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Basement Rocks in Far West Texas and South-Central New Mexico

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ABSTRACT

Far west Texas and south-central New Mexico contain eight areas of Precambrian exposure. Samples from twenty-five wells drilled to basement aid in the correlation of the outcropping units. Twenty-four new isotopic ages have been determined from outcrops and from subsurface samples. Four periods of activity can be defined on the basis of this and previous work. The oldest rocks exposed are in the San Andres Mountain trend. These largely granitic rocks are 1350 m.y. (million years) and older and represent the basic framework into or onto which younger rocks were intruded or deposited. The best age obtained for the Carrizo Mountain Group in the Van Horn area is 1240 m.y., based on a rather indistinct whole rock isochron from metarhyolites. These rocks were later metamorphosed at about 950 to 1000 m.y. The granite at Pajarito Peak, Otero County, New Mexico, yielded an age of 1170 m.y. and appears to be a restricted basement rock type. The Castner—Allamore carbonate rocks and the Hazel—Llanoria sandstones and shales, together with their subsurface equivalents, were deposited over a large area. This deposition was accompanied by basalts and diabase injection. Granite and rhyolite in the Franklin Mountain area and to the east were emplaced and injected essentially contemporaneously at 950 m.y. This igneous activity is the youngest recognized in the Precambrian of this area and caused the metamorphism of the slightly older clastic and carbonate sedimentary rocks where in contact.

INTRODUCTION

Far west Texas and south-central New Mexico contain eight areas of Precambrian exposure, ranging from the few acres at Bent Dome in Otero County, New Mexico, to more than one hundred square miles (260 square kilometers) around Van Horn, Texas. In addition, samples from twenty-five wells drilled in search of oil and gas are available for study in the area surrounding the outcrops. We have assembled information from the recent literature on these areas, determined an additional twenty-four isotopic ages both from surface and subsurface samples, and attempted to synthesize a workable geologic history and a basement geologic map of the area. Although certain parts of the history are imprecisely defined, a remarkably consistent evolution and correlation between outcrop and subsurface rocks can be made.

We first will describe each outcrop area and present the new isotopic ages; then we will examine the information from the subsurface, and finally we will use these data in formulating a geologic history.

FRANKLIN MOUNTAINS

The work of Harbour (1960) in the Franklin Mountains summarized previous studies as well as adding much significant original data. His work outlined four major stratigraphic units with an aggregated thickness in excess of 5000 feet (1520 meters). In addition, McAnulty (1967) studied the three lower units in considerable detail. Although the conclusions reached here do not wholly agree with McAnulty's his descriptions are the best to be found.

The lowermost unit is the Castner "Limestone." The base is not exposed, yet 1100 feet (335 meters) of marble, diabase, and related hornfels have been measured by Harbour in the Fusselman Canyon area. The term *limestone* does not seem appropriate for a rock characteristically carrying a variety of metamorphic minerals, including garnet, tremolite, diopside, and epidote. Therefore, we recommend changing the name to *Castner Marble.*

The lower part is characterized by white to gray or green carbonates showing delicately preserved structures including stromatozoan-like algal heads. These carbonates are interbedded with dark, fine-grained diabasic rocks and biotite argillites. The two are very difficult to distinguish in the field. The lower carbonate beds are dolomitic and in some instances almost pure dolomite. The basal unit must have contained only a little quartz; otherwise, the dolomite would have reacted with it to form more abundant diopside and tremolite.

The upper part was called a hornfels by Harbour. The carbonates were originally considerably less pure than in the lower intervals. The diversity of metamorphic minerals, including an abundance of garnet, is evidence of a substantial clay mineral content. Quartz grains as relicts are common, and the rock is considerably less dolomitic in general, as shown by analyses reported by Harbour. Edgewise conglomerates are common near the upper part, as are a wide variety of abundant microstructures. The uppermost part contains structures that are here interpreted as soft sediment deformation. The unit as a whole is lacking in any major schistose development. The sedimentary rock appears to have been converted to hornfels without attendant shearing.

The Mundy Breccia overlies the Castner Marble. It varies from 0 to 250 feet (76 meters) in thickness. Harbour interpreted this unit as basaltic fragments, in a "fine, dark-gray matrix resembling indurated mudstone." McAnulty interprets it as a basalt flow breccia. The petrography of this unit is not straightforward. The basaltic fragments are altered but only incipiently metamorphosed with a well-defined relict igneous texture. The matrix is not uniform but is composed mostly of altered feldspar, chlorite, actinolite, and lesser biotite and tourmaline. The suggestion is that the matrix is closely related to the basalt itself. Aside from blocks of Castner Marble in the lower part of the Mundy (reported by McAnulty), no material other than basalt has been found in the breccia. The matrix occupies only a small part of the total volume. We interpret the unit as a surface flow that extruded on a floor of soft Castner carbonates. Whether this was a surface or submarine flow breccia cannot be resolved with the available evidence. The soft sediment deformation in the Castner Marble is thus ascribed to differential loading by the basaltic debris. The appearance of the breccia has been altered by later metamorphism, by intrusive granite, and probably by trapped solutions from the Castner carbonates streaming along breccia zones.

Stratigraphically overlying the Mundy Breccia is the Llanoria Quartzite. The unit is composed of approximately 2600 feet (795 meters) of quartzite, siltstone, and shale. The lower part is mostly a rather pure quartzite containing only a minor amount of microcline. The upper part is separated from the lower by a granite sill. Harbour describes the upper part as "Sandstone, siltstone, and shale in thin beds which form brown-weathering slopes."

Overlying the Llanoria Quartzite is a sequence of as much as 1400 feet (425 meters) of rhyolite flows. This unit is here named the *Franklin Mountain Rhyolite* simply because this is what workers in the area call it.

The rhyolite generally carries sodic plagioclase and perthite phenocrysts in a groundmass of delicate devitrified quartz-feldspar. Quartz phenocrysts, where present, are abundant. Certain samples are poor in quartz and probably approach a trachytic composition. Locally, the rhyolite is converted to a hornfels by granite intrusion. This is particularly common in some areas on the western slopes.

Flow structures are difficult to find in place, although strongly banded types are easily found as boulders in stream beds. The general feeling, although difficult to demonstrate, is that the rhyolite is at least roughly conformable with the underlying sediments.

The Red Bluff Granite intrudes the entire Precambrian sequence. In addition, McAnulty reports an older microgranite porphyry in the Fusselman Canyon area. The microgranite is intrusive into the Precambrian sedimentary sequence, mostly as sills. The microgranite is in turn intruded by Red Bluff-type granite. The granites examined in this study were mostly medium- to fine-grained, characteristically carrying only perthite as the feldspar. Some are quartz poor and contain a pyroxene, but most are highly quartzose with less than five percent femic minerals, common hornblende, biotite, and riebeckite. Textures vary from porphyritic and micrographic to even-grained and hypidiomorphic. The granites have petrographic characteristics of epizone instrusions and were probably emplaced at depths of less than one mile.

Wasserburg et al. (1962) report K/Ar and Rb/Sr ages of 880 to 1030 m.y.* on a variety of granitic samples. Two zircon ages were determined with 1095 and 1080 m.y. being the Pb207/Pb206 ages. A whole rock age of 990 ± 50 m.y. was reported on a sample of metarhyolite by Muehlberger et al. (1966, p. 5415). We have determined ten Rb/Sr ages on whole rocks and feldspars from granites and rhyolites (table 1). We did not find any systematic difference in the ages of the granite and rhyolite and have grouped the two to obtain an isochron or "best" age. The determinations fall very closely along an isochron of 953 ± 13 m.y. with an initial ratio of 0.7081 ± 0.0010 (fig. 1). Two of the whole rock rhyolites fall below the line, but the other whole rocks and feldspars are close to the isochron age. The apparent low ages from the whole rocks are probably caused by minor alterations in the groundmass, because feldspars separated from the same specimens give higher ages.

We believe the sedimentary units were deposited in quick succession, soon became covered by rhyolite, and in the same time interval were intruded and metamorphosed by Red Bluff Granite. The granitic igneous activity took place at about 953 ± 13 m.y. The association of synchronous rhyolite-granite is common throughout the southern United States. Muehlberger, Denison, and Lidiak (1967, p. 2372-2373) drew attention to this relationship.

A succession of lower Paleozoic sedimentary rocks overlies both the granite and rhyolite. Although the structure is disrupted, the Paleozoic sequence appears to be only disconformable with the layered Precambrian rocks.

HUECO MOUNTAINS

Several small hills of red granite are exposed beneath Bliss Sandstone (Cambrian) near the south end of the Hueco Mountains (King, 1935). Wasserburg et al. report an Rb/Sr age of 990 ± 60 on feldspar from the granite. The rock is a partly micrographic perthite granite, petrographically indistinguishable from the Red Bluff Granite of the

* The Rb/Sr ages reported by Wasserburg et al. have been recalculated using the 47 b.y. half-life, resulting in ages six percent lower than those using the 50 b.y. half-life.

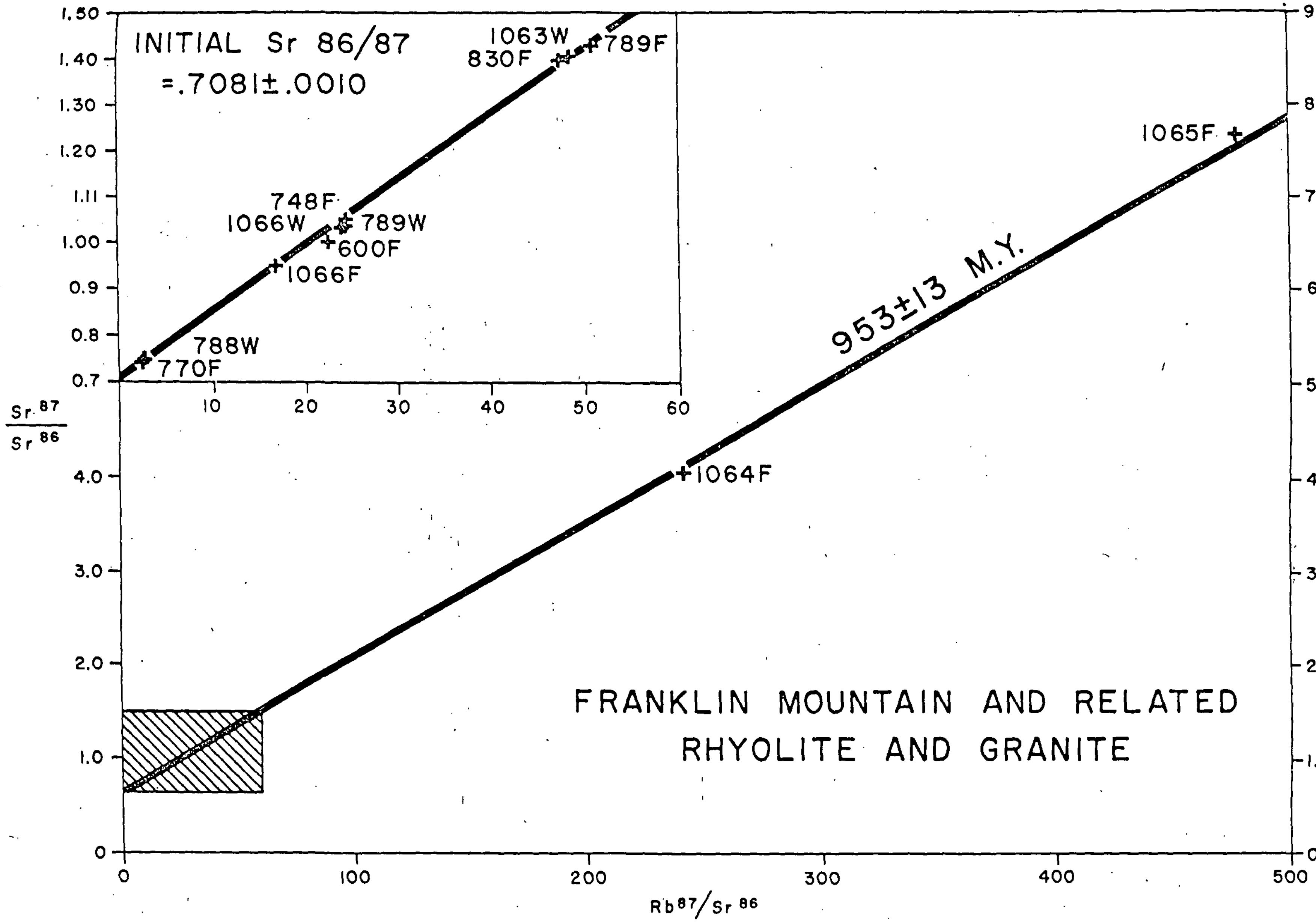


Figure 1

AN ISOCHRON PLOT OF FRANKLIN MOUNTAIN AND RELATED ROCK DETERMINATIONS

Franklin Mountains. The determined age is close to the isochron age of the Franklin Mountains and related rocks. We conclude that the granite exposed in the Hueco Mountains is related both in petrographic character and age to that exposed in the Franklin Mountains.

PUMP STATION HILLS

Masson (1956) described the igneous rocks exposed in a group of low-lying knolls, the Pump Station Hills, in some detail. The dominant rock type is rhyolite porphyry, but some fine micrographic granite porphyry and other rock types are also present. Wasserburg et al. determined an Rb/Sr whole rock age of 960 ± 60 m.y. and a feldspar age of 1000 ± 40 m.y. on a rhyolite sample. These ages and the general petrographic character clearly relate these rocks to those in the Franklin and Hueco mountains.

BENT DOME

At a locality near Bent, Otero County, the Permian Abo Formation rests upon rocks of Precambrian age. Bachman (1960) named the structure the *Bent Dome* and described it in some detail as part of the Pedernal landmass.

A light-gray quartzite is the principal rock type. In the sample examined in this study, the quartzite contained almost no lithic or feldspathic debris. No metamorphic minerals were seen and shearing is lacking. The quartzite is apparently intruded (exposures are poor) by a deep-red micrographic granite porphyry. No samples fresh enough for dating could be collected, even though there are prospect pits in the granite. The quartzite is considered equivalent to the Llanoria in the Franklin Mountains. The micrographic granite, by analogy, is part of the 950 m.y. igneous activity common to the south. This is the most northerly encounter of rocks considered equivalent to the granite-rhyolite sequence.

Bachman reported cobbles of rhyolite, granite, and quartzite in the overlying Abo. This suggests that, at least locally, the Franklin Mountain Rhyolite was deposited this far north and was subsequently removed by erosion. An alternate but less likely explanation is that the rhyolite was derived from the Panhandle Volcanic Terrane in the 1100 to 1200 m.y. range.

PAJARITO PEAK

The age of the granitic rocks at Pajarito Peak has been the subject of some disagreement. Thompson (1942) thought them Precambrian as part of the Pedernal landmass. Lloyd (1949) and Motts and Gaal (1960) argued for a Tertiary age, and the outcrop is so shown on the State Geologic Map (Dane and Bachman, 1965).

Kelley (1968) recently described the geology of Pajarito Peak in detail. His conclusion is for a definitely Precambrian age, based on field relations. Our laboratory performed the isotopic ages reported by Kelley, which demonstrate a Precambrian age. Kelley generally described the alkaline rocks and no résumé is needed here. The samples we examined and dated from Pajarito Peak are of a riebeckite granite and associated syenite-quartz syenite pegmatite. The granite is composed, in volume percent, of 38.0 perthite, 25.8 quartz, 24.7 riebeckite, 4.7 aegirine, and 6.8 iron oxides and alteration material. The latter appears to replace a former femic mineral. The quartz is mostly in large, discrete, single crystals with local poikilitic inclusions of perthite and riebecktite. This texture gives the rock a porphyritic-like appearance. The syenite is fine-grained, actually a microsyenite, and is gradational with a quartz-bearing pegmatitic phase. The rock is composed of perthite and common hornblende with lesser riebeckite, pyroxene (?) alteration material, rutile, apatite, and iron oxides. Quartz occurs only in the pegmatitic phase.

At the suggestion of Frank E. Kottlowski, ages were determined on two samples from the controversial outcrop. Riebeckite from the granite yielded a K/Ar age of 1170 ± 25 m.y. and common hornblende from the pegmatitic phase an age of 1190 ± 25 m.y. An Rb/Sr age of 1135 ± 15 m.y. was obtained from feldspar from the granite.

Similar ages are not found elsewhere in this area. However, to the east, a large volume of granite and rhyolite was injected and extruded during the period 1100 to 1200 m.y. (the Panhandle igneous activity of Muehlberger et al.). The rocks at Pajarito Peak are interpreted as a local extension of this igneous activity.

The crystalline rocks are overlain by sedimentary rocks equivalent to the Permian Yeso and San Andres Formations (Kelley). Significantly, all Precambrian sedimentary rocks are absent, although they are demonstrably thick nearby. Either by nondeposition or later erosion, the thick sandstones and diabase-basalt of the DeBaca Terrane are missing. This suggests that Pajarito Peak is and has been a structural high and is part of the Pedernal landmass.

SACRAMENTO MOUNTAINS

Three small outcrops of Precambrian rocks are found south of Alamogordo, Otero County, at the base of the Sacramento Mountains escarpment. Pray (1961) described 80 feet (24 meters) of sedimentary section composed of quartzite, siltstone, and shales. These clastic rocks are cut by diabasic rocks, mostly as sills. The Precambrian sedimentary rocks have an angular discordance of about 10 degrees with the overlying Bliss Sandstone.

These rocks are similar to others found in a large north-south band in south-central New Mexico (Muehlberger and Denison, 1964; Muehlberger, Denison, and Lidiak), the DeBaca Terrane.

SAN ANDRES MOUNTAINS

The San Andres Mountains expose Precambrian rocks along an 85-mile (137- kilometer) north-south length. The sequence is complex and diverse. Kottlowski (1959) reports

> Red to gray granites, including roof-pendants of various schists and gneisses, and cut by pegmatite and diabase dikes, occur in the northern and southern parts of the mountains. From Sulphur Canyon to south of Hembrillo Canyon a thick series of metamorphic rocks is exposed including mica and quartz-feldspar schists, quartzites, amphibolites, phyllites, talc schist, talc, and dolomite, intruded by diabase and aplite dikes and by small masses of granite. Foliation of the metamorphic rocks along Hembrillo Canyon strikes N. 30-45 °W. and dips steeply westward. In places, this metamorphic series is truncated by a light-gray quartzite with bedding almost parallel to that of the overlying Bliss sandstone; however, the quartzite is cut by pale-pink aplite dikes that are truncated by basal beds of the Bliss Sandstone.

Kottlowski also notes the similarity of the quartzite to the Precambrian sedimentary rocks in the Sacramento Mountains and to samples from a well near Cloudcroft, Otero County.

Four ages have been reported from the length of the San Andres Mountain trend (Muehlberger et al.). Potassium-argon ages from micas range from 1350 to 1400 m.y., and one Rb/Sr determination on a whole rock yielded an age of 1300 ± 70 m.y. In addition, two ages were determined on a core from the Sun No. 1 Bingham (Socorro County) oil test a few miles north of the north end of the Precambrian outcrops along the San Andres trend. This granite gneiss (described by Muehlberger and Denison) gave an Rb/Sr age of 1570 ± 100 m.y. on microcline and a K/Ar age of 1350 m.y. on biotite.

Clearly, this is a different type of Precambrian complex from that exposed to the south in the Franklin Mountains. It is older and composed of a massive igneous-metamorphic complex. The igneous rock composition is dioritic to granitic, considerably more diverse than the granite of the 950-m.y. activity.

VAN HORN AREA

The rocks in the Van Horn area have been the object of excellent studies by King and Flawn (1953) and King (1965). Our dating has substantiated their field interpretation and the following is taken largely from their work. We do differ in the interpretation of the origin of some of the metamorphic rocks. What Flawn called meta-arkose is interpreted here mainly as metarhyolite.

The area may be divided into two segments. The older is exposed in the Eagle, Wylie, Van Horn, and Carrizo mountains and the southern end of the Diablo platform. The Carrizo Mountain Group is composed of quartzite, schist, phyllite, and marble overlain and intruded by metarhyolite and amphibolite. The exposed thickness in the Carrizo Mountains is reported to be as much as 19,000 feet (5800 meters) and does not appear to be repeated. In the Van Horn Mountains, the entire sequence is intruded by abundant pegmatite and is a higher metamorphic grade than the rocks to the north. The rocks of the Carrizo Mountain Group are separated from the younger rocks cropping out on the Diablo platform by the Steeruwitz overthrust.

On the Diablo platform, the lowest unit is the Allamore Formation, composed of very thick marbles with interbedded phyllite, chert, and pyroclastic volcanic rocks. The Allamore is overlain by another thick but very different unit, the Hazel Formation, which is made up of coarse-grained conglomerate and sandstone. The Van Horn Sandstone rests with angular unconformity on these older metasedimentary units and is of probable Late Precambrian age. Bliss(?) Sandstone overlies parts of these units in the Diablo platform area, but the Carrizo Mountain Group is overlain by Hueco Limestone (Permian).

Wasserburg et al. determined a number of ages on rocks and minerals from the Van Horn area. There is considerable variation in the apparent ages, but the oldest center around 1000 m.y. We interpret this to be near the time of metamorphism. We have determined seven whole rock ages on the metarhyolites. Only one of these (No. 759) falls into the 1000-m.y. range; the others are distinctly older. The youngest sample is very muscovitic. The muscovite was formed during metamorphism and indicates that during the addition of water to form muscovite, a closed system was not maintained. A least-squares cubic fit of an isochron using the six older ages yields a best age of 1238 ± 65 m.y. with an initial ratio of 0.7002 ± 0.0058. The error is high and the scatter considerable (fig. 2). We are not confident that the determined age is actually the age of formation because of the scatter; however, it is clear the metarhyolites have an age of formation substantially older than similar rocks in the Franklin Mountains.

A feldspar was separated from a rhyolite dike (?) that cuts the Allamore. This rock is unmetamorphosed and distinctly different from other rhyolitic rocks in this area. The determined age is 950 ± 14 m.y., identical to the Franklin Mountain rhyolites.

Thus, the rhyolites of the Carrizo Mountain Group were formed at about 1250 m.y. and metamorphosed about 1000 m.y. The faulting and deformation that thrust the Carrizo Mountain Group over the Allamore–Hazel sequence is probably contemporaneous with the metamorphism. A postmetamorphic dike (?) rock yields an age of 950 m.y.

Granite and rhyolite boulders reported in the Hazel Formation (King *in* King and Flawn, p. 84) have not been dated. These cannot be derived from the Pump Station Hills–Hueco Mountains, as suggested by King, because this terrane is too young. However, these granitic rocks could be

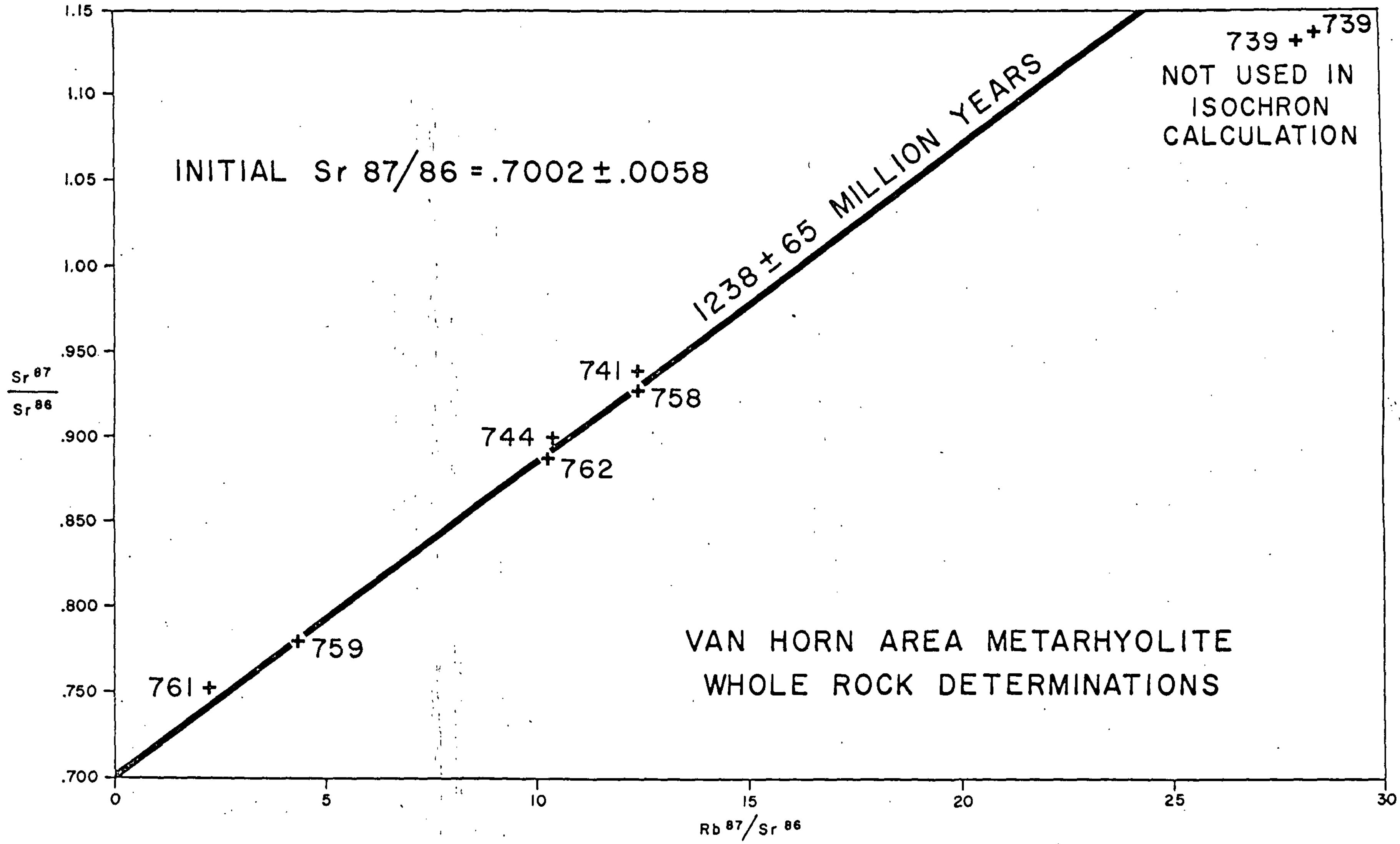


Figure 2

An Isochron Plot of whole rock determinations from the Metarhyolite in the Carrizo Mountain Group derived from the 1100 to 1200 m.y. terrane reported by Muehlberger et al. (p. 5422). The actual spread of ages in the volcanic rocks in this 1100 to 1200 m.y. terrane does not preclude the possibility that the Carrizo Mountain metarhyolite is related to some of those in the Panhandle area.

Unresolved problems remain in the Van Horn area. Perhaps the most puzzling is the difference in general strike of units in the Carrizo Mountain Group and those of the Hazel–Allamore sequence. This is best shown on King's (1965) map of the Sierra Diablo region. The dominant strike direction north of the Steeruwitz Fault is nearly east-west; south of the fault it is about N. 60° E. There is an interval covered by Van Horn and younger units, and there could be a general wrapping around of units beneath the two to three miles of cover. The lineations in the metarhyolite appear to be closer to the structural direction found to the north of the Steeruwitz Fault. In any event, the suggestion is that the Carrizo Mountain Group has undergone more than one period of major deformation. The area has been used as an example of major left lateral (Moody and Hill, 1956) and right lateral (Muehlberger, 1965) fault. The arguments are based on geometry, and specific support for the contentions is sparse.

SUBSURFACE

Scattered wells drilled to basement lie within the study area. Basement rocks from some of these wells have been described (Flawn, 1956; Foster, 1959; Muehlberger and Denison). Several basement rock units have been discussed and named by Muehlberger, Denison, and Lidiak. Much of the discussion to follow is taken from these works, particularly Muehlberger and Denison.

The oldest rocks in the subsurface are believed to be equivalent, in part, to those in the San Andres Mountains. Muehlberger, Denison, and Lidiak named these rocks the *Chaves Granitic Terrane.* The rocks penetrated are granitic in composition but diverse in petrography. Granites and granodiorites, some with a well-defined gneissic fabric, are the most common rock types. The only age determined on basement rocks of this terrane was from a biotite granite from the Humble No. 1 Huapache Unit oil test in sec. 35, T. 23 S., R. 22 E., Eddy County. The biotite yielded an age of 1310 ± 20 m.y. and the feldspar 1350 ±m, 20 m.y. This compares favorably with the outcrop ages from the San Andres Mountains. It is believed that some of the gneisses may be substantially older (possibly 1600 m.y.), becoming metamorphosed at about 1350 m.y. This unit is the basic framework rock, into which and onto which younger units were deposited or intruded, for much of southeast New Mexico.

The granite and related pegmatite dated at Pajarito Peak represent a basement rock unit that has not been drilled in the study area. However, numerous basement wells have penetrated petrologically related rock with the same ages in southeastern New Mexico, mainly in eastern Chaves and Eddy counties and Lea County. The unit is not yet named.

The vast majority of the map area shown in Figure 3 is underlain by rocks of the DeBaca Terrane. In the north, the rocks are argillites and feldspathic quartzites with interbedded basalts and are intruded by diabase. However, beginning with a line running east-west through central Otero County, carbonate rocks become a commonly drilled rock type.

The Turner No. 1 State in sec. 36, T. 25 S., R. 16 E., Otero County, drilled 2135 feet (651 meters) of altered diabase, talc-tremolite marble, quartz syenite, and micrographic granite porphyry. Nineteen intervals were examined petrographically in the drilled sequence. The similiarity between this and the section exposed in the Franklin Mountains is remarkable. In the LeFores No. 1 Federal oil test, sec. 22, T. 21 S., R. 16 E., wollastonite marble has been described by Muehlberger and Denison.

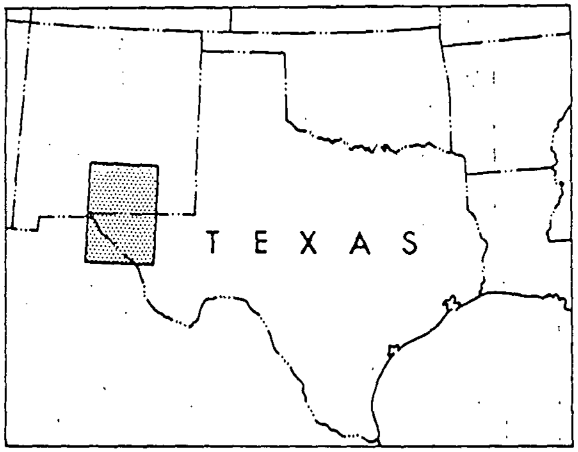
In southern Otero County and in Texas, the majority of wells penetrated rhyolite or micrographic granite. The only age determined from these rocks is on feldspar from the Gulf No. 1 Burner State in Hudspeth County. This fraction from a micrographic granite porphyry yielded an age of 890 ± 20 m.y. The age is younger than expected and may be due to alteration in the feldspar. In any event, we interpret these granites and rhyolites as equivalent to those cropping out in the Franklin and Hueco mountains and Pump Station Hills.

PRECAMBRIAN HISTORY

The oldest rocks exposed in this area are in the San Andres Mountains where micas from igneous rocks yield ages of 1350 to 1400 m.y. A suggestion of relict older ages of about 1600 m.y. is present, but how extensive these older rocks (later metamorphosed at 1350 to 1400 m.y.) are is not known. The metasedimentary rocks in this linear outcrop belt are not recognized in any of the wells penetrating basement in this area. These older layered rocks may be equivalent to the sequence found in the Los Pinos–Manzano mountains. The gneisses form the framework for all younger Precambrian units. These younger rocks are a veneer of sediments with locally significant intrusions.

To the south in Hudspeth and Culberson counties, the Carrizo Mountain Group was deposited and extruded. The exact time interval this took place is not so straightforward as might be hoped. Our best age of 1240 ± 65 m.y. on the age of extrusion of the rhyolite overlying sedimentary rocks shows they are significantly older than a comparable sequence in the Franklin Mountains. The former extent of this sedimentation and volcanic activity is not known, but it certainly extended considerably to the north of the present limited outcrop area. The inexactness of a best age for the rhyolite extrusion opens the door for speculation of its possible "real" age. The only other thick metasedimentary sequence fairly close at hand is that in the San Andres Mountains; this would require the rhyolite age to be lowered very significantly, probably ten or fifteen percent

BASEMENT GEOLOGIC MAP OF FAR WEST TEXAS AND SOUTH CENTRAL NEW MEXICO



INDEX MAP

EXPLANATION

950 M.Y.	FRANKLIN MTN. IGNEOUS ROCKS
950-1000 M.Y.	DEBACA TERRANE
1150 M.Y.	GRANITE AND SYENITE
~1250 M.Y.	CARRIZO MOUNTAIN GROUP
1350 M.Y. & OLDER	CHAVES GRANITIC TERRANE
o²	WELL REACHING BASEMENT SEE APPENDIX 2

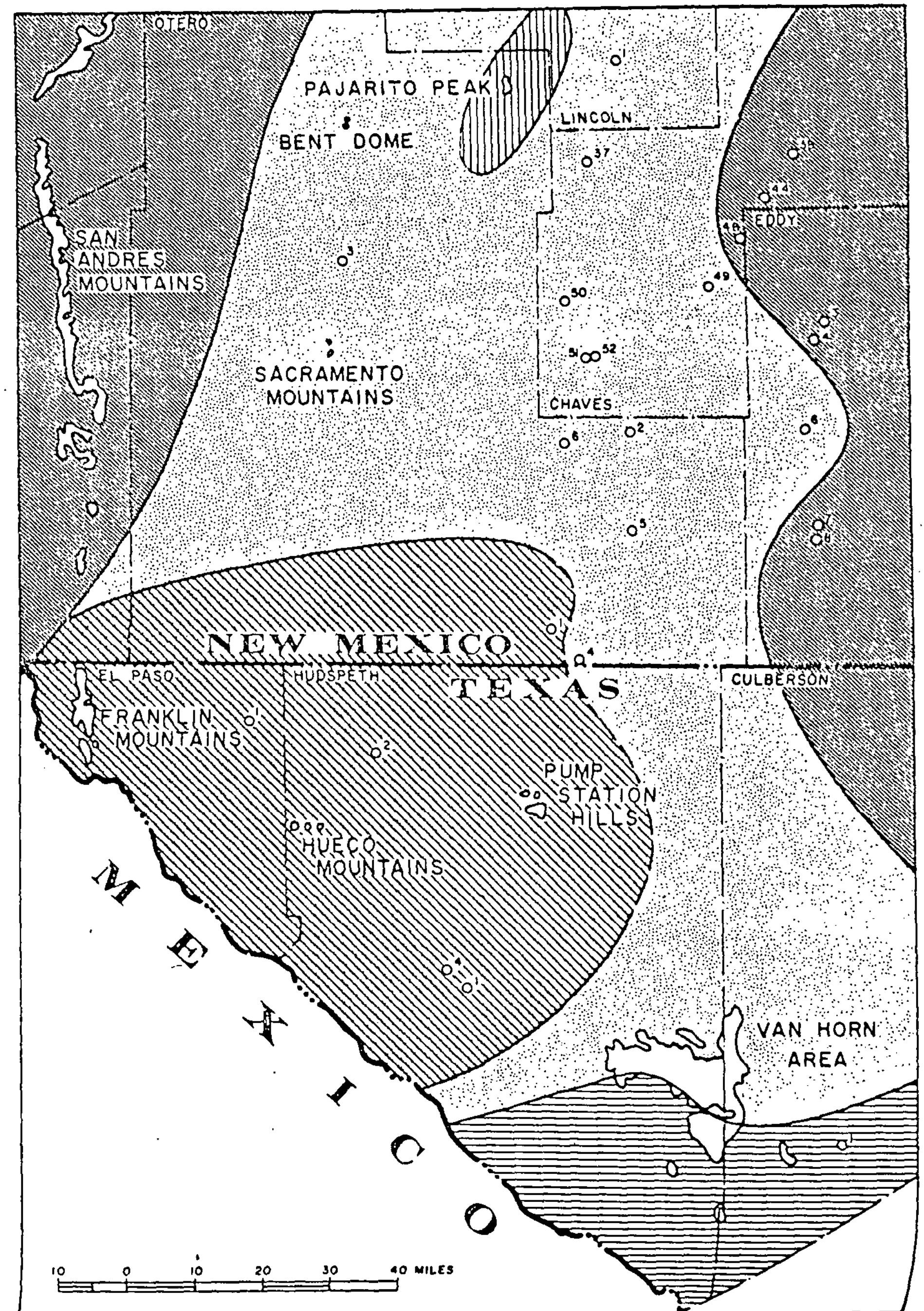


FIGURE 3

at the least. On the basis of our experience and considering the data, we believe this unlikely.

The isotopic ages determined on the rocks at Pajarito Peak in Otero County are interpreted to separate these rocks from those surrounding them. No trace of the 1140 to 1180 m.y. age or rock type can be found in the subsurface surrounding the Peak. The age is common to the east in eastern Eddy, Chaves, and Lea counties. We interpret this outcrop to be the westernmost known occurrence of this rock age in southern New Mexico. The outcrop is also significant because all the younger Precambrian sediments of the DeBaca Terrane are absent, whereas they are demonstrably thick nearby. Thus, by nondeposition or, more likely, by erosion during the lower Paleozoic, these sediments are no longer present from this structural high. Probably part of the Pedernal uplift affected sedimentation during Late Paleozoic time.

The period of 950 to 1000 m.y. saw the last major Precambrian activity. This is manifested in a variety of ways. The lowest stratigraphic unit that can be demonstrated is a carbonate rock sequence, the Castner–Allamore Marble. What these marbles rest upon or are underlain by is not known, for the base is nowhere exposed. This thick carbonate rock deposition was accompanied locally by diabase intrusions and basic volcanic rocks. The carbonate rocks were followed by a thick clastic sequence of variable composition. Pure sandstones, arkoses, shales, and conglomerates are found in the subsurface DeBaca Terrane, Hazel Formation, and Llanoria Quartzite. Diabases and basalts are common in the subsurface DeBaca Terrane but are not found on the outcrop in the Hazel–Llanoria. Movement had already begun in Hazel time, as evidenced by the abundant clasts of Allamore in the conglomerates of the Hazel Formation. This movement culminated with essentially synchronous igneous intrusions with pegmatite formation. The movement led to the Steeruwitz thrust with the older Carrizo Mountain Group rocks and associated younger intrusions being ramped over the Hazel–Allamore sequence.

To the west in the Franklin Mountains, activity was far less intense. Conglomerates present in the Llanoria are relatively minor. Widespread rhyolites were extruded, probably many of which were welded tuffs. The rhyolites provided a cover for the intrusion of comagmatic granites. This igneous activity was passive and relatively dry, as talc is sparse or absent in the Castner but diopside is common. A significant shearing component is not reflected in the metasedimentary sequence; the rocks are simply converted to hornfels.

To the north, the rocks of the DeBaca Terrane were being deposited. These were mostly impure sandstones and shales with abundant diabase and basalt. Limestones are not penetrated north of a line through central Otero County, probably through nondeposition. North of this arbitrary line, the rocks are characteristically unmetamorphosed. This reflects the absence of major igneous activity equivalent to that in the Franklin Mountains. The exception is at Bent Dome where a quartzite similar to the Llanoria is intruded by a finely micrographic granite. However, intrusions do not appear to be common, and the rocks of the DeBaca Terrane are only locally converted to hornfels but not regionally metamorphosed. The Franklin Mountain granite-rhyolite sequence is easily separated from the other rock units on the basis of petrography and age; however, it is difficult to define in terms of areal distribution. It is shown on the basement rock map as a distinct area, but one should recongize that this represents only that part of Texas and New Mexico where the granite-rhyolite sequence is most likely to occur. Areas outside that shown may be covered by rhyolite or have breached granite intrusions on the basement surface that are Franklin Mountain equivalents. Conversely, areas within the mapped area may have Van Horn Sandstone covering the rhyolite or granite, or the rhyolite may be removed by erosion to expose the underlying DeBaca Terrane.

The period between 950 m.y. and the Cambrian was marked by some differential movement and erosion that exposed the more deeply emplaced granites. The amount of uplift, folding, and faulting during this period is relatively small, as evidenced by the roughly conformable or mildly disconformable relationship between lower Paleozoic and the Precambrian layered sequences in the Franklin, Sacramento, and San Andres mountains.

CONCLUSION

This area, about 180 miles (290 kilometers) long and 130 miles (210 kilometers) wide, is one of the best in the United States to show very close correspondence between scattered Precambrian outcrops and intervening basement control from drill holes. The basement evolution can be developed using petrography and geochronology, though not so precisely as might be hoped in every instance. We believe any vagueness can be resolved by further, detailed work. The two main problems not resolved to our satisfaction are the possible "real" age of extrusion-deposition of the Carrizo Mountain Group and the complex San Andres Mountain Precambrian sequence, about which very little is known.

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TABLE 1. Rb/Sr AGES FOR SAMPLES IN FAR WEST TEXAS AND SOUTH-CENTRAL NEW MEXICO (cont)

NO. FRAC-TION	Rb (ppm)	Sr (ppm)	Rb/87 Sr 86	Sr87 Sr86	AGE	ROCK TYPE AND LOCATION
*770F	118.5	127.6	2.68	0.7475	990±50	Quartz syenite, pyroxene bearing. Dam spillway at base of Fusselman Canyon
788W	126.1	145.77	2.50	0.7420	915±50	Rhyolite porphyry. Middle part of the Franklin Mountain Rhyolite in Fusselman Canyon
789W	179.4	21.5	24.1	1.032	905±20	Rhyolite porphyry. Upper part of the Franklin Mountain Rhyolite on western dip slope opposite Fusselman Canyon
789F	375.7	21.2	51.2	1.430	950±15	
1064F	929.1	11.1	241.4	4.060	935±15	Granite. East of Tom Mayes Park at prospect pit in narrow part of Canyon
1063W	263.7	15.7	48.5	1.407	970±20	Metarhyolite porphyry. East of Tom Mayes Park east of sample 1064
1065F	442.3	2.67	477.5	7.378	980±15	Granite. McKelligon Canyon about 1000 m from end of road on southwest side of road
1066W	216.5	26.1	23.9	1.030	910±20	Metarhyolite porphyry. McKelligon Canyon near the end of the road at head of canyon
1066F	323.5	55.1	16.9	0.9452	940±15	
830F	446.5	27.1	47.6	1.394	970±15	Granite. Tin Mine locality about 2 miles north of North Franklin Mountain
					VAN HORN AREA	
	22.4	22.9	28.0	1.132	1040±40	Metarhyolite porphyry. Carrizo Mountains 3800′ N 30° 02′30″ N
739W						
	218.7	22.3	28.4	1.137	1040±40	5500′W of 105°55′W. The sample is highly muscovitic
741W	157.5	36.8	12.4	0.9381	1290±60	Metarhyolite porphyry. Carrizo Mountains, 4100′ N 31° 82′ 30″ N, 7200′W of 105° 55′ W
744W	178.1	49.7	10.4	0.8997	1290±80	Metarhyolite porphyry. Carrizo Mountains, Gifford-Hill Quarry 8500′N 30° 02′ 30″N, 1000′ W 105° 57′ [illegible]
748F	326.0	38.5	24.4	1.051	950±15	Rhyolite porphyry. Sierra Diablo, 10080′N 30° 5′, 3800′E 105° 2′30″ W. The sample is related to Franklin Mountain samples and is a dike in the Allamore Formation
758W	168.3	39.3	12.4	0.9275	1240±60	Metarhyolite porphyry. Carrizo Mountains, 900′N 31° 2′30″ 5300′ W 104° 57′ 30″
759W	122.3	80.8	4.36	0.7793	1220±200	Metarhyolite porphyry. Carrizo Mountains same location as 758

TABLE 1. Rb/Sr AGES FOR SAMPLES IN FAR WEST TEXAS AND SOUTH-CENTRAL NEW MEXICO (cont)

NO. FRAC-TION	Rb (ppm)	Sr (ppm)	Rb/87 Sr 86	Sr87 Sr86	AGE	ROCK TYPE AND LOCATION
761W	33.4	43.3	2.23	0.7520	1640±450	Metarhyolite porphyry. Wylie Mountains, location C-5 on the map of Flawn (in King and Flawn, 1953)
762W	137.7	38.6	10.3	0.8753	1140±100	Metarhyolite porphyry. Wylie Mountains, same as 761
				PAJARITO PEAK		
723F	1381.	9.96	400.3	7.472	1135±15	Riebeckite granite. Pajarito Peak, on boundary of sections 25 and 26 12S-15E, Otero County, New Mexico
				SUBSURFACE		
600F	372.7	44.3	24.3	1.008	840±15	Micrographic granite. Gulf No. 1 Burner State, Hudspeth County, Sec. 14. Blk. 19, PCL Sur., core at 9222′
607F	263.2	249.6	3.04	0.7674	1350±30	Granite. Humble No. 1 Huapache, Eddy
607B	634.8	11.7	156.7	3.767	1310±20	County, 35-235-22E. Core at 12616′

•F = feldspar

TABLE 2. K/Ar AGES FROM AMPHIBOLES AT PAJARITO PEAK, OTERO COUNTY, NEW MEXICO

SAMPLE NO.	SAMPLE WT (gms)	PERCENT K	Ar 40* MOLES X10-9	Ar 40* / Ar 40 TOTAL	AGE	ROCK TYPE
723	0.158	1.391	0.631	0.97	11.70 25	Riebeckite granite
724	0.167	1.297	0.641	0.95	1190 25	Syenite pegmatite

TABLE 3. ROCKS OF THE FRANKLIN MOUNTAINS AND VAN HORN AREA

AGE (m.y.)	FRANKLIN MOUNTAINS	VAN HORN AREA	SUBSURFACE LITHOLOGY
–950	----	VAN HORN SANDSTONE	----
	GRANITE	GRANITE AND PEGMATITE	GRANITE
	RHYOLITE	RHYOLITE INTRUSIVES	RHYOLITE
	LLANORIA QUARTZITE	HAZEL FORMATION	QUARTZITE
950-1000		POSSIBLY REPRESENTED BY	
	MUNDY BRECCIA	BASIC VOLCANIC ROCK	DIABASE
		IN THE ALLAMORE	
	CASTNER MARBLE	ALLAMORE	MARBLE
1250	----	CARRIZO MOUNTAIN GROUP	SCHIST

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APPENDIX A

ANALYTICAL PROCEDURES

The strontium measurements were determined on a 13-inch radius, 60-degree magnetic sector, 15.8-inch radius, 91-degree electric sector, second order double-focusing mass spectrometer.

The rubidium measurements were made on a symmetric 6-inch, 60-degree, single-focusing Nier-type mass spectrometer. Separate strontium measurements were made on spiked and unspiked aliquots. The unspiked strontium 87/86 measurements were normalized to Nier's value of $Sr^{86}/Sr^{88} = 0.1194$. Separations were made on an ion-exchange column and identified by using Sr^{85} and Rb^{83} tracers. The analytical precision based on replicate analysis is estimated to be ± 0.2 percent for isotope ratio measurements and ± 1 percent for both Rb and Sr concentrations. Our results compare favorably with published standards (*see* Lanphere and Dalrymple, 1967).

The argon measurements were made on a 4.5-inch Reynolds-type mass spectrometer. The samples were fused by induction coil heating in tungsten or columbium crucibles and purified through (1) dry ice, (2) copper oxide at 600°C, (3) liquid nitrogen, and (4) calcium at 900°C and then absorbed on charcoal at liquid-nitrogen temperature in a break seal. A typical blank is about 10^{-11} moles of atmospheric argon; the best are about 4×10^{-12} moles.

The constants used to compute the ages are

$$Rb^{87}\ \lambda_\beta = 1.47 \times 10^{-11}/\text{yrs}$$
$$Rb^{87} = 0.283\ \text{gm/gm Rb}$$
$$K^{40}\ \lambda_\epsilon = 0.585 \times 10^{-10}/\text{yrs}$$
$$\lambda_\beta = 4.72 \times 10^{-10}/\text{yrs}$$
$$K^{40} = 1.22 \times 10^{-4}\ \text{gm/gm K.}$$

APPENDIX B

The following are brief summaries of samples drilled to basement in the areas shown in Figure 1. The wells are numbered within each county. The numbers in New Mexico are the same as those used by Foster and Stipp (1961). The Texas numbers follow Flawn with additions for newer wells.

CULBERSON 1

Cosden No. 1 Cockrell, sec. 7, blk. 80, PSL Survey. Cuttings at 3210 to 3356 ft. The rock is fine-grained biotite granite gneiss, most of which is composed of microcline, plagioclase, and quartz in a granoblastic mosaic varying in grain size. Fresh olive-green biotite books show a high degree of preferred orientation parallel to grain size banding. It is interpreted as a metaigneous rock of granitic composition. Possibly, it is equivalent to the metarhyolites of the Carrizo Mountain Group, but petrographic evidence is unclear. In any event, the rock is interpreted as being related to the Carrizo Mountain sequence.

EL PASO 1*

Iones No. 1 Sorely, sec. 17, blk. 5, PSL Survey. Flawn (p. 155) reported a quartz diorite in cuttings from 2213-20 ft. The descriptions suggest a rock similar to some found as intrusions within the Castner Marble, but certain differences are apparent and no definite correlation can be made.

IUDSPETH 1*

lmerican Land No. 1 Roseborough, sec. 7, blk. 21, Tws 6, 'SL. Flawn (p.167) examined cuttings from two intervals, 600-10 ft. and 1625-1787 ft., and described a rhyolite orphyry. The rhyolite is interpreted here as being equivalent to the Franklin Mountain Rhyolite.

UDSPETH 2*

alifornia No. 1 Theison, sec. 19, blk. E. Univ. Lands. lawn (p. 169) described a micrographic granite in cuttings om 4844-48 ft. The well was drilled about 20 miles north f granite cropping out in the Hueco Mountains. The anite described in the well is interpreted as equivalent to at in the Hueco and Franklin mountains.

JDSPETH 4

ılf No. 1 Burner State, sec. 14, blk. 19, PSL. A core taken 9222 ft. is a micrographic granite porphyry. The feldspar ·lded an age of 840 ± 15 m.y., which is below the age of granites of the Red Bluff type. However, petrographic similarity prompts us to consider it equivalent to the granite in the Hueco and Franklin mountains. The age is possible too low because of alteration in the feldspar.

CHAVES 3‡

Humble No. 1 State N, 35-14S-17E. Muehlberger and Denison described five intervals from 2610 to 4010 ft. The well penetrated a sequence of quartzite, arkose, and olivine basalt, which comprise part of the DeBaca Terrane.

CHAVES 38‡

Magnolia No. 1 Turney, 23-14S-22E. Four intervals from 4920 to 5340 ft. were described by Muehlberger and Denison. The well penetrated diabase and a gneissic granitic rock. The petrography is not clear-cut, but the granitic rock is probably part of the Chaves Granitic Terrane and the diabase probably equivalent in age to those in the DeBaca Terrane.

CHAVES 44‡

Humble No. 1 Gorman, 30-15S-22E. An interval at 5805-25 ft. is in a banded granitic gneiss, part of the Chaves Granitic Terrane.

CHAVES 48‡

Black No. 1 Shildneck, 24-16S-20E. Four intervals from 6740 to 6990 ft. were examined. The upper interval penetrated a granite gneiss, the lower three were in diabase. The gneiss is part of the Chaves Granitic Terrane; the lower diabase is probably equivalent to those in the DeBaca Terrane.

CHAVES 49‡

Magnolia No. 1 Black Hills Unit, 31-17S-20E. Three intervals from 5915 to 6085 ft. penetrated quartzitic and arkosic sandstones and argillaceous siltstones of the DeBaca Terrane.

CHAVES 40‡

Gulf No. 1 Chaves "U", 10-18S-16E. One core interval at ±

* Described by Flawn, but the interpretation here does not necessarily agree.

† Described by Muehlberger and Denison.

‡Described by Flawn and by Muehlberger and Denison. Those not marked are described here for the first time.

3100 ft. was interpreted as an enigmatic, slightly metamorphosed rock of clastic sedimentary origin by Muehlberger and Denison. In this interpretation, the rock would be related to those in the DeBaca Terrane.

CHAVES 51‡

Sun No. 1 Pinon Unit, 19-19S-17E. Four intervals from 1732 to 1911 ft. all penetrated altered albite andesite porphyry. The rock is probably related to those in the DeBaca Terrane.

CHAVES 52‡

Sun No. 2 Pinon Unit, 20-19S-17E. One interval at 1650-59 ft. was in a meta-albite andesite. The rock is similar to that in Chaves 51 and is related to those in the DeBaca Terrane.

EDDY 3*

Southern Union No. 1 Elliot, 24-18S-23E. One core interval at 9886-87 ft. was in a foliated granite. The rock may be simply a granite gneiss. The well penetrated part of the Chaves Granitic Terrane.

EDDY 4†

Magnolia No. 1, Tres Rancho Unit, 10-19S-23E. The only interval examined, 10,000 to 10,010 ft., was interpreted as a banded granite gneiss related to the Chaves Granitic Terrane.

EDDY 6‡

Magnolia No. 1, State "W", 16-21S-22E. Three intervals from 11230 to 11312 ft. were interpreted as a quartzite intruded by an albite diabase later metamorphosed to lower greenschist facies or hydrothermally altered. The rocks are part of the DeBaca Terrane.

EDDY 7

Humble No. 2, Huapache, 23-23S-22E. A biotite granodiorite was penetrated from 12570 to 12580 ft. The rock is petrographically very similar to Eddy 8, although somewhat different in bulk composition. The rock is part of the Chaves Granitic Terrane.

EDDY 8

Humble No. 1 Huapache, 35-23S-22E. A core taken at 12629 ft. was a biotite granite. The biotite yielded an Rb/Sr age of 1310 ± 20 m.y. and the feldspar an age of 1350 ± 30 m.y. The granite is part of the Chaves Granitic Terrane.

LINCOLN 1†

Stanolind No. 1 Picacho, 10-12S-18E. Two intervals from 2538 to 2759 ft. penetrated a feldspathic sandstone. The rock is part of the DeBaca Terrane.

OTERO 1*

Hunt No. 1 McMillan–Turner, 5-26S-[illegible]E. Two intervals from 1887 to 2060 ft. were diabase, two lower intervals from 2860 to 2170 ft. were in rhyolite porphyry. The rhyolite is probably related to the Franklin Mountain Rhyolite and the diabse to that in the DeBaca Terrane. The petrographic-geometric relationship suggests that the diabase is younger than the rhyolite but this is not unequivocal.

OTERO 2‡

Standard of Texas No. 1 Scarp, 18-21S-[illegible]E. Diabase was penetrated in two examined intervals from [illegible]630-2660 ft. The rock is related to the DeBaca Terrane.

OTERO 3†

Southern Union No. 1 Cloudcroft, 5-1[illegible]S-12E. Fourteen thinsections were examined in the interval from 4520 to 4702 ft. These showed a quartzite and argillaceous quartzite cut by diabase dikes. The rocks are part of the DeBaca Terrane.

OTERO 4

Turner No. 1 State, 36-25S-16E. Nineteen thinsections were examined from 3115 to 5195 ft. The sequence was diabase with alternate talc-tremolite marble intruded by a sill of granite. The well was abandoned in micrographic granite porphyry at 5195 ft. The sequence is a remarkable parallel to the lower part of the section in the Franklin Mountains.

OTERO 5

Coral No. 1 Warren, 19-23S-18E. Cuttings taken at 2300 to 2330 ft. show an olivine diabase. The rock is probably related to those of the DeBaca Terrane.

OTERO 6†

LeFores No. 1 Federal, 22-21S-16E. The well penetrated diverse metamorphic rocks. In the interval from 2230 to 2250 ft., four thinsections showed a marble with wollastonite, garnet, tremolite, and calcite. The origin of the rock is contact metamorphism of an impure limestone. The rock is probably related to the Allamore–Castner sequence.