PRECAMBRIAN FORMATIONS AND PRECAMBRIAN HISTORY IN COCHISE COUNTY, SOUTHEASTERN ARIZONA*

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INTRODUCTION

Precambrian rocks of southeastern Arizona typically are exposed in isolated masses in a number of the tectonically complex ranges of the southern Basin and Range province. Preservation of original sedimentary and igneous textures and structures is commonly excellent, but the combination of extended Precambrian histories, discontinuous exposure and variable overlay of Mesozoic and Cenozoic deformation, magmatism and metamorphism provides major challenges for regional Precambrian correlations and historical interpretations. For all of the problems, however, the early work of F. L. Ransome (1903, 1904, 1915, 1919, 1923, and elsewhere) and N. L. Darton (1924, 1925) successfully established a basic Precambrian stratigraphic framework for this region which subsequent studies have refined but not replaced.

In this brief article primary attention is given to the problems of the Precambrian record in Cochise County, in the southeast corner of Arizona, with some references to the larger regional setting involving adjacent areas of Arizona, New Mexico and Sonora, Mexico. In addition to available literature sources, this report draws on unpublished, currently active investigations of geochronology, petrology and geochemistry in Precambrian terranes of southwestern North America by the author, colleagues and his students.

The leading modern field investigator of the Precambrian formations of Cochise County has been J. R. Cooper, U.S. Geological Survey. He mapped the Precambrian rocks of the Dos Cabezas, Chiricahua and Swisshelm mountains and the Circle J and Fisher hills (Cooper, 1959, 1960). Together with colleagues, he published a detailed study of Precambrian stratigraphy and structure in the Dragoon quadrangle (Cooper and Silver, 1964) which is the current reference study for the Precambrian stratigraphy and structure of southeastern Arizona (fig. 1). Other important field studies include those by Gilluly (1956) in the Dragoon Mountains; Sabins (1957) in parts of the Chiricahua and Dos Cabezas mountains; Erickson (1968) in the Dos Cabezas Mountains; Hayes and Landis (1964) in the southern Mule Mountains; Hayes and Raup (1968) in the Huachuca Mountains; Creasey (1967) in the Whetstone Mountains; and Drewes (1975) in the Happy Valley quadrangle, on the east side of the Rincon Mountains.

The summary geochronological information offered here is based largely on extensive studies of U-Pb isotope systematics in cogenetic zircon populations from igneous and metamorphic components, utilizing techniques and interpretations developed originally for, and applied to, rocks of this region (Silver, 1963, 1964; Silver and Deutsch, 1963). These methods have shown remarkable internal consistency and compatability with observed field relations in this region, whereas other geochronological techniques (whole rock and mineral ^{87}Rb-^{87}Sr and mineral ^{40}K-^{40}Ar) commonly have reflected the widespread isotopic disturbances induced upon Precambrian materials during the Phanerozoic. The decay constants on which the U-Pb apparent ages are based are the values recently adopted by international convention [$\lambda^{238}U=0.155125 \times 10^{-9}$; $\lambda^{235}U=0.98485 \times 10^{-9}$; $^{238}U/^{235}U=137.88$] from the work of Jaffe and others (1971).

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DRAGOON QUADRANGLE

Precambrian rocks of the Dragoon quadrangle (fig. 1) represent the most complete and best preserved section in southeastern Arizona (Table 1). The oldest rocks, the Pinal Schist, form a thick sedimentary and volcanic stratified sequence, which can be correlated lithologically and geochronologically with the type section established in the Pinal Mountains by Ransome (1903). The base of the Pinal Schist is nowhere exposed. A suite of hypabyssal rhyodacite and rhyolite stocks, plugs, dikes and intrusive sheets, at least in part contemporaneous with the stratified volcanic component, is widespread in Pinal Schist. Cutting Pinal Schist are two distinct generations of large plutons of felsic igneous rocks. Resting unconformably on these middle Proterozoic rocks is a part of the upper Proterozoic Apache Group, a sedimentary sequence which has been intruded by widespread diabase sheets.

The important Precambrian lithological characteristics and structural relations are displayed in the cores of two Laramide structural domes, the Johnny Lyon Hills (fig. 2) and Little Dragoon Mountains (fig. 3).

Johnny Lyon Hills

Pinal Schist in the Johnny Lyon Hills (fig. 2) is comprised of a large thickness of northeast-striking beds of siliceous gray-

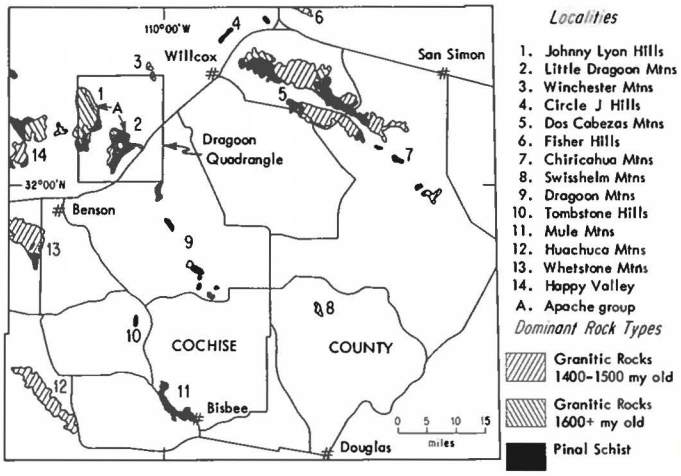

Figure 1. Outcrop map showing localities and dominant rock types of principal exposures of Precambrian rocks in Cochise County.

Table 1. Precambrian rock formations in the Dragoon quadrangle (from Cooper and Silver, 1964)

Age		Group, formation and member		Lithology and remarks	Thickness, m [ft]
Cambrian	Middle (?)		Bolsa Quartzite	Quartzite, white to purple or brown, medium- to coarse-grained, in part pebbly; commonly contains conglomerate at base.	6(?)-146 [20(?)-480]
			Unconformity		
Precambrian	Upper Proterozoic			Diabase, gray-green, weathering brown, altered. Forms extensive sills at and near top of Pioneer Shale.	
			Intrusive contact		
		Apache Group	Dripping Spring Quartzite	Quartzite, pink, arkosic, fine- to medium-grained, with color and grain-size banding.	90 [300]
			Barnes Conglomerate	Conglomerate characterized by well-rounded pebbles of quartzite and jasper, 1 to 5 m thick, in places underlain by 0.3 to 15 m of quartzite like Dripping Spring.	1-18 [3-60]
			Pioneer Shale	Siltstone, purple, thin-bedded with purple sandstone or gray quartzite at base	45-90 [150-300]
			Scanlan Conglomerate	Conglomerate made up of subangular fragments in a sandy matrix. Commonly has interbeds of sandstone or quartzite.	0-9 [0-30]
			Unconformity		
	Middle Proterozoic		Aplite	Sugary-textured white rock occurring as dikes and irregular intrusive bodies in Tungsten King Granite and adjacent Pinal Schist.	
			Intrusive contact		
			Tungsten King Granite	Biotite granite, medium- to coarse-grained porphyritic; has intruded Pinal Schist on west side of Little Dragoons; also at north end of Dragoon Mountains, and in Winchester Mountains. The mass in the Winchester Mountains is certainly Precambrian; the other could be younger.	
			Intrusive contact		
			Johnny Lyon Granodiorite	Hornblende-biotite granodiorite, medium- to coarse-grained; intrusive into Pinal Schist and overlain unconformably by Scanlan Conglomerate.	
			Intrusive contact		
			Intrusive rhyolite porphyry	Rhyolite of two generations; stocks and narrow sheets that intruded Pinal Schist before its metamorphism; and petrographically different rhyolite sheets intruded after metamorphism but probably still in middle Proterozoic.	
			Intrusive contact		
			Pinal Schist	Schists and slates derived from graywacke, shale, siltstone and minor small lenses of conglomerate. Contains at least one rhyolite flow, lenses of amphibolite and chlorite schist probably derived from basic volcanic rock, and scarce other rock types of undetermined origin.	6000(?) [20,000(?)]

wacke, subgraywacke, slate and local jasperoid chert masses and volcanic pebble conglomerate, predominantly in the lower greenschist facies but with some local higher-grade, metamorphic equivalents (Silver, 1955). Most of this section is a turbidite sequence of alternating volcaniclastic graywacke and slate characterized by excellent preservation of graded bedding which greatly assists stratigraphic and structural analysis. Locally, soft-sediment deformation is common. One continuous interval of persistently overturned beds is at least 2,450 m (8,000 ft) thick. A zone of numerous thick sheets of intrusive rhyodacite can be traced along the northeast strike in essentially constant stratigraphic position for more than 10 km.

Pinal Schist has been tightly folded on all scales with amplitudes ranging from less than 1 cm to more than 10 km. Axial plane cleavage and schistosity are generally but not invariably parallel to bedding. Analysis of minor and intermediate structures suggests the Pinal section in the Johnny Lyon Hills forms the limb and core of a partly concealed major anticline whose axial plane strikes approximately N. 50° E. and which appears to be more than 10 km in amplitude. The exposed northwest limb is overturned to the northwest, and the apparent plunges of most minor folds average 56°, S. 12° W. *overturned.* This implies the major fold is overturned. Part of this rotation can be attributed to post-Apache Group tilting on the order of 40°-45°, but the data still requires very steep plunges for all Precambrian structures.

The deformational characteristics of Pinal Schist are shared by the intrusive rhyolite sheets. Both are cross-cut by the essentially unfoliated, discordant Johnny Lyon Granodiorite, a great calcalkaline pluton of hornblende-biotite granodiorite centered on the San Pedro River to the west of the Dragoon quadrangle. Probably less than a third of the pluton (some 50 km^2) is exposed in a series of striking pediment surfaces in the western Johnny Lyon Hills.

Studies of apparent ages of pre-deformational volcaniclastic components in Pinal Schist and of the deformed intrusive rhyodacite sheets (1680 to 1700 million years; Silver, 1963)

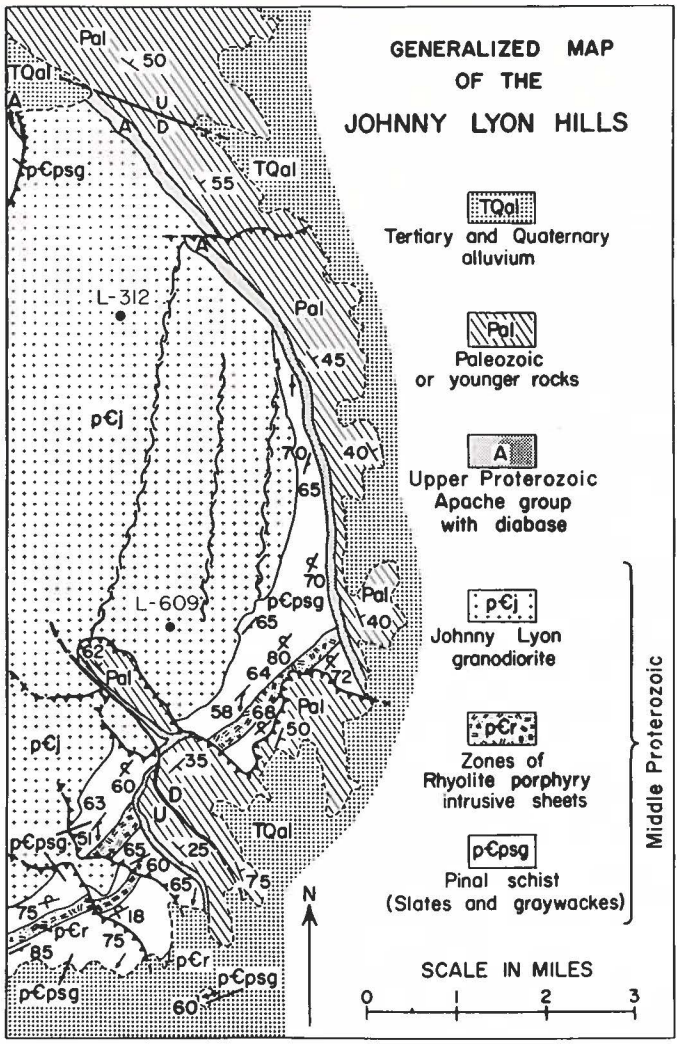

Figure 2. Generalized geologic map of the Johnny Lyon Hills in the Dragoon quadrangle, Cochise County. Special symbols are used to indicate three major north-northeast-trending shear zones (), and sample localities for geochronological studies (L-312). Adapted from Cooper and Silver (1964).

and of the post-deformational Johnny Lyon Granodiorite (1625 ± 10 m.y., Silver and Deutsch, 1963) place a close time limit on the time of major Precambrian deformation in the Dragoon quadrangle and in southeastern Arizona.

Subsequently the Johnny Lyon Granodiorite was transected by an extensive series of north-northeast-trending shear zones along which some sub-economic mineralization-alteration and silicification were localized. The entire middle Proterozoic metamorphic and igneous sequence was then bevelled by a remarkably regular erosion surface, on which were deposited the unconformable strata of the Apache Group.

In the Johnny Lyon Hills only the two lowest formations of the Apache Group have been preserved from pre-Bolsa Quartzite (middle Cambrian) erosion. The Pioneer Shale (Ransome, 1903) consists of maroon and brown argillite, in part volcanogenic, resting on basal gray quartzite which contains local, discontinuous, thin conglomeratic layers assigned to the Scanlan Conglomerate. Basal conglomeratic quartzites range in thickness from 0 to 9 m (0 to 30 ft). Intruded into the upper part of the Pioneer Shale is a ubiquitious diabase sheet, up to 75 m (250 ft) thick, whose roof has everywhere been stripped by erosion, leaving a well-developed, ancient, lateritic soil profile underneath the unconformable Bolsa Quartzite.

Little Dragoon Mountains

Pinal Schist in the central Little Dragoon Mountains (fig. 3) is more diverse lithologically than in the Johnny Lyon Hills. In addition to sequences of abundant cyclical, graded-beds of graywacke and slate, there are irregular lenses of tuff(?), locally massive sandstone, pebbly sandstone and slate (sericite-schist). A number of concordant masses of amphibolite and greenstone (chlorite-albite-epidote-calcite-muscovite) carry relict amygdules and possible pyroclastic and (or) pillow structures, suggesting former basalt flows. They are closely associated with large masses of purple jasperoid silica, inferred to have originally been ferruginous chert. Minor, but geochronologically significant constituents are metamorphosed rhyolite flows which form a string of lenses northwest of Lime Peak, with brecciated flowtops consistently facing *up* to the northwest in agreement with adjacent overturned graded beds. Metamorphic grade is dominantly greenschist facies but locally attains albite-epidote amphibolite facies.

Intruded into Pinal Schist in the northwestern Little Dragoons and sharing the imprint of the northeast-trending folding, shearing and metamorphism are stocks and plugs of rhyodacite porphyry. Geochronological studies indicate that both the rhyolite flows and the rhyodacite porphyry are the same age within analytical error as the volcanic components in Pinal Schist of the Johnny Lyon Hills.

Relict bedding and schistosity in the Little Dragoons are virtually parallel to structures in the Johnny Lyon Hills. There is a variety of evidence suggesting that strata dominantly face northwest, in the northwestern part of the range, but are reversed on many isoclinal folds. Axial planes trend northeast and axes plunge to the south and southwest in folds up to 3 km in amplitude, closely resembling the structures of the Johnny Lyon Hills. A crude calculation suggests that there may be as much as 3,650 m (12,000 ft) of section, probably not repeated in the Johnny Lyon Hills, indicating that the total thickness of the Pinal Schist may exceed 6 km.

On the west side of the Little Dragoons, near the Tungsten King mine, a large mass of coarse, porphyritic biotite granite with zoned, alkali-feldspar megacrysts up to 4 cm long, intruded Pinal Schist and is associated with swarms of felsic, aplite dikes. Similar granite is exposed in Severin Canyon in the southern Winchester Mountains. Zircon studies indicate the Tungsten King Granite is 1,420 ± 10 m.y. old. No Precambrian deformation imprints are recognized, although Laramide cataclasis is locally intense.

The Apache Group is represented by Dripping Spring Quartzite and Barnes Conglomerate, in addition to Pioneer Shale and Scanlan Conglomerate. The pre-Bolsa Quartzite erosion surface locally has 90 m (300 ft) of relief which Bolsa sedimentation appears to have barely succeeded in burying. The thickness of the formations in the Apache Group preserved in the Little Dragoons is comparable to that in the Globe-Ray area, where they were originally described by Ransome (1903, 1923). Although this is the southeastern limit of their preservation, there is no evidence that these outcrops are near the margins of the original basins of Apache Group deposition (see also Shride, 1967).

Two sills of diabase have intruded Pioneer Shale at remarkably constant stratigraphic positions immediately below Barnes Conglomerate in the northern Little Dragoon Mountains. The lower sill is 4.5 to 21 m (15 to 70 ft) thick; the upper is 12 to 43 m (40 to 140 ft) thick; they are separated by only a few feet of shale and quartzite. Lenses of distinctive red albite diabase pegmatite occur at several places near the top of the diabase. Zircons from one of these yield an age of 1100 ± 15 m.y., based on the $^{207}Pb/^{206}Pb$ radiogenic isotope ratio; this value is considered to be a minimum age. It can be compared with a series of ages from granophyres of diabase sills in the Apache Group of the Sierra Ancha in Gila County, central Arizona, which average about 1120 ± 10 m.y. (Silver, 1960, 1963).

Summary of the Precambrian History of the Dragoon Quadrangle

A simplified chronological outline for the major events of the Precambrian is suggested below.

	Time Before Present (millions of years)	Geological Event
(1)	1680-1700	Accumulation of a thick sequence of turbidites and volcanic rocks in a major sedimentary basin, i.e. a classic eugeosynclinal setting.
(2)	1625-1680	The major orogenic deformation and metamorphism of Pinal Schist.
(3)	1625±10	Emplacement of post-kinematic Johnny Lyon Granodiorite.
(4)	1420-1625	No identified activity; possible time of shear development in Johnny Lyon Granodiorite.
(5)	1420±10	Emplacement of anorogenic Tungsten King Granite.
(6)	1100-1420	Development of remarkable erosion surface on older crystalline rocks, followed by accumulation of sedimentary and volcanic strata of Apache Group in a shallow marginal or interior basin.
(7)	1100±15 or earlier	Emplacement of widespread diabase intrusive sheets in Apache Group.
(8)	550(?)-1100	Development of low to moderate relief surface on which transgressive Bolsa Quartzite was deposited.

COMPARISONS WITH OTHER PRECAMBRIAN AREAS IN COCHISE COUNTY

The general characteristics of Precambrian rocks elsewhere in Cochise County have many similarities to exposures in the Dragoon quadrangle, with the exception that the Apache Group is nowhere identified to the east and south. Brief summaries of the nature of the outcrops and suggested correlations for a number of ranges follows.

Dos Cabezas Mountains, Circle J Hills, Fisher Hills and northern Chiricahua Mountains

Pinal Schist is exposed intermittently in these areas; its principal lithologies are metagraywacke and sericitic schist. Amphibolites and metarhyolites are present in the northwestern Dos Cabezas range as well as near the east end of Apache Pass. In the vicinity of Bowie Mountain, Pinal Schist contains a rather pure, light-gray cross-bedded quartzite with a local basal conglomerate of quartzite and amphibolite cobbles and pebbles. Isotopic studies suggest a chronology comparable to the Little Dragoon region. Structural studies indicate tight folds with steep northeast-trending foliations parallel to relict bedding in the northwestern Dos Cabezas and Fisher Hills, but the foliations swing to easterly and southeasterly trends between Sheep Canyon and Fort Bowie.

Post-kinematic, but somewhat deformed granites of the Johnny Lyon Granodiorite generation are found at the northwestern end of the Dos Cabezas Mountains. Elsewhere, Precambrian plutons are dominantly porphyritic quartz monzonite or granite, whose ages are slightly older than 1400 million years. The Rattlesnake Point Granite of Sabins (1957) is the most prominent example; similar granites are found in the Fisher Hills, Maverick Mountain and Apache Pass areas, as well as in windows through volcanic rocks of the northern Chiricahua Mountains. Erickson (1968) has suggested that some gneissic granitic masses may have been deformed about 1400 million years ago. This timing has not been confirmed.

Swisshelm Mountains

Limited exposures reveal generally deeply weathered, but undeformed porphyritic granites with coarse megacrysts of alkali feldspar, exposed unconformably underneath Bolsa Quartzite. These are correlated with the generation of Tungsten King and Rattlesnake Point granites.

Dragoon Mountains and Tombstone Hills

Pinal Schist, principally sericite-chlorite-quartz schist and chlorite-oligoclase-microcline-quartz schist, crops out as scattered small exposures of Precambrian rock in this range. Minor occurrences of amphibolite schist are reported by Gilluly (1956). Profound younger structures have complicated the structural interpretation of all of the Precambrian rocks. Gilluly (p. 123) tentatively suggested that the dominant Precambrian trend of structures in the Pinal Schist was northeasterly.

Outcrops of intrusive rocks are limited but include, near Tombstone, small bodies of quartz diorite, perhaps of the Johnny Lyon Granodiorite generation, and sheared granitic augen gneiss 5 km south of Dragoon inferred to be the product of Laramide deformation of granite similar to the Tungsten King Granite.

Southern Mule Mountains

Ransome (1904) extended the name Pinal Schist from nearly 160 km to the north to the pre-Paleozoic metamorphic rocks of the Bisbee area on the basis of lithologic similarities. The sericite-chlorite-quartz schists and phyllites are probably metasedimentary but primary bedding is difficult to establish. Foliations are dominantly northeast-trending in the vicinity of Bisbee but swing more northerly and northwesterly at the north end of Banning Canyon. No Precambrian granitic rocks crop out in the Mule Mountains according to Ransome, or Hayes and Landis (1964).

Huachuca and Whetstone Mountains

In both of these westward-tilted structural blocks, Precambrian rocks, exposed on the east and northeast flanks, are predominantly granitic. In each case the lithology is similar; undeformed, coarse porphyritic biotite quartz monzonite to granite with abundant large potassium feldspar phenocrysts up

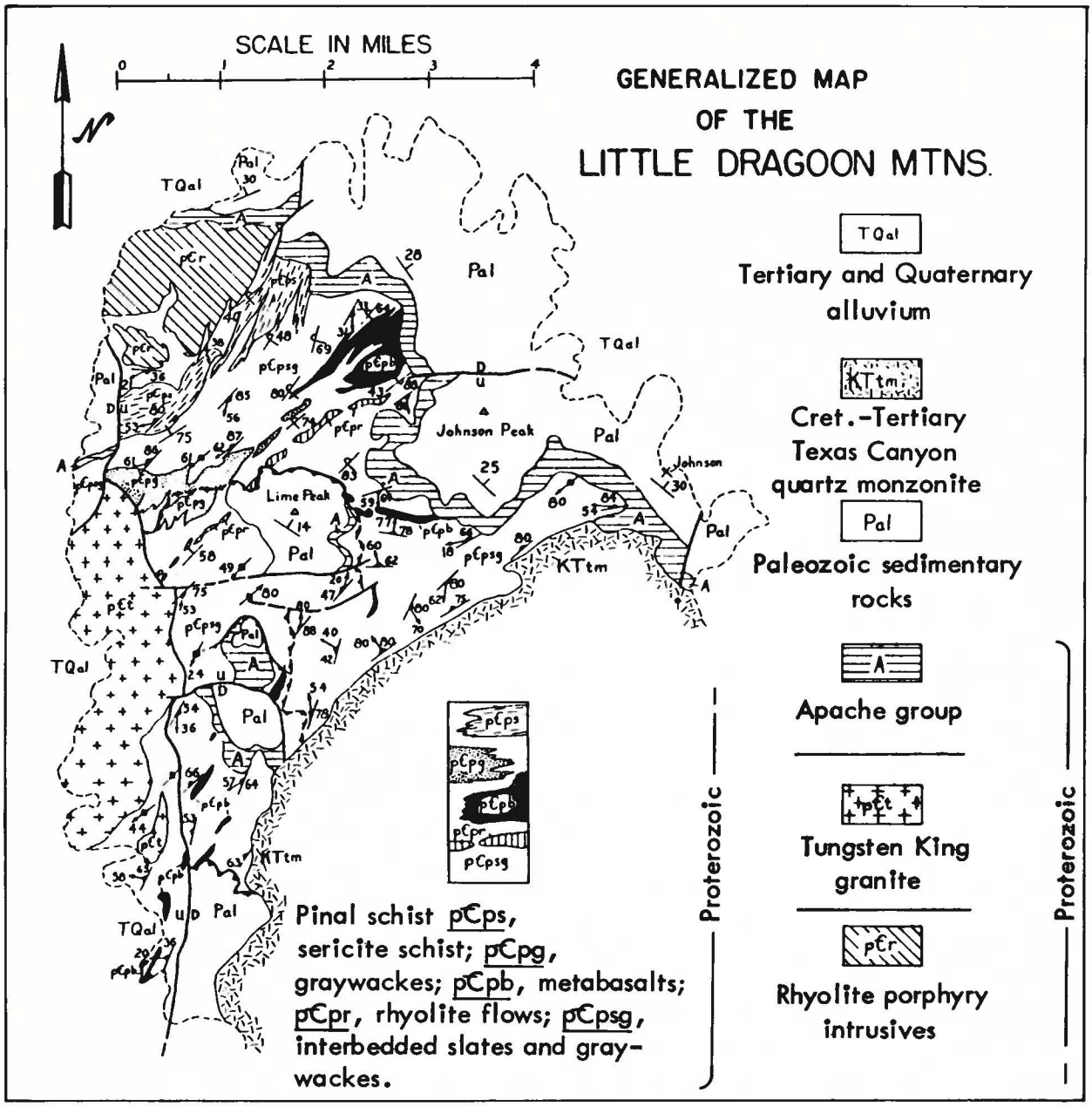

Figure 3. Generalized geologic map of the Little Dragoon Mountains in the Dragoon quadrangle, Cochise County, with emphasis on Precambrian formations. Adapted from Cooper and Silver (1964).

to several cm in diameter. Geochronological studies indicate these granites are of the same 1400-1450 million year generation as the Tungsten King Granite of the Little Dragoon Mountains. Pinal Schist is very sparse in the Huachuca Mountains (Hayes and Raup, 1968), occurring primarily as micaceous hornfelsic xenoliths within the porphyritic granite. Limited occurrences of characteristic sericite-chlorite-quartz schists are found between East Peak and French Joe Canyon in the Whetstone Mountains, where Creasey (1967) mapped steep foliations trending northeasterly to northerly, without lithologic subdivisions or structural interpretations.

Happy Valley Quadrangle

Extensive exposures of structurally complicated crystalline rocks are found in the Happy Valley quadrangle, mapped recently by Drewes (1975). Several years ago Cooper and I extended Johnny Lyon Granodiorite from the Dragoon quadrangle, via lithologically consistent exposures in windows in fill of the San Pedro River Valley, to the eastern half of the Happy Valley quadrangle. Drewes has adopted this correlation and has recognized a number of other Precambrian intrusive units, including the granodiorite of Rincon Valley, the Continental Granodiorite and the quartz monzonite of Wrong Mountain. I have examined these units for regional comparisons and offer some alternate perspectives.

(1) The granodiorite of Rincon Valley bears a close textural and mineralogical resemblance to, and is of the same generation as the adjacent Johnny Lyon Granodiorite; a separate stratigraphic assignment seems inappropriate.
(2) The Continental Granodiorite is considered by Drewes

to be older than the Johnny Lyon Granodiorite in Happy Valley. The name Continental Granodiorite has been carried by Drewes from the Santa Rita Mountains in Santa Cruz County, where he believed the type Continental Granodiorite to be at least 1450 million years old, and possibly as old as 1700 million years, based on somewhat inconsistent lead-alpha, Rb-Sr and K-Ar age determinations ranging from 55 to 1450 million years (Drewes, 1976, p. 15-17). Field and laboratory studies reveal the type Continental Granodiorite to be at least two independent intrusions, one 1430 m.y. old and the other more than 1600 m.y. old. Neither is older than the Johnny Lyon Granodiorite, although one is of the same magmatic generation. In Happy Valley, at least part of the porphyritic granodiorite has the same apparent age (1420 m.y.) as the Tungsten King Granite of the Little Dragoon Mountains across the San Pedro River, and cannot be considered older than the nearby Johnny Lyon Granodiorite. A revision of the nomenclature proposed by Drewes should be considered; usage of an appropriate local name based on field relations and more adequate geochronological information would minimize confusion.

(3) The quartz monzonite of Wrong Mountain has not been studied radiometrically. Its petrographic characteristics, however, lead me to believe that it may possibly be correlated with Tertiary granites and gneisses of the Catalina and Rincon fore-ranges (Creasey and others, 1977; Banks, 1977; Shakel and others, 1977). Its present Precambrian assignment should be held in abeyance pending further investigation.

These comments point out some of the complexities in the Precambrian stratigraphy in the region of the Rincon and Santa Catalina Mountains, where Tertiary tectonics have made even the positive identification of metaigneous versus metasedimentary rocks, much less Precambrian or Tertiary primary ages, a difficult task.

REGIONAL PRECAMBRIAN SUMMARY

A number of persistent aspects of the Precambrian formations of Cochise County deserve emphasis.

Pinal Schist is dominantly a clastic section of immature sedimentary rocks with subordinate components of mafic to felsic volcanic flows and shallow intrusives. Quartzites are locally present but volumetrically are not significant. Carbonates are conspicuously absent. The better preserved sedimentary sections are characterized by turbidite textures and structures, suggesting deep water accumulation in a major geosyncline of regional extent, with thicknesses in excess of 6 km (Cooper and Silver, 1954).

The entire Pinal Schist section has been deformed and metamorphosed but not sufficiently to erase primary features in many cases. The deformation represents part of a major northeast-trending regional orogeny, unnamed here, active in the interval 1625-1680 million years ago. It has been suggested elsewhere (Silver, 1964) that this orogeny is correlative in part with the "Mazatzal orogeny" defined in central Arizona by Eldred Wilson (1939). Controversy concerning the exact nature and timing of this event has weakened the potential usefulness of the term "Mazatzal orogeny." Continuing research by the writer and his colleagues indicates the geosyncline, the culminating orogeny and the associated magmatic arc encountered in Cochise County extended from at least north-central New Mexico to southern Arizona and northern Sonora, Mexico (Anderson and others, 1978) and probably was considerably more extensive. Available information indicates this was the initial crust-forming episode in most of these regions.

The most important Precambrian plutonic episode in southeastern Arizona occurred 1420 to 1440 million years ago, when great batholiths of distinctive potassium-feldspar megacrystic porphyritic granites were emplaced. This episode appears to have been free of association in space or time with sedimentation or deformation and is termed anorogenic. Its widespread occurrence throughout Arizona has been recognized for more than a decade (Silver, 1968), and it is now believed to extend in a broad belt northeast across the entire North American continent (Silver and others, 1977). Completion of this second batholithic episode appears to have marked the final maturation of the North American craton in this region. Subsequent stability lasted at least 1200 million years.

Knowledge of the late Proterozoic history is limited to the areas of known distribution of the Apache Group and associated diabase intrusives. These rocks probably were originally far more extensive in distribution, and probably extended across all of southeastern Arizona. Indeed, a variety of data suggests that the Apache Group probably was once continuous to the Franklin Mountains of west Texas where it may be represented, in part, by rocks of the Castner limestone, Mundy breccia and Llanoria quartzite (Harbour, 1972).

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