# PRECAMBRIAN GEOCHRONOLOGY OF THE SEVILLITA METARHYOLITE AND THE LOS PINOS, SEPULTURA, AND PRIEST PLUTONS OF THE SOUTHERN SANDIA UPLIFT, CENTRAL NEW MEXICO

by

W.R. Bolton

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# ABSTRACT

The dates reported here relate to three Precambrian granitic plutons and a Precambrian metarhyolite exposed in the southern part of the Sandia Uplift of central New Mexico. The Rb-Sr whole-rock method was employed. Rb and Sr concentrations were determined by X-ray flourescence and the $^{87}$Sr/$^{86}$Sr ratios measured by mass spectrometer analysis. The X-ray fluorescence and mass spectrometric techniques are described fully.

Analyses of four samples of the Sevillita metarhyolite yield a date of 1700 ± 58 m.y. with initial $^{87}$Sr/$^{36}$Sr equal to 0.7021 ± 0.0022. The initial ratio is low and results from the fact that only a small number of points (4) were used. A date between 1660 and 1700 m.y. is believed to be representative with a deep seated source.

Six samples of the Priest quartz monzonite define a 1470 ± 30 m.y. isochron with initial $^{87}$Sr/$^{86}$Sr equal to 0.7054 ± 0.0012. This date is in fair agreement with that reported for the Sandia granite of the northern Sandia Uplift. The 0.7054 initial ratio may reflect derivation from older sialic material, or may indicate contamination of the magma by radiogenic strontium.

The dates and initial ratios of the Los Pinos and Sepultura granites are indistinguishagle within the limits

of error. Six samples of the Los Pinos granite define a 1410 ± 30 m.y. isochron with initial $^{87}Sr/^{86}Sr$ equal to 0.7267 ± 0.0080. Six samples of the Sepultura granite define a 1430 ± 60 m.y. isochron with initial $^{87}Sr/^{86}Sr$ equal to 0.7227 ± 0.0055. The anomalously high initial ratios and younger dates may have resulted by contamination of the magmas by radiogenic strontium.

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# INTRODUCTION

The South Manzano Mountains and the Los Pinos Mountains of central New Mexico contain large exposures of Precambrian rocks of volcanic, plutonic, and sedimentary origins. These mountains trend north-south and are separated by Abo Pass through which runs U.S. Highway 60 affording east and west access. The exposures result from erosion of a northeast trending horst bounded on the east by the Montosa Reverse Fault and on the west by the Tio Bartolo Fault Zone which also forms the eastern boundary of the Rio Grande Rift in this area (Beers, 1976). The Manzano and Los Pinos Mountains make up the southern structural province of the Sandia Uplift.

This paper relates to three Precambrian granitic plutons and a Precambrian metavolcanic series occuring in the above mountains. The Rb-Sr whole-rock isochron method was employed for the age determinations. These rocks have undergone a period of regional metamorphism of the upper greenschist facies. Eighteen whole-rock samples from the granitic rocks and five whole-rock samples from the metavolcanics were analyzed.

The current mapping of the Los Pinos Mountains was done by Beers (1976). K.C. Condie collected the samples used for the isochrons. Other work in the area includes J.T. Stark's (1956) Geology of the South Manzano Mountains, Mallon's (1966) summary of the Precambrian geology of the Los Pinos Mountains, and Stark and Dapples' (1946) Geology of the Los Pinos Mountains.

The maps used in this study are the U.S.G.S. topographic sheets: N3422.5-W10630/7.5 (Becker), N3415-W10630/7.5 (Cerro Montosa), and N3415-W10637.5/7.5 (Becker SW); along with J.T. Stark's geological map of the South Manzano Mountains.

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## SPACIAL DISTRIBUTION OF PRECAMBRIAN AGES IN THE SOUTHWEST

From recent data available concerning the Precambrian of Arizona, Colorado, California, Texas, and New Mexico it is readily apparent that there exist basically three major periods of igneous activity. From older to younger these are 1.6-1.8 b.y., 1.3-1.5 b.y., and 0.9-1.2 b.y. In spite of some geographical overlap these periods seem to be regionally defined; the oldest is the most northernly and the others occur as successively younger belts to the south.

The older terrane is predominatly composed of granitic rocks, gneiss, silicecus metavolcanic rocks, and pegmatite and occurs generally north of 35° latitude with scattered exposures to the south. It is best represented in the Colorado, northern New Mexico area along with grouped exposures in northwestern Arizona, southern Nevada, and southeastern California.

The 1.3-1.5 b.y. terrane is best represented in central New Mexico where the Sandia Uplift contains four granitic plutons of this age range (three reported in this study). Dates from the San Andres, Caballo, and Oscura Mountains along with the Pedernal granite also fall within this range. The rocks of this age range are generally granitic in composition and intrude quartzites, schists, and metavolcanics.

The 0.9-1.2 b.y. terrane is found in all cited states but is best and most frequently represented in southernmost New Mexico and west Texas extending from here to at least the Llano Uplift of central Texas, some 500 miles distant. The rock assemblage here is almost identical to those rocks found north of the area which have ages from 1.3-1.5 b.y.

The only relatively continuous exposure of Rb-Sr whole-rock dates in the southwest extends from southern Colorado south to western Texas along the Rio Grande Rift. These exposures have in common a general association of granitic rocks with metarhyolite and metasediments. In southern Colorado the older granitic rocks (1.7 b.y.) are intruded by younger granitic rocks (≅ 1.4 b.y.) and rhyolite dikes (≅ 1.35 b.y.). During the emplacement of the latter intrusives the area under went low-to intermediate-grade metamorphism (Bickford et al., 1969). To the south, occurences of 1.6-1.8 b.y. old intrusive rocks become more scarce and scattered while the 1.3-1.5 b.y. old igneous rocks begin to predominate. The last exposures of this middle period and the first exposures of the younger period are found just north of the Texas-New Mexico border; the area south of this border contains dates of only the younger period.

The Precambrian metamorphic rocks in central New Mexico are typical Precambrian supracrustal assembleges. They are composed chiefly of quartzites, arkosites, shale or slate, siliceous volcanics, high-potassium 'punch' granites, and minor basalts. This assemblage is normally associated with older cratonic edges and in some cases with Precambrian mobile belts such as the Coronation and Circum-Ungava geosynclines of Canada. The siliceous volcanics and 'punch' granites indicate crustal heating on a wide scale as this type of terrane extends from southeastern California at least to central New Mexico, and from here north into Colorado.

It may be summarized that the country rocks of this area were deposited along the edge of a craton, probably to the north, as a blanket of supracrustal rocks which were subsequently deformed, metamorphosed to greenschist or higher facies, intruded by 1.3-1.5 b.y. old granitic rocks, uplifted and eroded. While it is tempting to try and label portions of the southwestern Precambrian according to plate tectonic models, the data at this time are too widely separated in space and time to provide a base on which to work.

# PRECAMBRIAN ROCKS OF THE SOUTH MANZANO AND LOS PINOS MOUNTAINS

## Introduction

The Precambrian metasedimentary and metavolcanic section of the South Manzano and Los Pinos Mountains consists of four mapped units which in ascending order are as follows: (1), the basal Sais quartzite; (2), the Blue Springs schist; (3), the White Ridge quartzite; and (4), the Sevillita metarhyolite. Into this section the Priest quartz monzonite and the Los Pinos and Sepultura granites are inturded. The Los Pinos and Sepultura granites of the Los Pinos Mountains intrude (in outcrop) only the Sevillita metarhyolite and its probable equivalent, the Bootleg Canyon sequence. The Priest quartz monzonite of the South Manzano Mountains is observed intruding the Sais quartzite, the Blue Springs schist, and the White Ridge quartzite (Stark, 1956). Rock descriptions follow for the granites, the quartz monzonite, and the metarhyolite.

## The Sevillita metarhyolite

Beers (1976) has examined the Sevillita metarhyolite in the Los Pinos Mountains, and Stark (1956) has examined it in the South Manzano Mountains. They agree that it is made up of intercalated siliceous metavolcanics and metasediments, (predominately quartzites and arkosites), at approximately a 1 to 1 ratio. The different units are readily distinguished geochemically.

The majority of the metamorphosed igneous rock has the appearance of ash flow tuff with the individual flows approaching 30 ft. in thickness. Thickness of the Sevillita metarhyolite varies, due to erosion, but a good estimate of preserved thickness is approximately 6,500 ft. Stark (1956) describes the rock as follows (p. 11-12):

> "The typical rhyolite is a pink to grey, brittle, blocky-fracturing porphyritic aphanite. Closely spaced flow lines are evident on weatered surfaces. Phenocrysts range from 1 to 4 mm. and are most commonly of quartz and or pink feldspar.
>
> Mineral percentages in the rhyolite average: orthoclase, 15%-25%; albite, 10%-20%; quartz, 50%-60%; biotite, 1%-10%; magnetite, less than 1%, with scattered grains of apatite and zircon. Much of the feldspar is altered to masses of white mica, quartz, and epidote. Euhedral phenocrysts of quartz and feldspar make up from 5 to 10 percent of the banded flows. Quartz phenocrysts are commonly embayed. In the groundmass the grain size averages .005 mm. and is composed of quartz and untwinned feldspar. In many sections, the cloudy, patchy moltting is suggestive of devitrification."

Samples used for the isochron study of the metarhyolite were collected in the Pinion Canyon area of the Los Pinos Mountains by K.C. Condie. For sample locations see Beers, (1976), Plate 1.

### The Bootleg Canyon sequence

The Bootleg Canyon sequence noted in the descriptions of the Los Pinos and Sepultura granites was so named by Beers (1976) as it could not be correlated with units in the Sevillita metarhyolite previously described in the area. His description is included here due to the signicant location of the unit (p. 26):

> "The stratigraphy of this unit is very similar to the Sevillita Metarhyolite and may in fact be its equivalent. Hornblende schists account for perhaps half of this unit, the remainder is a quartz-mica schist. In outcrop the rocks are very dark, generally black; fresh surfaces show a light grey color for the quartz-mica schist, and a dark green color for the hornblende schists. Biotite is quite common in these rocks as opposed to the Sevillita Metarhyolite, and may be due to a slight increase in the metamorphic grade as the unit is situated between two granite plutons. The quartz-mica schist is nearly identical to the Sevillita Metarhyolite, with the exception that biotite replaces muscovite."

### The Los Pinos granite

Beers (1976, p. 26-29) describes the Los Pinos granite as follows:

> "The pluton is bounded to the west by the Tio Bartolo Fault Zone, to the southwest by the Bootleg Canyon Sequence, and to the east and north by the Sevillita Metarhyolite. In general, the Los Pinos Granite appears concordant with the Sevillita Metarhyolite. However on a small scale, discordant relationships exist... The Los Pinos Granite is a porphyritic granite with phenocrysts comprising 10-15% of the volume. The phenocrysts are predominately plagioclase ($An_{34}$) with minor (10-15%) quartz and potassic feldspar phenocrysts... Occasionally the phenocrysts show evidence of both resorption and overgrowth...The groundmass of the Los Pinos Granite is composed predominately of quartz and potassium feldspar averaging 1mm. in diameter. Approximately one half of the groundmass shows a myrmekitic intergrowth of quartz and plagioclase, which is not found in the Sepultura Granite. Rapakivi texture... was noted in some slides and is unique to the Los Pinos Granite...Miarolitic cavities are not uncommon throughout the...(granite), but are most common at its northern most exposures."

The modal analyses (made by Beers (1976) and the author) of the whole-rock samples used, yield an average composition of 44% quartz, 12% plagioclase, 38% potassium feldspar, 4% biotite, 1.5% magnetite, and <1% sericite. The sericite is evenly distributed throughout the plagioclase with a minor amount in the groundmass. For sample locations see Beers (1976), Plate 1.

## The Sepultura granite

The composition of the Los Pinos and Sepultura granites is macroscopically similar, which, along with the near proximity of the two accounts for their being mapped as a single unit by previous workers. Beers (1976) describes the rock as follows (p. 29-33):

> "The Sepultura Granite is porphyritic and the phenocrysts, which compose less than 15% of the rock by volume, are predominately potassium feldspar with minor (<10%) plagioclase ($An_{32}$). Most of the phenocrysts are subhedral,... grain boundaries show evidence of resportion during the final stages of crystallization. In general the phenocrysts range from 3 to 4 millimeters in length and the groundmass minerals range from 0.5 to 1 millimeter in length. The groundmass consists predominatly of anhedral quartz and potassium feldspar and minor euhedral plagioclase (An32).
>
> The Sepultura Granite is exposed to the southwest of the Los Pinos Granite and is separated from it by the Bootleg Canyon Sequence which forms its northern and eastern boundaries. The western boundary of the Sepultura Granite is formed by the Tio Bartolo Fault Zone. (The southern boundary) is overlain by Pennsylvania sediments..."

The modal analyses of the Sepultura granite as compiled by Beers (1976) and the author yield an average composition of 36% quartz, 18% plagioclase, 43% potassium feldspar, 2% biotite, 1% magnetite, and <1%

sericite. As in the Los Pinos granite the sericite is evenly distributed throughout the plagioclase with a minor amount in the groundmass. For sample locations see Beers (1976), Plate 1..

The Priest quartz monzonite

The Priest quartz monzonite outcrops in the South Manzano Mountains from just north of Abo Pass to a point some six miles to the northeast. Stark (1956) describes the pluton as follows (p. 19-20):

> "The main mass of the Priest... is a coarse grained biotite-quartz-feldspar phanerite with large phenocrysts or porphyroblasts of light-pink microcline. The (body) is light red on fresh surfaces, but in most outcrops it is deeply weathered to a grey rock which readily crumbles... Inclusion of schist and quartzite are numerous near the contact with the metaclastics, and in places abundant pegmatite and apalite dikes and quartz veins characterize the border zones... Sills and dikes of granite from 1 to 200 ft. thick intrude the metaclastics.
>
> Mineral percentages in the (body) average: total feldspar (including orthoclase, microcline, and albite ($Ab_{92}$), 63%; quartz, 30%; biotite, 5%; epidote, 1%; with small amounts of magnetite, apatite, hematite, zircon, and allanite.
>
> Euhedral crystals of microcline, from 0.5 to 30 mm. in length are slightly altered to kaolin and sericite. Some albite crystals show rims of clear orthoclase. The albite is largely saussuritized to fine grained masses of epidote, quartz, and white mica...Much of the biotite is altered to chlorite and epidote.
>
> The southern boundary is an intrusive contact with the Blue Springs schist and White Ridge quartzite. On the southwest, the (body) is overlapped by pediment gravels for 1¼ miles... From here northeastward for 2 2/3 miles, the (body) is in intrusive contact with the Sais quartzite. At the north, the (body) intrudes Sais quartzite and Blue Springs schist. The eastern boundary is the Montosa thrust fault..."

The samples used in the isochron were collected by K.C. Condie. Stark (1956) believes the Priest quartz monzonite possesses a red and a grey facies, through field work in the area by Condie (pers. comm., 1976) did not disclose any evidence of two facies. For sample locations see Figure 6.

# METAMORPHISM

The Precambrian supracrustal rocks of the Manzano and Los Pinos Mountains exhibit regional metamorphism typical of the upper greenschist facies along with accompaning dynamic features. Beers (1976) states that the agreement between thin section data and predicted mineral assemblages suggests the area approached equilibria at a temperature of 400 to 600 °C. and with a pressure range of 3 to 6.5 Kb. This is upper greenschist or lower amphibolite facies. Dynamic aspects of regional metamorphism served to impart flow cleavage and penetrative deformation sufficient to partially transpose bedding (Beers, 1976). Relict quartz and plagioclase phenocrysts of the Sevillita metarhyolite in some thin sections show rotated textures with quartz-filled, sigmoidal pressure-shadow zones. Other dynamic aspects of metamorphism consist of broad open-folding developed in the metasediments and metavolcanics. This occurred before the intrusion of the Priest quartz monzonite as shown by numerous dikes and pegmatite veins, associated with the quartz monzonite, which crosscut the folding without being themselves deformed (Stark, 1956).

Intrusion of the plutons produced varying degrees of contact metamorphism. Stark (1956) states that the

Priest quartz monzonite was intruded into partially metamorphosed country rocks forming a thermal aureole best developed in the Blue Springs schist. Muscovite, not found outside the aureole, becomes increasingly more apparent as one nears the contact where it accounts for approximately 50% of the rock. Pegmatite dikes, rich in muscovite, crosscut the aureole. Sericite in the Blue Springs schist increases from approximately 2%, over 1500 feet from the contact, to about 60%, 15 feet from the contact. Contact metamorphism of the Sevillita metarhyolite by the Priest quartz monzonite developed porphyroblasts of garnet and chloritoid in the rhyolite. Stark (1956) concludes that the contact metamorphic zoning of the country rocks is dependent upon the original composition of the host rocks, due to the varying mineral assemblages found at different horizons.

The Los Pinos and Sepultura granites to the south have not shown the same degree of thermal metamorphism in relation to the surrounding country rocks. Beers (1976) has observed that immediately adjacent to the plutons, the effects are marked by destruction of foliation, layering, and phenocrysts normally present in the Sevillita metarhyolite. The metarhyolite also takes on a highly siliceous nature though there is no evidence for the growth of minerals not previously recognized. Beers (1976) believes this lack of contact metamorphism is due to three major factors: (1), the regional metamorphic temperature is similar to that of the intruding granites; (2), the low volitile content of the Los Pinos and Sepultura granites as shown by the relative lack of quartz veins associated with fluid-rich intrusives; and (3), the shallow depth of emplacement evidenced by miarolitic cavities normally associated with near-surface plutonic environments, resulting in a low overall pressure.

The final stages of metamorphism consisted of cataclastic deformation accompaning the development of, and displacement along, the Montosa and Paloma Faults during the Mesozoic (Beers, 1976). The Montosa Fault, which cuts Cretaceous limestones but not Tertiary volcanics south of the Los Pinos Mountains, is thought to be of Laramide age. The Paloma Fault is thought to be of the same age. Local drag folding is associated with the faulting.

# ANALYTICAL METHODS

## Sample Preparation

The hand specimens were selected on the basis of freshness (i.e. lack of weathering, contamination, or any other effects which would render them nonrepresentative of the original bodies). The size of the hand specimens was at least ten times the size of the largest grains in order to eliminate any mineral bias, and sufficiently large (300-500 grams) to provide enough powder for both X-ray fluorescence (XRF) and mass spectrometer analyses. The samples were crushed with a hammer and plate, taking care so as to avoid any contamination. These smaller fragments were then run through a jaw crusher followed by a pulverizer. The resulting coarse powder was ground in a Fisher mortar grinder for 20 minutes and a suitable portion was removed for mass spectrometer analysis. The remaining powder was reground for 30 minutes with the addition of acetone. The acetone served to prevent the fine powder from clumping under the pedestal.

## X-ray Fluorescence

For XRF work, approximately three grams of the resulting fine powder from each sample were pelletized using tapered cylinders and pistons of two sizes, the smaller cylinder being the diameter of the larger piston. The smaller diameter cylinder and piston were used to form the sample into a flat cake within the base using slight hand pressure and from three to five drops of deionized water. The smaller diameter components were then removed, leaving the larger cylinder within the base. Approximately three grams of bakelite were then poured into this receptacle and the larger piston inserted. This complete unit was placed in a 25kg hydraulic press and held at approximately 21kg for 30 seconds. The pressure was then released slowly over a 5 minute period until the unit was free to the touch. The unit was then taken from the press and the base removed leaving the sample pellet in the larger diameter cylinder and piston. The pellet was then removed using a hollow drift and a hand press. The pellet then consists of a sample powder cake, backed and laterally surrounded by bakelite. The sample surface of the pellet should be smooth, flat, and free from defects. The author found that the addition of four drops of deionized water to the sample coupled with the inverted coning of both the sample and bakelite in the cylinders consistantly produced pellets which were not prone to expansion and or fracture after leaving the hydraulic press.

When all the samples were pelletized and labeled, they were analyzed by XRF to determine their major and trace element composition. The major element data were compiled by K.C. Condie (pers. comm., 1975). The analyses were done using Norelco components with a teletype interface.

The raw data for Rb and Sr was collected in counts per second (cps) over 20 separate, 10 second intervals.

Drift correction was accomplished by the use of standards GH and G2. For explanatory graphs and corrections, see appendix 1. The results were analyzed using a computer program which utilized Reynolds' (1963,1967) approach to determinization of trace element concentrations in rocks and minerals. The mass absorption coefficient, $\mu_\lambda$, is computed first from a linear relationship which exists between $\mu_\lambda$ (with $\lambda$ equal to 0.9 Å), and the intensity of the Comption scattered portion of $Mo_{K\alpha}$ primary beam measured in cps. The program internally computes the relationship with reference to a series of ten punched-in standards and computes the mass absorption coefficients of the unknowns. The program then computes the trace element concentrations using an equation of the form:

$$\text{ppm } Z_{x} \qquad \frac{\text{cps } Z\, K_{\alpha,x}}{\text{cps } Z\, K_{\alpha,\text{std.}}} \cdot \frac{\mu_{0.9\,\text{Å},x}}{\mu_{0.9\,\text{Å},\,\text{std.}}} \cdot \text{ppm } Z_{\text{std.}}$$

Here cps $Z\,K_{\alpha,x}$ and cps $Z\,K_{\alpha,\text{ std.}}$ refer respectively to the intensities in counts per second of the background corrected $Z\,K_{\alpha}$ peaks in the unknown and standard, $\mu_{0.9\,\text{Å},x} / \mu_{0.9\,\text{Å},\text{ std.}}$ refers to the mass absorption coefficients at 0.9 angstroms of unknown and standard, and ppm $Z_x$ and ppm $Z_{\text{std.}}$ refer to the concentration of element Z in the unknown and standard respectively. The results are listed in Table 1.

## Mass Spectrometry

Data from the above study allows a selection of samples with the widest range of Rb/Sr ratios which permits a better definition of the isochron. From the Sr concentrations one is able to determine the amount of sample needed to provide the 50-100 micrograms of Sr which are necessary for mass spectrometry. Most samples contained 100-200 ppm which rendered one gram of sample powder sufficient. The powder from each sample was placed in a 100 ml teflon evaporating dish which was previously wetted with deionized water so as to almost cover the bottom of the dish. If the dish is not wetted the powder has a tendency to be repulsed by static charge. The dishes were placed under a hood and 40 ml per gram of sample of reagent grade hydrofluoric (HF) acid was added followed by 3-5 ml vycor distilled perchloric acid (v.d. $HClO_4$). The mixture was stirred with a teflon rod until a slurry was obtained. The samples were then placed on a hot plate and were stirred until the dissolution appeared to be as complete as possible (approximately 15 minutes). Additional HF was added occasionally to obtain near complete solution. The samples were then taken to dryness, lowering the hot plate setting to avoid boiling and splattering. Dryness was indicated by the lack of fumes and generally, a yellow-brown cake. The dishes containing the cakes were then removed from the hot plate and allowed to cool for 15 minutes followed by the addition of 20 ml each of v.d. 2 normal hydrochloric acid (v.d. 2N HCl) and deionized water.

The mixtures were returned to the hot plate, at a lower temperature, and stirred until the cloudy solution became relatively clear. There sometimes remains a pale yellow tint due to $FeCl_x$ complexes. The solutions were evaporated to approximately 25 ml, removed from the hot plate, and allowed to cool for 6 to 8 hours, (preferably overnight), covered with parafin to prevent the entry of contaminats.

Filtrates were prepared for each sample using S&S #576 filter papers (Whatman 42), taking care to avoid touching the paper. One filter paper was used as a glove during the forming of the filters. The formed filter cones were placed in the funnels, and collecting beakers were placed beneath. The solutions were poured into the filters and the residue was completely flushed several times with a few drops of v.d. 2N HCl. Parafin was used to cover the funnels and the collecting beakers during the filtering.

Before the solutions underwent ion exchange chromatography a few drops of c.f. $^{85}Sr$ tracer were added. This made it possible to follow the Sr through the columns by the use of a narrow-window $\gamma$ counter. The tracer was added a drop at a time until the intensity of the resulting radiation reached a degree three times that of the previously measured background.

In preparation for Sr collection, six 40 ml beakers were labeled consecutively, covered and set aside for each sample along with a large waste beaker. The waste beaker was placed under the column stand. The columns to be used were removed from the stands and checked to make sure the surface of the resin was flat. It was important for the flat surface on the resin to remain throughout the collection so that an even initial distribution of the ions could be obtained. The sample solution was added by pouring the solution down the side of the column while holding the column in an inclined position. The beaker which held the solution was then rinsed with v.d. 2N HCl and this wash was added to the column in the same manner. The column was replaced in the stand, the mouth covered with parafin, and the solution was allowed to completely dry into the resin. This was followed by the addition of a series of 10 ml v.d. 2N HCl aliquots which were used to wash the walls of the columns. Each was allowed to dry completely into the resin. This process was continued until the activity (detected as before) was at least 1.5 inches below the flat resin surface. When this point was reached the columns were carefully filled and kept relatively full for the duration. The column efluent was collected in the waste beaker until the activity was within one inch of the basal glass wool. The first of the six previous beakers was then placed under the columns with the tip of the column and the mouth of the beaker covered by a parafin shield. Constant monitoring was accomplished from this point on by use of the $\gamma$ counter and flame tests of the efluent. By collecting approximately 20 ml per beaker it was possible to concentrate the majority of the Sr into the third and fourth beakers with only minor activity in the second and fifth. The amount of efluent collected per beaker was dependent upon the Sr travel-time through each column. The beakers which had the highest concentration of Sr were taken to dryness on a hot plate and inspected for the amount of precipitate. The concentrated Sr was typically a thin, whitish film; those beakers with larger amounts of precipitate contained excess calcium or barium. The contents of the beakers with the highest activity and the least contamination were redissolved with v.d. 2N HCl and combined in a teflon beaker and taken to dryness. Each Sr concentrate was then redissolved with a few drops of v.d. 6N nitric acid ($HNO_3$) and transferred to a quartz microbeaker which had been labeled beforehand with a diamond stylus. The beakers were then taken to dryness followed by fusing of the residue over a Meeker burner to a red-orange heat for a period of two minutes. The residue turned black on the outset as the resin present was eliminated, and then white as the fusion was completed. The microbeakers were then covered and stored for mass spectrometer analysis.

The Sr was analyzed by thermionic emission using a Nier-type, Nuclide 90-degree, 12-inch mass spectrometer. The sample analyses were run by D.G. Brookins along with the staff of the geochemical laboratory of the University of New Mexico. Twenty-four scanning cycles of the peaks were averaged for the analyses. All $^{87}Sr/^{86}Sr$ ratios were normalized to $^{86}Sr/^{88}Sr = 0.1194$. The calculated $^{87}Sr/^{86}Sr$

ratios are precise to ± 0.1%. The decay constant ($\lambda$) used in the age calculations is $1.39 \times 10^{-11}$ yrs. The York (1966) method of least-squares regression was used to calculate the slope and errors of the isochrons. The results are listed in Table 1.

## Table 1. Results of Analyses

|  | sample no. | ppm Rb | ppm Sr | Rb/Sr | $^{87}$Rb/$^{86}$Sr | $^{87}$Sr/$^{86}$Sr |
|---|---|---|---|---|---|---|
| Sevillita metarhyolite | NP-36 | 135 | 136 | 0.996 | 2.90 | 0.771 |
|  | NP-46 | 142 | 67.7 | 2.091 | 6.11 | 0.845 |
|  | NP-47 | 154 | 53.1 | 2.896 | 8.48 | 0.903 |
|  | NP-52 | 44.5 | 51.6 | 0.861 | 2.50 | 0.756 |
|  | NP-63 | 14.4 | 192 | 0.075 | 0.22 | 0.711 |
|  | (NP-63 is the amphibolite sample) |  |  |  |  |  |
| Priest quartz monzonite | MAN-38 | 186 | 372 | 0.500 | 1.45 | 0.7324 |
|  | MAN-41 | 130 | 328 | 0.395 | 1.15 | 0.731 |
|  | MAN-44 | 164 | 250 | 0.657 | 1.91 | 0.745 |
|  | MAN-46 | 166 | 322 | 0.516 | 1.498 | 0.7366 |
|  | MAN-60 | 142 | 275 | 0.515 | 1.495 | 0.7373 |
|  | MAN-G | 155 | 329 | 0.470 | 1.36 | 0.7315 |
| Los Pinos granite | N-2 | 152 | 42.4 | 3.57 | 8.52 | 0.888 |
|  | N-3 | 105 | 61.1 | 1.73 | 5.05 | 0.822 |
|  | N-4 | 155 | 52.3 | 2.96 | 4.98 | 0.827 |
|  | NP-4 | 113 | 55.1 | 2.05 | 6.01 | 0.840 |
|  | NP-8 | 138 | 57.4 | 2.41 | 7.07 | 0.860 |
|  | NP-9 | 158 | 64.8 | 2.43 | 7.15 | 0.884 |
| Sepultura granite | N-6 | 248 | 17.5 | 14.1 | 44.3 | 1.56 |
|  | N-9 | 148 | 30.3 | 4.87 | 14.5 | 1.061 |
|  | NP-12 | 237 | 13.0 | 18.2 | 58.9 | 1.90 |
|  | NP-14 | 173 | 30.6 | 5.66 | 16.9 | 1.059 |
|  | NP-16 | 192 | 10.5 | 18.3 | 59.3 | 1.92 |
|  | NP-19 | 212 | 32.8 | 6.46 | 19.4 | 1.08 |

# RESULTS

Four samples of the Sevillita metarhyolite and one sample of amphibolite interbedded with the metarhyolite define a 1660 ± 50 m.y. isochron with an initial $^{87}Sr/^{86}Sr$ ratio equal to 0.7021 ± 0.0022 (Fig. 1). Geochemical model studies (K.C. Condie, pers. comm., 1976) suggest that the metarhyolites may have been produced by partial melting of the lower crust, while the amphibolite represents a basaltic sill derived from a deeper source. If the amphibolite is excluded from the isochron, the four metarhyolite samples define a 1700 ± 58 m.y. isochron with an impossibly low initial $^{87}Sr/^{86}Sr$ ratil of 0.6995 ± 0.0008 (Fig. 1).

Six samples of the Priest quartz monzonite define a 1470 ± 30 m.y. isochron with initial $^{87}Sr/^{86}Sr = 0.7054 \pm 0.0012$ (Fig. 2). The $^{87}Rb/^{86}Sr$ ratios vary between 1.146 and 1.909 in these samples. While this is a small spread for an isochron investigation, these points do define an isochron with an error that is comparable to the other systems considered.

Six samples of the Los Pinos granite define a 1410 ± 30 m.y. isochron with initial $^{87}Sr/^{86}Sr = 0.7267 \pm 0.0080$ (Fig. 3). Six samples of the Sepultura granite define a 1430 ± 60 m.y. isochron with initial $^{87}Sr/^{86}Sr = 0.7227 \pm 0.0055$ (Fig. 4). The dates and initial ratios for the

Los Pinos and Sepultura granites are identical within the limits of analytical uncertainty and both bodies exhibit very high initial ratios.

# DISCUSSION AND CONCLUSIONS

That the oldest date was obtained for the Sevillita metarhyolite is supported by the intrusive relationship of the granites. The very low initial ratio (0.7021) may indicate some error in the isochron while at the same time pointing to a probable deep seated source for the metarhyolite; further, the isochron must include the amphibolite. From the results summarized in Faure and Powell (1972) it is evident that even for source regions in the mantle at 1.6-1.7 b.y. ago, the initial ratio of 0.6995 is impossible. As the probable intercept is indeed higher (0.7021), the apparent age of 1.7 by., based on 0.6995, is also too high. Unfortunately, the exclusion from the isochron of the amphibolite and failure on thermionic emmision of another sample of the metarhyolite leaves only four points with which to work. There exists the possibility that the 1.7 b.y. isochron has been rotated to an older date and a lower intercept by the apparent, minor alteration of the feldspars as suggested by the work of Brooks (1968), but this remains unsubstantial. The net gain of $^{*87}$Sr by the feldspars would require open system conditions. The scatter of the points about the isochron and the resultant error allows for this possibility. Mineral isochrons are needed to test this hypothesis. It may be safely said that more points are needed to better define the isochron and that a date between the two isochron dates is indicated with the source region being deficient in $^{*87}Sr$. Mineral isochrons and calculations of growth lines are necessary for the determination of open or closed isotopic systomatics within the metarhyolite.

The Priest quartz monzonite is intrusive into the surrounding schists and quartzites. Its date (1470 ± 30 m.y.) is, within analytical error, identical to that reported for the Sandia granite (1504 ± 15 m.y., Taggert and Brookins, 1975), on the basis of the limited data available. The initial ratios of the two plutons differ (0.7027 ± 0.0005 for the Sandia granite and 0.7054 ± 0.0012 for the Priest quartz monzonite), but may be resolved with more extensive data.

If these two bodies are in fact of the same date and their initial ratios are different, then some mechanism is responsible for their different initial ratios.

Weathering of the Priest quartz monzonite has served to (1), slightly alter the potassium feldspar to sericite and kaolin; (2), saussuritize much of the plagioclase to fine grained masses of epidote, quartz, and white mica; and (3), produce incomplete alteration of biotite to chlorite (Stark, 1956). In addition, the samples collected were slightly friable. In their study of the effects of weathering on whole rock isochrons, Fullagar and Ragland (1975) determined that the early stages of chemical weathering of rocks of felsic composition result in an increase in the Rb/Sr and $^{87}Sr/^{86}Sr$ ratios. They suggest that continued weathering causes data points to plot below the isochron due to preferential loss of $^{*87}$Sr from biotite. This preferential loss of common Sr from plagioclase would result in the lowering of the age and could serve to raise the initial ratio. In light of the weathering effects observed in the Priest quartz monzonite, this appears to be one valid interpretation, capable of lowering the age slightly (≅2%) and increasing the initial ratio.

To determine if contamination served as the mechanism whereby the initial $^{87}$Sr/$^{86}$Sr was increased, the nature of the contamination may be calculated. Pushkar, et al., 1967, presents the following empirical equation for this purpose:

$$P \qquad \frac{C_1 - C_o}{C_c - C_1} \qquad \frac{C_o(S_1 - S_o)}{C_c(S_c - S_1}$$

$$(1) \qquad\qquad (2)$$

where P equals the fraction of contaminant assimilated by one part of magma; $C_c$, the concentration of Sr in the contaminant; $C_o$, the concentration of Sr in the parent magma; $C_1$, the concentration of Sr in the contaminated magma; $S_1$, the isotopic composition of the contaminated magma; $S_o$, the isotopic composition of the parent magma; and $S_c$, the isotopic composition of the contaminant. The percent contamination equals P/(1+P)x100.

The data available for country rocks of the gereral area is limited to those of the Pedernal Hills. Some samples from this area contain high concentrations of Sr but have been influenced by open system conditions, evidenced by apparent ages less than that of the Pedernal granite which is intrusive into these country rocks (Mukhopadhyay, et al., 1975). However, the country rocks of the Southern Manzano and Los Pinos Mountians are not expected to contain Sr concentrations in excess of those observed in the country rocks of the Pedernal Hills. Using the highest Sr concentrations (an average of 600 ppm from two schists samples) measured in the country rocks of the Pedernal Hills, the model requires the parent magma to have assimilated 24% of such rocks. Arguments against contamination as a mechanism for increasing the initial ratio are based on the high amount of superheat required and the fact that the average Sr concentration in the schists is only 311 ppm compared to the enriched concentration used in the previous model of 600 ppm. In addition, there exists too little difference in the dates (using the maximum range provided by the limits of error) for isotopic homogenization to have raised the initial $^{87}Sr/^{86}Sr$ ratio of the Priest to its measured value from a starting point of approximately 0.703.

Wasserburg, et al. (1964) interpreted anamalously high initial $^{87}Sr/^{86}Sr$ ratios in metamorphosed basic dikes as evidence of selective migration of isotopic fractions of Sr from the Precambrian country rock into the dikes during metamorphism. In some samples, clear evidence for the migration of up to 1 ppm radiogenic Sr from the wall rocks into samples was shown by apparent ages older than the age of the earth by a factor of 8. It must be noted here that the rock examined by Wasserburg, et al. (1964) is composed of small bodies and may not be representative of isotope systematics involving plutonic masses. However, if such a process were operative in the Priest quartz monzonite, then the necseeary enrichment of radiogenic Sr can be calculated. Assuming that the Priest quartz monzonite roughly maintained its overall Sr concentration of 313 ppm, and its initial $^{87}Sr/^{86}Sr$ ratio was identical to that of the Sandia granite, the equivalent of about 0.08 ppm of $^{*87}Sr$ must be added to raise the ratio to 0.7054. The same calculations may be used to determine the $^{*87}Sr$ concentration of the schists of Mukhopadhyay, et al. (1975). The results from an average of six samples show that the schists contain approximately 22 ppm of $^{*87}Sr$. Similar schists in the Manzano Mountains could serve as a source for the migrating $^{*87}Sr$. This appears to be one valid interpretation of the date and initial ratio of the Priest quartz monzonite, but the reader is cautioned that alternate explanations could account for the variations noted.

The initial $^{87}Sr/^{86}Sr$ ratio of 0.7054 is also compatable with an origin for the Priest quartz monzonite involving partial melting of an older sialic basement. Figure 5 shows Faure and Powell's (1972) model of the evolution of strontium in the source regions of the upper mantle and continental crust. Plotting the initial ratio (0.7054) of the Priest at 1470 m.y. ago and regressing along an Rb/Sr slope equal to 0.18 yields crustal source material 1700 to 1800 m.y. in age. The Rb/Sr ratio of 0.18 is employed because it is believed to be representative of rocks exposed on the Precambrian Shield of North America (Faure and Powell, 1972). Such an origin is consistent with that proposed for other late-stage, high potassium granitic plutons of the Southwest (Condie, pers. comm., 1976).

However, to distinguish between the possibilities the examination of mineral growth lines is necessary to determine if they intersect at a single point with the whole-rock isochron. Compliance with the preceeding would indicate closed system conditions and favor the latter interpretation; if the growth lines did not intersect at a point, then fractional migration of Sr isotopes has occurred and the Priest quartz monzonite could therefore have an older date and a lower initial ratio.

The relative dates and initial ratios of the Sepultura and Los Pinos granites are indistinguishable within the limits of analytical uncertainty. The field relationships of the two are also similar. While they may be distinguished on the basis of their $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ ratios, it will be assumed that they represent different facies of the same pluton because of their high but nearly equal $^{87}Sr/^{86}Sr$ ratios.

In considering the possible origins of the Los Pinos and Sepultura granites, one is faced with at least five choices: (1), partial melting of Archean (2.7 b.y.) crust; (2), complete melting of 1.6-1.9 b.y. old crust; (3), contamination of the magma by very radiogenic country rocks; (4), selective incorporation of radiogenic Sr; and (5), homogenization of Sr isotopes at the time of the apparent age (closed system migration). All five choices must result in uniformly high $^{87}Sr/^{86}Sr$ ratios in the respective magmas.

The major problem with alternative (1) is the lack of any exposures of crustal material in south-central New Mexico of 2.7 b.y. old rocks. Archean crust has its closest exposures in Wyoming (Reed and Zartman, 1973), and while such an origin is possible, it is not regarded as reasonable. The only older crust likely to be associated at depth with the Los Pinos and Sepultura granites is 1.6 to possibly 1.9 b.y. in age. Examination of these rocks, as reported by Bickford, et al., 1969, shows that even with complete melting of granites in this age range, initial ratios no higher than approximately 0.72 are attainable. This agrument also applies to the complete melting of most Archean granitic rocks analyzed to date. According to Faure and Powell (1972), it is unlikely that the average age and Rb/Sr ratio of the continental crust are much greater than 2500 m.y. and 0.18. Therefore, in order to produce the high initial ratios observed in the Los Pinos and Sepultura granites, partial or complete melting of a nonrepresentative, Archean, granitic-composition rock with either an anomalously high initial ratio (0.722) or a high Rb/Sr ratio is required. This may or may not be considered a viable alternative.

To determine if contamination served as the mechanism whereby the initial $^{87}Sr/^{86}Sr$ ratio was increased, the nature of the contaminant may be calculated as in the Priest quartz monzonite. Assuming a relatively large amount of contamination of 20%, and employing equation (1) using the Priest quartz monzonite and the Sandia granite as the parent magmas, contaminant Sr concentrations of 986 and 1331 ppm are needed respectively. Employing equation (2), using the figures derived from equation (1), yields isotopic $^{87}Sr/^{86}Sr$ compositions of the contaminants of 0.755 and 0.736 respectively. Again, there is the problem of the necessary superheat and the lack of such rocks existing in the area at roughly 1.5 b.y. ago. Brookins (pers. comm., 1976) has described some high $^{87}Sr/^{86}Sr$ rocks from the northern Nacimiento Mountains but their total Sr content is low.

If a process of preferential extraction of radiogenic Sr from the country rocks is considered, then the only apparent candidates are wall rocks at depth. Again, the only applicable data from the area concerns the schists previously mentioned. The average concentration of Sr in the Los Pinos and Sepultura granites is only 39 ppm. In the calculations, it was assumed that they possessed this amount of Sr before contamination, and had an initial ratio equal to that of the Sandia granite. Calculations indicate that the addition of about 0.08 ppm of $^{87}Sr$ is necessary to raise the initial ratio from 0.7027 to 0.7247, the average of the Los Pinos and Sepultura granites. The addition of an identical amount of radiogenic Sr (0.08 ppm) to both the Priest and to the the Los Pinos and Sepultura plutons is indicative of a common source and further suggests that the contamination took place during or after the intrusion of the plutons. If the contamination affected the parental body or bodies of all three plutons, an identical amount of contamination will not suffice to produce the different initial ratios due to Sr depletion during fractionation.

The compositional and radiogenic difference between the Priest and the Los Pinos and Sepultura plutons may be explained by the Priest being a fairly early derivitive of a relatively non-fractionated melt, while the high percentage of $SiO_2$ and the high K/Rb and Rb/Sr ratios of the Los Pinos and Sepultura granites indicate a late-stage, highly fractionated melt, possibly from a cupola (Brooks and Compston, 1965). The contamination of the Los Pinos and Sepultura granites after fractionation of the parent magma could also lower their ages. This mechanism is considered viable and may serve to equate the initial ratios and dates of the Sandia, Priest, Los Pinos, and Sepultura plutons along with indicating deep source material (i.e. lower crustal) for all four bodies. The reader is again cautioned that this model is a first approximation and may be invalidated by subsequent studies providing more extensive data.

Closed system isotopic homogenization by regional heating of the Los Pinos and Sepultura granites at approximately 1.42 b.y. ago can raise the initial ratios to their observed values (within the limits of error) utilizing a source with either a 0.7027 or 0.7054 initial ratio and dates of 1.5 and 1.47 b.y. respectively. The resulting calculated initial ratios are within the intercept errors of the two isochrons of the Los Pinos and Sepultura granites. There is a better approximation of the average intercept of the granites using the lower initial ratio (0.7027) and the older isochron date (1.504 b.y.). However, regional heating should have produced a similar date for the Priest quartz monzonite and this has not been observed.

It remains to be seen, through the construction of mineral growth lines, which mechanism or combination of mechanisms is responsible for the anamalously high initial $^{87}Sr/^{86}Sr$ ratios of the Los Pinos and Sepultura granites.

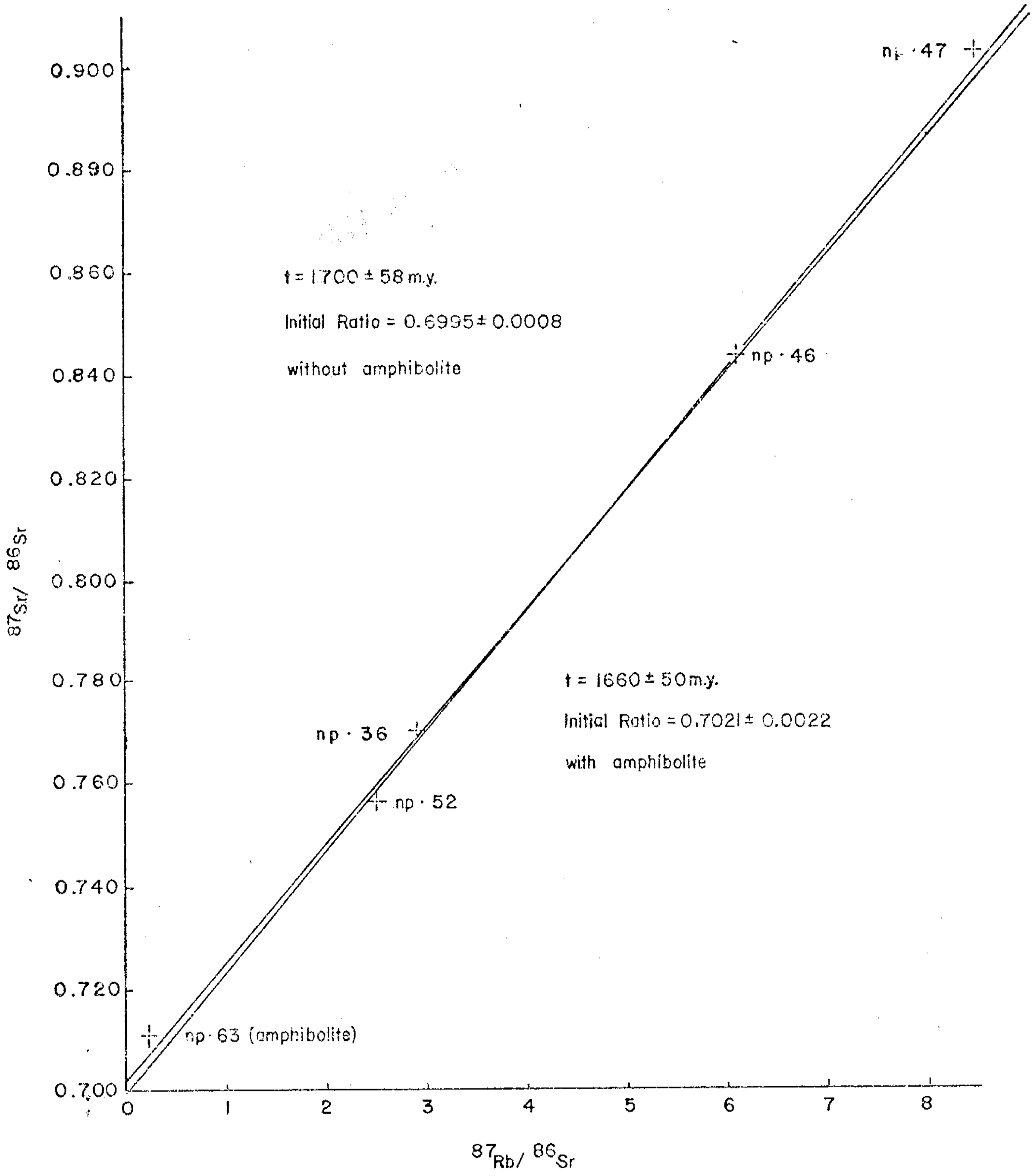


FIGURE I. Rb-Sr Whole Rock Isochron, Sevillita Metarhyolite.

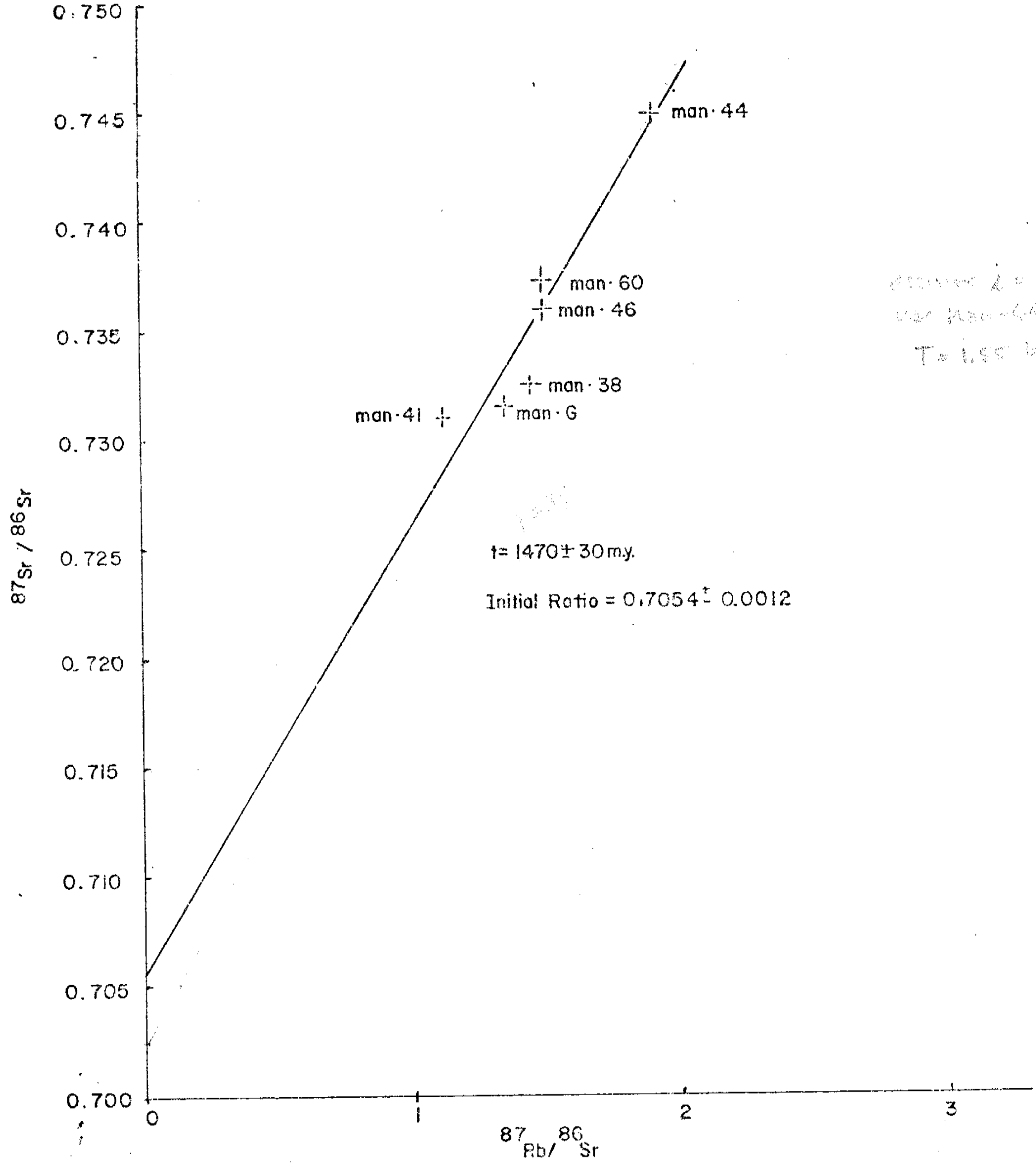


FIGURE 2. Rb-Sr Whole Rock Isochron, Priest Quartz Monzonite.

assume λ = 0.7045
via Man-44
T = 1.55 by, [illegible]

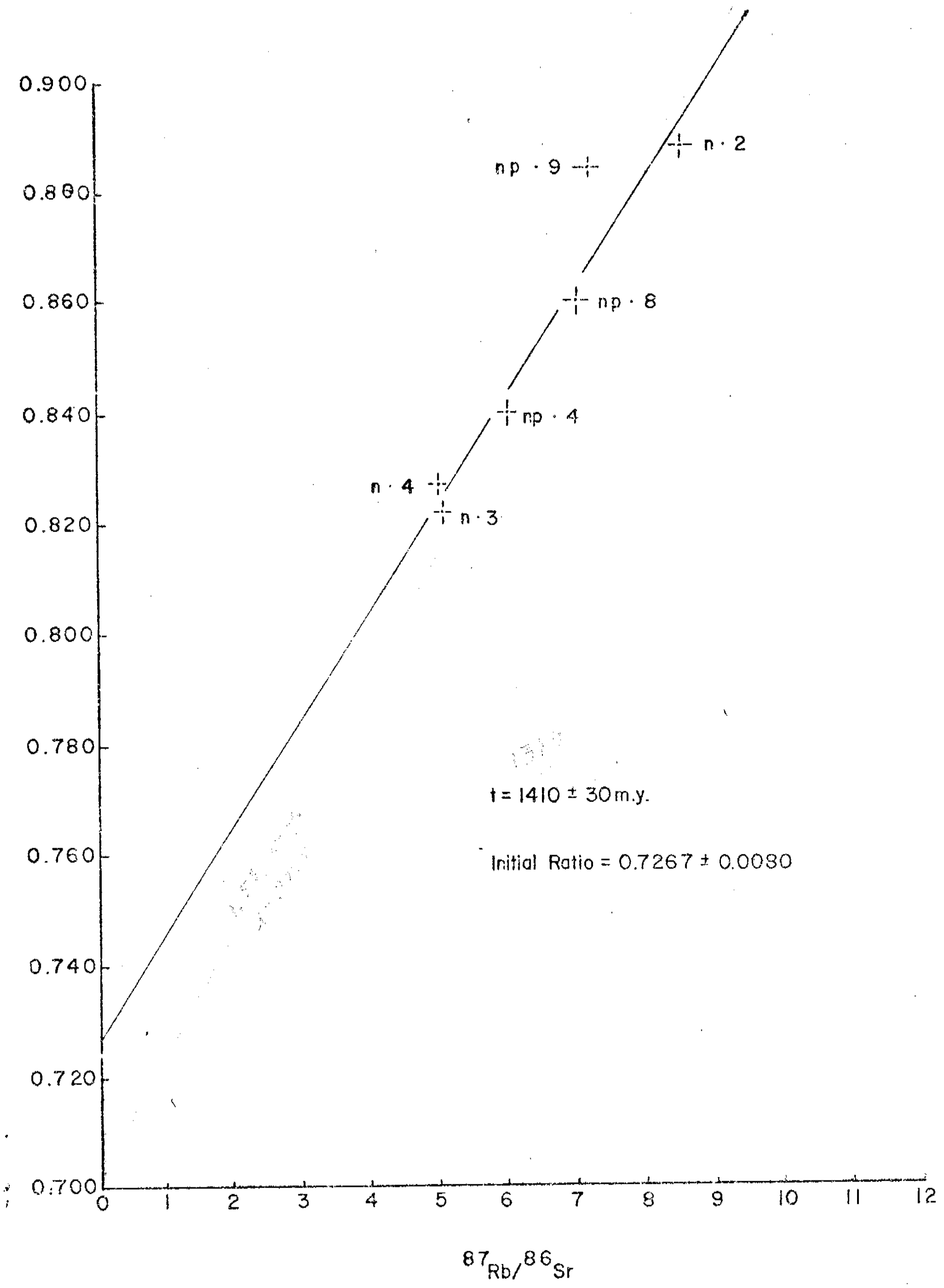


FIGURE 3. Rb-Sr Whole Rock Isochron, Los Pinos Granite.

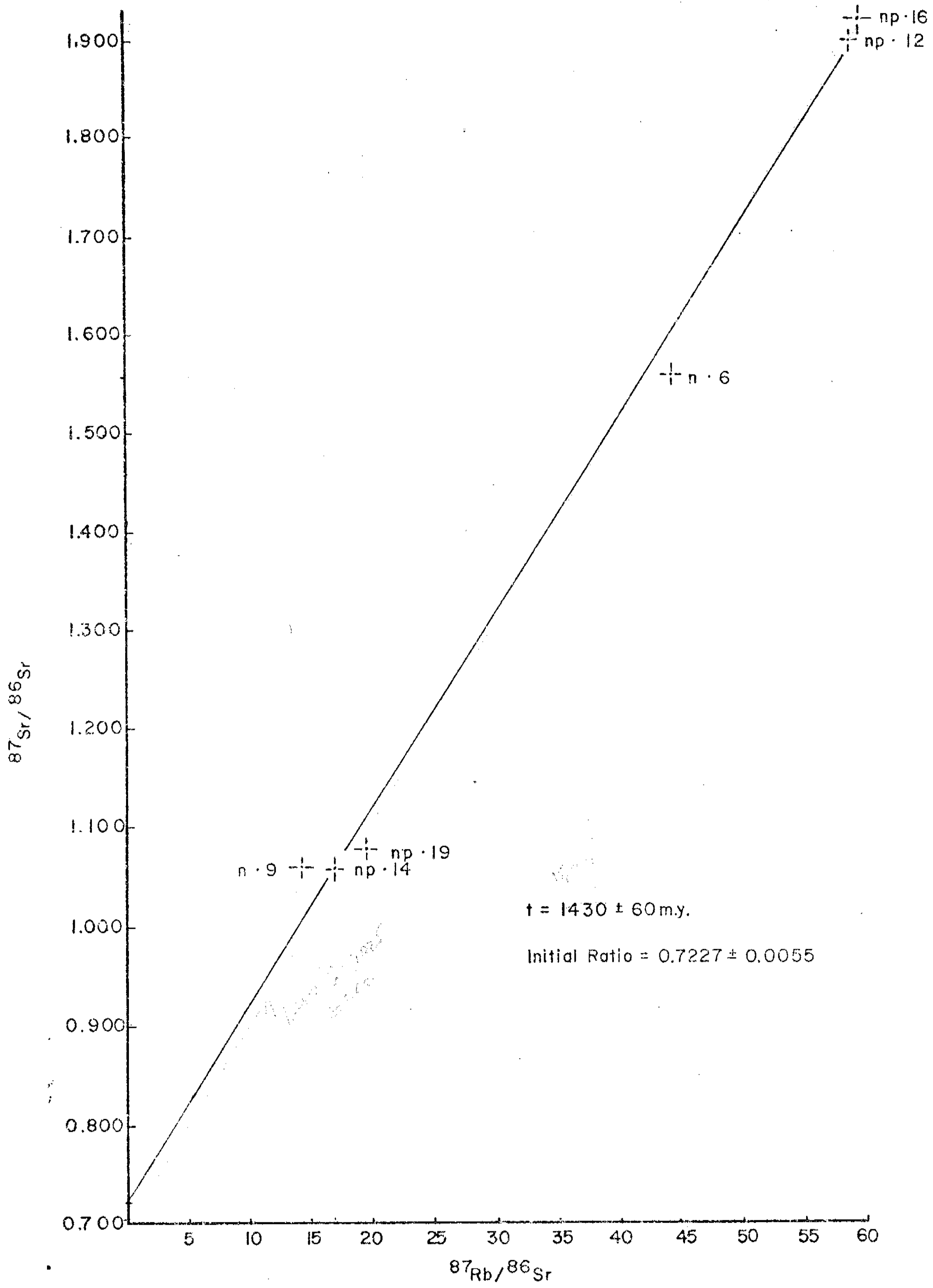
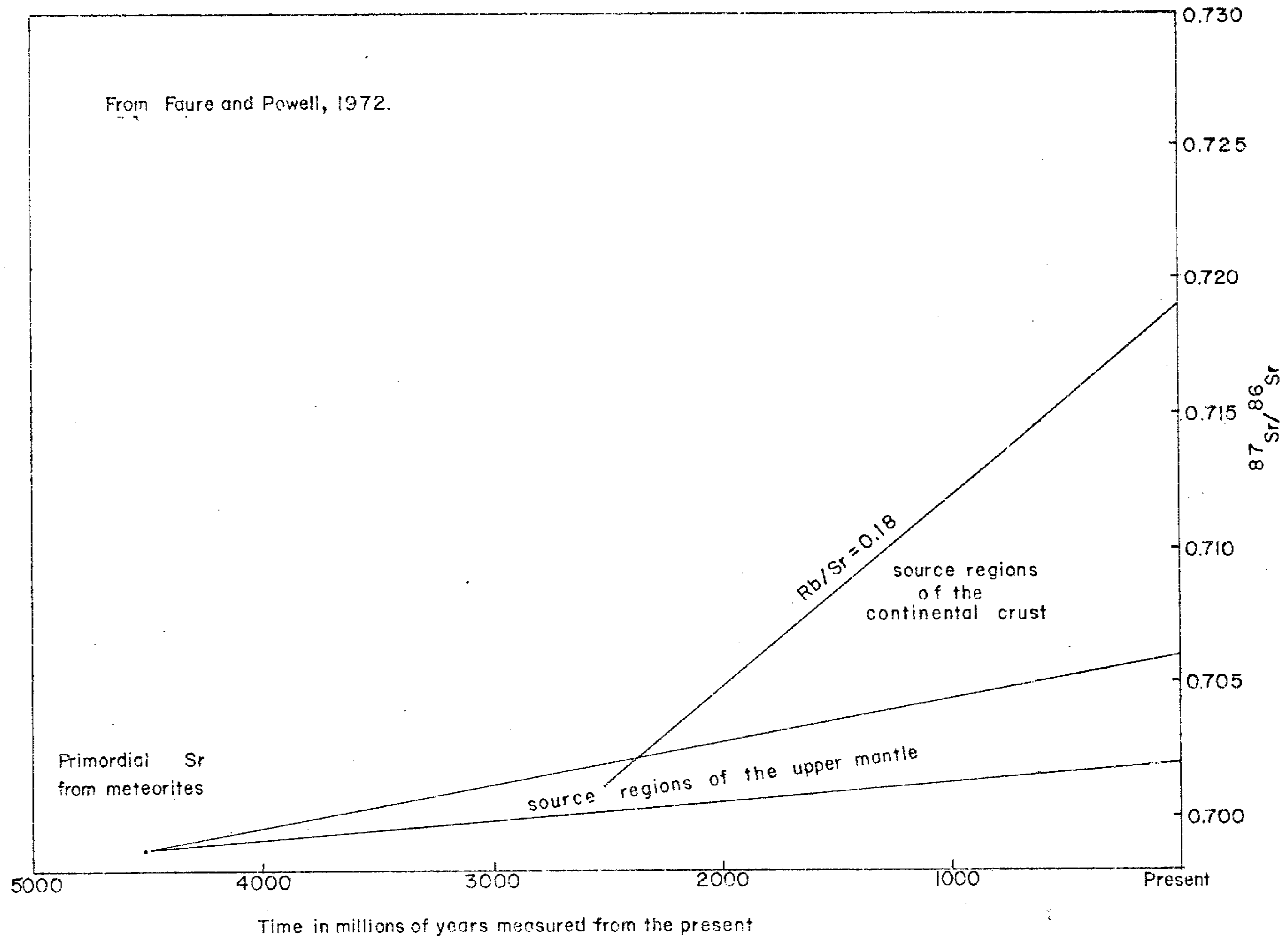


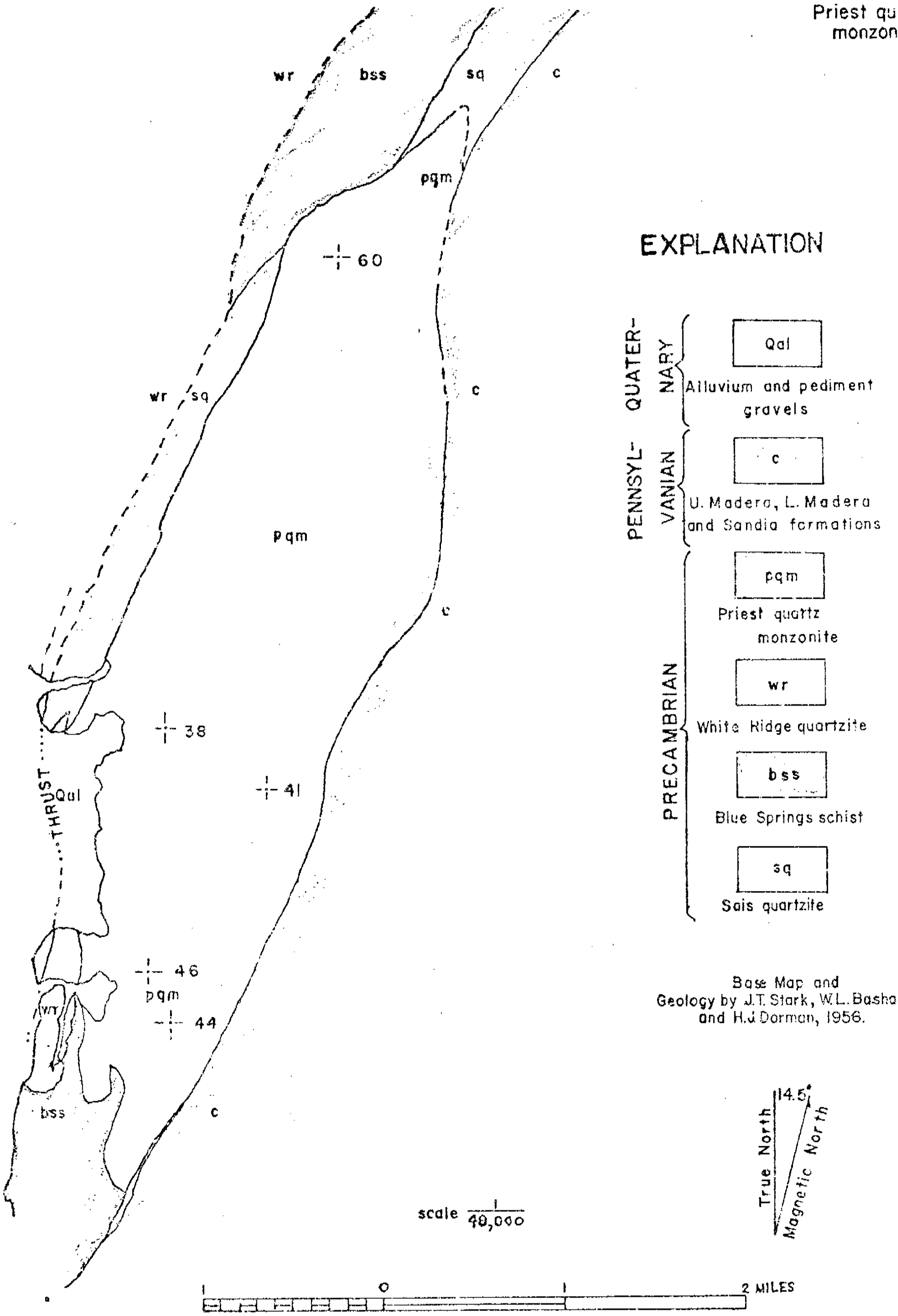
FIGURE 4. Rb-Sr Whole Rock Isochron, Sepultura Granite.



From Faure and Powell, 1972.

FIGURE 5. The evolution of strontium in the source regions of the upper mantle and the continental crust.

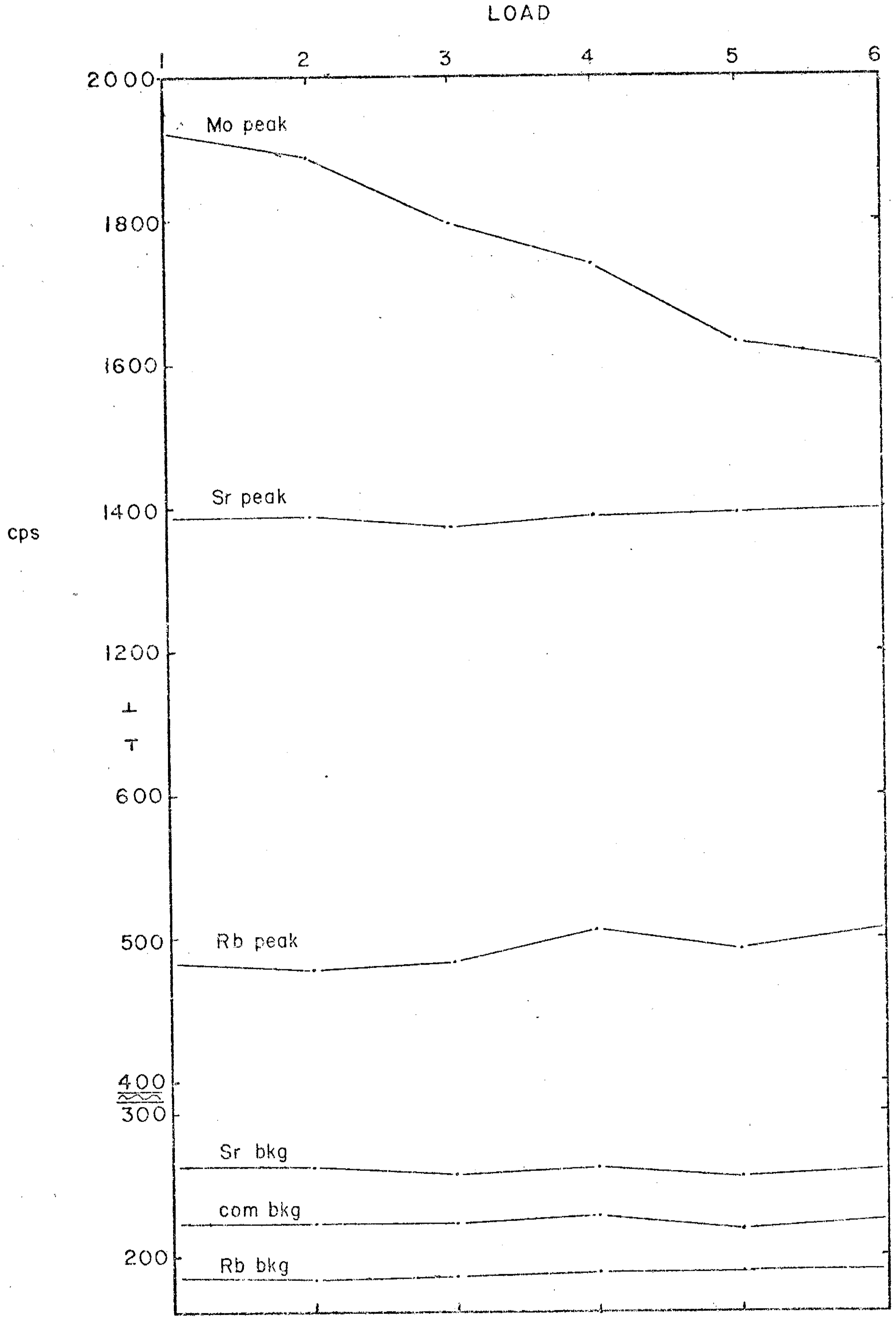
FIGURE 6. Sample Locations Priest quartz monzonite



# APPENDIX 1

## Drift Corrections

The following graph shows the plot of the counts-per-second, (cps), measured on standard G-2 which was included in each load of samples subjected to X-ray fluorescence. The Mo, Sr, and Rb peaks are plotted for G-2, along with the Sr, Rb, and common (com) backgrounds. The drift is negligible with the exception of the Mo peak. To correct for the drift of the Mo peaks, the samples of loads two through five were equated to load one on the basis of the difference between the cps measured for standard G-2 included in the particular load, and the cps measured for standard G-2 in load one. Each sample of each load was multiplied by the percent difference between the G-2 cps of that load and the G-2 cps of load one, times 100, to obtain the corrected cps for the Mo peaks of each sample.


LOAD
1
2
3
4
5
6
2000
1800
1600
1400
1200
600
500
400
300
200
cps
Mo peak
Sr peak
Rb peak
Sr bkg
com bkg
Rb bkg

# APPENDIX II

## Modal and Geochemical Analysis of Igneous Rocks from the Los Pinos Mountains, New Mexico

Geochemical analyses were supplied by Dr. K.C. Condie of New Mexico Institute of Mining and Technology.

Modal analyses of samples N2, N4, N9, N13, NP6, NP9, NP12, NP16, and NP 19 were supplied by C.A. Beers, 1976.

# Modal Analyses

(Percent)

| | sample # | # of points counted | plagio-clase | quartz | potassium feldspar | biotite & chlorite | hematite & magnetite | sericite |
|---|---|---|---|---|---|---|---|---|
| **Priest** | M-38 | 2322 | 36 | 15 | 33 | 10 | 0.3 | 1 |
| | M-60 | 2242 | 35 | 34.2 | 20 | 6 | 1 | 2 |
| | M-44 | 1611 | 44 | 33 | 12 | 9.3 | 1 | 1.6 |
| | M-46 | No thin section | | | | | | |
| | M-41 | 2276 | 31 | 33 | 24 | 9 | 1 | 1.6 |
| (M-38 and M-60 contained 3 and 2 percent epidote, respectively) | | | | | | | | |
| **Los Pinos** | N-2 | 1000 | 12 | 47 | 33 | 5 | 2 | <1 |
| | N-3 | 2164 | 10 | 45 | 37 | 4 | 2 | <1 |
| | N-4 | 1000 | 8 | 41 | 43 | 6 | 1 | 1 |
| | NP-4 | 1697 | 2 | 50.7 | 40.2 | 4.1 | 1.9 | 1.1 |
| | NP-8 | 1792 | 23 | 36 | 36 | 4 | <1 | <1 |
| | NP-9 | No thin section | | | | | | |
| **Sepultura** | N-6 | 1237 | 16.5 | 36 | 44 | 1.5 | 0.5 | 0.5 |
| | N-9 | 817 | 34 | 35 | 28 | 2 | 1 | 0.6 |
| | NP-12 | 1550 | 4.4 | 47 | 45.8 | 1.8 | 0.9 | .5 |
| | NP-14 | 1352 | 19 | 33 | 45 | 1.5 | 1 | 0.5 |
| | NP-16 | 1000 | 17.5 | 32.2 | 47 | 0.6 | 2.2 | 0.3 |
| | NP-19 | 1000 | 18 | 35 | 40 | 6 | 0.6 | 0.5 |

# Igneous Rocks of the Los Pinos Mountains

## Metavolcanics

Total Weight Percent Oxides

Recalculated to 99.500 Percent

5 Samples

| NO | Name | NP36 | NP46 | NP47 | NP52 | NP63 |
|---|---|---|---|---|---|---|
| 1 | $SiO_2$ | 70.860 | 75.850 | 74.330 | 76.260 | 50.874 |
| 2 | $TiO_2$ | 0.665 | 0.240 | 0.220 | 0.270 | 1.289 |
| 3 | $Al_2O_3$ | 13.997 | 13.790 | 13.280 | 14.760 | 11.420 |
| 4 | MgO | 0.635 | 0.0 | 0.0 | 0.0 | 7.743 |
| 5 | $Fe_2O_3$ | 3.591 | 2.550 | 2.420 | 2.460 | 13.628 |
| 6 | CaO | 1.796 | 0.770 | 0.710 | 1.230 | 10.930 |
| 7 | $Na_2O$ | 3.859 | 3.850 | 4.280 | 4.420 | 1.978 |
| 8 | $K_2O$ | 4.097 | 4.730 | 4.570 | 1.480 | 0.639 |
| 9 | Rb | 135.000 | 142.000 | 154.000 | 44.500 | 14.400 |
| 10 | Sr | 136.000 | 67.700 | 53.100 | 51.600 | 192.000 |
| 11 | Ba | 940.000 | 1096.000 | 1013.000 | 700.000 | 0.0 |
| 12 | Cs | 11.920 | 7.100 | 6.400 | 1.600 | 0.900 |
| 13 | Co | 5.500 | 0.340 | 0.420 | 0.950 | 68.000 |
| 14 | Cr | 16.000 | 3.000 | 1.000 | 2.000 | 234.000 |
| 15 | La | 49.000 | 88.000 | 64.000 | 66.000 | 7.200 |
| 16 | Ce | 126.000 | 168.000 | 143.000 | 151.000 | 22.000 |
| 17 | Sm | 14.000 | 25.000 | 20.000 | 19.000 | 4.000 |
| 18 | Eu | 3.400 | 3.300 | 2.500 | 3.200 | 1.300 |
| 19 | Tb | 0.0 | 0.0 | 0.0 | 0.0 | 0.550 |
| 20 | Yb | 9.400 | 12.000 | 11.000 | 11.000 | 2.700 |
| 21 | Lu | 1.600 | 2.000 | 2.500 | 1.800 | 0.490 |
| 22 | K | 34012 | 39267 | 37938 | 12286 | 5308 |
| 23 | Ti | 3985 | 1439 | 1319 | 1619 | 7726 |
| 24 | Na | 28634 | 28567 | 31758 | 32796 | 14678 |
| 25 | K/Rb | 229.700 | 276.500 | 245.400 | 276.100 | 368.600 |
| 26 | REE | 203.400 | 298.300 | 243.000 | 252.000 | 38.240 |

# Igneous Rocks of the Los Pinos Mountains

## Priest quartz monzonite

Total Weight Percent Oxides

Recalculated to 99.500 Percent

6 Samples

| NO | Name | MAN38 | MAN60 | MAN46 | MAN41 | MAN44 | MAN G |
|---|---|---|---|---|---|---|---|
| 1 | $SiO_2$ | 65.7 | 73.1 | 67.8 | 66.9 | 67.1 | 65.8 |
| 2 | $TiO_2$ | 0.44 | 0.29 | 0.36 | 0.25 | ——— | 0.4 |
| 3 | $Al_2O_3$ | 15.9 | 13.8 | 14.5 | 14.9 | ——— | 14.5 |
| 4 | $Fe_2O_3$ | 3.67 | 2.49 | 3.11 | 2.04 | ——— | 2.5 |
| 5 | MgO | 1.42 | 1.29 | 1.35 | 1.03 | ——— | 2.3 |
| 6 | CaO | 3.04 | 1.81 | 2.50 | 2.57 | ——— | 2.0 |
| 7 | $Na_2O$ | 3.91 | 3.32 | 3.65 | 4.19 | 3.71 | 3.8 |
| 8 | $K_2O$ | 4.05 | 4.05 | 3.85 | 4.18 | 3.75 | 4.2 |
| 9 | Cr | 29.0 | 29.0 | 18.0 | 17.0 | ——— | 25.0 |
| 10 | Rb | 186.0 | 142.0 | 166.0 | 130.0 | 164.0 | 155.0 |
| 11 | Sr | 372.0 | 275.0 | 322.0 | 328.0 | 250.0 | 329.0 |
| 12 | Zr | 198.0 | 103.0 | 122.0 | 113.0 | ——— | 82.0 |
| 13 | Ba | 446.0 | 530.0 | 640.0 | 689.0 | ——— | 614.0 |
| 14 | Cs | 9.1 | 6.0 | 12.0 | 6.1 | ——— | 8.0 |
| 15 | Co | 8.6 | 5.5 | 6.7 | 4.9 | ——— | 6.1 |
| 16 | La | 66.0 | 22.0 | 30.0 | 34.0 | ——— | 47.0 |
| 17 | Ce | 136.0 | 61.0 | 78.0 | 86.0 | ——— | 90.0 |
| 18 | Sm | 8.7 | 3.9 | 6.1 | 5.4 | ——— | 6.6 |
| 19 | Eu | 0.84 | 0.59 | 0.70 | 0.74 | ——— | 0.8 |
| 20 | Tb | 0.48 | 0.52 | 0.59 | 0.72 | ——— | 0.7 |
| 21 | Yb | 1.8 | 1.5 | 1.6 | 1.1 | ——— | 1.8 |
| 22 | Lu | 0.28 | 0.32 | 0.26 | 0.31 | ——— | 0.2 |

Analyses which are unavailable are designated by: ——— .

# Igneous Rocks of the Los Pinos Mountains

## Los Pinos granite

Total Weight Percent Oxides

Recalculated to 99.500 Percent

6 Samples

| NO | Name | N2 | N3 | N4 | NP4 | NP8 | NP9 |
|---|---|---|---|---|---|---|---|
| 1 | $SiO_2$ | 75.197 | 75.590 | 74.840 | 73.420 | 75.200 | 76.1 |
| 2 | $TiO_2$ | 0.249 | 0.240 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | $Al_2O_3$ | 11.748 | 13.220 | 13.290 | 11.020 | 12.450 | 12.3 |
| 4 | $Fe_2O_3$ | 2.748 | 2.540 | 2.970 | 2.520 | 2.690 | 2.3 |
| 5 | MgO | 0.169 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6 | CaO | 0.737 | 1.030 | 1.090 | 0.730 | 0.940 | 0.6 |
| 7 | $Na_2O$ | 4.321 | 4.440 | 4.230 | 3.770 | 5.470 | 3.9 |
| 8 | $K_2O$ | 4.331 | 4.320 | 4.240 | 4.440 | 4.370 | 4.4 |
| 9 | Rb | 152.000 | 105.000 | 155.000 | 113.000 | 138.000 | 158.0 |
| 10 | Sr | 42.400 | 61.100 | 52.300 | 55.100 | 57.400 | 64.8 |
| 11 | Ba | 1090.000 | 978.000 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12 | Cs | 2.500 | 2.800 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13 | Co | 1.000 | 0.700 | 0.0 | 0.0 | 0.0 | 0.0 |
| 14 | Cr | 0.0 | 2.000 | 0.0 | 0.0 | 0.0 | 0.0 |
| 15 | La | 65.000 | 75.000 | 0.0 | 0.0 | 0.0 | 0.0 |
| 16 | Ce | 176.000 | 163.000 | 0.0 | 0.0 | 0.0 | 0.0 |
| 17 | Sm | 22.000 | 21.000 | 0.0 | 0.0 | 0.0 | 0.0 |
| 18 | Eu | 3.100 | 3.200 | 0.0 | 0.0 | 0.0 | 0.0 |
| 19 | Tb | 4.100 | 3.900 | 0.0 | 0.0 | 0.0 | 0.0 |
| 20 | Yb | 13.000 | 10.000 | 0.0 | 0.0 | 0.0 | 0.0 |
| 21 | Lu | 2.000 | 1.900 | 0.0 | 0.0 | 0.0 | 0.0 |
| 22 | K | 35953 | 35863 | 35199 | 36859 | 36278 | 3710 |
| 23 | Na | 32061 | 32945 | 31387 | 27973 | 40587 | 2945 |
| 24 | Ti | 1492 | 1439 | 0.0 | 0.0 | 0.0 | 0.0 |
| 25 | K/Rb | 236.500 | 341.600 | 227.100 | 326.200 | 262.900 | 234.9 |
| 26 | REE | 285.200 | 278.000 | 0.0 | 0.0 | 0.0 | 0.0 |

Igneous Rocks of the Los Pinos Mountains

Sepultura granite

Total Weight Percent Oxides

Recalculated to 99.500 Percent

6 Samples

| NO | Name | N6 | N9 | NP12 | NP14 | NP16 | NP1 |
|---|---|---|---|---|---|---|---|
| 1 | $SiO_2$ | 71.490 | 75.870 | 75.520 | 75.700 | 75.740 | 75.0 |
| 2 | $TiO_2$ | 0.090 | 0.120 | 0.500 | 0.090 | 0.0 | 0.0 |
| 3 | $Al_2O_3$ | 12.160 | 13.740 | 13.710 | 13.800 | 13.360 | 13,2 |
| 4 | $Fe_2O_3$ | 0.420 | 1.320 | 0.770 | 1.130 | 0.730 | 1.5 |
| 5 | CaO | 0.380 | 0.500 | 0.580 | 0.700 | 0.560 | 0.7 |
| 6 | $Na_2O$ | 4.430 | 4.180 | 4.140 | 3.920 | 4.450 | 4.2 |
| 7 | $K_2O$ | 4.640 | 4.800 | 4.770 | 4.770 | 4.770 | 4.7 |
| 8 | Rb | 248.000 | 148.000 | 237.000 | 173.000 | 192.000 | 212.0 |
| 9 | Sr | 17.500 | 30.300 | 13.000 | 30.600 | 10.500 | 32.8 |
| 10 | Ba | 249.000 | 678.000 | 111.000 | 576.000 | 0.0 | 0.0 |
| 11 | Cs | 3.600 | 2.300 | 0.500 | 3.100 | 0.0 | 0.0 |
| 12 | Co | 0.200 | 0.300 | 0.600 | 0.800 | 0.0 | 0.0 |
| 13 | Cr | 0.0 | 8.000 | 0.0 | 2.000 | 0.0 | 0.0 |
| 14 | La | 68.000 | 49.000 | 48.000 | 60.000 | 0.0 | 0.0 |
| 15 | Ce | 148.000 | 142.000 | 135.000 | 145.000 | 0.0 | 0.0 |
| 16 | Sm | 13.000 | 18.100 | 17.000 | 18.600 | 0.0 | 0.0 |
| 17 | Eu | 0.880 | 2.200 | 3.600 | 1.700 | 0.0 | 0.0 |
| 18 | Tb | 2.200 | 3.200 | 2.700 | 2.400 | 0.0 | 0.0 |
| 19 | Yb | 14.000 | 11.000 | 13.000 | 9.000 | 0.0 | 0.0 |
| 20 | Lu | 1.900 | 1.900 | 2.000 | 1.500 | 0.0 | 0.0 |
| 21 | K | 38519 | 39848 | 39599 | 39599 | 39599 | 3910 |
| 22 | Ti | 540 | 719 | 2998 | 540 | 0.0 | 0.0 |
| 23 | Na | 32871 | 31016 | 30719 | 29086 | 33039 | 3183 |
| 24 | K/Rb | 155.320 | 269.240 | 167.084 | 228.900 | 206.240 | 184.4 |
| 25 | REE | 247.980 | 227.400 | 221.300 | 238.000 | 1.000 | 1.0 |

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