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CONTRASTING TYPES OF PRECAMBRIAN GRANITIC ROCKS IN THE DIXON-PENASCO AREA, NORTHERN NEW MEXICO

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INTRODUCTION

Precambrian granitic rocks are extensively exposed in the area between Dixon and Penasco, northern New Mexico, where they form major parts of a complex terrane that includes older metasedimentary and metavolcanic rocks. Contrasting textures, compositional variations, and implied styles of emplacement suggest that the granitic rocks were emplaced under conditions that ranged progressively from near-surface during the earliest episode of magmatism to depths of several kilometers during the last major episode. If the available age-dates, including those for pegmatites in the area, are interpreted in a manner consistent with the field relations, it appears that the granitic rocks were emplaced over a time span of at least 300 million years. In addition, post-magmatic alteration of these rocks may be the most prominent expression of a major thermal event that consistently reset K-Ar and Rb-Sr mineral ages but was not represented by major amounts of granite at the present level of erosion.

The first geologic investigation of the Dixon-Penasco area was undertaken by Just (1937) as part of a three-week reconnaissance of pegmatites in Rio Arriba and Taos counties. While noting textural and compositional variations in the granites, he had no opportunity to distinguish and map different units and perforce referred to all these rocks as a single entity, the Dixon Granite. Montgomery (1953) mapped the metamorphic rocks

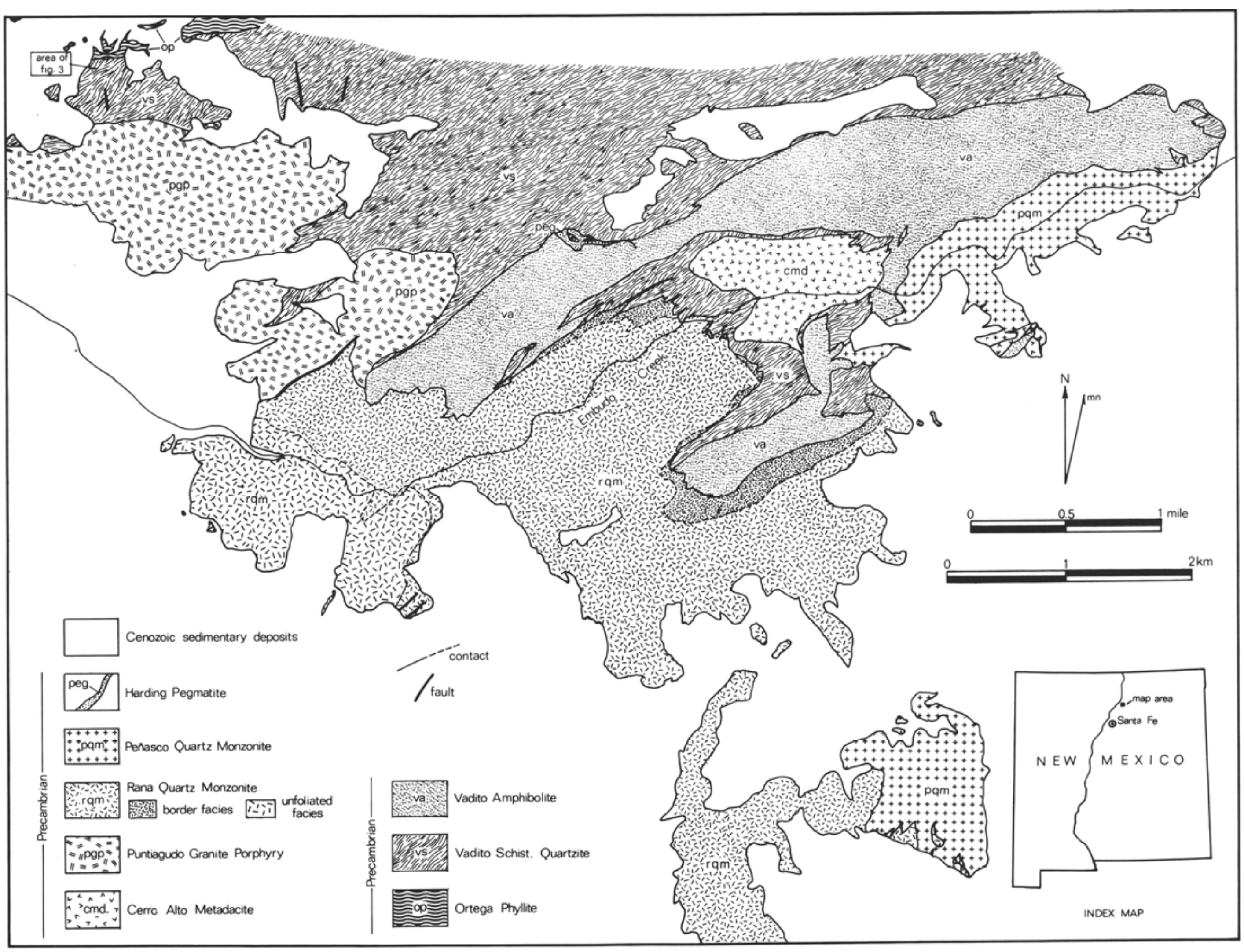

Figure 1. Generalized geologic map of the Dixon-Penasco area.

of the Picuris Range and included on the southern portion of his map the granitic rocks of this study. Recognizing that the name "Dixon" had been preoccupied by earlier usage elsewhere, he renamed these rocks the Embudo Granite. Like Just (1937), he noted textural and compositional differences among the various exposed rock types, but he concluded that they were best explained in terms of differences in degrees of metamorphism and assimilation, and that they probably were derived from a single magma source but perhaps emplaced over a protracted period of geologic time. Montgomery later extended his mapping to the south (Miller and others, 1963), and applied the term Embudo to all of the Precambrian granitic rocks exposed between the Picuris Range and Santa Fe, about thirty miles to the south.

More recently, Fullagar and Shiver (1973) have interpreted whole-rock Rb-Sr data to indicate a single age of 1673 ± 41 m.y. for the Embudo Granite, thus lending support to Montgomery's hypothesis of a single magmatic source for these rocks. Widespread field and petrographic evidence, however, indicates a more complicated igneous history than Fullagar and Shiver imply from their analytical data.

FIELD RELATIONS

Metamorphic Rocks

Montgomery defined two broad units in the metamorphic terrane of the Picuris Range and the Dixon-Periasco area: 1) an older assemblage, the Ortega Formation, consisting of metaquartzite, schist, and phyllite, and 2) a younger assemblage, the Vadito Formation, consisting of metaquartzites, metaconglomerate, schist, and amphibolite. The age relation between these two formations was established through recognition of cross-bedding in the sequence. A general stratigraphic section is shown in Figure 2, and a specific section demonstrating the age relations is shown in Figure 3.

It is here suggested that the Ortega and Vadito Formations be raised to group status, and that they be subdivided into units with formation names. Thus the Vadito can be subdivided into a lower metasedimentary unit comprising conglomerate, quartzite, and schist members, as well as an upper amphibolite unit that consists of interlayered mafic flows, metavolcanic conglomerates, and mafic metasediments with minor discontinuous beds of recrystallized chert.

Figure 1, a generalized geologic map of the area, shows the distribution of the granitic rocks and Vadito rocks, along with the location of the stratigraphic section (Fig. 3). Stratigraphic relations are complicated southeast of the area represented by Figure 3 by isoclinal folds and by the presence of the main Vadito amphibolite unit. The amphibolite is the youngest stratigraphic unit, but its relationship to the quartzite and schist exposed southeast of the Harding mine is not yet fully understood. The quartzite and schist may be coeval equivalents of the schists north of the amphibolite belt, or they may be the upward extensions of a thick schist sequence that is unconformably overlain by the amphibolite. In either case the exposed amphibolite appears to occupy the central parts of synforms and is the youngest Precambrian stratigraphic unit exposed in the area.

The complexity of the rocks of the Vadito Group is increased by the presence of amphibolite dikes, mainly in the schist north and northwest of the main amphibolite unit, and felsite dikes that occur primarily in the amphibolite unit itself. The amphibolite dikes probably were emplaced at about the time when rocks of the main amphibolite unit were accumulating on the then-existing surface. The felsite dikes were emplaced later on and probably in several episodes; they may have marked the onset of granitic magmatism, and in part may also have been related to one of the later granite intrusions.

Granitic Rocks

General Statement

The granitic rocks of the area, as shown in Figure 1, comprise four major units plus abundant smaller bodies of pegmatite. The sequence of granitic magmatism began with emplacement of a metadacite stock (Cerro Alto metadacite), along with widespread sills and dikes of similar lithology. This was followed by emplacement of a more coarse grained and foliated granite to quartz monzonite prophyry (Puntiagudo Granite porphyry) with distinctive phenocrysts of microcline and quartz. This rock in turn was apparently intruded by a large body of foliated biotite quartz monzonite (Rana quartz monzonite). The last major episode resulted in intrusion of a sphene-bearing biotite quartz monzonite (the Pefiasco quartz monzonite). All of these units were, at least in part, post-dated by pegmatites distinctly younger than the last granitic intrusion. But the pegmatites in the area probably represent more than one generation of magmatism.

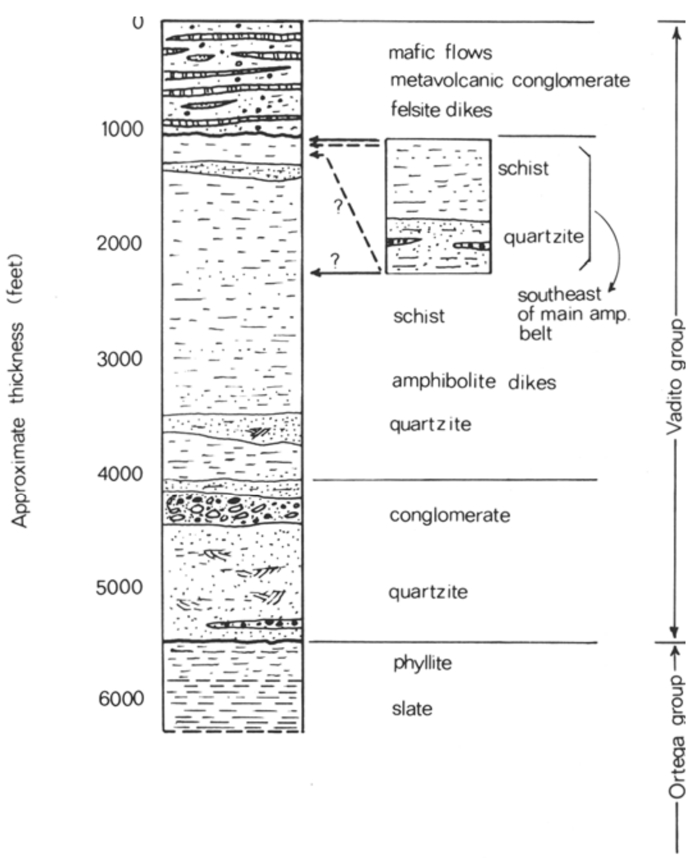

Figure 2. Generalized stratigraphic section of the Vadito metamorphic rocks, showing stratigraphic relationships between the main Vadito sequence and the schists and quartzites southeast of the main amphibolite belt.

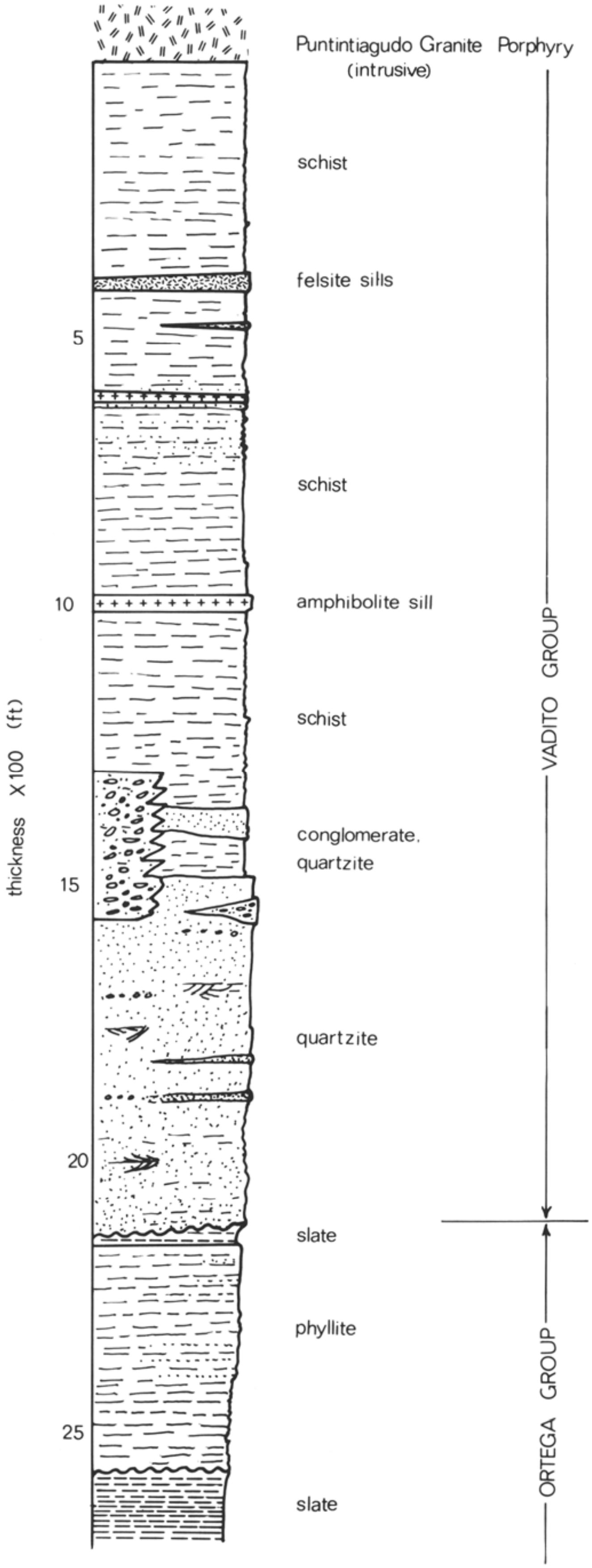

Figure 3. Detailed stratigraphic section showing the contact between Ortega and Vadito rocks.

Cerro Alto Metadacite

The metadacite, oldest of the granitic units in the area, is a dark to medium gray, fine-grained, slightly foliated rock containing scattered small (-2mm) phenocrysts of quartz and plagioclase. The groundmass consists principally of quartz, plagioclase, and potassium feldspar with flecks of biotite, muscovite, and magnetite. The rock occurs primarily as a stock-like body shown approximately at the center of the map. The westerly margin of the body is in discordant intrusive contact with Vadito metamorphic rocks. Along the easterly margin, however, the relationships are less clear. Here the rock is marked by slabby jointing that resembles bedding or flow banding, and it is more conformably related to the country rocks.

Many isolated sills of metadacite are present in the main amphibolite unit. They are similar in shape and size to the felsite sills but invariably pre-date them. In a few places there are lithologic gradations between the metadacite sills and the lighter colored, more leucocratic felsite sills.

The metadacite is cut by the other granitic rocks and occurs as inclusions within them. The inclusions, though not abundant, are so widespread that it is reasonable to assume a once-extensive distribution of the metadacite prior to intrusion of the younger granitic rocks. Here it should be noted that the Cerro Alto metadacite constitutes part of what Montgomery (Miller and others, 1963) mapped as "Vadito Conglomerate-felsite" (Vcf). The remainder of Vcf in this area comprises schist, fine-grained quartzites, and minor conglomeratic rocks.

Puntiaguclo Granite Porphyry

The Puntiagudo granite porphyry has a fabric distinguished by subequant and subhedral, Carlsbad-twinned phenocrysts of microcline (-1 cm in maximum dimension) and rounded phenocrysts of quartz set in a fine- to medium-grained matrix of plagioclase, potassium feldspar, biotite, and muscovite. Modally the rock is a quartz monzonite, locally grading to granodiorite (see Table 1, Fig. 4). It occurs as a massive body of irregular shape that is in very sharp discordant contact with the Vadito rocks. This body is featured by a thin border zone (0-30 m) of finer-grained rhyolitic rock that appears to reflect marginal chilling. Dikes of fine-grained rhyolite also are present, mainly in marginal parts of the body. Aside from the border zone and the dikes, the unit consists of mineralogically homogeneous rocks. Marked textural variations, however, are

Table 1. Typical modes of the principle granitic rocks.

ROCK TYPE	Cerro Alto metadacite	Puntiagudo granite porphyry	Rana quartz monzonite	Penasco quartz monzonite
SAMPLE NUMBER	PL71-53	PL71-44	PL71-14	PL71-56
Quartz	41	29	34	27
Plagioclase	32	37	31	36
Microcline	12	24	21	18
Biotite	10	4	6	13
Muscovite	2	4	5	3
Epidote	2	1	2	2
Sphene	tr	-	-	1
Opaque	1	1	tr	tr
Clinozoisite	-	-	1	tr

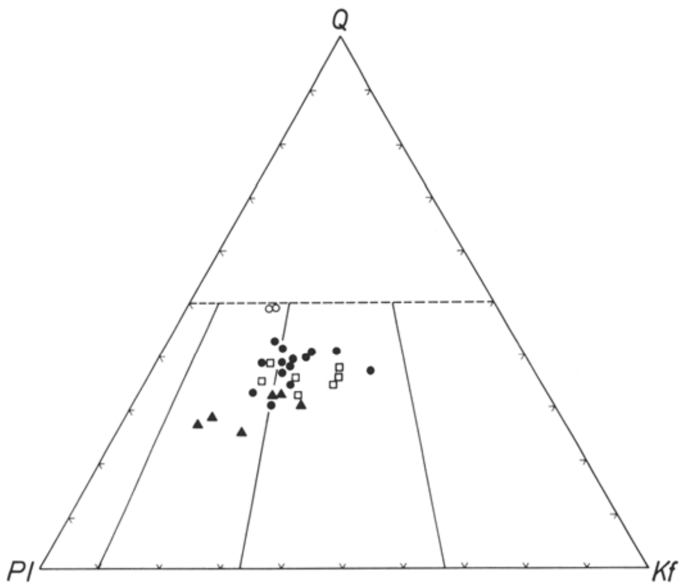

Figure 4. Modal compositions of the principle granitic rocks. Open circles are Cerro Alto metadacite, open squares are Puntiagudo granite porphyry, closed circles are Rana quartz monzonite and the trianales are Peñasco quartz monzonite.

expressed by differences in abundance of phenocrysts and varying degrees of rock deformation. Foliation is evident in most places, and generally parallels the regional northeast- to east-trending structural features in the Precambrian rocks.

Rana Quartz Monzonite

The Rana quartz monzonite is dominant among the granitic rocks exposed in the area. Available field evidence suggests that it is younger than the Puntiagudo granite porphyry, although that cannot be definitely established. Most of the Rana is a medium-grained, foliated, biotite quartz monzonite to granodiorite (see Table 1, Fig. 4). The biotite grains have been partly shredded and recrystallized, and they are transected by larger, fresh grains of muscovite. The plagioclase has been partly granulated and extensively altered to sericite, epidote, and clinozoisite. The degree of deformation increases somewhat to the south so that the rock in some of the southernmost outcrops shown in Figure 1 is strongly lineated. In addition to a prevailing foliation that follows the regional structural trend, closely spaced fractures (—N 50° W) and narrow ductile shears trending northeast are present in some places. The Rana quartz monzonite, then, appears to reflect at least two and probably three events of regional deformation. This is consistent with the regional deformations inferred by Nielsen and Dunn (1974) from Ortega rocks to the north.

In addition to the main mass of foliated material, the quartz monzonite body is marked by a discontinuous border zone of fine-grained leucocratic muscovite granite that contains oblate phenocrysts of quartz and, locally, phenocrysts of microcline instead, and by a mass of unfoliated biotite quartz monzonite that is modally similar to the foliated quartz monzonite but lacks biotite alignment and extensive granulation of plagioclase. Both these subunits are in gradational contact with the main mass of foliated biotite quartz monzonite.

The Rana quartz monzonite in general shows strong discordance with the rocks it intrudes, although apophyses of the border-zone rock are commonly concordant and appear much like the isolated felsite dikes in the amphibolite. This suggests that at least some of these discrete felsite dikes may be directly related to the intrusion of the Rana quartz monzonite. Textural, compositional, and structural variations among the dikes, however, indicate that more than one generation may well be present.

Penasco Quartz Monzonite

The youngest major granitic unit is the Penasco quartz monzonite, which is in intrusive contact with the Rana quartz monzonite, as shown in the southeast part of Figure 1. Like the Rana, it is a biotite quartz monzonite to granodiorite, but it has higher biotite content, distinctive wedge-like crystals of sphene, and, in some places, less quartz and more plagioclase (see Fig. 4). Further, the Penasco rocks lack the strongly pervasive foliation so prevalent in the earlier granitic rocks.

The intrusive body of Penasco rocks is generally conformable with the amphibolite country rock, particularly in the area just north of Embudo Creek (eastern part of Fig. 1). It lacks a distinctive border zone, contains mafic inclusions that are most abundant near its margins, and shows minor migmatization along its contacts. Local chevron folding in the amphibolite near the intrusive contact indicates that forceful injection was important in the emplacement of the quartz monzonite.

Locally, the rock contains abundant tabular megacrysts of Carlsbad-twinned microcline as much as 9 cm in maximum dimension. It is uncertain whether these are porphyroblasts or phenocrysts, but some evidence suggests they are phenocrysts. They exhibit growth zones defined by the arrangement of tiny plagioclase crystals, which may indicate either synneusis or boundary-layer enrichment in sodium and calcium during growth from a melt. Further, alignment of the megacrysts parallel to the walls of a narrow dike suggests that the megacrysts were emplaced in a magma, the alignment being caused by laminar flow of the magma. The relationships are far from conclusive, but they tend to support the hypothesis that the megacrysts existed as phenocrysts in a melt now principally represented by the medium- to coarse-grained portion of the rock.

Pegmatites

Bodies of pegmatite cut all of the granitic rocks in the area and hence at least some of them are younger than the youngest granitic intrusion. They can be characterized according to five groups: 1) simple pegmatites in bodies of relatively small size, containing microcline, quartz, albite, and muscovite with minor green beryl (the most abundant type), 2) faintly- to well-zoned bodies of generally larger size with various amounts of exotic mineralization (the Harding pegmatites belong in this category), 3) small, zoned bodies of pegmatite containing only albite, quartz, and muscovite, 4) pegmatite-aplite pairs occurring as small dikes (primarily in one locality near Penasco), and 5) tourmaline-bearing pegmatite in medium-sized, slightly zoned dikes consisting mainly of potassium feldspar, plagioclase, quartz, and tourmaline (one locality observed). In addition, pink to white aplite dikes, which are apparently unrelated to any pegmatites, occur in both the Rana and Penasco quartz monzonites. Quartz veins and pods typically occur in all the Precambrian rocks of the area.

The diverse types of pegmatite suggest that more than one age of pegmatite formation is represented in the area. Further, the pegmatites are consistently younger than the aplite dikes and quartz veins. These aplites may represent the residual liquid of the granites that enclose them, as they are restricted to the granites and are in part gradational with them. If this is the case, it suggests that the pegmatites, being later, may have originated not as residual liquids of the granites that they cut, but perhaps as residual liquids of a granite not now exposed at the surface. The fact that the pegmatites cut quartz veins indicates that they are younger than a period of post- or late-magmatic hydrothermal activity—again pointing toward a separate magmatic event for the pegmatites. Two other field observations also support this idea. First, the pegmatites are not related to any of the exposed granites in a spatially consistent manner. That is, they are distributed sporadically throughout the area, possibly increasing in abundance to the south along with increasing deformation in the Rana granite. Second, the granites do not show compositional variation with time that would lead ultimately to pegmatite formation. Instead the youngest granite unit is one of the most mafic and thus is apparently the least likely to give rise to pegmatites. Available radiometric dates, although open to some question, indicate that the Harding pegmatite is as much as 100 million years younger than the youngest granite. This casts doubt upon any proposed genetic relationship between the pegmatites of the Harding type and the granitic rocks exposed in the area.

Alteration of the Granitic Rocks

Three main types of alteration have been observed in the area: 1) Alteration along shear zones, resulting in a quartz-muscovite assemblage. 2) Alteration resulting in reddening of the feldspars and ultimately in deposition of vein epidote. This type of alteration occurs in random patches in the Puntiagudo granite porphyry and in the Rana quartz monzonite. 3) Alteration resulting in deposition of tourmaline and tourmaline-quartz veins. Age relationships among these types of alteration are uncertain, but it is likely that the quartz-muscovite alteration preceeded the other two, as it is clear that the epidote alteration post-dates the latest shearing event, the quartz veins, and the pegmatites. The epidote alteration is the most prevalent, and except for the fact that it is joint-controlled in some localities, there appears to have been little structural influence on its development. Nor is it spatially correlated with pegmatite bodies. The available evidence implies that this type of alteration may have been the result of a thermal event occurring after the time of pegmatite emplacement. No significant megascopic alteration has been observed in the Penasco quartz monzonite, but there is some alteration of plagioclase on a microscopic scale. The tourmaline alteration is very common in some localities, especially in the Vadito metasediments, and it also occurs in the Rana quartz monzonite. This type of alteration probably occurred at nearly the same time as the rare tourmaline-bearing pegmatites. These pegmatites cut the Penasco quartz monzonite, hence the tourmaline alteration probably is younger than that rock.

RADIOMETRIC GEOCHRONOLOGY

Relatively little radiometric dating has been done on rocks from this area. Rb-Sr dates were obtained on muscovite from the Harding pegmatite by Aldrich and others (1958), but these are model Rb-SR ages and hence are of limited value. They range from 1350 to 1260 million years, with an average of about 1300 million years. Recasting the data for these dates in terms of an estimated Rb-Sr mineral isochron suggests that the Harding pegmatite may be somewhat older than the 1300 million year average, possibly as old as about 1375 million years. Modern determinations of Rb-Sr mineral and whole-rock ages on various pegmatites of this area would be extremely useful, as the Harding pegmatite represents only one of the several types that are present.

Fullagar and Shiver (1973) have dated the "Embudo granite" by Rb-Sr whole-rock methods, and have assigned to it an age of 1673 ± 41 million years. The field relations of the rocks that are involved, however, invite reinterpretation of their data to give a 1400 million year age for the Penasco quartz monzonite, with the age of the Rana quartz monzonite still being about 1673 million years (see Fig. 5). Such ages, though compatible with geologic and petrologic relationships, must be regarded as rather imprecise because there are so few geologically well-controlled points on each isochron. Additional data are needed in order to firmly establish the ages.

The absolute ages of the Cerro Alto metadacite and the Puntiagudo granite porphyry are unknown. Bearing this in mind and allowing for the possibility of a 1375 million year age for the pegmatites, it is possible to state that granitic magmatism in this area took place over a period of *at least* three hundred million years.

Rb-Sr mineral ages on Rana quartz monzonite and Penasco quartz monzonite are 1208 ± 63 million years and 1212 ± 23 million years, respectively (Fullagar and Shiver, 1973). Gresens (1972) reports a K-Ar age of 1235 ± 19 million years on biotite from "Embudo granite" about five miles southeast of Figure 1. The similarity of these dates suggests that they represent a maximum age of a major thermal event which may have been responsible for the alteration of the granitic rocks.

INTERPRETATION OF THE HISTORY OF GRANITIC MAGMATISM

Buddington (1959) proposed a three-fold classification of granitic plutons—epizonal, mesozonal, and catazonal—and inferred a depth-range of intrusion for each zone as shown in Figure 6. He based his classification on the following criteria:

1) The relationship between the country rock and the intrusive body. Discordant bodies are typical of the epizone, and concordant bodies can show either relationship.
2) Manner of emplacement. Passive block stoping is predominant in the epizone, and forceful injection is most evident in the catazone.
3) The nature of intrusive contacts. Sharp contacts characterize the epizone, whereas migmatization becomes significant in the mesozone and catazone.
4) The presence or absence of a border zone. Border zones are essentially restricted to plutons of the epizone.
5) The metamorphic grade of the country rock. Very low-grade metamorphism or none is found in areas of epizonal intrusion, lower middle-grades appear in the mesozone, and high-grade metamorphism occurs in catazonal regions.

Applying the above criteria to the granites of the Dixon-Penasco area yields the chart shown in Figure 7. It becomes

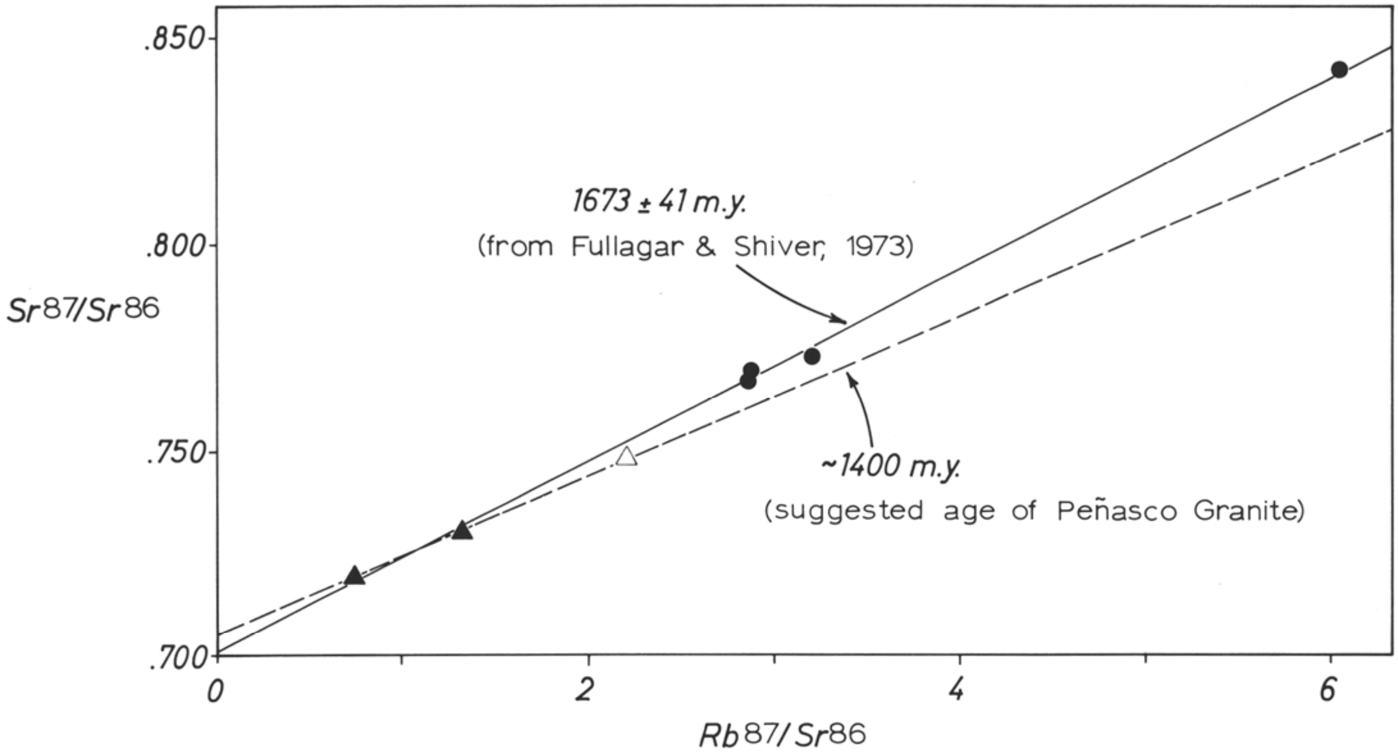

Figure 5. Possible reinterpretation of the Rb-Sr data from Fullagar and Shiver (1973). Closed triangles are Peñasco quartz monzonite. The open triangle is an apparently cogentic granite but is not a Peñasco quartz monzonite lithology. It is from an isolated outcrop about five miles southeast of the map area. The closed circles are in part Rana quartz monzonite and in part granites from outside the map-area.

immediately apparent that the estimated depth of intrusion increases with the passage of time, starting at near-surface levels with the Cerro Alto metadacite and ending with the intrusion of pegmatite at mesozonal or deeper levels. This time-depth relationship is illustrated in Figure 8.

The metadacite is thought to be a near-surface, perhaps subvolcanic rock, owing to its fine grain size, fabric, and partially intertonguing relationships with the country rocks. It seems unlikely that such a fine-grained rock could have been formed at depths greater than about two kilometers. The Puntiagudo granite porphyry is also a shallow-level intrusive body, but its large potassium feldspar and quartz phenocrysts, chilled margin, and associated fine-grained dikes suggest that it was intruded at somewhat deeper levels than the Cerro Alto metadacite. It may or may not have been associated with acidic volcanism at the surface. Its depth of intrusion is estimated at one to four kilometers. Since the absolute ages of the Cerro Alto metadacite and Puntiagudo granite porphyry are not known, their age positions shown in Figure 7 are purely schematic. They may actually belong closer to the Rana quartz monzonite or farther away from it in time.

The estimated depth of intrusion of the Rana quartz

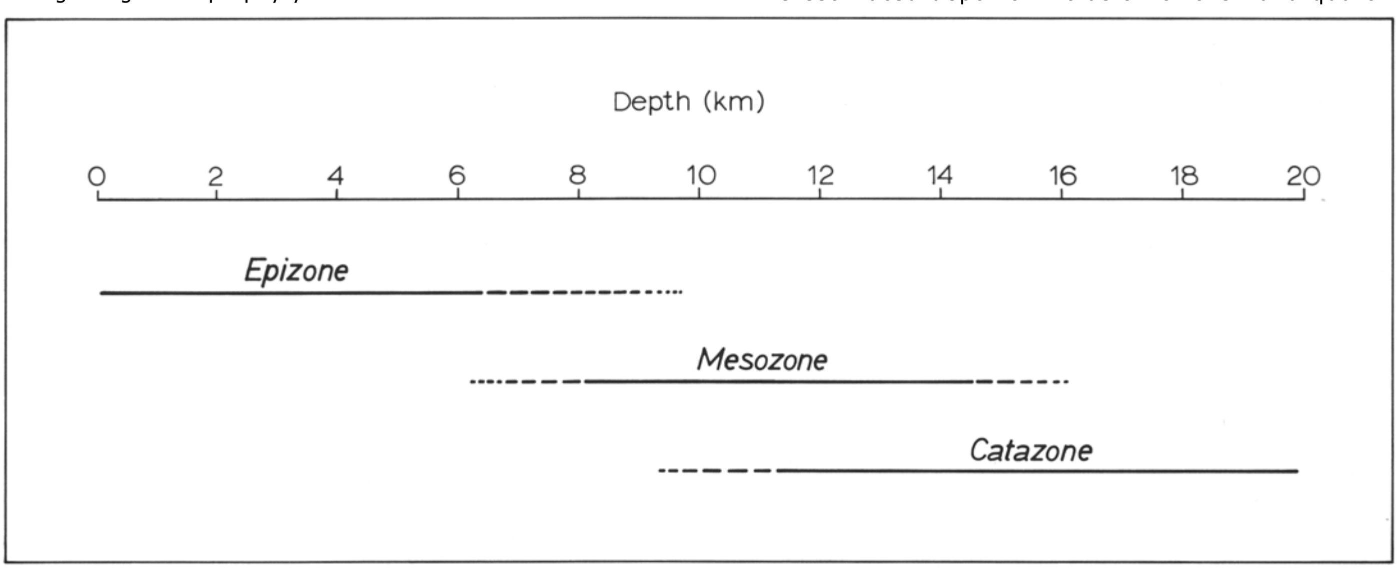

Figure 6. Schematic representation of the emplacement zones of Buddington (1959).

DEPTH CRITERIA → / GRANITIC UNITS ↓	RELATIONSHIP TO COUNTRY ROCK	MANNER OF EMPLACEMENT	NATURE OF CONTACTS	PRESENCE OR ABSENCE OF A BORDER ZONE	METAMORPHIC GRADE OF COUNTRY ROCK	ESTIMATED DEPTH OF INTRUSION
CERRO ALTO METADACITE	discordant-- in part extrusive (?)	uncertain	sharp	entire unit fine grained	uncertain	upper epizone 0-2 km
PUNTIAGUDO GRANITE PORPHYRY	discordant	uncertain	very sharp	narrow one present	uncertain	epizone 2-4 km
RANA QUARTZ MONZONITE	discordant	in part forceful injection	fairly sharp	extensive but discontinuous one present	uncertain	lower epizone 3-6 km
PEÑASCO QUARTZ MONZONITE	mostly concordant	forceful injection	minor migmatization along contacts	absent	lower middle grade (epidote-andesine-amphibolite)	mesozone 8-13 km
PEGMATITES	--	forceful injection (dilation)	sharp in most places	--	lower middle grade(?)	mesozone or deeper (?) 9-14 km

Figure 7. Summary of characteristics of the granitic rocks.

monzonite is three to six kilometers. This is based on the medium to coarse equigranular texture of the non-foliated facies, which suggests a deeper environment of crystallization than that of the Puntiagudo granite porphyry. However, the presence of an extensive border zone suggests that the intrusion is epizonal, so it is here assigned to the lower epizone. Additional support for this estimate is indicated by the slightly less-sharp contacts of this unit suggesting a depth of intrusion somewhat greater than that of the Puntiagudo granite porphyry.

The Penasco quartz monzonite, on the other hand, has characteristics indicating it was emplaced in the mesozone. In particular, minor migmatization along contacts, generally equigranular texture typical of moderate- to deep-seated plutonic rocks, and the lower middle grade of metamorphism of the adjacent country rocks all point to a mesozonal environment. Its conformable northerly margin and the evidence of forceful intrusion suggest the possibility of a catazonal environment, and its depth of intrusion is thus inferred to have been within the fairly wide range of eight to thirteen kilometers.

Pegmatites present a problem in estimating depth of intrusion, as none of Buddington's criteria can be applied directly. These rocks are relatively rare in the epizone, and most are exposed in Precambrian terranes that probably have been eroded to mesozonal levels or deeper. Those few pegmatites known to have formed at shallow levels are characterized by sanidine and by quartz in bi-pyramidal crystals, features that are absent from the pegmatites in the region here studied. On the basis of relatively low-temperature assemblages of essential minerals, lack of cavities or "pockets," and degree of metamorphism of the enclosing rocks, these pegmatites are inferred to have been emplaced at depths of nine to fourteen kilometers. This broad range seems reasonable since the four or five generations of pegmatites may well have developed at different times and over a wide range of depths.

CONCLUSIONS

Field and petrographic evidence from a rather complex Precambrian terrane of relatively limited exposure prompts the conclusion that at least five episodes of granitic magmatism are represented there. They resulted in the emplacement of granitic rocks first at shallow depths and then at successively greater ones. Isotopic age data, as interpreted in the light of structural and petrologic relations, suggest that these episodes must have spanned a period of at least three hundred million years. However, the evidence for increasing depth of intrusion

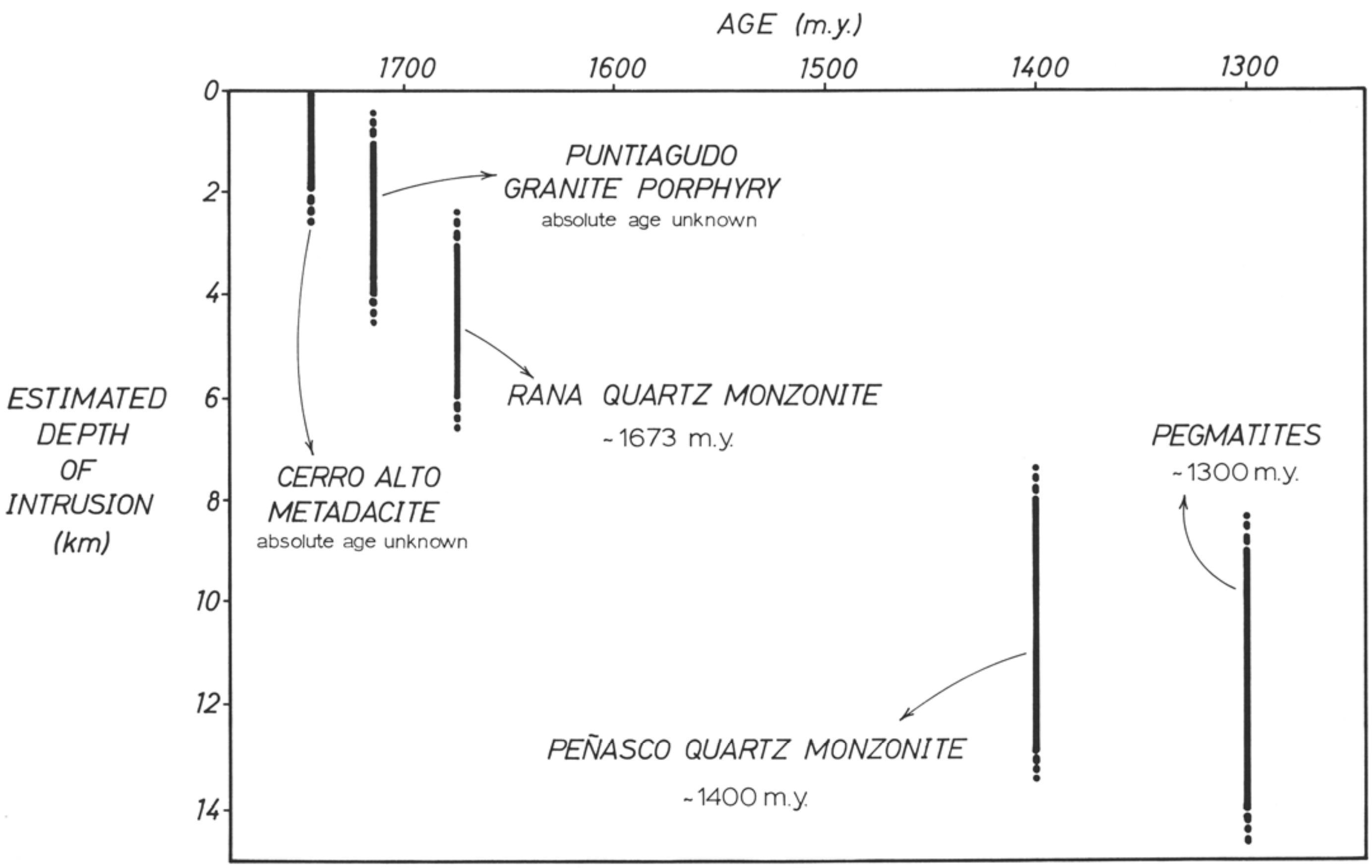

Figure 8. Plot of age vs. estimated depth of intrusion for the granitic units.

is questionable on several grounds, as the final characteristics of an intrusive body must be influenced by a large number of variables such as volatile content, rate of intrusion, volume of magma, temperature difference between magma and wall rock, wall rock type, and pressure on the magma. The interaction of such variables gives rise, in some complex way, to what one observes in the field. Even though some of them may be related to depth of intrusion, it is clearly a simplification of a very complex situation to attribute all of the diverse characteristics of the granitic rocks of this area to the single variable of depth. Buddington recognized this in stating that his depth zones are not related entirely to depth but also are "intensity zones" in which depth plays a major role. It is the contention here that depth of intrusion was, in fact, one of the most important variables in the development of the contrasting types of granitic rocks in the Dixon-Pefiasco area. This hypothesis is open to testing by geochronologists through careful dating of the intrusive events, and by geochemists through estimates of the pressure-temperature paths that both the metamorphic rocks and the granitic magmas must have experienced. Regardless of results from such tests, however, the field evidence demonstrates that characteristics of the intrusive activity changed progressively with time, and it is this progressive change that must be explained by any theory of the development of the Precambrian crust in the area.

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