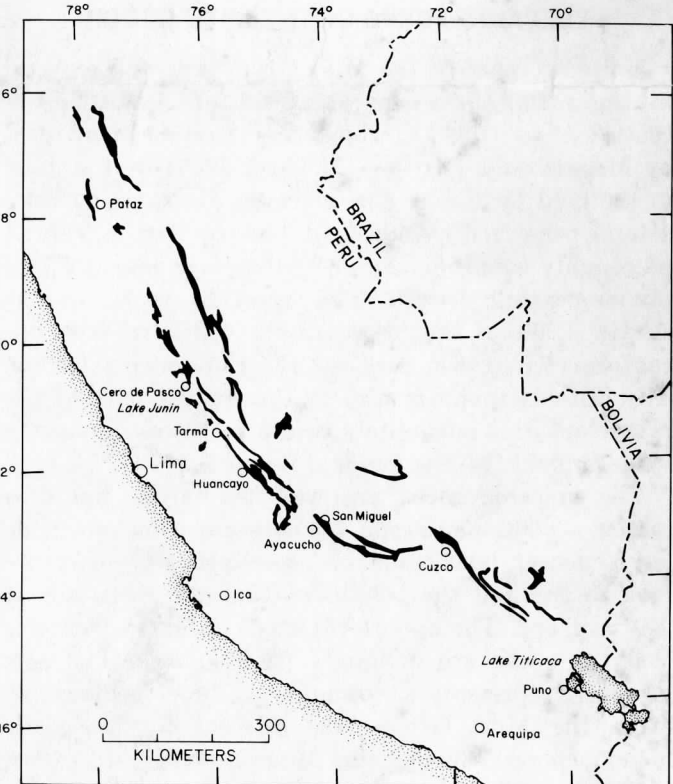


FIGURE 1.—Map of Peru showing distribution of rocks of Mitu Group and correlative units (from Dalmayrac and others, 1971) and locations referred to in text.

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Lower Permian marine rocks and is unconformably overlain by rocks of the upper part of the Mitu Group and by Ladinian marine strata. Both radiometric ages suggest that an appreciable part of the Mitu Group is of Permian age.

Although the volcanic rocks of the Mitu Group are voluminous, areally extensive, and, in many places, remarkably well exposed and preserved, they are virtually unstudied. This paper reports on preliminary field, petrographic, and chemical studies which demonstrate that certain volcanic rocks of the Mitu Group are of the type commonly erupted in regions undergoing active extension.

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### VOLCANIC ROCKS OF THE MITU GROUP

Volcanic rocks of the Mitu Group are well exposed in the mountain range northeast of Ayacucho, in central Peru (fig. 1), where they have been mapped by Mégard and Paredes (Mégard, 1973) and studied in the field by Noble. The volcanic rocks, which have a total preserved thickness of 1500 to 2000 m, consist of roughly equal amounts of silicic lava and tuff and olivine-bearing basalt. The volcanic rocks overlie clastic strata of the Mitu Group, which in turn unconformably overlie rocks of the Copacabana Group. The Mitu is subhorizontal in the central part of the range and dips moderately to the southwest along the western flank of the range (Mégard, 1973).

The volcanic rocks are well preserved. For this reason, a potassium-argon age determination was made on a dense, holocrystalline specimen of comendite lava to rule out the possibility that the rocks are of Tertiary age. The age of 131 m.y. (table 1) indicates that the rocks are definitely pre-Cenozoic. The age, however, represents a minimum age for the lava because the Mitu Group was affected by low-grade metamorphism during the Mesozoic (Mégard, 1968, 1973; Stewart and others, 1974; and petrologic evidence presented below).

Many outcrops of silicic lava show the coarse granophyric texture typical of crystallized peralkaline

TABLE 1.—Analytical data for potassium-argon age determination on comendite sample AYA-PAN

[Argon analyses by M. L. Silberman using standard isotope dilution procedures; potassium analyses by L. F. Espos using X-ray fluorescence methods. Constants:  $^{40}\text{K}\lambda\epsilon + ^{40}\text{K}\lambda\epsilon' = 0.581 \times 10^{-10}/\text{yr}$ ;  $^{40}\text{K}\lambda\beta = 4.962 \times 10^{-10}/\text{yr}$ . Atomic abundance  $^{40}\text{K} = 1.167 \times 10^{-4}$  mole/mole.]

K <sub>2</sub> O (wt.%)	Radiogenic Ar (mole/gm x 10 <sup>-10</sup> )	Radiogenic Ar (percent)	Age (m.y.)
3.80	7.079	98	
3.72	7.621	94	
3.76 (Average)	7.350 (Average)		131±5

12 outcrops, most along the road between Ayacucho and San Miguel (fig. 1), reveal micrographic intergrowths of quartz and alkali feldspar. The feldspar is clouded with fine-grained white mica probably formed during the low-grade metamorphism. Phenocrysts of quartz and alkali feldspar are present in some

TABLE 2.—Major-element analyses of comendites and a basalt

Specimen Type of analysis	AYA-PAN		Tower	AYA-10A
	A	B	C	D
SiO <sub>2</sub>	76.7	--	75.3	49.8
Al <sub>2</sub> O <sub>3</sub>	11.6	11.1	12.2	16.3
Fe as FeO	2.68	2.52	3.8	11.6
MgO	0.13	--	0.21	4.92
CaO	0.125	--	0.31	9.8
Na <sub>2</sub> O	3.5	3.28	4.5	2.62
K <sub>2</sub> O	4.12	--	3.4	0.98
H <sub>2</sub> O	--	--	--	1.0
TiO <sub>2</sub>	0.13	0.10	0.23	2.0
MnO	0.050	0.063	--	0.19
Total	99.9		100.0	99.2

- A. Average of three determinations by X-ray fluorescence methods (Hebert and Street, 1974).  
 B. By neutron activation methods similar to those described by Perlman and Asaro (1969).  
 C. By nondestructive X-ray fluorescence methods; W. Kemp, analyst.  
 D. By atomic absorption methods, D. Bowden, analyst. S = <0.005 weight percent.

Sample locations:

AYA-PAN, 13°00.4' S., 74°06.0' W.  
 Tower, 12°58.7' S., 74°06.2' W.  
 AYA-10A, 12°57.2' S., 74°01.4' W.

TABLE 3.—Minor-element analyses, in parts per million, of peralkaline rhyolite AYA-PAN

[Analysis A by neutron activation methods similar to those of Perlman and Asaro (1969); analysis B by semiquantitative (six-step) optical emission spectrographic methods similar to those of Myers, Havens, and Dunton (1961), Chris Heropoulos, analyst, except values in parentheses by X-ray fluorescence methods, L. F. Espos, analyst;—, not determined; N, not detected.]

Element	A	B
Cs	3.3	--
Rb	167	(148)
Ba	80	70
Sr	--	20(48)
Pb	--	30
La	44.4	50
Ce	116	150
Nd	34	N
Sm	7.5	N
Eu	0.064	N
Tb	2.2	N
Dy	14.0	N
Yb	9.8	10
Lu	1.40	--
Y	--	100
Th	30	N
U	6.0	N
Zr	--	700
Hf	17	N
Nb	--	30
Ta	2.64	N
Cu	--	3
Co	0.40	N
Ni	3	N
Sc	1.78	N
V	--	10
Cr	2	2
Zn	51	N
Ga	--	15
Be	--	3
As	19	--
Sb	0.6	--

rhyolite. Thin sections of peralkaline rhyolites from of the rocks. Aggregates of very fine grained iron oxides are texturally akin to those that replace original poikilitic grains and granular aggregates of groundmass sodic amphibole in comendites and pantellerites that have cooled under oxidizing conditions.

Chemical analyses have been made on two specimens

of comendite (samples AYA-PAN and Tower, tables 2 and 3). An original peralkaline chemistry is shown by a number of major- and minor-element characteristics. The most distinctive chemical feature of peralkaline silicic rocks is their unusually high iron content (Noble, 1968; Macdonald, 1975). The comendites from the Mitu Group are very highly differentiated, as shown by the very low contents of Ca, Mg, Sr, Ba, Eu, Co, Cr, and Ni. Nonperalkaline rhyolites with comparably high SiO<sub>2</sub> and depleted alkaline earth contents have total iron contents of less than 1.5 weight percent and typically less than 1 weight percent, whereas the rhyolites from the Mitu Group have total iron as FeO contents of 2.6 and 3.8 weight percent. Peralkaline rhyolites also have high to very high concentrations of zirconium, hafnium, yttrium, and the heavy rare earths (Ewart and others, 1968; Noble and others, 1969; Macdonald and Bailey, 1973), elements that are markedly depleted in very highly differentiated nonperalkaline rhyolites. The high contents of iron, zirconium, hafnium, yttrium, and the heavy rare earths result from the presence of excess alkali in the magma, which stabilizes iron and large highly charged cations within the melt (Dietrich, 1968; Noble, 1968; Noble and Haffty, 1969; Melchior-Larsen and Steenfelt, 1974). Peralkaline silicic melts have high Fe<sup>+2</sup>/Fe<sup>+3</sup> ratios and are characterized by low oxygen fugacities (Noble, 1968; Nicholls and Carmichael, 1969). Very extensive feldspar separation and low oxygen fugacity during intratelluric crystallization are demonstrated by the extreme europium depletion of specimen AYA-PAN (table 3); the rock possesses only 2 percent of the europium that would be present in an unfractionated specimen having identical contents of the other rare earth elements. Similar depletion of europium has been found for a number of peralkaline rhyolites from the Western United States (D. C. Noble, unpub. data, 1976). Appreciable, although not as extreme, depletion of europium also has been reported in peralkaline rhyolites from New Zealand (Ewart and others, 1968) and Pantelleria (Villari, 1975). Also highly suggestive of original peralkaline chemistry are the somewhat low Al<sub>2</sub>O<sub>3</sub> and high TiO<sub>2</sub> contents of the rocks (see Noble, 1968; Macdonald and Bailey, 1973).

Despite the strong indications of peralkaline chemistry, the rocks do not presently have an atomic excess of alkali over aluminum, the chemical definition of peralkalinity. Loss of sodium during primary crystallization is a ubiquitous feature of peralkaline silicic igneous rocks (Noble, 1968; 1970; Macdonald and Bailey, 1973). Appreciable amounts of sodium thus almost certainly were lost during primary granophyric

crystallization. Potassium and perhaps additional sodium appear to have been lost later, probably during metamorphism (compare Anderson, 1968); deuteric alteration producing fine-grained white micas does not occur during natural primary crystallization of peralkaline silicic magmas. Experience with Cenozoic volcanic rocks suggests that small amounts of magnesium, calcium, and strontium may have been added by groundwater subsequent to eruption.

Peralkaline rhyolite is exposed over an area of at least 50 km<sup>2</sup> between Ayacucho and San Miguel, and reconnaissance observations strongly suggest that similar rocks are present over a much larger area. A belt of rocks of the Mitu Group extends for almost 200 km from north of Ayacucho southeastward towards Cuzco (fig. 1), and much of this belt may consist of originally peralkaline rhyolite.

Silicic tuffs of the Mitu Group exposed east of Lake Junin, near Tarma, and east of Huancayo (fig. 1) have been examined by Noble. These rocks contain appreciable amounts of phenocrystic biotite, a mineral that is rare in peralkaline rhyolite. It thus appears that part of the volcanic rocks of the Mitu Group consists of nonperalkaline rhyolite.

A chemical analysis of a specimen of olivine-bearing basalt (sample AYA-10A, table 2) is very similar to those of many moderately potassic, somewhat differentiated, subalkaline basalts commonly erupted in continental areas undergoing crustal extension, such as the Western United States (for example, Wright and others, 1973; Gunn and Watkins, 1970; Noble and others, 1973).

## DISCUSSION

Peralkaline silicic volcanic rocks typically are erupted in regions undergoing crustal extension. These include spreading centers in oceanic regions and areas of continental rifting and back-arc extension (for example, Barth, 1945; LeBas, 1971; Baker and others, 1972; Noble and Parker, 1975). In such settings, peralkaline rhyolites are commonly associated with appreciable volumes of nonperalkaline silicic volcanic rock, and the presence of nonperalkaline rhyolite in the Mitu Group does not contradict the tectonic implications of the peralkaline types.

Available geologic and geochemical evidence strongly suggests that peralkaline silicic rocks are produced by the protracted fractionation of originally hypersthene-normative basaltic magma. The parental basaltic magma may have a considerable range in the contents of large-ion lithophile elements (for example, Korrington and Noble, 1972; Noble and Christiansen,

1974). The presence of peralkaline rhyolite thus implies the generation and presence at relatively shallow levels of large volumes of mafic magma, a conclusion supported by the voluminous basalts associated with the peralkaline rhyolites.

The tectonic regime responsible for crustal extension and basalt-related volcanism in Peru during latest Paleozoic and (or) earliest Mesozoic time is unclear. Scattered data (for example, Burgl, 1967; Radelli, 1962; Pushcharovskiy and Arkhipov, 1972) suggest that extension and silicic alkaline volcanism occurred elsewhere along the west coast of South America at about the same time. Thus, extension and related volcanism could be ascribed to rifting associated with the onset of major crustal fragmentation at the end of the Paleozoic. Both tectonic (Mégard and others, 1971; Miller, 1971) and paleogeographic (Isaacson, 1975) arguments favor the existence of a western extracontinental land mass during the Devonian. This inferred land mass perhaps may be explained by alternative reconstructions (Le Pichon and Fox, 1971; Walper and Rowett, 1972; Vine, 1973; Van der Voo and others, 1976) that place northwestern South America in contact with southeastern North America in the Permian. Such a land mass may have separated during the latest Paleozoic along a rift line approximately parallel to the present Peru-Chile trench.

The presence of a magmatic arc parallel to the axis of the Peru-Chile trench (Mégard, 1973; James, 1971) shows unquestionably that by late Triassic time subduction was occurring along the western coast of central South America. The onset of subduction probably followed an episode of rifting, as discussed above. However, if, as suggested by Helwig (1972, 1973), subduction occurred along the western coast of central South America during Mitu time, then the faulting and peralkaline volcanism could perhaps be interpreted as an intracontinental analog of back-arc extension.

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