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GEOCHRONOLOGIC AND RARE-EARTH STUDY OF THE EMBUDO GRANITE AND RELATED ROCKS

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INTRODUCTION

The Embudo Granite is located in north-central New Mexico in the Picuris Range of the southern Sangre de Cristo Mountains. Montgomery (1953) applied the term "Embudo" to all the Precambrian granitic rocks exposed between the Picuris Range and Santa Fe, about 48 km to the south. Samples analyzed in this study were collected from the area mapped by Montgomery (Miller and others, 1963) and Long (1974) (fig. 1).

The purpose of this study was to add to the framework for studies in the Picuris Range by: (1) determining the crystallization sequence of the Embudo Granite and (2) analyzing for rare-earth and other trace elements of two of the subunits of the Embudo Granite.

GEOLOGY AND PETROGRAPHY

The Precambrian rocks in the Sangre de Cristo Mountains consist of metasedimentary and metavolcanic rocks and the intrusive Embudo Granite. The Embudo Granite intrudes all Precambrian rocks in the area, namely the Ortega Formation, including the Rinconada and Pilar Members, and the Vadito Formation.

The granitic rocks in the northern part of the area may be divided into four distinct units. According to Long (1974), the sequence of granitic magmatism began with the emplacement of a dark to medium gray, fine-grained metadacite stock (Cerro Alto metadacite), along with sills and dikes of similar lithology. This event was followed by the emplacement of a more coarse-grained and foliated granite-to-quartz-monzonite porphyry with distinctive phenocrysts of microcline (Puntiagudo granite porphyry) (see Long and Luth, this guidebook). This rock was intruded by a foliated biotite quartz monzonite (Rana quartz monzonite), followed by the intrusion of the Pefiasco quartz monzonite. The granitic rocks in the southern part of the area of study have not been subdivided into distinctive units, and it is unknown whether the two bodies are related genetically.

PREVIOUS AGE DETERMINATIONS

Muehlberger and others (1966) summarized Precambrian ages for metamorphic and igneous events in north-central New Mexico and south-central Colorado. They recognized four Precambrian thermal events in New Mexico, primarily on the basis of Rb-Sr whole-rock and mineral ages. Using a 47 b.y. half-life for ^{87}Rb, the recognized events occurred about 1600, between 1430 and 1350, at 1280 and at 1100 m.y.

A K-Ar age of 1,235 ± 19 m.y. for biotite from the Embudo Granite was obtained by Gresens (1972), and Fullagar and Shiver (1973) found by Rb-Sr dating that the most likely age of formation for the Embudo Granite was 1,673 ± 41 m.y.

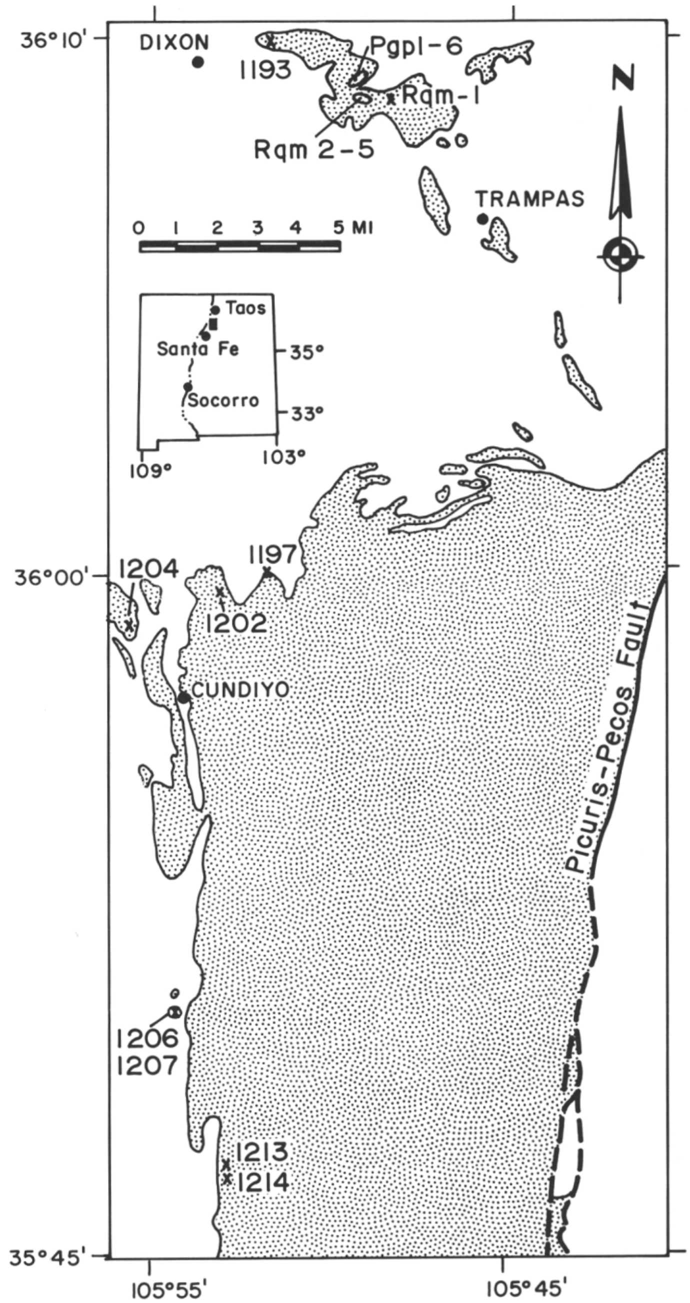

Figure 1. Index map and sample locations. Stippled pattern indicates outcrop of the Embudo Granite (from Miller and others, 1963). Pgp = Puntiagudo granite porphyry; Rqm = Rana quartz monzonite; other numbers = Embudo Granite undivided.

Table 1. Major element analyses of the Puntiagudo granite porphyry and the Rana quartz monzonite.

Oxide	Pgp-1	Pgp-2	Pgp-3	Pgp-4	Pgp-5	Pgp-6	Rqm-1	Rqm-2	Rqm-3	Rqm-4	Rqm-5
SiO_2	74.30	73.36	73.35	73.83	71.60	75.60	77.26	74.82	71.87	71.50	71.54
TiO_2	0.34	0.43	0.33	0.30	0.36	0.32	0.37	0.27	0.36	0.44	0.38
Al_2O_3	12.20	13.17	13.20	13.00	14.41	12.50	12.70	13.00	14.08	13.60	13.80
Fe_2O_3	1.78	1.59	1.61	1.52	1.40	1.54	1.09	1.35	1.30	1.64	1.68
FeO	0.72	1.00	0.71	0.64	0.88	0.62	0.41	0.58	1.32	1.22	1.19
MnO	0.065	0.060	0.072	0.049	0.051	0.040	0.036	0.061	0.048	0.059	0.099
MgO	0.46	0.58	0.42	0.40	0.52	0.40	0.59	0.38	0.52	0.52	0.50
CaO	1.55	1.19	0.88	1.23	1.25	0.86	0.48	0.90	2.20	2.10	1.97
SrO	0.014	0.018	0.015	0.030	0.013	0.011	0.003	0.014	0.020	0.016	0.018
BaO	0.076	0.110	0.095	0.107	0.115	0.098	0.073	0.067	0.086	0.082	0.090
Na_2O	3.62	3.65	3.62	3.49	3.59	3.55	0.62	3.40	3.63	3.30	3.78
K_2O	3.63	3.82	4.02	3.90	4.58	3.33	4.10	4.02	3.52	3.63	3.70
Li_2O	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.01
P_2O_5	0.08	0.10	0.08	0.06	0.09	0.07	0.17	0.08	0.11	0.13	0.11
H_2O^+ $(+CO_2)$	0.58	0.82	0.79	0.81	0.78	0.66	1.68	0.73	0.69	0.90	0.66
H_2O^-	0.08	0.06	0.08	0.21	0.06	0.06	0.10	0.12	0.10	0.14	0.10
Total	99.50	99.97	99.28	99.51	99.72	99.67	99.70	99.80	99.86	99.30	99.63

Long I i/f) sunaiviaeu tne granite arm reinterpreteu I umtgai and Shiver's data to obtain separate ages for the subunits, ranging from 1673 to 1400 my.

ANALYTICAL PROCEDURES AND RESULTS

From the northern part of the study area, six samples from the Puntiagudo granite porphyry and five from the Rana quartz monzonite were analyzed for major elements, Rb and Sr concentrations, Sr isotopic ratios, and rare-earth and other trace-element data (Register, 1979). From the southern part of the study area, eight samples of the Embudo Granite (undivided) were analyzed for Rb and Sr concentrations and Sr isotopic ratios by P. D. Fullagar (personal commun., 1978).

Major-element analyses (Table 1) were carried out by atomic absorption spectrophotometry and other standard wet-chemical analytical techniques.

Rb and Sr concentrations and Sr isotopic compositions (Table 2) were determined by mass spectrometric techniques. Rb and Sr concentrations were determined by standard isotope-dilution techniques using 87 Rb and 84Sr spikes. The 85 Rb/87 Rb ratio was taken to be 2.591, and the decay constant for 87 Rb was taken as 1.42 x

Analyses of Eimer and Amend standard SrCO3 give an average normalized 87Sr/86Sr ratio of 0.7080 with a standard deviation of 0.0003. All Rb-Sr ages and initial 87 Sr/86 Sr ratios have been calculated using the least-squares cubic-regression method of York (1969). One-standard-deviation experimental errors of 0.05 percent and 1 percent have been assigned to the (87Sr/86SO N and 87 RID/86 Sr, respectively.

Samples from the northern part of the study area were analyzed for rare-earth and other trace elements by instrumental neutron activation analysis (INAA); data are presented in Register (1979). The uranium content for each sample was determined by delayed neutron activation analysis (DNAA). Both INAA and DNAA were carried out at the Los Alamos Scientific Laboratory (LASL) using their 8MW Omega West Reactor as a neutron source. Procedures for analyses are similar to those described by Della Valle and Brookins (in press).

DISCUSSION

The linear fit to the Rb-Sr data for whole rocks from the Puntiagudo granite porphyry (fig. 2a) yields an age of 1,547 ± 138 m.y. and an initial 87Sr/86Sr ratio of 0.7056 ± 0.0053 (1a). This age is younger than that reported by Fullagar and Shiver (1973) for all units of the Embudo Granite, and Long's (1974) reinterpretation of those data, unless a maximum error is used.

The low 87Sr/86Sr initial ratio of the Puntiagudo granite porphyry implies that the original magma, from which the granitic magma fractionated, may have originated in the lower

Table 2. Rb-Sr data for samples from the Puntiagudo granite porphyry and the Rana quartz monzonite from Register (1979), and from the Embudo Granite (undivided) (Fullagar, personal commun., 1978).

Sample	Sr (ppm)	Rb (ppm)	$^{87}Sr/^{86}Sr$	$^{87}Rb/^{86}Sr$
Pgp-1	132.33	126.16	0.7682	2.7763
Pgp-2	171.97	142.10	0.7565	2.4036
Pgp-3	145.59	151.46	0.7729	3.0308
Pgp-4	293.36	135.44	0.7370	1.3404
Pgp-5	122.60	192.52	0.8118	4.5920
Pgp-6	100.69	135.67	0.7822	3.9288
Rqm-1	30.62	173.11	1.0353	16.8851
Rqm-2	132.96	163.34	0.7947	3.5865
Rqm-3	179.15	144.48	0.7607	2.3468
Rqm-4	158.80	141.29	0.7576	2.5883
Rqm-5	172.80	145.21	0.7612	2.4455
1193	79.5	132	0.8069	4.84
1197	39.4	147	0.9219	11.06
1202	116	178	0.7914	4.48
1204	122	135	0.7760	3.23
1206	101	166	0.8022	4.79
1207	108	533	1.0027	14.76
1213	43.3	255	1.0802	17.67
1214	32.8	241	1.1916	22.24

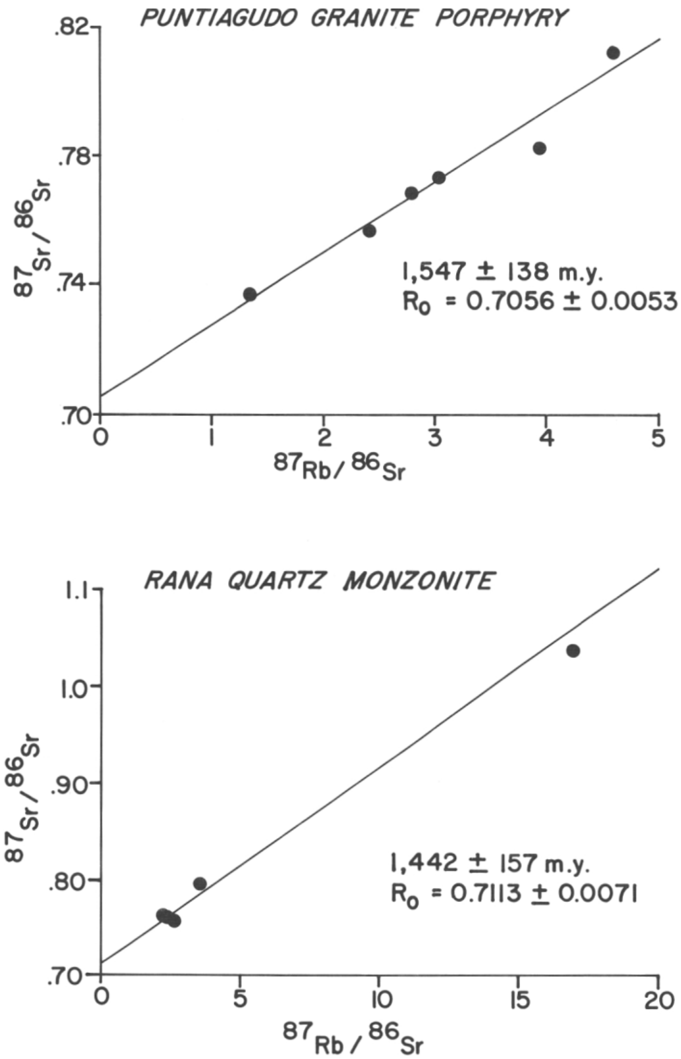

Figure 2. (A) (top) Puntiagudo granite porphyry isochron. (B) (bottom) Rana quartz monzonite isochron.

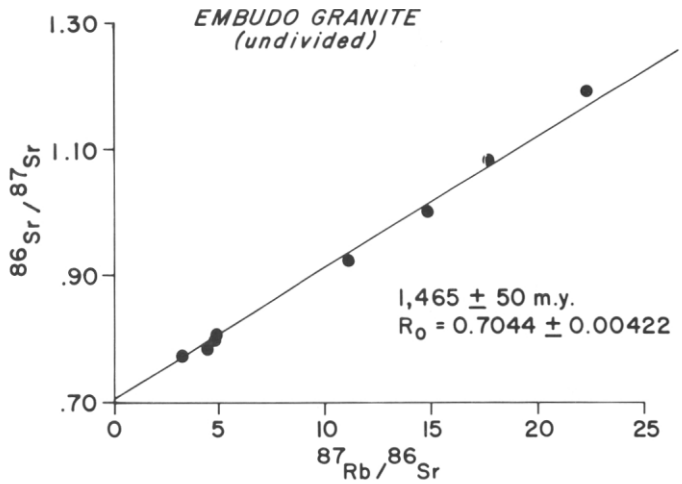

Figure 3. Embudo Granite (undivided) isochron.

crust from material not long removed from a low $^{87}Sr/^{86}Sr$ source. The granitic magma incorporated little radiogenic Sr from old crustal rocks, as evidenced by the low initial ratio.

The linear fit to the Rb-Sr data for whole rocks from the Rana quartz monzonite (fig. 2b) yields an age of 1,441 ± 157 my. and an $^{87}Sr/^{86}Sr$ initial ratio of 0.7113 ± 0.0071. This age is also younger than that suggested by Long (1974); however, the slope is extremely dependent on sample Rqm-1, and any slight variation in this point would cause changes in slope, and thus, the age.

The apparently high 875r/86Sr initial ratio of the Rana quartz monzonite is puzzling, especially when one considers that most of the points from Fullagar and Shiver (1973), which yield an initial ratio of 0.7012, are probably samples from the Rana quartz monzonite. The dependence of the slope of Rqm-1 could be a possible explanation of this high ratio. This particular sample is highly foliated, and if the post-tectonic metamorphic event or one of the two subsequent thermal events (reported by Nielsen and Dunn (1974) and confirmed by Holdaway (1978)) were accompanied by local metasomatism in the quartz monzonite, this could result in an apparent lowering of that point, resulting in a higher initial ratio.

The linear fit to the Rb-Sr data for eight whole-rock samples from the Embudo Granite in the southern part of the study area (fig. 3) yields an age of 1,464 ± 50 m.y. (very close to the age obtained for the Rana quartz monzonite to the north), and an initial ratio of 0.7044 ± 0.0042. It is unknown whether these rocks are related genetically; however, they are related temporally and spatially. These ages fall within the 1,430-to-1,350 m.y. event reported by Muehlberger and others (1966) (when using 1.42 x 10-11y-1 as the decay constant as opposed to 1.47 x 10-11y-1).

Chemical differentiation trends (Register, 1979) for the whole rocks from the northern part of the study area are the same as those reported for the Embudo Granite (undivided) by Fullagar and Shiver (1973), suggesting that the analyzed rocks are comagmatic.

Trace elements in both the Puntiagudo granite porphyry and the Rana quartz monzonite fall within the same range of reported concentrations of other granitic rocks. Both show similar REE concentrations to those reported for a composite granite with more than 70% Si02 (Haskin and Frey, 1966). The rare-earth patterns for both suites (figs. 4a, 4b) show typical granitic trends with relative enrichment in the light rare-earths (La to Sm) and depletion in the heavy rare-earths. Slight negative cerium and europium anomalies are observed in both groups, which is also typical for most granites, due, presumably, to oxidation effects.

CONCLUSIONS

The results of this study support the following conclusions:

(1) The Puntiagudo granite porphyry and the Rana quartz monzonite were intruded at 1,547 ± 138 m.y. and 1,441 ± 157 m.y., respectively.

(2) The Embudo Granite (undivided) to the south yields an age of 1,465 ± 50 m.y., contemporaneous with the Rana quartz monzonite.

(3) The granites in the northern part of the area are probably cogmagmatic with those analyzed by Fullagar and Shiver (1973) to which they are spatially related.

(4) Typical granitic REE and other trace-element distributions are seen for the Puntiagudo granite porphyry and the Rana quartz monzonite.

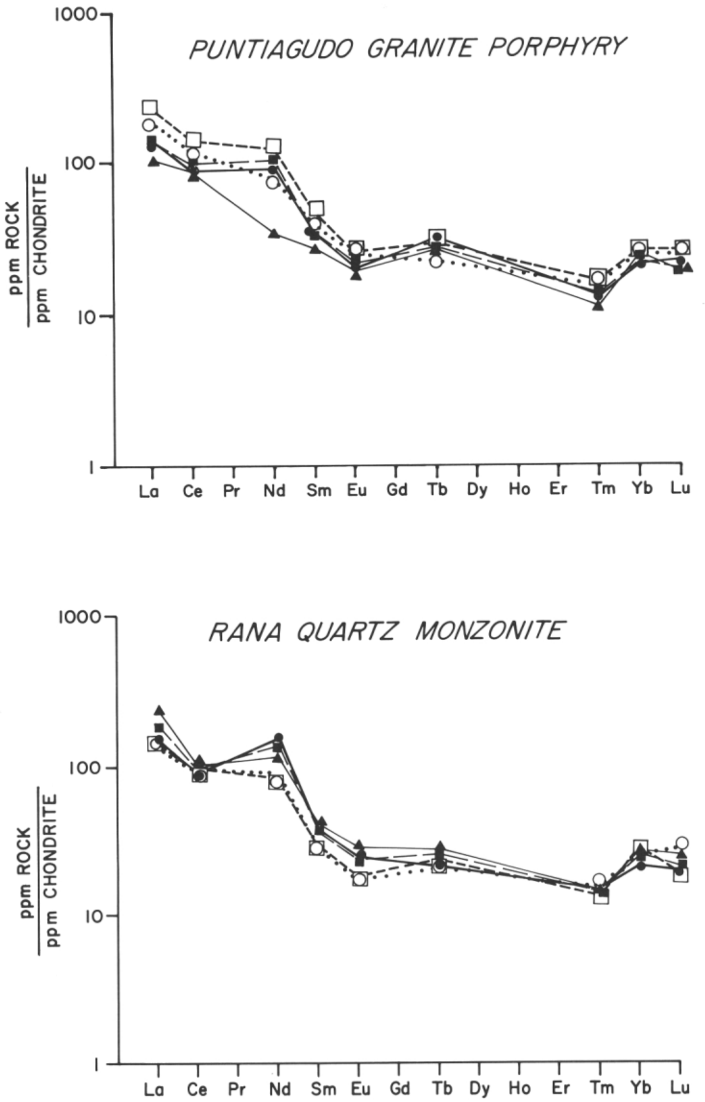

Figure 4. (A) (top) Rare-earth-element distribution pattern for the Puntiagudo granite porphyry. (B) (bottom) Rare-earth-element distribution pattern for the Rana quartz monzonite.

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