



Summary of Precambrian geology and geochronology of northeastern New Mexico

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1976, pp. 129-135. <https://doi.org/10.56577/FFC-27.129>

in:

Vermejo Park, Ewing, R. C.; Kues, B. S.; [eds.], New Mexico Geological Society 27th Annual Fall Field Conference Guidebook, 306 p. <https://doi.org/10.56577/FFC-27>

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SUMMARY OF PRECAMBRIAN GEOLOGY AND GEOCHRONOLOGY OF NORTHEASTERN NEW MEXICO

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INTRODUCTION

The Precambrian of northeastern New Mexico received little detailed geologic attention until 1974, when the Pecos Mine in western San Miguel County was re-interpreted as a volcano-genic massive sulfide deposit (Giles, 1974). This hypothesis stimulated new industrial and academic interest in Precambrian lithology, stratigraphy, structure and mineralization in the Sangre de Cristo Mountains and elsewhere in New Mexico and Colorado (*c.f.*, Giles, 1976).

In northeastern New Mexico, Precambrian exposures are restricted to the Sangre de Cristo Mountains of western Colfax, Mora and San Miguel Counties and easternmost Santa Fe County (Fig. 1). Within this north-trending mountain belt are two geographically distinct Precambrian terrains: a northern, generally granitic region in the Costilla Lake-Cimarron Range-Moreno Valley area, and a southern, predominantly metasedimentary and amphibolitic belt in the Pecos River-Las Vegas Range area.

The geologic map which accompanies this report (Fig. 1) is mainly compiled from the following sources: McKinlay (1956) (Costilla Lake area), Clark and Read (1972) (Eagle Nest area), Smith and Ray (1943) and Wanek and others (1964) (Cimarron Range), Montgomery (1963) (upper Pecos River area), Budding (in preparation) and Schowalter (1969) (Mora area), and Dane and Bachman (1965). Much of the following discussion is also based upon the work of these authors.

PREVIOUS WORK

A number of workers (Darton, 1928; Harley, 1940; Smith and Ray, 1943; Northrop and others, 1946; Bachman, 1953; Johnson, 1970; Baltz, 1972) have noted the presence of Precambrian rocks in northeastern New Mexico. These studies did not describe Precambrian rocks in detail but rather lumped them into generalized categories such as "metamorphic," "igneous" or undifferentiated. Aeromagnetic, gravity and drill-hole data have been used to prepare regional structure contour maps on Precambrian basement (Foster and Stipp, 1961; Andreasen and others, 1962; Woodward and others, 1975; Woodward and Snyder, this Guidebook) and to outline broad lithologic zones (Foster and others, 1972). Only recently have detailed studies (Montgomery, 1963; Schowalter, 1969; Clark and Read, 1972; Cepeda, 1972; Goodknight, 1973; Budding, in preparation; Mathewson, in preparation; Riesmeyer, in preparation) more precisely defined the lithology and structure of Precambrian rocks in specific areas of northeastern New Mexico.

COSTILLA LAKE-CIMARRON RANGE-

MORENO VALLEY

Distribution

Precambrian rock along the western edge of Colfax County (Fig. 1) represents only a small part of the widespread Precambrian exposures in the northern Sangre de Cristo Mountains of New Mexico. Most of the Precambrian outcrops lie to the west in Taos County (*c.f.*, McKinlay, 1956, 1957; Gruner, 1920; Clark and Read, 1972; Montgomery, 1953; Callender, 1975). The Precambrian of Colfax County is confined to three major areas: 1) adjacent to Costilla Lake, where Precambrian rocks lie along the western edge of Vermejo Park and make up the eastern flank of the Costilla Massif (McKinlay, 1956); 2) on the eastern edge of the Taos Range, west of Moreno Valley, from Red River Pass to a few miles north of Agua Fria; and 3) in the Cimarron Range southeast of Eagle Nest.

Lithology

The oldest Precambrian rocks are amphibolites, hornblende schists, mafic gneisses and metasediments of diverse lithology. Exposures vary from isolated outcrops along the crest of the Costilla Massif and near the intersection of Rio Costilla and Comanche Creek in easternmost Taos County (McKinlay, 1956) to a broad, east-trending band near Red River Pass (Clark and Read, 1972). The metasediments range from lenses or bands of massive metaquartzite [Cabresto (?) metaquartzite of McKinlay (1956)] with relic sedimentary features to muscovite-hematite granulite, quartz-mica gneiss, graphite-mica gneiss and schist, hornblende gneiss, chlorite and talc schist, and greenstone. The mafic rocks are presumably derived from basic volcanic rocks, primarily flows and sills, and may be in part equivalent to the Vadito Formation of Montgomery (1953) in the Picuris Range (McKinlay, 1956; Clark and Read, 1972). The metasediments formed from regional metamorphism of intercalated quartz sand, siltstone and subordinate shale, and feldspathic layers (McKinlay, 1956; Clark and Read, 1972; Goodknight, 1973). Clark and Read (1972) suggested that the original thickness of the metasedimentary and mafic metamorphic rocks in this area, including localities in eastern Taos County, may be as much as 12,000 ft.

The metamorphic rocks were subsequently intruded by an extensive body of relatively uniform microcline granite and granite gneiss (Smith and Ray, 1943; McKinlay, 1956; Clark and Read, 1972) or slightly gneissoid granodiorite (Wanek and others, 1964; Goodknight, 1973). Local zones of migmatite

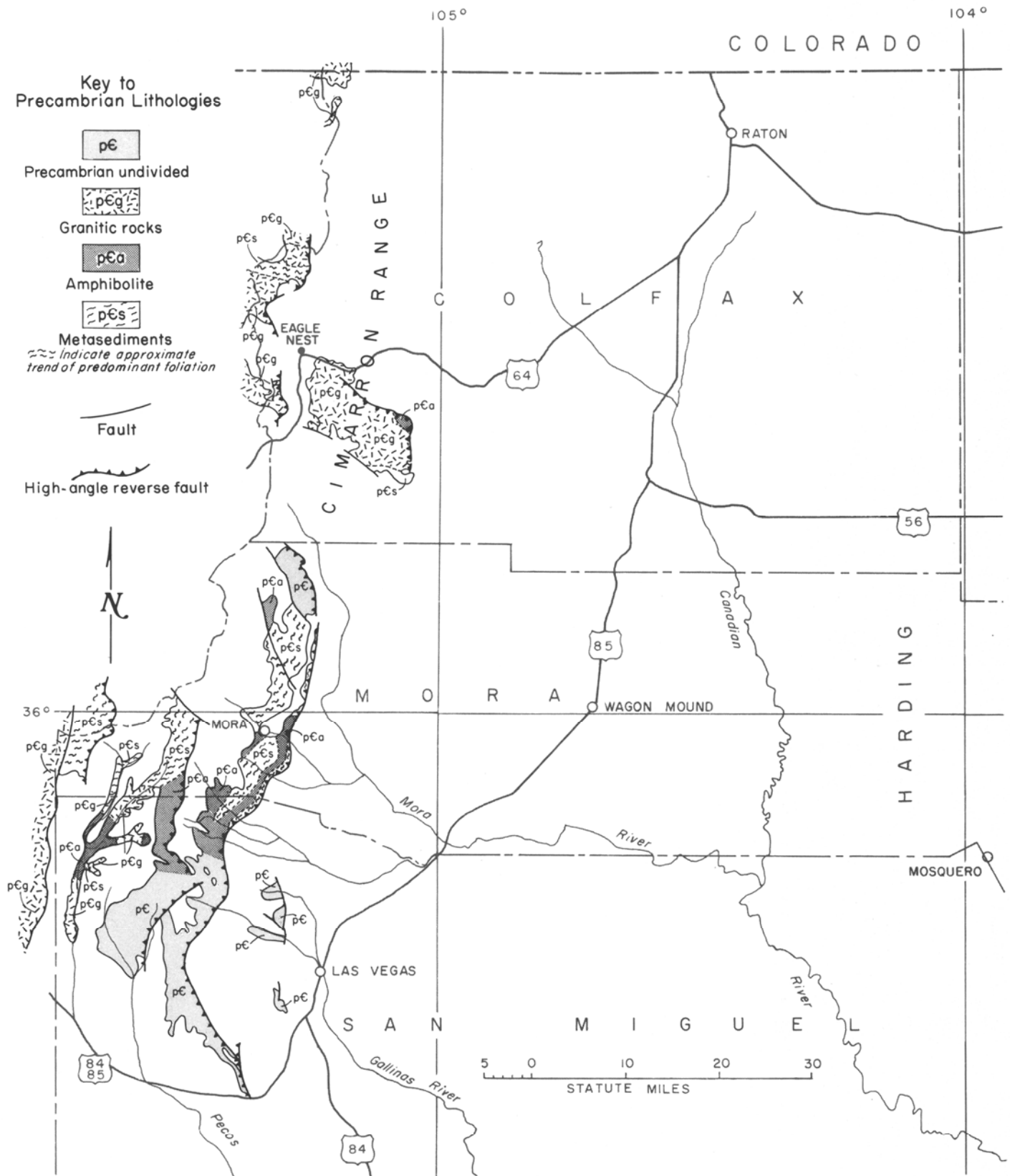


Figure 1. Precambrian geology of northeastern New Mexico.

formed in the metamorphic rocks adjacent to the intrusive. In addition, microcline or microcline-orthoclase pegmatites, ranging from stringers to dikes 50 ft wide, are common in both the granitic and metamorphic rocks. According to Clark and Read (1972) the sequence of granitic rocks exposed in the Taos Range is equivalent to the Embudo Granite of Montgomery (1953).

A relatively widespread terrain of biotite-rich granitic gneiss is exposed north of Moreno Valley and northeast of Red River Pass. Although similar in composition to the granitic intrusives described above, this body does not appear to intrude the metamorphic rocks. For this and other reasons, Clark and Read (1972) suggested that this rock may be an older metasedimentary unit. This observation is one of many which point out the complicated and still incompletely known temporal and stratigraphic relations within the Precambrian of this region.

Weakly metamorphosed and locally foliated gabbro and diabase dikes cut the granitic and metamorphic rocks throughout the area and are presumably Precambrian in age, since they are metamorphosed and do not cut the overlying Paleozoic rocks (McKinlay, 1956; Clark and Read, 1972; Goodknight, 1973). These dikes are apparently the youngest Precambrian rocks in the region.

Structure

According to McKinlay (1956), the structure of Precambrian rock in the Costilla Lake region is relatively simple. The principal structural feature is a thrust of Laramide age which carried Precambrian basement eastward over Paleozoic and Mesozoic sedimentary rocks along the eastern border of the Sangre de Cristo Mountains. Locally the metamorphic rocks show a northeast-trending foliation that implies folding along a series of N. 70° E. axes. The patchy nature of metamorphic rock exposures suggests they are roof pendants suspended in the granite batholith of the Costilla Massif. The Costilla Massif was apparently uplifted in Tertiary time along steeply dipping normal faults.

The structure of Precambrian rocks in the Moreno Valley-Cimarron Range is somewhat more complicated. As in the Costilla Lake area, Laramide thrusts dominate the regional structure, but Neogene normal faulting has given rise to superimposed block-faulted ranges and valleys. The Moreno Valley, for example, is the result of both Laramide synclinal folding and subsequent Neogene down-faulting (Clark and Read, 1972). Down-faulting of the Moreno Valley is particularly well shown on its eastern side, where the Cimarron Range has risen along high-angle normal faults (Goodknight, 1973).

Precambrian metamorphic rocks of the Moreno Valley-Cimarron Range generally show a northeast-trending foliation, but regional fold patterns are difficult to decipher. The majority of the rocks are relatively unfoliated granites and gneisses. According to Clark and Read (1972), belts of migmatite tend to follow foliation trends in the metamorphic rocks. In addition, the trends of pegmatite and diabase dikes suggest Precambrian fracture systems with east-northeast, northwest and northeast attitudes.

Metamorphism

McKinlay (1956) and Clark and Read (1972) demonstrated that at least two metamorphic events have affected the rocks of this region: low- to medium-grade regional metamorphism

and local contact metamorphism near intrusive boundaries. Rock composition has influenced the development of metamorphic indicator minerals in many areas. Mafic rocks apparently show relatively lower metamorphic grade than the metasediments. Mafic rocks generally belong to the chlorite and biotite zones of the greenschist facies in the Eagle Nest area (Clark and Read, 1972) and the lower amphibolite facies in the Cimarron Range (Goodknight, 1973) and Costilla Peak area (McKinlay, 1956). Metasedimentary rocks, on the other hand, commonly contain sillimanite and are considered to be relatively high-grade in the Eagle Nest area (Clark and Read, 1972). However, the potential for metasomatic influence on sillimanite development (Montgomery, 1953; Berkley and Callender, in preparation) makes this determination difficult.

Contact metamorphism and metasomatic effects related to granite intrusion include zones of lit-par-lit injection, migmatite, sericitization and chloritization, sillimanite-muscovite reaction zones, and local indicator minerals of contact metamorphic facies. Hydrothermal activity has apparently added boron (in the form of tourmaline), potassium (microcline) and silica to the metamorphic rocks (Clark and Read, 1972). An extensive phase of pegmatite intrusion followed emplacement of granite and may be related to late-stage hydrothermal activity.

PECOS RIVER-LAS VEGAS RANGE

Distribution

Precambrian rock in the Pecos River-Las Vegas Range is exposed in five north-northeast-trending belts that parallel the structural axis of the Sangre de Cristo Mountains in western Mora and San Miguel Counties (Fig. 1). From east to west, these belts comprise: 1) unconnected exposures within and adjacent to Gallinas Canyon immediately west of Montezuma; 2) continuous exposure from the northern border of Mora County northwest of Guadalupita to Interstate 25 (U.S. 84 and 85) at Sarafina in west-central San Miguel County; 3) continuous exposure along the eastern crest of the Las Vegas Range from the border of Mora County west of Mora to the upper reaches of Cow Creek east of Pecos in western San Miguel County; 4) relatively continuous exposure along the upper Pecos River and its tributaries, especially the Rio Mora; and 5) continuous exposure along the crest and high eastern slopes of the Santa Fe Range in Santa Fe and westernmost Mora Counties.

Lithology

The oldest Precambrian rocks in the area are metasediments, mainly quartz-feldspar-mica gneiss and quartzite, that form an east-trending band across western Mora County. Quartzite predominates in the western part of the band, where Montgomery (1963) placed these rocks within the Ortega Formation. In the eastern part of the band, north and south of Mora, quartz-feldspar-mica gneiss is the dominant rock type, along with relatively minor amounts of quartz-muscovite schist and quartzite (Cepeda, 1972). Well-banded quartz-feldspar-biotite gneiss exposed along Gallinas Canyon northwest of Las Vegas is most likely of sedimentary origin. A relatively narrow outcrop of highly siliceous rock along the north side of Willow Creek near its confluence with the Pecos River at Tererro may also be, in part, metasedimentary. A volcanogenic suite of metarhyolite, metabasalt, metagraywacke and other constitu-

ents has also been described in this area (Riesmeyer, in preparation).

Amphibolitic rocks form a second east-trending band immediately south of the metasedimentary terrain. These hornblende-plagioclase rocks may locally intertongue with the metasediments, particularly in the Mora-Rociada area, and probably represent mafic sills and flows. Elsewhere the amphibolites crosscut, engulf and partially blot out the older metasediments. In the eastern Santa Fe Range, screens of amphibolite are found in a complex intrusive-assimilation relation with granitic rocks (Budding, 1972; Kottowski, 1963).

The youngest Precambrian rocks in the Pecos River-Las Vegas Range are gray to pink, medium- to coarse-grained, well-foliated to massive granites, accompanied by pegmatite and aplite dikes and quartz veins. Baltz and Bachman (1965) suggested the granites may be of more than one generation, noting that gray, well-foliated biotite granite is commonly cut by pink, non-foliated leucogranite. Similar relations are observed in the southeastern Santa Fe Range (Budding, 1972). These granitic rocks occur as dikes, sills and stock-like bodies up to several miles or more across and are exposed in a number of places along the upper Pecos River and its tributaries, and from the canyon of the Gallinas River north to Hermit Peak. The major mass of granitic rock in the southern Sangre de Cristo Mountains has been called the Embudo Granite by Montgomery (1953), and it crops out mainly to the west of the present map area. Pegmatite and aplite dikes, ranging from several inches to several tens of feet in thickness, crosscut both metasediments and amphibolites, although they seem to be more abundant in the latter. Near Mora, pegmatite lenses up to 300 ft thick occur extensively in muscovite schist (Cepeda, 1972).

Structure

Precambrian rock in the Pecos River-Las Vegas Range area is exposed along the upthrown western side of a series of north-east-trending, westward-dipping thrust faults of probable Laramide age that form the southeastern margin of the Sangre de Cristo Mountains. Relatively flat-lying Paleozoic sediments have been dragged up and in some places overturned by the eastward movement of the upthrown blocks.

Faulting of Precambrian age is apparently mainly strike-slip. The most important example is the north-trending Picuris Pecos fault along which there may have been more than 20 miles of right-lateral movement (Montgomery, 1963), although significant superimposed Cenozoic dip-slip motion (Budding, 1972; Montgomery, 1963) may have obscured important pre-Pennsylvanian vertical movement along this fault zone. This major fault marks the eastern edge of the main mass of Embudo Granite exposed in the Santa Fe Range and more or less coincides with a part of the western borders of Mora and San Miguel Counties.

Lithologic variation and well-developed metamorphic foliation in Precambrian metasedimentary and amphibolitic rocks define a series of anticlinal and synclinal folds. In the north-western part of the area these folds trend approximately east-west and are overturned to the north (Montgomery, 1963), while beds exposed along the Pecos River and its tributaries between Tererro and Cowles strike north-northeasterly and dip steeply. To the east, fold axes swing toward the northeast, where they roughly parallel the trend of Laramide thrusting. This folding represents only the latest event in an undoubtedly

longer and more complex Precambrian deformational history. Cepeda (1972) reports evidence for at least two periods of Precambrian deformation in the Mora area, and a similar history has been observed in the Lake Peak-Santa Fe Baldy area of the Santa Fe Range.

Metamorphism

Precambrian rocks have been subjected to two major metamorphic events in the Pecos River-Las Vegas Range: an earlier, deep-seated regional dynamothermal metamorphism that raised pre-existing sediments and igneous rocks to amphibolite grade, and a later, hydrothermal metamorphism associated with granitic intrusion. Inasmuch as some of the granitic rocks show the effects of dynamic metamorphism, regional compressive forces probably persisted during at least part of the intrusive episode.

Diagnostic regional metamorphic minerals are not widely developed in this area. Scattered small lenses of sillimanite occur in quartz-muscovite schist southwest of Mora (Cepeda, 1972). Montgomery (1963) noted the presence of minor sillimanite and kyanite in metasediments of the Ortega Formation, but concluded that these minerals are most likely related to hydrothermal metamorphism because of their close and consistent association with quartz veins and pegmatite dikes. The principal metasomatic additions during hydrothermal metamorphism were boron, yielding abundant tourmaline, and potassium, resulting in widespread formation of pink microcline.

GEOCHRONOLOGY

The radiometric data for Precambrian rocks from outcrop and wells drilled into basement are sparse for northeastern New Mexico, and a clear-cut picture of "events" in the Precambrian is tenuous at best. Table 1 summarizes the published radiometric age information for northeastern New Mexico.

Radiometric dates in excess of 1,600 m.y. have been obtained by the Rb-Sr whole rock method for both the Embudo Granite (broad sense) and for granite core from Guadalupe County (Table 1). Long (1974) criticized the single age by Fullagar and Shiver (1973) for the Embudo Granite and suggested a spread in ages from more than 1,600 m.y. to possibly 1,400 m.y. for the Embudo Granite suite. Long argued that the "Embudo Granite" sampled by Fullagar and Shiver actually includes samples from at least four distinct granites. The Harding Pegmatite (Jahns and Ewing, this Guidebook) may or may not be a late phase of granitic emplacement; certainly the age data are insufficient to resolve this problem. Additional discussion of the dates for the Harding Pegmatite and other rocks of the Picuris Range will be found in Gresens (1975). The Harding Pegmatite locality has been given to the University of New Mexico by Dr. Arthur Montgomery and is currently being studied in detail by Brookins and M. E. Register by the Rb-Sr method.

The only U, Th-Pb dates reported are for monazite from Las Vegas (Wetherill and others, 1965; see Table 1). It is interesting to note that the oldest date was obtained by the 238-U/206-Pb method; no 207-Pb/206-Pb date was reported. The 238-U/206-Pb dates for ancient uranium minerals are commonly lower than the 235-U/207-Pb dates for the same minerals because of loss of some of the intermediate daughter products. However, in rare cases the 235-U/207-Pb date is less than the 238-U/206-Pb date, and 207-Pb/206-Pb dates are

Table 1. Radiometric dates for Precambrian rocks from northeastern New Mexico.

Rock or Mineral Dated; Locality	Location	Age (m.y.) ²	Method	Reference ⁴
Biotite, Pidlite Mine	Mora Co. ¹	1280 1459	K/Ar Rb/Sr	A A
Monazite, Las Vegas	San Miguel Co. ¹	1730 770 1340 ± 200	238-U/206-Pb 235-U/207-Pb 232-Th/208-Pb	A A A
Pegmatite, Harding Mine	Taos Co., Sec. 29, T.23 N., R.11 E.			
i) Muscovite (average of two)		1255	K/Ar	A
ii) Muscovite (average of four)		1277	Rb/Sr	A
iii) Microcline (average of three)		940	Rb/Sr	A
iv) Lepidolite		1372	Rb/Sr	A
v) Muscovite		1335 ± 20	K/Ar	B
Picuris Range ³	Taos Co. ¹			
i) Muscovite from schist		1273 ± 19	K/Ar	B
ii) Muscovite from schist		1316 ± 20	K/Ar	B
iii) Biotite from granite		1235 ± 19	K/Ar	B
Embudo Granite (whole rock) Sangre de Cristo Mountains ³	Taos Co. ¹	1673 ± 41	Rb/Sr	C
Pedernal Hills				
i) Granite (whole rock)	Torrance Co., T.6 N., R.12 E.	1471 ± 97	Rb/Sr	D
ii) Schist, quartzite (whole rock)	Torrance Co., T.7 N., R.12 E.	1364 ± 27	Rb/Sr	D
Dates from core or cuttings from wells drilled into Precambrian basement				
i) Granite cuttings, Sierra Grande No. 1 Rogers.	Union Co., Sec. 4, T.29 N., R.29 E.			
(a) Biotite		1315	Rb/Sr	E
ii) Granite core, Shamrock No. 1 McArthur	Mora Co., Sec. 12, T.19 N., R.21 E.			
(a) Feldspar		1397	Rb/Sr	E
(b) Muscovite		1320	K/Ar	E
iii) Cities Service No. 1 Driggers	Guadalupe Co., Sec. 22, T.11 N., R.21 E.			
(a) Granite (whole rock)		1667	Rb/Sr	E
(b) Biotite		1350	K/Ar	E
iv) Granite core, Husky-General Crude No. 1 Hanthett State	Guadalupe Co., Sec. 16, T.8 N., R.24 E.			
(a) whole rock		1040	Rb/Sr	E

Notes:

- Reference gives general location map only.
- All Rb/Sr data from references A and E have been recalculated using $\lambda = 1.42 \times 10^{-11}/\text{yr}$.
- Additional dates for samples from the Picuris Range and from the Embudo Granite will be found in Long (1974) and Gresens (1975).
- References:
 - Wetherill and others (1965)
 - Gresens (1975)
 - Fullagar and Shiver (1973)
 - Mukhopadhyay and others (1975)
 - Muehlberger and others (1966)

meaningless; in this event, there is reason to suspect that open system conditions existed. This suggests that the rocks from Las Vegas should be re-investigated not only by the U, Th-Pb method but by other methods as well.

West of the Rio Grande, "events" are noted or suggested at pre-1,700 m.y. (i.e., 1,800 m.y. old granites and metavolcanics, Brookins, 1974), 1,700 m.y. (Brookins, 1974; Brookins and Laughlin, 1976), 1,400 to 1,450 m.y. (to 1,500 m.y. ?) (Brookins and Laughlin, 1976; Turner and Forbes, 1976) and 1,200 to 1,250 m.y. to 1,350 m.y. (?) (Gresens, 1975; Brookins, 1974). Gresens (1975) and Brookins (1974) have summarized and discussed some of these dates and again much scatter is evident. Only the 1,700, 1,400 and possibly 1,250 ($\pm$) m.y. magmatic-metamorphic events appear with any appreciable regularity.

East of the Rio Grande, the data of Table 1 may be interpreted to support a 1,700 m.y. event, whereas data from the Pedernal Hills, about 60 miles southwest of Albuquerque, and a 1,500 m.y. date for the Sandia Granite near Albuquerque (Taggart and Brookins, 1975) suggest magmatism-metamorphism from 1,450 to 1,500 m.y. No clear event is noted in the 1,300 to 1,400 m.y. time bracket, although it is significant that many data average about 1,340 m.y. (Table 1; Brookins and Shafiqullah, 1975; Brookins and others, 1975). Metamorphism-magmatism in the 1,200-1,300 m.y. bracket is substantiated by the data of Table 1. Post-1,200 m.y. dates (Table 1) are few and suspect; additional dates from both outcrop and well cores and cuttings from basement rock are sorely needed.

SUMMARY

The history of the Precambrian of northeastern New Mexico can be summarized schematically as follows (Callender, 1975):

1. Clastic and volcanic deposition in one or two major stages beginning about 1,800 m.y. ago;
2. Folding and synkinematic regional metamorphism in one to three stages, with "early" granitic intrusion locally developed;
3. Major "granitic" intrusion, metasomatism, contact metamorphism and mineralization, occurring in from one to five stages in a complex manner;
4. Dilation, jointing, faulting, shearing and mafic dike intrusion; and
5. Uplift, beginning after 1,200 m.y.

A significant number of important problems remain to be solved in the Precambrian of northeastern New Mexico. The stratigraphy of the older metasedimentary and metaigneous rocks of the region is not well understood. The careful work by Montgomery (1953; 1963) in the Picuris Range and Truchas Peaks area serves as a model for future work, but many of the stratigraphic units described by Montgomery may not correlate with similar rocks in northeastern New Mexico. The key to correlation among metamorphic terranes may be the isolated outcrops of metamorphic rock in the granite which make up the bulk of the crystalline rock of the northern Sangre de Cristo Mountains.

Another critical problem is an understanding of the tectonic, metamorphic and magmatic history of the region. Bingler (1965), Montgomery (1953, 1963), Barker (1958), Woodward and others (1974) and Nielsen (1972) have detailed diverse deformational and thermal events, with variable intensities and timing, in the Precambrian of northern New Mexico.

CALLENDER, ROBERTSON, BROOKINS
Careful studies are thus required to unravel the tectonic and metamorphic history of any specific area. Detailed work on the igneous rocks of the region suggests that regional diversity also extends to magmatic evolution. Many workers have noted numerous phases of mafic to silicic igneous activity in the Precambrian of northern New Mexico (c.f., Long, 1974; Budding, 1972; Kottowski, 1963; Montgomery, 1953, 1963; Woodward and others, 1974; Berkley and Callender, in preparation). Thus, regional correlation between similar granitic bodies may be premature. Indeed, granitic and pegmatitic intrusive activity may have taken place in a relatively continuous manner over the interval from 1,800 m.y. to 1,100 m.y. B.P.

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