Geology of the Oracle Ridge Mine and Mining District Pima County, Arizona

Contributions from the Staff of Oracle Ridge Mining Partners, Jon Spencer,
and Excerpts from GSA Memoir 153
Edited by Mark Miller

Guidebook for the
Arizona Geological Society
Spring Field Trip
[April 1995]

Arizona Geological Society
P.O. Box 40952, Tucson, AZ 85717

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April 15, 1995

Dear Field Trip Participant:

I bid you welcome to the 1995 spring field trip of the Arizona Geological Society. Today, we will be visiting the Oracle Ridge Mine owned and operated by the Oracle Ridge Mining Partners. The trip will encompass both a surface and underground look at a 1000TPD copper mine. The orebodies are hosted in Paleozoic carbonates which occur as a roof pendant above a Laramide quartz diorite intrusion and have been later structurally deformed. ORMP list reserves (in the proven and probable catagory) at 9.6 million tons at 2.32% Cu principally as chalcopyrite, chalcocite and bornite, There is a little gold and silver byproduct.

I wish to thank the staff and management of ORMP for their permission to visit their operation. I would also like to thank Jon Spencer for his resume on the geology of the Catalina Mountains.

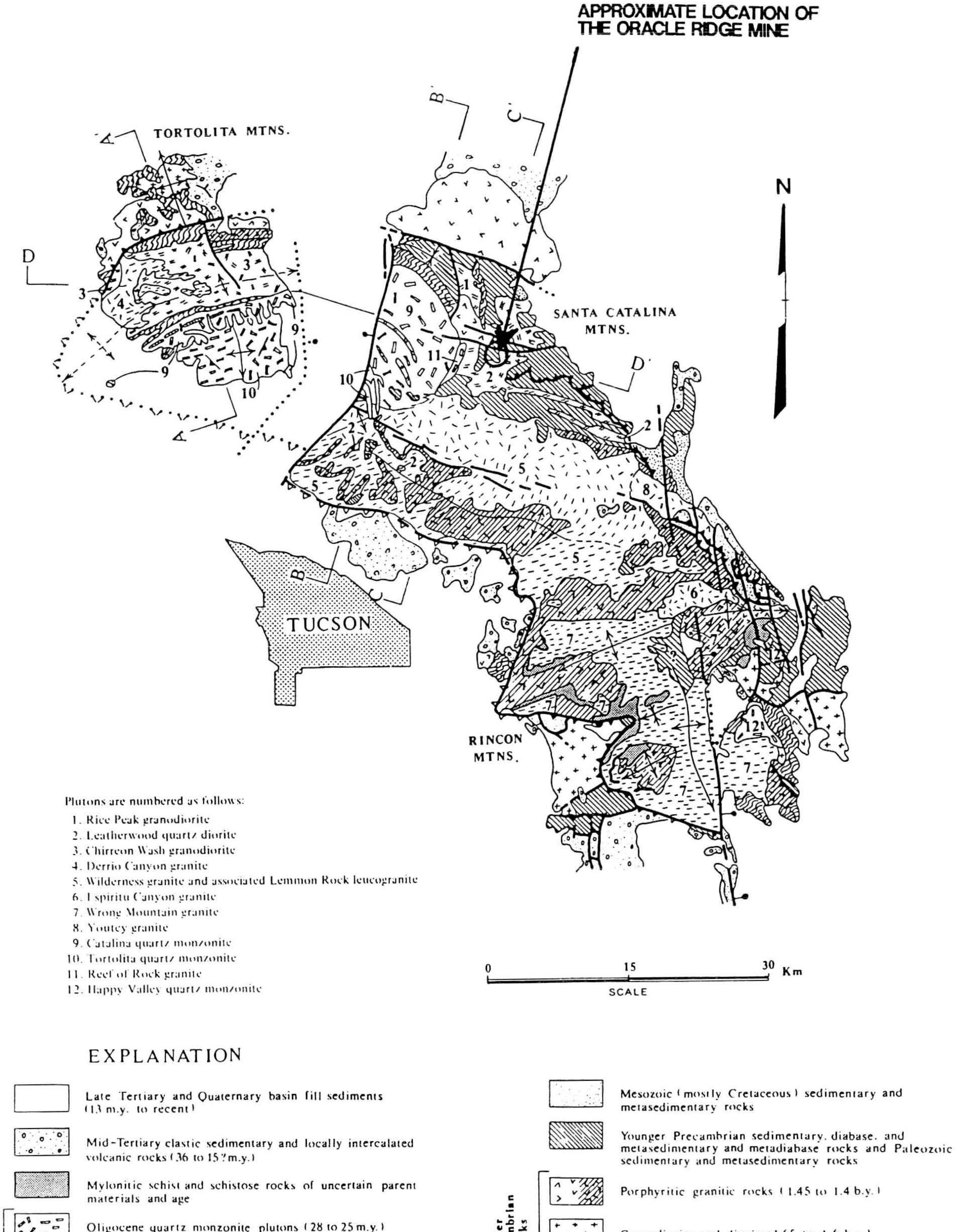
Mark Miller
Editor

Geologic setting of the Santa Catalina Mountains and the Oracle Ridge Mine

Jon Spencer
Arizona Geological Survey

The Santa Catalina Mountains are part of the Catalina-Rincon metamorphic core complex in southeastern Arizona (Figure 1; Keith et al., 1980; Naruk and Bykerk-Kauffman, 1990; Dickinson 1991). The Santa Catalina, Rincon, Tortolita, and Picacho Mountains were tectonically exhumed by displacement from beneath bedrock that now underlies basins and ranges to the southwest of these ranges. Crystalline rocks in the Catalina forerange and on the southwest flanks of the other ranges were at mid-crustal depths (>10km) and corresponding temperatures (>300 °C) before tectonic exhumation. Movement on the Catalina-Rincon detachment fault and its downdip extension as a ductile shear zone accommodated mid-Tertiary crustal extension and uplift of footwall rocks in the Santa Catalina and Rincon Mountains. Movement within the ductile shear zone caused penetrative mylonitic deformation of crystalline rocks that are now exposed in the forerange of the Santa Catalina Mountains (Davis, 1980, 1983; Spencer and Reynolds, 1989).

Bedrock of the Santa Catalina and Rincon Mountains was tilted to the northeast during mid-Tertiary uplift and exhumation. The ranges now expose what was formerly a cross section through the upper crust. The variably mylonitic gneissic and granitic rocks that make up the Catalina forerange and the west flank of the Rincon Mountains were at the greatest depth, and the upper Paleozoic and Mesozoic sedimentary rocks on the northeast flank of the ranges were at the shallowest depth. Most of the Santa Catalina Mountains are made up of the Eocene peraluminous Wilderness suite granites and the Oligocene Catalina Quartz Monzonite. The Laramide Leatherwood Quartz Diorite and Rice Peak Granodiorite intrude Proterozoic and Paleozoic strata in the northern Santa Catalina Mountains (Banks, 1976; Creasy and Theodore, 1975; Creasey, 1967; Keith et al., 1980). The Oracle Ridge skarn deposit is along the contact between the Leatherwood Quartz Diorite and Paleozoic carbonates (Peterson, and Creasey, 1943; Braun, 1969), and is within the Marble Peak mineral district of Keith et al. (1983).



Plutons are numbered as follows:

1. Rice Peak granodiorite
2. Leatherwood quartz diorite
3. Chirreon Wash granodiorite
4. Derrio Canyon granite
5. Wilderness granite and associated Lemmon Rock leucogranite
6. Espiritu Canyon granite
7. Wrong Mountain granite
8. Youtey granite
9. Catalina quartz monzonite
10. Tortolita quartz monzonite
11. Reef of Rock granite
12. Happy Valley quartz monzonite

EXPLANATION

- Late Tertiary and Quaternary basin fill sediments (13 m.y. to recent)
- Mid-Tertiary clastic sedimentary and locally intercalated volcanic rocks (36 to 15?m.y.)
- Mylonitic schist and schistose rocks of uncertain parent materials and age

Late Cretaceous to Oligocene batholithic intrusions

- Oligocene quartz monzonite plutons (28 to 25 m.y.)
- Eocene muscovite granites and associated aplo-pegmatites (51 to 44 m.y.)
- Late Cretaceous - early Tertiary diorite to granodiorite plutons (75 to 60 m.y.)

- Mesozoic (mostly Cretaceous) sedimentary and metasedimentary rocks
- Younger Precambrian sedimentary, diabase, and metasedimentary and metadiabase rocks and Paleozoic sedimentary and metasedimentary rocks

Older Precambrian rocks

- Porphyritic granitic rocks (1.45 to 1.4 b.y.)
- Granodiorite and diorite (1.65 to 1.6 b.y.)
- Pinal schist (1.7 b.y.)

FIGURE 1:

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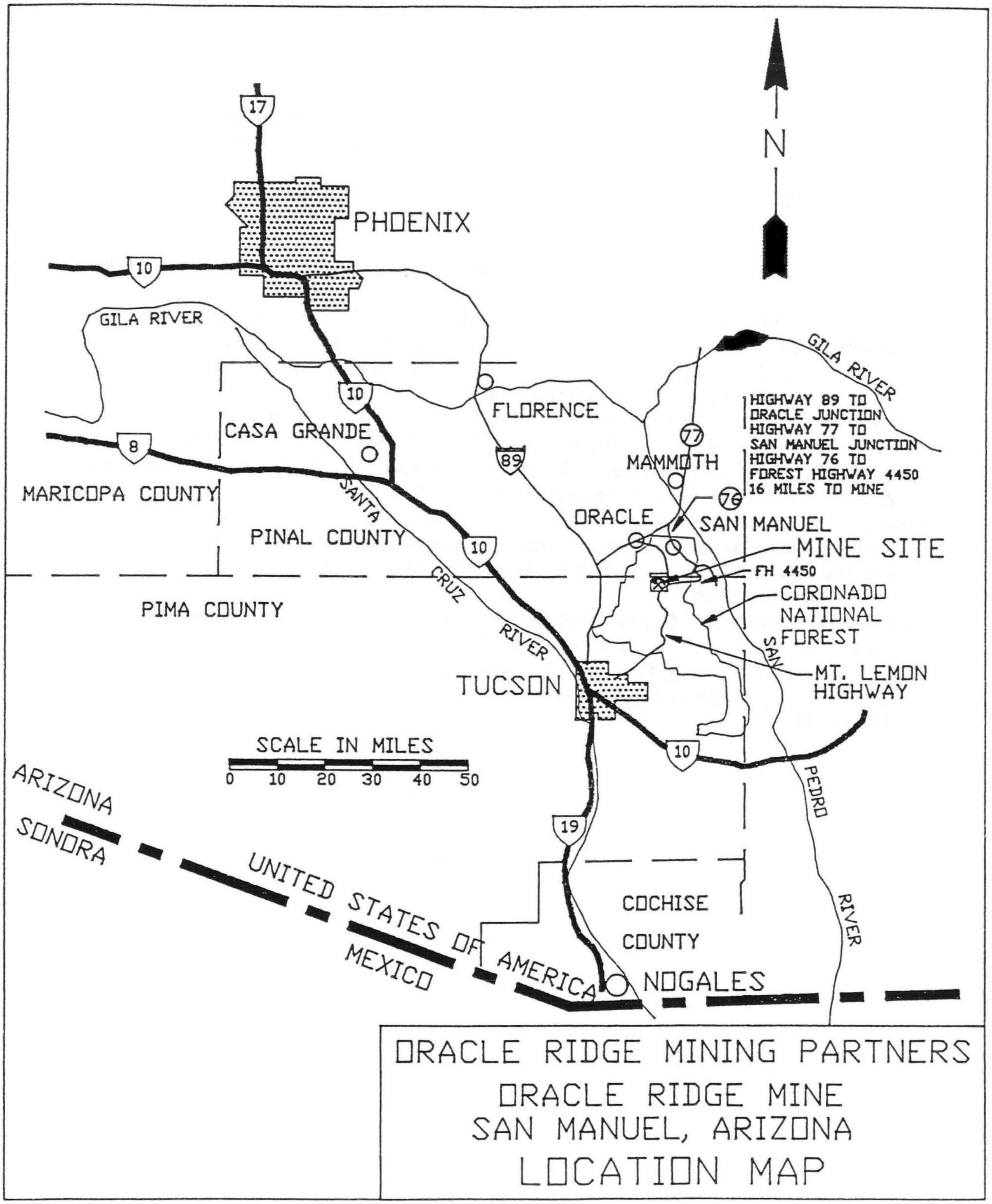

ORACLE RIDGE MINING PARTNERS

ORACLE RIDGE MINE

SAN MANUEL, ARIZONA

LOCATION MAP

ORACLE RIDGE MINING PARTNERS

P. O. Box 70, San Manuel, AZ 85631
Phone: (602) 576-1412 Fax: (602) 576-1539

History

The mining district came into being in 1873 with the founding of the Old Hat Mine. In 1881 a ton per day copper smelter had been erected at Apache Camp approximately 5000' or a mile from the present mill. Ore supplied to the smelter came from numerous small adits located on Marble Peak which includes: Hartman Homestake, Leather Wood, Stratton and Greesaman workings.

In 1937, Catalina Consolidated acquired the property and set up a 100 ton per day flotation mill near the present ORMP Mill Site. Ore was processed from the Geesaman and Daily workings. Records show that 115,000 tons of ore were processed to produce 1081 tons of concentrate averaging 27% copper, 8.6 troy oz./ton silver and 0.015 troy oz./ton gold.

Operations at the property continued intermittently through to 1984. In 1968, Continental Copper leased (to purchase) the property and conducted exploration drilling and underground drifting. By 1974, a total of 106,535 feet of core had been drilled and 2651 feet of adit had been driven to delineate geological resources estimated at 11 million tons of ore grading 2.25% copper.

In 1977, Union Miniere and Continental Copper entered into a joint venture to evaluate a 2000ton per day feasibility study with Union Miniere being the operator. Between 1977 and 1979, an office building, maintenance shops, and warehouse buildings were constructed. In 1979, a major review of the project suggested that further underground exploration was necessary to define and expand ore reserves, to provide more information for mine planning and to estimate actual mining costs. This resulted in an underground exploration program commencing in April of 1980. By 1981, low copper prices forced work to be suspended. By 1983, the project had stockpiled 85,000 tons of ore grading 2.56% copper, and total development included 28,675 ft. Of drifting, 125,607 feet of surface diamond drilling and 46,916 feet of underground diamond drill core.

In October 1988, South Atlantic Ventures acquired Union Minere's interest (70%) in the Oracle Ridge Mine and entered into a partnership with Continental Copper to develop the mine. In April 1990, production decision was made and work commenced on the construction of a 750 ton per day concentrator. Milling commended February 28, 1991, and the first saleable concentrate was shipped on March 4, 1991.

Production has continued to present at intermittent times with ore being derived from both stopes and development headings. In 1993, South Atlantic Ventures changed its name to Southern Copper. A production shutdown between August and October 1993 was recorded during which time the mill was expanded to process 1000 tons per day ore. This production rate has remained constant to the present.

Geology

A. Regional

The Oracle Ridge Mining claims are situated in the Santa Catalina Mountain which were formed some 31 million years ago when the ground was uplifted, folded and intruded by the laramide intrusion. Regionally, the area consist sof Precambrian granites found to the north of the Geesaman Fault, metal sediments and quartz diorites. Later intrusions in the form of Lampophyre, Alaskite quartz, and rhyolite dikes and sills have been located. Structurally, the ground had undergone multi stages of folding and faulting.

With the intrusion, mineralizing fluids have created ore horizons both as strata bound and contact metamorphic skarn veins.

B. Geology of Mine

Ore horisons in the mine occur both as a stratabound deposit with copper ore occurring in stratigraphically defined sedimentary units and as steeply dipping contact metamorphic skarn veins.

1. Stratabound Deposits

These deposits occur in the upper parts of the mine and are the result of mineralizing fluids depositing copper, silver and gold minerals in select sedimentary units located as a roof pendent above the Laramide quartz diorite intrusion. These beds have been folded and faulted with widths varying up to 40 feet thick and strike lengts up to 300 feet long. The angle of dip of the beds vary from 35 degrees to 60 degrees.

2. Contact Metamorphic Skarns Deposits

The contact metamorphic deposits occur in basins and on the flanks of the Laramide intrusion in contact with the limestones and dolomitic sediments. Typically ore shoots vary from 10 to 50 feet wide and possess strike lengths from 50 to 500 feet long. The ore shoots are generally steeply dipping.

3. Mineralogy

Ore grade mineralization occurs primarily in the minerals chalcopyrite, chalcocite and bornite. Copper is also found in lesser amounts in the form of covallite, cuprite, native copper, vallurite and other rare copper minerals. Gold and silver are recovered as by products.

Reserves

Published reserves (proven and probable) calculated with a cut off grade of 1.5% copper totalled 5,098,000 tons averaging 2.24% copper and 0.67 troy oz. Per ton silver as of October 31, 1993. Drill indicated (possible) reserves totalled an additional 4,355,000 tons at an average grade of 2.41% copper and 0.67 troy oz. per ton silver. Development work conduced between October 1993 and February of 1994 had upgraded the proven and probable reserves to 5,300,000 tons of ore averaging 2.24% copper and 0.67 troy oz. per ton silver. The possible reserves remain at 4,355,000 tons averaging 2.41% copper and 0.67 oz. Per ton silver.

Ore Reserves

Date	Proven & Probable Reserves		Possible Reserves		Total Reserves	
	Tons	Grade	Tons	Grade	Tons	Grade
March 1, 1994	5,300,000	2.24	4,355,000	2.41	9,655,000	2.32
Oct. 31, 1993	5,097,000	2.24	4,355,000	2.41	6,453,300	2.32

Ore Reserves are classified by the following critreia:

A.	Proven reserves -	Exposed by underground workings and projected up to 50 feet fro proven reserves or where sufficient geological data exists to show continuity and confidence in the ore structure.
B.	Probable reserves -	Projected up to 50 feet from proven reserves or where sufficient geological data exists to show continuity and confidence in the ore structure.
C.	Prossible reserves -	Projected up to 50 feet from possible reserves or 50 feet from an ore grade intersection obtained in drill core.

Ore reserves are blocked out by geologists and mining engineers with a nominal 10% dilution applied for the mining method. In 1993/1994, the mine recorded a waste/ore stripping ratio of 1/6.72.

Mining

The mining method employed at Oracle Ridge was changed in 1992 from a room and pillar to a longhole open stoping mining method. The longhole open stope mining method is a low cost, high productivity method that generally recovers 90-95% of blocked out reserves. It is the intention of Oracle Ridge to use this mining method in all stopes.

Mining Plan

Mining in 1994 has been concentrated in 3 stopes in ore reserve blocks 6 & 7. By the end of 1994, all currently accesible stoping areas in block 6 will have been mined out. Oracle Ridge is currently driving a 3,000 foot ramp to an elevation where previous development has defined 3,874,000 tons averaging 2.28% copper in ore reserve blocks 1,2,8 & 9. At the current rates of mining (1000 tons per day) a total of ovr 15 years of mine life remain in the proven and probable ore reserve base.

Mining plans for 1995 call for the commencement of stope mining in ore reserve blocks 1 and 2 on the 6400 level while maintaining sufficient development to sustain production. In addition, an underground exploration program consisting of diamond drilling costing nearly $900,000 is planned.

Traditionally development drifting and diamond drilling have not only offset production but recorded significant gains to the reserve base. This is evident in the increase of published reserves from October 1993 to March of 1994. The reason for this is the fact that th eproperty is not fully explored (by drilling and drifting) and past experience has located new ore veins. An example of this is the 970 stope which was virtually unknown in May of 1993 and to date from which we have mined out over 120,000 tons of ore averaging approximately 2% copper.

Exploration techniques employed at Oracle Ridge include ramping and drifting. The incline that is currently being driven is designed in untested ground. This incline will allow the testing of the ground by drilling and drifting.

Number and Types of Employees

The Oracle Ridge Mine is a non union operation. There are 76 full time employees, comprised of 20 salaried and 56 hourly. The underground operation has 30 miners, 4 shift bosses, 2 geologists and a mine superintendent. Also, supporting the underground is a maintenance shop staffed with 10 hourly employees. The mill and crusher operation have a total of 15 operators, a metallurgist, 2 lab technicians, general foreman and a mill superintendent. The office staff includes 1 purchasing agent, 3 warehouse employees, 1 mine accountant, 1 secretary and a general manager.

Infrastructure

Electrical power is provided to the mine shop by service from Trico Electric. Electric power for the mine, crusher and mill is produced by use of two on site 1000 KW diesel generator sets.

Mine water is taken from drainage from the 6400 level that is collected in a storage tank. Mill water is recirculated from thickener overflows and the tailing pond. Mill makeup water requirements come from mine drainage from the 5900 level, excess water in the mine storage tank and water pumped from a permitted well located near Alder Canyon approximately three miles west of the tailings pond.

Three unpaved roads are available for access to the mine. The best quality of these is Forest Highway 4450; this connects the mine to the south limit of a paved road pavement south of San Manuel and seventeen miles from the mine ste. The other two are the portions of Forest Highway 38 that extend from the mine to Oracle and from the mine to the Mount Lemon Highway. Three Tucson telephone lines are relayed via microwave to the mine site.

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Memoir 153
1980

Evidence for multiple intrusion and deformation within the Santa Catalina–Rincon–Tortolita crystalline complex, southeastern Arizona

STANLEY B. KEITH *Bureau of Geology and Mineral Technology*
University of Arizona, Tucson, Arizona 85721

STEPHEN J. REYNOLDS *Department of Geosciences*
University of Arizona, Tucson, Arizona 85721

PAUL E. DAMON AND MUHAMMAD SHAFIQULLAH
Laboratory of Isotope Geochemistry, Department of Geosciences
University of Arizona, Tucson, Arizona 85721

DONALD E. LIVINGSTON *Bendix Field Engineering, Geochemical Division*
P.O. Box 1569, Grand Junction, Colorado 81501

PAUL D. PUSHKAR *Department of Geology*
Wright State University, Dayton, Ohio 45431

> *The central feature of the range, as worked out by Mr. Tolman, is a great post-Carboniferous intrusive mass of siliceous muscovite granite modified to a gneissic rock near its margins, surrounded by an intense contact metamorphism in which rocks of widely different kinds have been conspicuously affected. The oldest rock cut by this granite is a coarse biotite granite which apparently as a result of the later granitic intrusion, grades into augen gneiss, and locally this rock in turn has been transformed into a thinly fissile schist.*
>
> Interpretation by C. F. Tolman of the geology of the Santa Catalina Mountains as told by Ransome, 1916, p. 144

ABSTRACT

Recent field work and accumulated Rb-Sr studies, when combined with previous U-Th-Pb and K-Ar investigations, allow a new synthesis of the crystalline terrane within the Santa Catalina–Rincon–Tortolita crystalline complex. When all the available data are integrated, it is apparent that the crystalline core is mainly a composite batholith that has been deformed by variable amounts of cataclasis. The batholith was formed by three episodes of geologically, mineralogically, geochemically, and geochronologically distinct plutons. The first episode (75 to 60 m.y. B.P.) consisted of at least two (and probably three) calc-alkalic, epidote-bearing biotite granodiorite plutons (Leatherwood suite). The Leatherwood suite is intruded by distinctive leucocratic muscovite-bearing peraluminous granitic plutons (Wilderness suite), which are 44 to 50 m.y. old. At least three Wilderness suite plutons are known, and their origin has been much debated. Leatherwood and Wilderness plutons are intruded by a third suite of four biotite quartz monzonite to granite plutons (Catalina suite) that mark the final consolidation of the batholith 29 to 25 m.y. ago.

Much of the mylonitic (cataclastic) deformation of the plutonic rocks and recrystallization of the enclosing host rocks may be related to intrusion of the various plutons. At least three episodes of mylonitization (cataclasis) may be delineated by observing relations between mylonitic and nonmylonitic crosscutting plutons. The southern part of the Leatherwood pluton bears a moderate to strong mylonitic foliation that is cut by undeformed leucogranites and pegmatite phases of the Wilderness pluton.

Elsewhere in the Santa Catalina–Rincon–Tortolita crystalline core, Wilderness suite plutons contain penetrative mylonitic foliation. Foliated Wilderness suite plutons are intruded by an undeformed portion of a Catalina suite pluton. In the Tortolita Mountains, however, intrusions of the Catalina suite themselves contain evidence for at least two events of mylonitic deformation. The most significant of these events is clearly constrained to the Catalina intrusive episode because it formed during or after the emplacement of Tortolita quartz monzonite (about 27 m.y. B.P.) but before the intrusion of postfoliation dikes (about 24 m.y. B.P.). All three episodes of mylonitization contain the distinctive and much discussed east-northeast–trending lineations. All events of mylonitization are constrained to a 50-m.y. interval of time from 70 to 20 m.y. ago. Although continuous mylonitization from 70 to 20 m.y. ago cannot be unequivocally disproved, the strong association of mylonitization with the three plutonic episodes suggests that deformation in the Santa Catalina–Rincon–Tortolita crystalline core, like intrusion, was episodic.

INTRODUCTION

The Santa Catalina–Rincon–Tortolita crystalline complex is located (Fig. 1) at the southeast end of a zone of crystalline complexes that trends northwest through southern Arizona (Rehrig and Reynolds, this volume; Banks, this volume; Davis and others, this volume; Davis, this volume). Crystalline complexes in this zone are in part characterized by chiefly mylonitic varieties of cataclastic rocks whose gently dipping foliation defines broad arches or domes (Davis, this volume; Coney, 1979 and this volume; Rehrig and Reynolds, this volume; Reynolds and Rehrig, this volume). Evidence of post-Paleozoic plutonism, metamorphism, mylonitization, and cataclasis abound in all of the complexes. Latest cooling ages in the Arizona crystalline complexes are generally middle Tertiary (Damon and others, 1963; Mauger and others, 1968; Creasey and others, 1977; Banks and others, 1978; Banks, this volume; Rehrig and Reynolds, this volume). On some gently dipping sides of the domes, the upper levels of the mylonitic gneisses are jointed, brecciated, chloritic, and hematitic. The mylonitic gneisses are overlain by a low-angle dislocation surface (for definition of this term, see Rehrig and Reynolds, this volume). Above the dislocation surface lie highly faulted and locally folded (Davis, 1975) rocks that are generally unmetamorphosed and lack the mylonitic textures that characterize the basement below the dislocation surface.

The Santa Catalina–Rincon–Tortolita crystalline complex is within the Basin and Range province, an area characterized by late Tertiary fault-block mountain ranges and valleys. The oldest rocks exposed in the ranges (Fig. 2) consist of middle Proterozoic metasedimentary and metaigneous rocks that underwent a major metamorphic-deformational-plutonic event about 1.65 b.y. ago and a later episode of granitic intrusion 1.45 b.y. ago (Silver, 1978). These rocks were beveled by erosion and

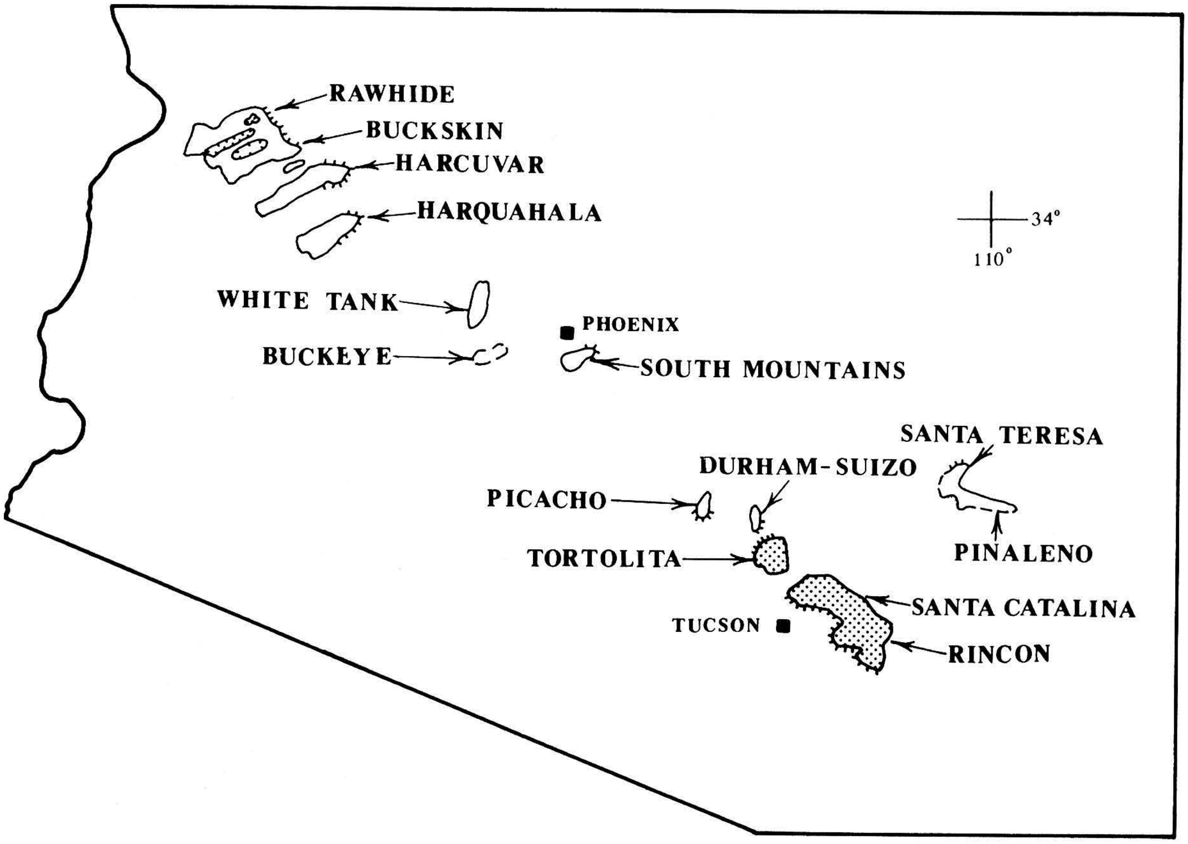
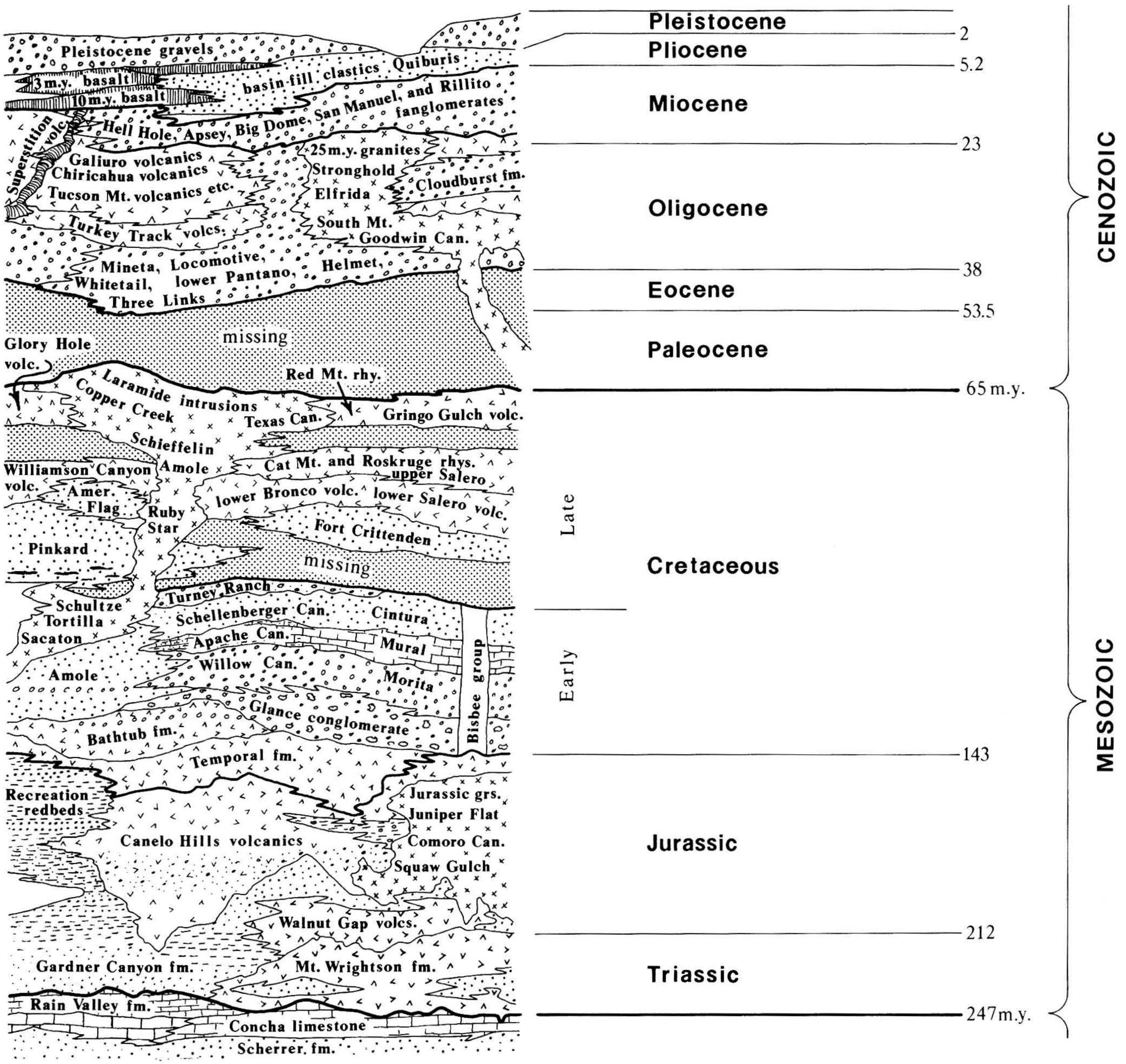


Figure 1. Map of southern Arizona showing location of Santa Catalina–Rincon–Tortolita crystalline complex (dot pattern). Similar complexes are outlined, and dislocation surfaces are depicted by hachures (from Rehrig and Reynolds, this volume).

overlain by 1.4- to 1.1-b.y.-old sedimentary rocks of the Apache Group and associated diabase (Shride, 1967). Apache Group rocks are overlain by a cratonic sequence of Paleozoic carbonate and fine-grained clastic rocks (Bryant, 1968; Peirce, 1976). Mesozoic rocks of the region represent a period of volcanism, plutonism, and tectonic instability (Hayes, 1970; Hayes and Drewes, 1968, 1978; Titley, 1976). The Late Cretaceous–early Tertiary Laramide orogeny was also a time of deformation (Drewes, 1976a; Davis, 1979) and alkali-calcic to calc-alkalic magmatism (Keith, 1978). After a period of *relative* quiescence, high potassium-calc-alkalic magmatism and deformation were renewed in middle Tertiary time (Damon and Mauger, 1966; Shafiqullah and others, 1978; Keith, 1978). These events were followed after 15 m.y. B.P. by block faulting and basaltic volcanism (Shafiqullah and others, 1976; Eberly and Stanley, 1978; Scarborough and Peirce, 1978).

Within this regional geologic framework, the Santa Catalina–Rincon–Tortolita crystalline complex has been an enigma since research started on it in the early 1900s. The purpose of this paper is to summarize published and unpublished geologic and geochronologic studies and to integrate these into a discussion concerning ages and correlations of major rock units within the complex. Particular attention will be given to post-Paleozoic intrusions that together constitute a composite batholith which dominates the geology of the complex.

Igneous rock nomenclature in this paper follows traditional usage of rock names within the Santa Catalina–Rincon–Tortolita crystalline complex except where noted in the text. Rocks described by the term "mylonitic" possess a foliation (fluxion structure of Higgins, 1971) and in thin section show comminuted and brittlely deformed feldspars (from 60% to 80% of rock) and recrystallized, sutured aggregates of quartz (as much as 40% of rock). The mylonitic rocks are similar to photographs of hand



Pleistocene gravels
3 m.y. basalt
10 m.y. basalt
basin-fill clastics
Quiburis
Superstition volc.
Hell Hole, Apsey, Big Dome, San Manuel, and Rillito fanglomerates
25 m.y. granites
Galiuro volcanics
Chiricahua volcanics
Tucson Mt. volcanics etc.
Stronghold
Elfrida
Cloudburst fm.
Turkey Track volcs.
South Mt.
Goodwin Can.
Mineta, Locomotive, Helmet,
Whitetail, lower Pantano,
Three Links
missing
Glory Hole volc.
Red Mt. rhy.
Laramide intrusions
Copper Creek
Texas Can.
Gringo Gulch volc.
Schieffelin
Williamson Canyon volc.
Amole
Cat Mt. and Roskruge rhys.
upper Salero
Amer.
Flag
Ruby Star
lower Bronco volc.
lower Salero volc.
Fort Crittenden
Pinkard
missing
Turney Ranch
Schultze
Tortilla
Sacaton
Schellenberger Can.
Cintura
Apache Can.
Mural
Willow Can.
Amole
Morita
Glance conglomerate
Bathtub fm.
Bisbee group
Temporal fm.
Recreation redbeds
Jurassic grs.
Juniper Flat
Canelo Hills volcanics
Comoro Can.
Squaw Gulch
Walnut Gap volcs.
Gardner Canyon fm.
Mt. Wrightson fm.
Rain Valley fm.
Concha limestone
Scherrer fm.
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Paleocene
Late
Early
Cretaceous
Jurassic
Triassic
2
5.2
23
38
53.5
65 m.y.
143
212
247 m.y.
CENOZOIC
MESOZOIC

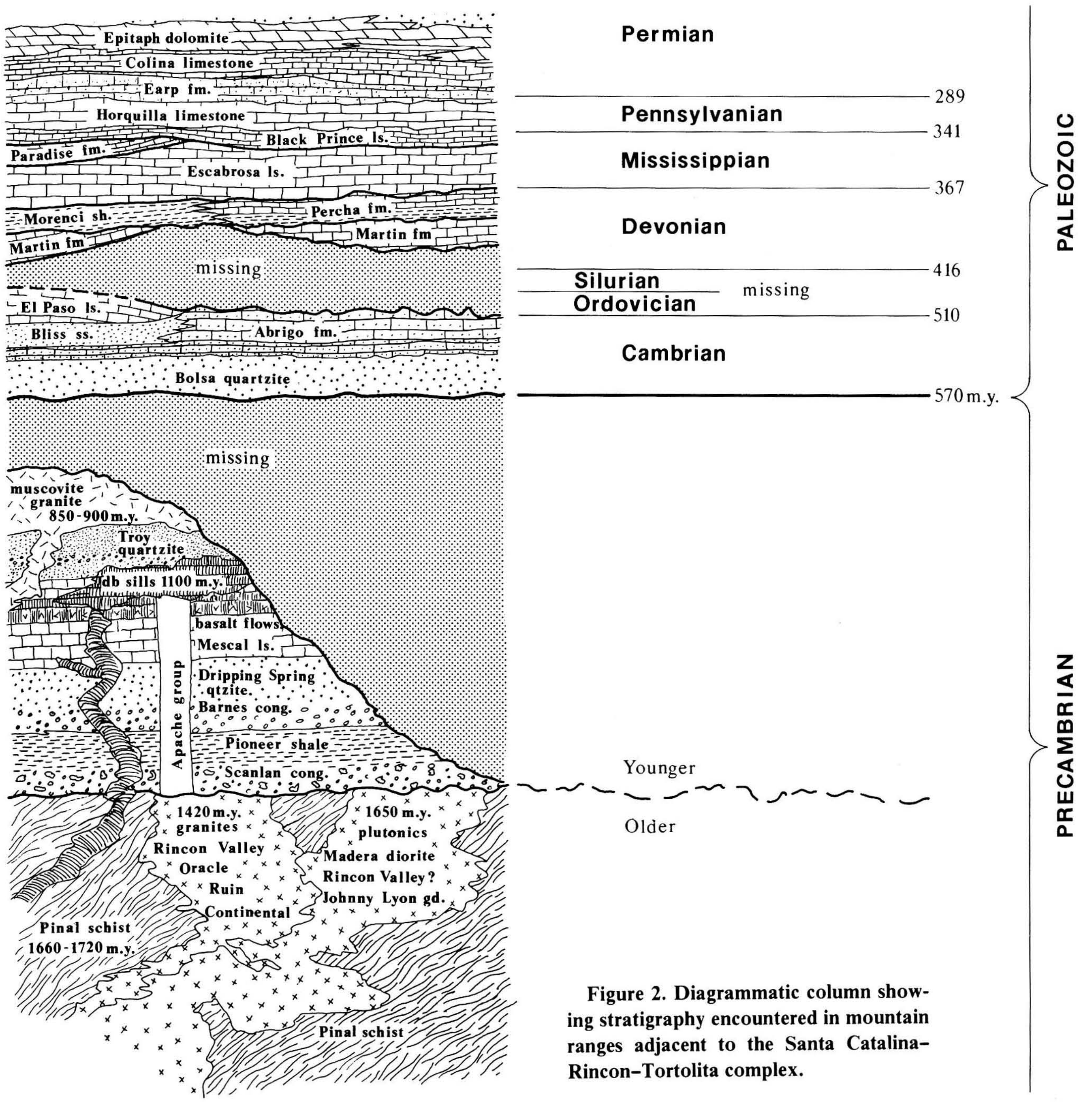


Figure 2. Diagrammatic column showing stratigraphy encountered in mountain ranges adjacent to the Santa Catalina–Rincon–Tortolita complex.

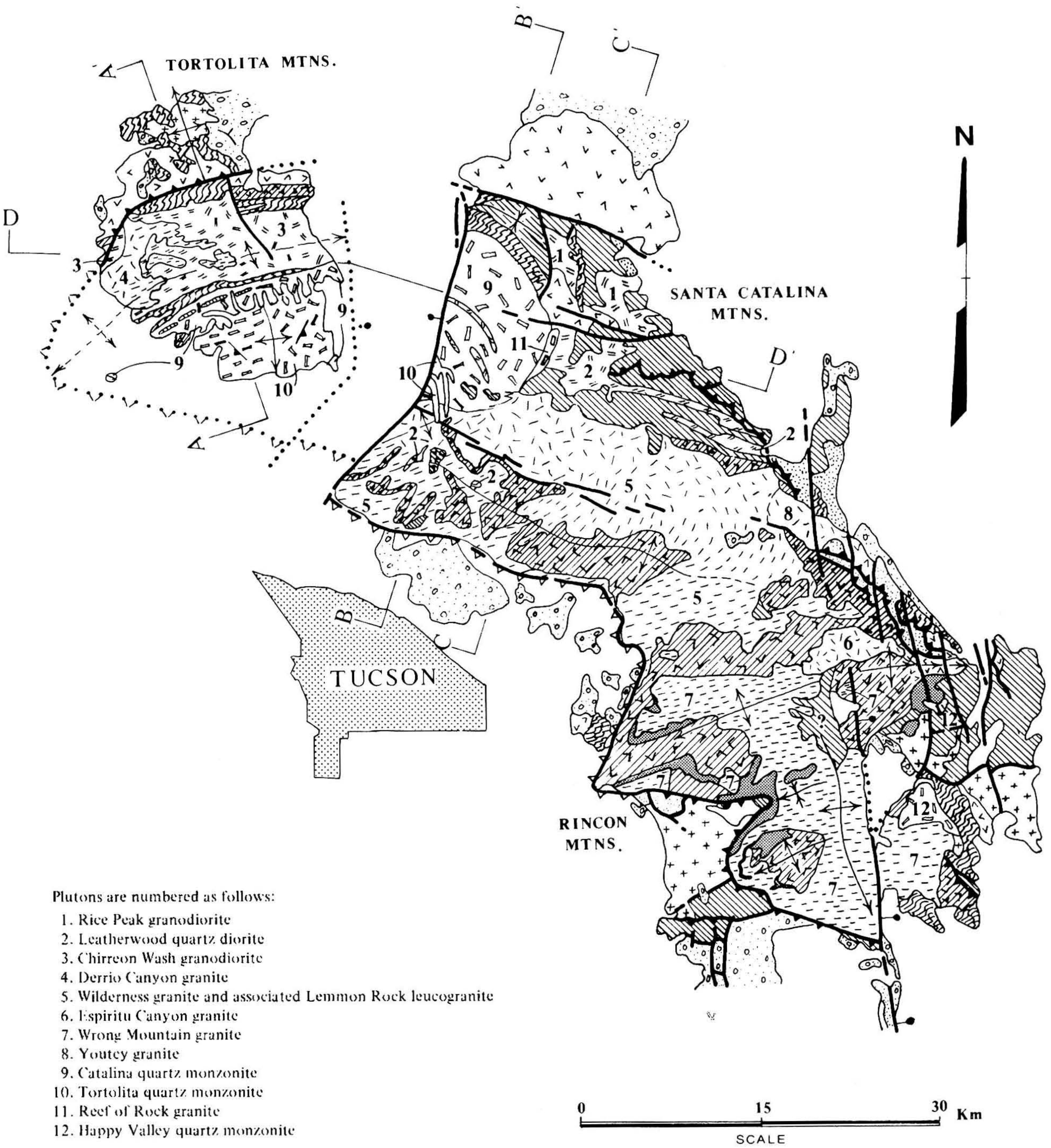
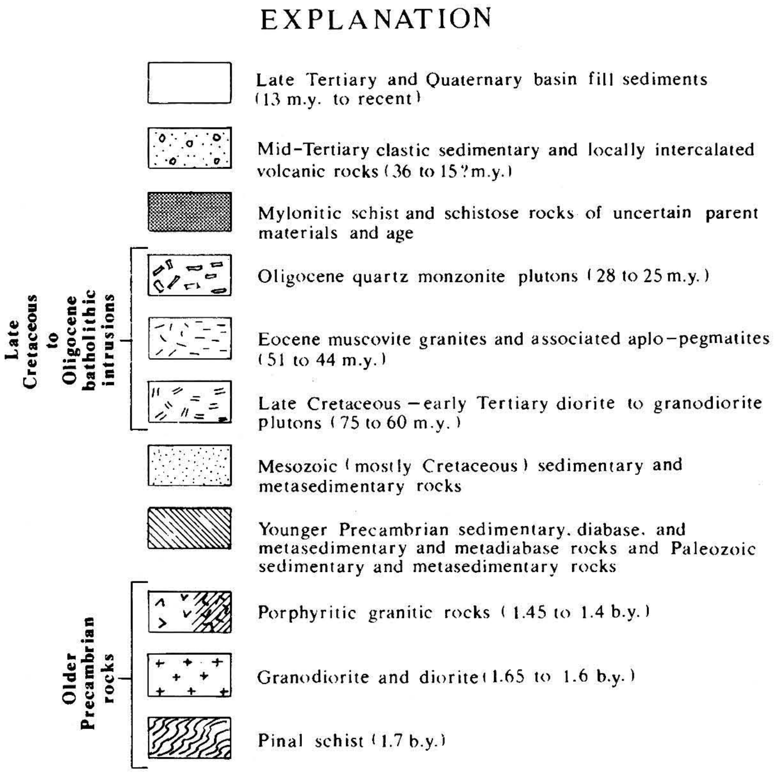


Figure 3. Generalized geologic map of Santa Catalina–Rincon–Tortolita crystalline complex showing locations of cross sections and plutons discussed in text. Sources of map data are as follows: for Tortolita Mountains—Budden (1975), Banks and others (1977), and Keith (unpub. mapping); for Santa Catalina Mountains—Tolman (1914, unpub. mapping as presented in Wilson and others, 1969), Creasey (1967), Shakel (1974), Creasey and Theodore (1975), Banks (1976), Hoelle (1976), Suemnicht (1977), Wilson (1977), and Keith (unpub. mapping); for Rincon Mountains—Drewes (1974, 1977) and Thorman and Drewes (1978). Aligned patterns in Late Cretaceous through Oligocene intrusions show deformed areas of mylonitic gneiss, and random patterns show undeformed areas. East-northeast–trending ruled lines show areas of mylonitically deformed porphyritic mesocratic gneiss believed to have been previously undeformed 1,400- to 1,450-m.y.-old biotite granitic rocks (shown by random pattern). Barbed heavy lines are low-angle faults with barbs in upper plate. Heavy lines are high-angle normal faults with bar and ball on downthrown side.



specimens and photomicrographs of protomylonite, mylonite, and mylonite gneiss as presented in the classification of cataclastic rocks proposed by Higgins (1971). Some areas of mylonitic gneiss contain very coarse-grained pegmatites concordantly interlayered with the mylonitic augen gneisses. The interiors of these pegmatites are commonly highly broken or brecciated, possess no foliation, and are more properly referred to as cataclasites in the classification scheme of Higgins (1971). Areas we call "mylonitic" may contain variable fractions (usually minor) of pegmatite cataclasites.

GENERAL GEOLOGY OF THE CRYSTALLINE COMPLEX

General geology of the Santa Catalina–Rincon–Tortolita crystalline complex is presented in simplified map form in Figure 3 and depicted diagrammatically in four cross sections (Figs. 4, 5, 6, and 7). Frequently mentioned localities are shown geographically in Figure 8. Readers are directed to discussions and references cited in Creasey and others (1977), Budden (1975), Shakel (1974, 1978), Davis (1975, 1977a, 1977b, 1978, and this volume), Drewes (1977), Drewes and Thorman (1978), Thorman (1977), Davis and Coney (1979), and Banks (this volume) for other recent perspectives.

In a general way, the Santa Catalina–Rincon–Tortolita complex is composed of a crystalline core that is dominated by Phanerozoic plutonic rocks (~75% of outcrop). The remainder of the crystalline core consists of middle Proterozoic plutonic rocks (~20% of outcrop) and subordinate amounts of middle Proterozoic and Phanerozoic metasedimentary rocks. The crystalline core is mostly fault-bounded, except for segments of its north and northeast margins which are intrusive in nature.

The Phanerozoic plutonic rocks form a large composite batholith within which at least 10 and possibly 12 or more individual plutons (Fig. 3) have been delineated (see App. 1 for discussion of nomenclature of these bodies). Individual plutons are generally compositionally zoned and commonly

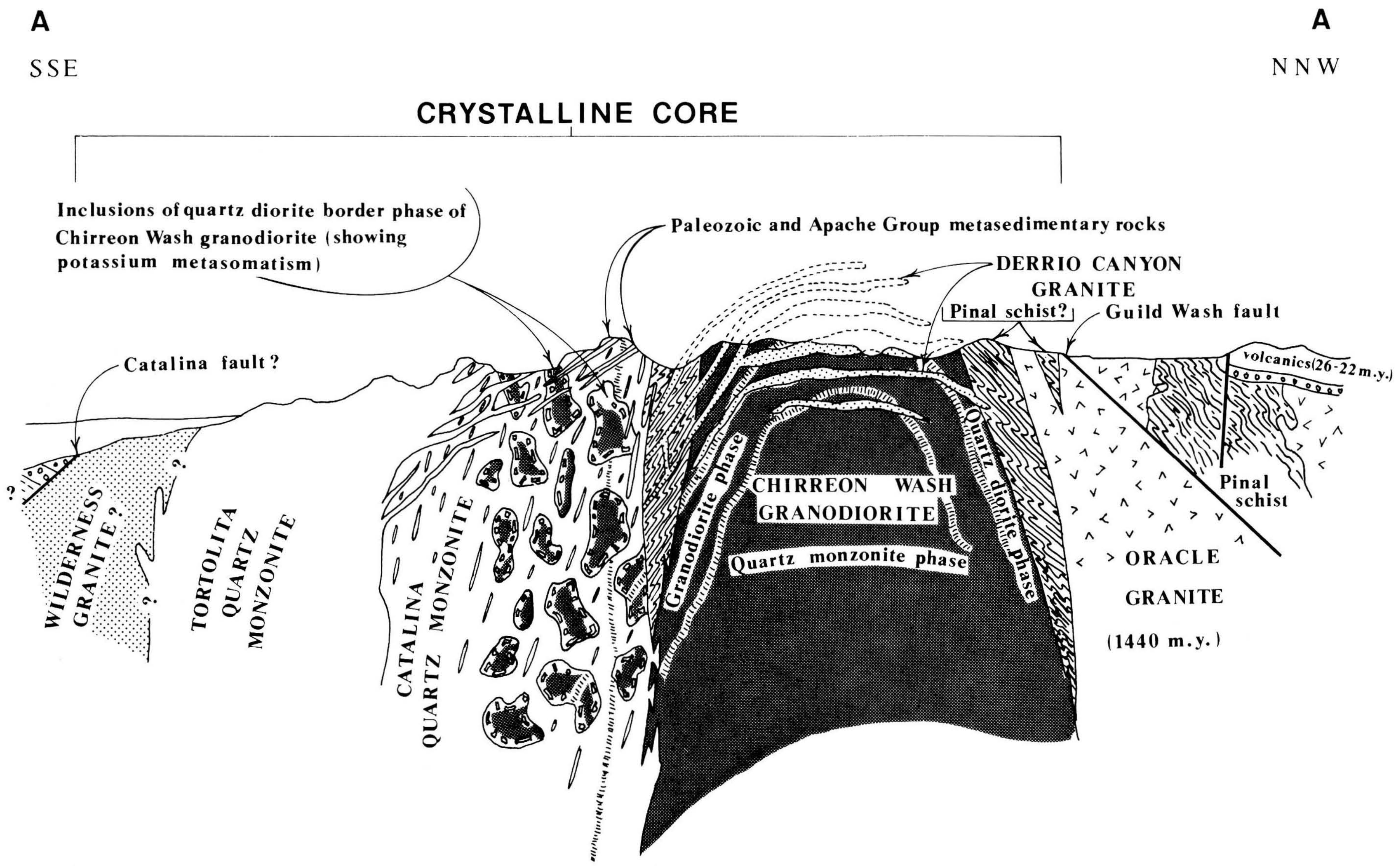


Figure 4. Diagrammatic cross section A–A′ through Tortolita Mountains. Location of section shown in Figure 3.

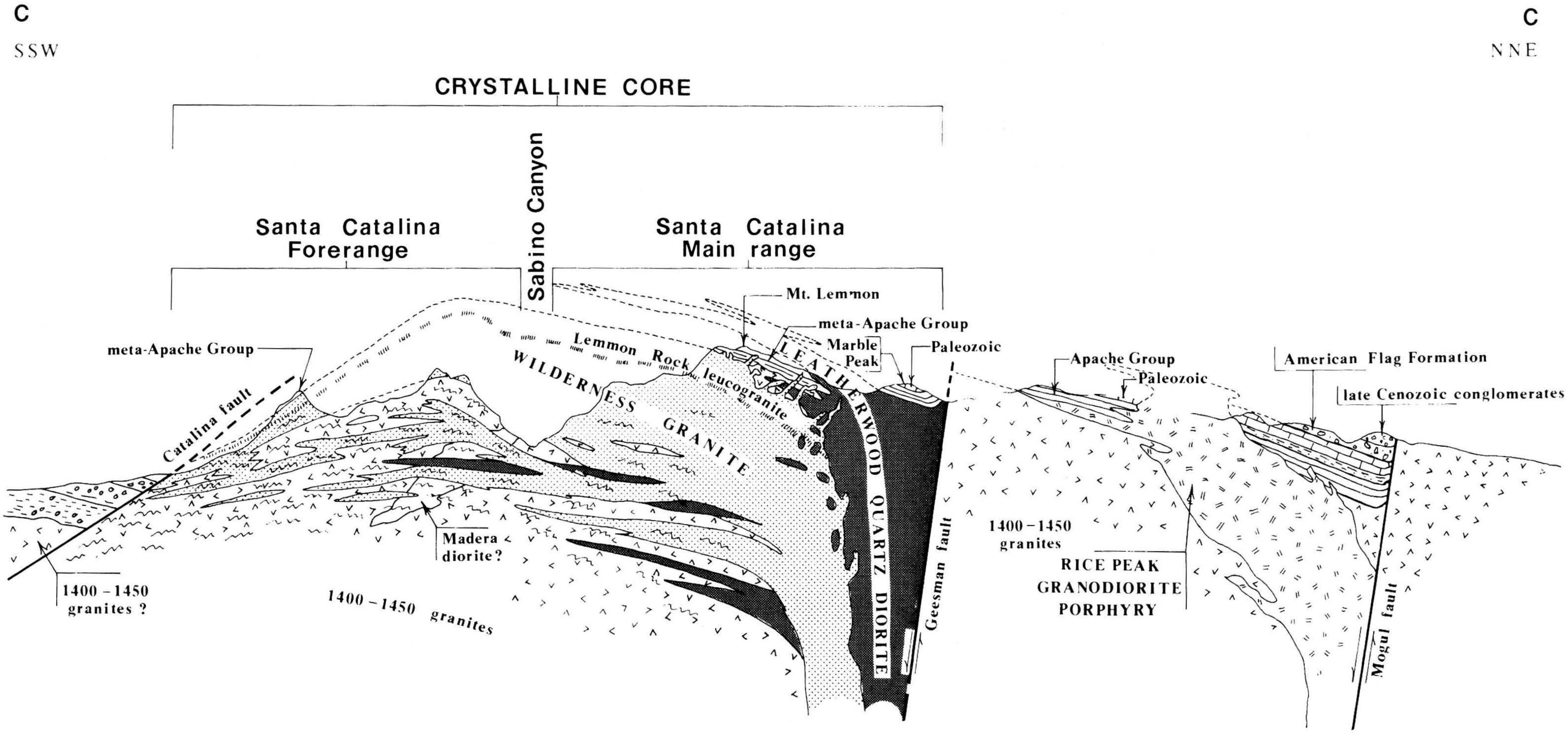
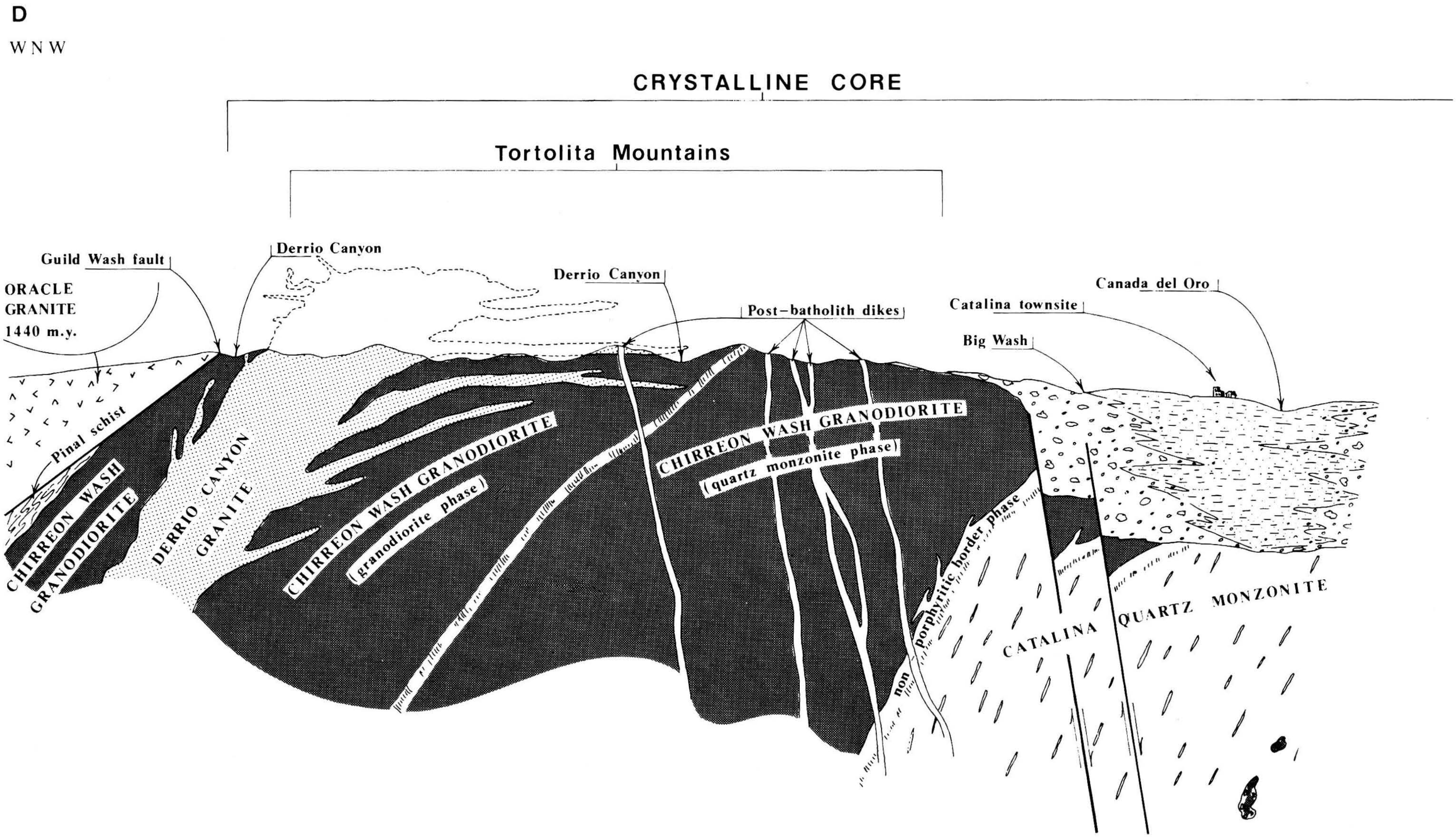


Figure 6. Diagrammatic cross section C–C′ through central Santa Catalina Mountains. Location of section shown in Figure 3. Mylonitic rocks shown by wavy lines.


D
WNW
CRYSTALLINE CORE
Tortolita Mountains
Guild Wash fault
ORACLE GRANITE 1440 m.y.
Derrio Canyon
Derrio Canyon
Post-batholith dikes
Catalina townsite
Canada del Oro
Big Wash
Pinal schist
CHIRREON WASH GRANODIORITE
DERRIO CANYON GRANITE
CHIRREON WASH GRANODIORITE (granodiorite phase)
CHIRREON WASH GRANODIORITE (quartz monzonite phase)
non porphyritic border phase
CATALINA QUARTZ MONZONITE

Mesozoic strata—all intruded by the Rice Peak granodiorite porphyry of presumed Laramide age and middle Tertiary porphyritic sphene-bearing hornblende-biotite Catalina quartz monzonite (Hoelle, 1976; Suemnicht, 1977; Shakel, 1978). At the far north end of the range, the Mogul fault juxtaposes these rocks against Oracle Granite in the upthrown northern block. In the western part of the Santa Catalina Mountains, undeformed Catalina quartz monzonite intrudes foliated Wilderness granite in Cargodera Canyon. Catalina quartz monzonite also intrudes and contains inclusions of Leatherwood quartz diorite (Suemnicht, 1977).

Tortolita Mountains

The western termination of the Santa Catalina Mountains is along the Pirate fault, a north-northeast–trending fault of late Tertiary age. Except for the alluvium-covered interval west of the Pirate fault, much of the Santa Catalina Mountains geology continues (Fig. 7) westward into the Tortolita Mountains (Budden, 1975; Banks and others, 1977; Davis, this volume). In this range, arches in mylonitic foliation are difficult to place precisely, but probably exist. The northern part of the crystalline core in the Tortolita Mountains consists of the Chirreon Wash granodiorite, an east-northeast–to due-east–trending composite pluton with quartz diorite, granodiorite, and quartz monzonite phases (Fig. 7). Intruding the granodiorite in its western exposures are abundant tabular bodies of granite, pegmatites, and alaskite herein referred to as Derrio Canyon granite. These plutons are locally mylonitic and bordered by east-trending schistose bands on both the north and south. To the

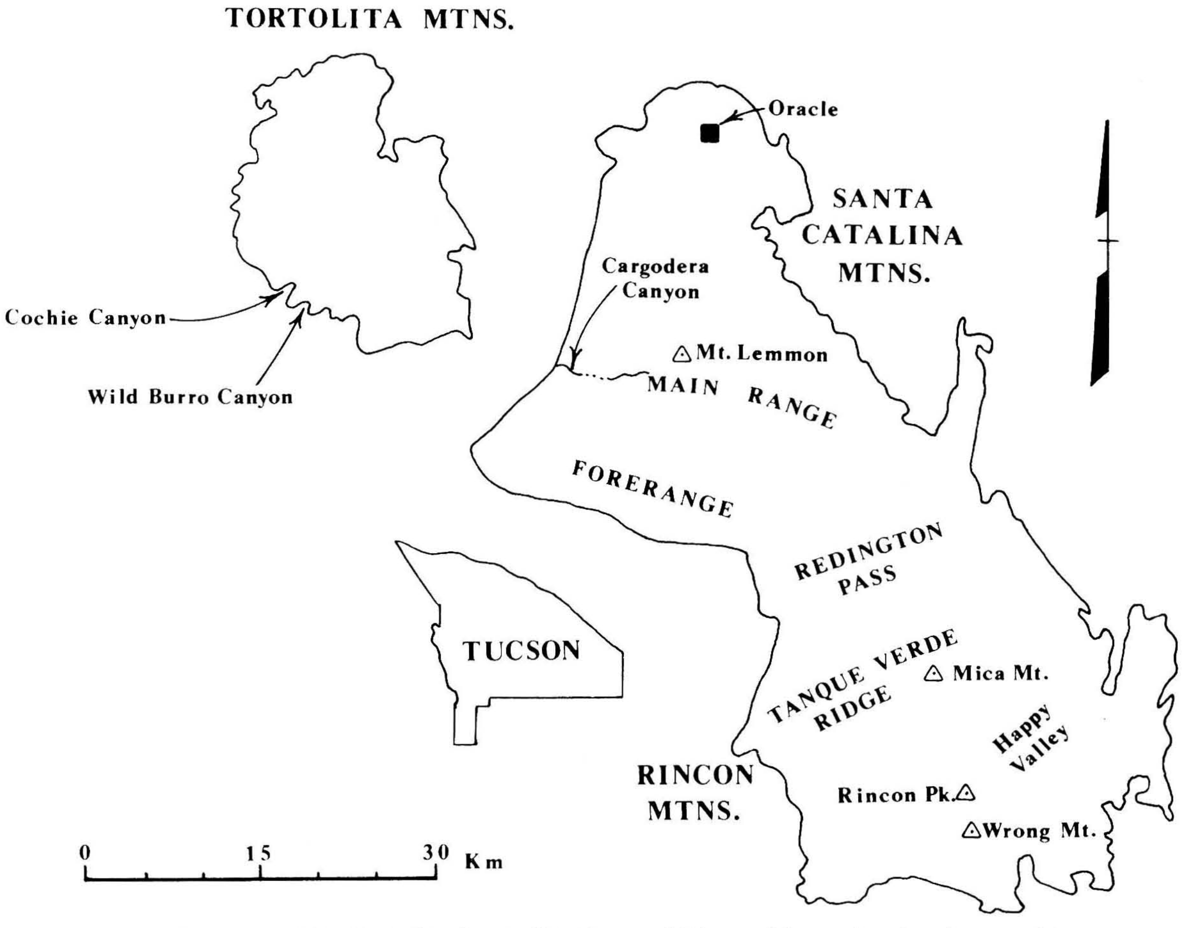


Figure 8. Outline map of the Tortolita, Santa Catalina, and Rincon Mountains showing localities frequently mentioned in text and Appendix 1.

north, the schistose rocks are in contact with mylonitized Oracle Granite. Farther to the northwest, both Oracle Granite and the schistose rocks are chloritized, brecciated, and overlain by a dislocation surface (Guild Wash fault). The schistose band that borders the Chirreon Wash pluton on the south is intruded on its south side by an east-northeast–trending mass of quartz monzonite which is lithologically similar to and correlated by us with the Catalina quartz monzonite of the northwest Santa Catalina Mountains. The Catalina quartz monzonite locally contains large quartz diorite inclusions of presumed Chirreon Wash granodiorite and truncates pegmatite apophyses of Derrio Canyon granite in the east-central Tortolita Mountains. In turn, the Catalina quartz monzonite is intruded by numerous apophyses of the Tortolita quartz monzonite pluton that crops out to the south-southeast. Both the Catalina and Tortolita intrusions locally contain a low-angle mylonitic foliation. The mylonitic foliation in all plutons is crosscut by northwest-striking, high-angle normal faults and shears that in many places are intruded by northwest-striking, undeformed to locally foliated granodiorite, quartz monzonite, and quartz latite dikes.

Rincon Mountains

The Rincon Mountains are geologically more similar to the Santa Catalina Mountains than they are to the Tortolita Mountains. Much of the Rincon Mountains is composed of muscovite-garnet–bearing granite (Wrong Mountain Quartz Monzonite of Drewes, 1977). The granite commonly envelops a dark biotitic augen gneiss (Continental Granodiorite of Drewes, 1977). Some parts of the granite have abundant pegmatite and alaskite. Both the granite and the dark augen gneiss exhibit the distinctive low-angle mylonitic foliation. This mylonitic gneiss complex is overlain to the northeast by metamorphosed and locally highly deformed younger Precambrian and Paleozoic rocks which become lower grade and less deformed up section (Drewes, 1974; Frost, 1977; Davis, this volume). The western and southern boundaries of the mylonitic complex are—like those of the southern Santa Catalina forerange—highly jointed, brecciated, chloritized, and overlain by the Catalina fault, a dislocation surface which dips gently off the flanks of the range (Pashley, 1966; Davis, 1975; Davis and Frost, 1976; Drewes, 1977). The low-angle mylonitic fabric has been deformed into several broad west-southwest–plunging arches and one north-northwest–trending arch and is intruded by several north-northwest–striking undeformed dikes (Thorman and Drewes, 1978).

CORRELATION AND GEOCHRONOLOGY OF ROCK UNITS

We have correlated rock units throughout the Santa Catalina–Rincon–Tortolita crystalline complex by considering rock types and field relationships in conjunction with trace-element and isotope geochemistry. Where possible, we have suggested correlation of rocks exposed within the complex to those exposed outside it. Correlation of rock units within the complex has been hampered by problems in nomenclature, presence of a pervasive mylonitic overprint, intense metamorphism of sedimentary protoliths adjacent to plutons, and, for all rock types, ubiquitous 20- to 30-m.y. K-Ar and fission-track cooling ages that present difficulties in determining original emplacement ages.

Perhaps the most serious problem is nomenclature because genetic bias is inherent in most of the terminology (see App. 1 for detailed discussion). Terms that contain the term "gneiss" in the Santa Catalina–Rincon–Tortolita complex commonly carry a metamorphic connotation of in situ anatexis, partial melting, hydrothermal metamorphism, or alkali-silica metasomatism (see, for example, Hernon, 1932; DuBois, 1959a, 1959b; Mayo, 1964; Peterson, 1968; Shakel, 1974; Sherwonit, 1974; Drewes, 1977; Banks, this volume). Terms that carry a plutonic name (such as quartz monzonite) in the complex traditionally have the genetic connotation of being fundamentally intrusive in origin (see for example, Tolman, as reported in Ransome, 1916; Creasey and others, 1977).

Another serious obstacle for correlation has resulted from one or more pervasive events of mylonitization. Large areas of the complex have been affected by an event (or by events) of mylonitization that largely obliterated original rock textures. Recognition of the importance of mylonitization (Creasey and Theodore, 1975; Davis and others, 1975; Banks, 1976) represents a fundamental change from earlier workers who regarded the mylonitic fabric as a "minor" event that was secondary to processes of metamorphism, anatexis, and alkali-silica metasomatism (Hernon, 1932; DuBois, 1959a, 1959b; Pilkington, 1962; Mayo, 1964; Peterson, 1968; Sherwonit, 1974; Shakel, 1974). These earlier workers believed that original protolith compositions were greatly obscured by drastic chemical changes which accompanied a "metamorphic transformation." In contrast, implicit in a "mylonitic model" is that a rock's present-day fabric is only a *textural* modification of an earlier protolith and that the bulk-rock chemistry need not have been significantly affected. In other words, "metamorphism" (mylonitization) could have been largely isochemical. The "mylonitic model" is strongly supported by our data because we can match Rb-Sr geochemistry of mylonitically deformed rocks within the Santa Catalina–Rincon–Tortolita crystalline complex to nondeformed counterparts in or adjacent to it (see succeeding sections).

The mylonitic model provides an additional caveat to the interpretation of various schistose tracts within the Santa Catalina–Rincon–Tortolita crystalline complex. It was or is widely believed that many of the gneissic rocks were derived from possible Precambrian Pinal Schist (Blake, 1908a, 1908b; DuBois, 1959a, 1959b; Pilkington, 1962; Mayo, 1964; Peterson, 1968; Sherwonit, 1974; Drewes, 1974, 1977). As a result, many of the schistose exposures in the gneisses have been mapped as Pinal Schist (for example, Drewes, 1974, 1977). However, the distinct probability now exists that many of these schistose bodies are mylonite schists derived during mylonitization at contacts between igneous protoliths of different compositions (for example, Davis, 1978, this volume). Conversely, it is equally possible, as we shall attempt to show in the Tortolita Mountains, to mistake real Pinal Schist for mylonitic schist. It is also possible to mistake recrystallized clastic rocks of the Apache Group for Pinal Schist or vice versa.

Most K-Ar and fission-track dates fall within the range of 20 to 30 m.y. B.P. (Damon and others, 1963; Mauger and others, 1968; Marvin and others, 1973, 1978; Creasey and others, 1977; Banks and others, 1978; this paper). These dates, which represent the termination of a thermal event, cannot alone be used to distinguish and correlate intrusive events within the complex. However, they do provide a cooling history for the most recent thermal events which suggests that the structurally lowest part of the complex cooled from about 400 °C 28 m.y. ago to 100 °C about 21 m.y. ago (Damon, 1968; Creasey and others, 1977) under a steep geothermal gradient (Mauger and others, 1968).

In order to document events that occurred before the late cooling history, Rb-Sr whole-rock studies were instituted in 1962. Little has been reported (Shakel, 1972, 1974; Shakel and others, 1972; Hoelle, 1976) until now because the results obtained were difficult to interpret. Reported U-Th-Pb studies (Shakel and others, 1977), the rediscovery of Tolman's deformed laccolith model by Creasey and others (1977), and recent field observations by us have provided a new perspective from which to evaluate the Rb-Sr data. Consequently, this is the first discussion that has as its data base the recently reported U-Pb studies (Shakel and others, 1977; Shakel, 1978), the recently summarized K-Ar and fission-track data (Creasey and others, 1977; Marvin and others, 1978; Damon and others, 1980), and numerous, previously unpublished Rb-Sr analyses determined by workers of the Laboratory of Isotope Geochemistry, University of Arizona, during the past 18 yr. When data from all these methods are considered together, an internally consistent evolutionary picture of the complex emerges. We will discuss rocks of the complex from oldest to youngest, beginning with Pinal Schist. The reader is referred to Damon and others (1980) for location, rock type, Rb-Sr analytical data, and geologic significance of each data point and to Table 1 for a summary of all available isotopic dates. Selected

TABLE 1. SUMMARY OF ISOTOPIC DATA FOR PLUTONS IN AND ADJACENT TO THE SANTA CATALINA—RINCON—TORTOLITA CRYSTALLINE COMPLEX

Rock name and comments	Reference* and sample no.	Age (m.y.)	Method	Area
MIDDLE PROTEROZOIC GRANITIC ROCKS				
Madera Diorite				
Emplacement age is probably around 1,670 m.y. Younger ages are variously reduced by younger metamorphisms or intrusive events	11: DEL-9 - 13-65	1,695 ± 30	Rb-Sr whole-rock isochron	Pinal Mts.
	6: PED-2-59	1,665 ± 40	K-Ar biotite	Pinal Mts.
	1: 24H	1,645 ± 60	K-Ar hornblende	Ray mine area
	1: 24B	100 ± 2	K-Ar biotite	Ray mine area
	11: DEL-12 & 16-65	1,540 ± 50	Rb-Sr mineral isochron	Pinal Mts.
	2: TMN-93	1,440 ± 10	K-Ar biotite	Tortolita Mts.
Johnny Lyon Granodiorite				
1,625 m.y. is probably emplacement age. 1,545-m.y. age is reduced age on Rincon Valley Granodiorite mapped by Drewes (1974). Correlated with Johnny Lyon Granodiorite by Silver (1978)	21: L-312, L-609	1,625 ± 10	U-Pb zircon	Johnny Lyon Hills
	14: 69D64	1,545 ± 60	K-Ar biotite	E. Rincon Mts.
Rincon Valley Granodiorite				
Rock petrographically resembles Johnny Lyon Granodiorite. K-Ar ages probably reduced (Silver, 1978)	14: 69D61	1,455 ± 50	K-Ar biotite	Rincon Valley
	14: 69D61	1,560 ± 100	K-Ar hornblende	Rincon Valley
Oracle Granite				
Emplacement age is about 1,440 m.y. Cenozoic ages reflect resetting by Late Cretaceous-Tertiary thermal events	6: PED-3-58	1,425 ± 40	K-Ar muscovite	near Oracle
	12: PED-2-58	1,410 ± 40	Rb-Sr biotite	near Oracle
	6: PED-2-58	1,430 ± 40	K-Ar biotite	near Oracle
	12: DEL-13-62	1,380 ± 39	K-Ar biotite	near Oracle
	12: DEL-13-62	1,425 ± 40	K-Ar plagioclase	near Oracle
	19: Unknown	1,440	U-Pb zircon	near Oracle
	11: Several	1,380	Rb-Sr whole-rock isochron	Oracle-Sierra Ancha regions
	7: PED-27-57	39.4 ± 1.2	K-Ar biotite	Oracle
Ruin Granite				
Emplacement age is about 1,425 m.y.	12: PED-32-61	1,470 ± 40	K-Ar biotite	Sierra Ancha
	12: DEL-3-62	1,415 ± 40	K-Ar biotite	Hess Canyon, Gila Mts.
	12: DEL-3-62	1,435 ± 40	K-Ar plagioclase	Hess Canyon, Gila Mts.
	12: DEL-3-62	1,455 ± 40	K-Ar biotite	Hess Canyon, Gila Mts.
	12: DEL-3-62	1,385	Rb-Sr biotite	Hess Canyon, Gila Mts.
Continental Granodiorite				
Most exposures are coarsely porphyritic and petrographically resemble other members of the 1,400- to 1,450-m.y. granitic suite. Silver (1978) showed that outcrops in type area in northern Santa Rita Mountains contain rocks of Johnny Lyon and and Oracle ages. Most of the Precambrian ages of various exposures suggest most outcrops of Continental Granodiorite are 1,400 m.y. old. We have restricted the term "Continental Granodiorite" to exposures of coarsely porphyritic 1,400-m.y.-old rocks and their mylonitic equivalents within the Rincon Mountain part of the crystalline core of the complex. Younger ages reflect subsequent thermal events	14: 66D46	1,360 ± 200	Pb-α zircon	N. Santa Rita Mts.
	14: 66D46	56.8 ± 2.5	K-Ar biotite	N. Santa Rita Mts.
	14: 65D914	1,450 ± 160	Pb-α zircon	N. Santa Rita Mts.
	14: 65D914	825 ± 80	Rb-Sr whole rock	N. Santa Rita Mts.
	13: 74D62	1,340 ± 60	K-Ar biotite	Tanque Verde Mts.
	13: 74D62	1,415 ± 50	K-Ar muscovite	Tanque Verde Mts.
	13: 74D62	1,410 ± 50	Rb-Sr whole rock	Tanque Verde Mts.
	13: 74D62	26.1 ± 3.5	Fission-track apatite	Tanque Verde Mts.
	13: 74D57	1,395 ± 50	K-Ar biotite	Tanque Verde Mts.
	13: 74D57	1,390 ± 50	K-Ar muscovite	Tanque Verde Mts.
	13: 74D57	∿800	Fission-track zircon	Tanque Verde Mts.
	13: 74D57	55.0 ± 4.2	Fission-track apatite	Tanque Verde Mts.
	20: Unknown	1,430	U-Pb zircon	N. Santa Rita Mts.
	20: Unknown	1,600+	U-Pb zircon	N. Santa Rita Mts.
	20: Unknown	1,420	U-Pb zircon	Little Rincon Mts.
	9: PED-14-59	1,375 ± 40	K-Ar muscovite	N. Empire Mts.
POST-PALEOZOIC BATHOLITHIC ROCKS				
Quartz diorite-granodiorite (Leatherwood) suite				
Chirreon Wash Granodiorite	2: UAKA-75-86	25.1 ± 0.5	K-Ar biotite	N.-central Tortolita Mts.
Leatherwood quartz diorite				
Emplacement age is probably 75 to 65 m.y. Younger ages are interpreted as reduced ages (see text). 73-m.y. Rb-Sr whole-rock isochron is a composite of Leatherwood plus Chirreon Wash plutons. 70-m.y. Rb-Sr whole-rock isochron is Leatherwood only. 38-m.y. K-Ar sericite age is from quartz vein that cuts Leatherwood quartz diorite	5: BR 2	27.1 ± 0.5	K-Ar biotite	N. Santa Catalina Mts.
	5: BR 2	64.4 ± 1.0	K-Ar hornblende	N. Santa Catalina Mts.
	5: Unknown	27.1 ± 0.5	K-Ar biotite	N. Santa Catalina Mts.
	5: Unknown	38.4 ± 0.6	K-Ar hornblende	N. Santa Catalina Mts.
	4: ML-60†	23.5 ± 0.7	K-Ar biotite	N. Santa Catalina Mts.
	4: ML-60†	36.8 ± 1.0	K-Ar hornblende	N. Santa Catalina Mts.
	4: ML-60†	21.2 ± 0.7	Fission-track apatite	N. Santa Catalina Mts.
	4: ML-60†	28.6 ± 3.7	Fission-track sphene	N. Santa Catalina Mts.
	22: 24	24.9 ± 1.0	K-Ar whole rock	N. Santa Catalina Mts.
	22: 51	29.6 ± 1.1	K-Ar biotite	N. Santa Catalina Mts.
	22: 30	36.7 ± 2.0	K-Ar hornblende	N. Santa Catalina Mts.
	22: 45	32.2 ± 1.2	K-Ar biotite	N. Santa Catalina Mts.
	22: 52	28.9 ± 1.1	K-Ar biotite	N. Santa Catalina Mts.
	22: 69	28.5 ± 1.1	K-Ar biotite	N. Santa Catalina Mts.
	8: PED-1-68	30.2 ± 0.8	K-Ar biotite	N. Santa Catalina Mts.
	9: PED-1-68	25.7 ± 7.1	Rb-Sr mineral isochron	N. Santa Catalina Mts.
	9: UAKA-76-116	31.7 ± 0.7	K-Ar biotite	N. Santa Catalina Mts.
	9: Several	73	Rb-Sr w.-r. ref. isochron	N. Santa Catalina Mts.
	9: Several	70	Rb-Sr w.-r. ref. isochron	N. Santa Catalina Mts.
	9: UAKA-78-66	37.7 ± 0.8	K-Ar sericite	N. Santa Catalina Mts.
	12: PED-18-62D§	28.3 ± 0.9	K-Ar biotite	Santa Catalina forerange
Muscovite granite (Wilderness) suite				
Wilderness granite				
Emplacement age is probably 44 to 50 m.y. Younger ages are interpreted as variably reduced (see text)	7: PED-4-58	26.5 ± 1.0	K-Ar muscovite	Santa Catalina forerange
	7: PED-4a-58	25.4 ± 1.0	K-Ar biotite	Windy Point, Santa Catalina main range
	7: PED-4a-58	30.2 ± 0.9	K-Ar muscovite	
	7: PED-4a-58	23.3 ± 1.4	Rb-Sr biotite	
	12: PED-4a-58	36.9 ± 1.0	Rb-Sr muscovite	
	3: 100	33 ± 3	K-Ar muscovite	
	3: 100	1,340 ± 30	^{206}Pb/^{207}Pb-zircon	
	3: 100	50	U-Pb zircon	
	4: GGN-S1	23.3 ± 0.7	K-Ar biotite	
	4: GGN-S1	24.8 ± 0.7	K-Ar muscovite	
	4: GGN-S1	19.3 ± 2.7	Fission-track apatite	
	12: PED-18-62L§	25.6 ± 1.0	K-Ar biotite	Santa Catalina forerange
	12: PED-18-62L§	26.1 ± 1.0	K-Ar muscovite	Santa Catalina forerange

TABLE 1. *(Continued)*

Rock name and comments	Reference* and sample no.	Age (m.y.)	Method	Area
	Muscovite granite (Wilderness suite *(continued)*			
Wilderness granite *(continued)*	12: PED-18-62L§	27.5 ± 0.8	K-Ar orthoclase	Santa Catalina forerange
	12: PED-18-62L§	30.0 ± 1.0	K-Ar plagioclase	Santa Catalina forerange
	16: RM-1-66§	32.0 ± 0.3	K-Ar muscovite	Santa Catalina forerange
	16: PED-56-66§	31.9 ± 0.9	K-Ar muscovite	Santa Catalina forerange
	9: UAKA-71-11§	23.1 ± 0.5	K-Ar muscovite	Santa Catalina forerange
	9: UAKA-72-76§	24.0 ± 0.6	K-Ar K-feldspar	Santa Catalina forerange
	7: PED-15-59	47.9 ± 2.1	K-Ar muscovite	Santa Catalina main range
	15: 77-D-68	21.9 ± 0.8	K-Ar biotite	Redington Pass
	15: 77-D-68	35.1 ± 1.2	K-Ar muscovite	Redington Pass
	19: Unknown	44-47	U-Th-Pb monazite	Santa Catalina main range
	19: Unknown	44-47	U-Th-Pb monazite	W. Santa Catalina forerange
	9: Numerous	47	Rb-Sr w.-r. ref. isochron	Santa Catalina main range
	9: UAKA-71-21	46.5 ± 10.4	K-Ar garnet	Santa Catalina forerange
Youtcy granite Possibly an extension of Wilderness pluton; date may reflect age of emplacement	15: 77D81	45.8 ± 1.6	K-Ar muscovite	Redington Pass
Espiritu Canyon granite Ages are probably reduced	13: 71D194	27.6 ± 0.9	K-Ar biotite	Mica Mtn.
	13: 71D194	28.5 ± 0.6	K-Ar muscovite	Mica Mtn.
Wrong Mountain granite K-Ar ages are probably reduced. Rb-Sr sample plots on 47-m.y. Wilderness Granite isochron. Former older age reported by Drewes (1977) was a model age which assumed a 0.703 initial ratio for $^{87}Sr/^{86}Sr$	14: 71D17	24.1 ± 0.9	K-Ar biotite	E. Rincon Mts.
	14: 71D17	25.4 ± 0.9	K-Ar muscovite	E. Rincon Mts.
	13: 71D17	23.3 ± 5.8	Fission-track apatite	E. Rincon Mts.
	13: 71D17	24.6 ± 4.0	Fission-track zircon	E. Rincon Mts.
	13: 73D52	25.0 ± 0.8	K-Ar biotite	Central Rincon Mts.
	13: 73D52	25.3 ± 2.9	Fission-track apatite	Central Rincon Mts.
	13: 73D52	20-30	Fission-track zircon	Central Rincon Mts.
	9: 73D52	47	Rb-Sr w.-r. ref. isochron	Central Rincon Mts.
	7: PED-30-60	33.5 ± 1.1	K-Ar muscovite	Mica Mtn.
	9: UAKA-74-80	25.4 ± 0.5	K-Ar biotite	E. Rincon Mts.
	Quartz monzonite (Catalina) suite			
Catalina quartz monzonite Large degree of concordance implies emplacement age of about 28 to 25 m.y. 90-m.y. isochron included samples of xenoliths (probably Leatherwood), contaminated border phase, and a radiogenically enriched aplite. 90-m.y. age is too old	7: PED-16-59	25.6 ± 0.8	K-Ar biotite	NW. Santa Catalina Mts.
	4: BR 21	23.9 ± 1.2	K-Ar biotite	NW. Santa Catalina Mts.
	4: BR 21	23.7 ± 0.7	K-Ar hornblende	NW. Santa Catalina Mts.
	4: BR 21	30.0 ± 3.0	Fission-track sphene	NW. Santa Catalina Mts.
	4: BR 21	28.9 ± 3.3	Fission-track zircon	NW. Santa Catalina Mts.
	4: BR 21	23.5 ± 2.8	Fission-track apatite	NW. Santa Catalina Mts.
	4: ML 61	22.9 ± 0.7	K-Ar hornblende	NW. Santa Catalina Mts.
	4: ML 61	24.7 ± 0.7	K-Ar biotite	NW. Santa Catalina Mts.
	4: ML 61	28.3 ± 3.1	Fission-track sphene	NW. Santa Catalina Mts.
	4: ML 61	27 1 ± 3.4	Fission-track zircon	NW. Santa Catalina Mts.
	4: ML 61	20.8 ± 2.1	Fission-track apatite	NW. Santa Catalina Mts.
	4: BR 16	23.8 ± 0.7	K-Ar biotite	NW. Santa Catalina Mts.
	4: BR 16	28.0 ± 3.0	Fission-track sphene	NW. Santa Catalina Mts.
	4: BR 16	25.9 ± 2.5	Fission-track zircon	NW. Santa Catalina Mts.
	4: BR 16	21.7 ± 2.1	Fission-track apatite	NW. Santa Catalina Mts.
	16: PED-20-62	28.0 ± 0.9	K-Ar biotite	SW. Tortolita Mts.
	4: RC 3	21.6 ± 0.6	K-Ar hornblende	SW. Tortolita Mts.
	4: RC 3	21.1 ± 0.6	K-Ar biotite	SW. Tortolita Mts.
	19: Unknown	27	U-Pb zircon	NW. Santa Catalina Mts.
	9: Numerous	26	Rb-Sr w.-r. ref. isochron	NW. Santa Catalina Mts.
	18, 10: Numerous	90	Rb-Sr whole-rock isochron	NW. Santa Catalina Mts.
Tortolita quartz monzonite Age of emplacement is about 25 m.y.	7: PED-17-59	24.5 ± 0.5	K-Ar biotite	Cargodera Canyon, Santa Catalina Mts.
	4: RC 25	22.7 ± 0.7	K-Ar biotite	Tortolita Mts.
	4: RC 25	18.5 ± 2.4	Fission-track apatite	
	4: ML 105	17.0 ± 2.1	Fission-track apatite	
	9: Numerous	26	Rb-Sr w.-r. ref. isochron	
Happy Valley quartz monzonite 28 and 38 m.y. K-Ar dates on northern mass may be reduced if pluton is a member of the Wilderness suite	14: 69D93	28.0 ± 1.1	K-Ar biotite	Happy Valley
	14: 69D95	37.7 ± 1.6	K-Ar muscovite	Happy Valley
	14: 71D122	26.9 ± 0.9	K-Ar biotite	Happy Valley
	MISCELLANEOUS ROCKS			
Postbatholith dikes Probable emplacement ages	9: UAKA-74-83	24.3 ± 0.5	K-Ar whole rocks	Rincon Mts.
	9, 17: UAKA-72-21	21.0 ± 0.3	K-Ar whole rock	Santa Catalina forerange
	2: UAKA-75-87	24.0 ± 0.5	K-Ar biotite	North-Central Tortolita Mts.
Schistose rocks Ages are probably reduced	7: PED-29-60	27.7 ± 1.0	K-Ar muscovite	Mica Mtn.
	14: 69D92	29.1 ± 1.1	K-Ar muscovite	Happy Valley
	14: 70D143	34.6 ± 1.2	K-Ar biotite	Happy Valley
	14: 70D143	29.6 ± 0.9	K-Ar muscovite	Happy Valley

Note: Constants used are $\lambda_\beta = 4.963 \times 10^{-10}yr^{-1}$; $\lambda_e = 0.581 \times 10^{-10}yr^{-1}$, $\lambda = 5.544 \times 10^{-10}yr^{-1}$; $^{40}K/K = 1.167 \times 10^{-4}$ atom/atom; $\lambda_{Rb} = 1.42 \times 10^{-11}yr^{-1}$. Fission-track dates reported by Creasey and others (1977) are recalculated 2.6% older to conform with new K-Ar constants. Rb-Sr w.-r. ref. isochron = Rb-Sr whole-rock reference isochron.

*References as follows: 1, Banks and others (1972); 2, Banks and others (1978); 3, Catanzaro and Kulp (1964); 4, Creasey and others (1977); 5, Creasey (1979, written commun.); 6, Damon and others (1962); 7, Damon and others (1963); 8, Damon and others (1969); 9, Damon and others (1980); 10, Hoelle (1976); 11, Livingston (1969); 12, Livingston and others (1967); 13, Marvin and Cole (1978); 14, Marvin and others (1973); 15, Marvin and others (1978); 16, Mauger and others (1968); 17, Shakel (1974); 18, Shakel and others (1972); 19, Shakel and others (1977); 20, Silver (1978); 21, Silver and Deutsch (1963); 22, Soderman (1979, written commun.).

†Mafic inclusion in Catalina quartz monzonite of unassigned protolith by Creasey and others (1977). Creasey (1979, written commun.) assigned this inclusion to the Leatherwood quartz diorite.

§These samples are found within the forerange mylonitic gneiss complex and are correlated with presumed nonmylonitic counterparts pending further work.

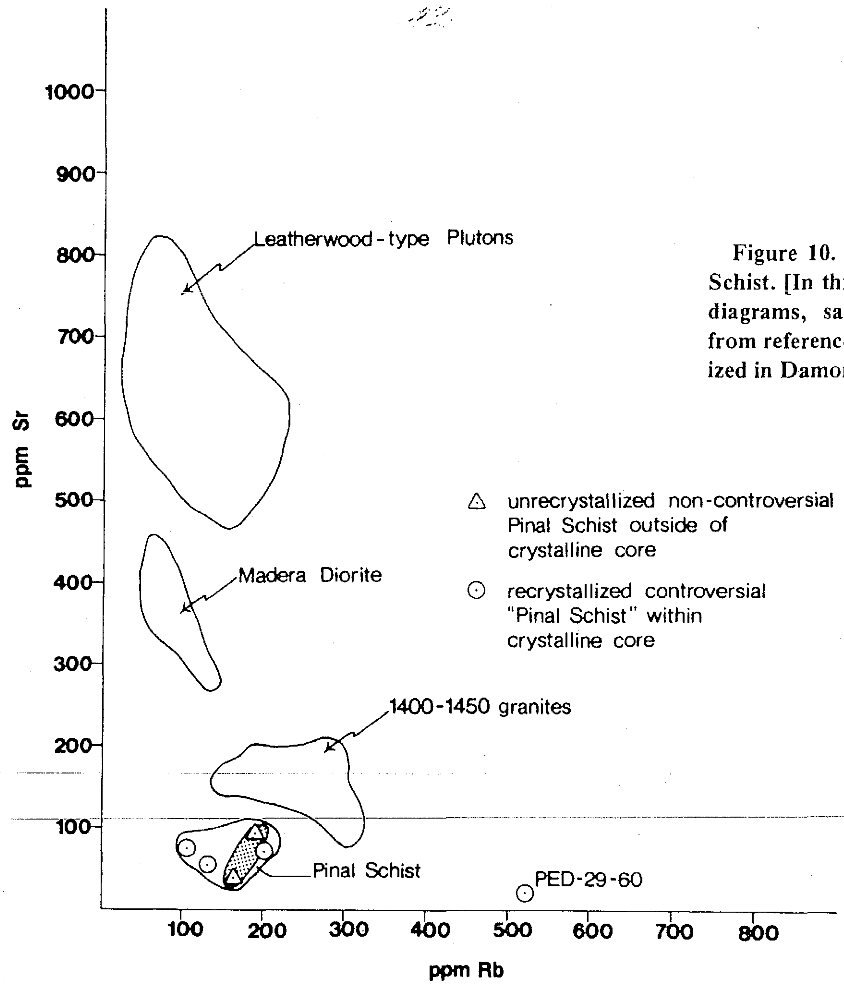


Figure 10. Rb-Sr abundances in Pinal Schist. [In this and all subsequent Rb-Sr diagrams, sample numbers shown are from references cited and will be summarized in Damon and others (1980).]

data points of particular interest are identified in the figures and are discussed in Damon and others (1980).

Pinal Schist

The oldest rocks within the complex are exposures of probable 1.7-b.y.-old Pinal Schist (Fig. 3). Different interpretations currently exist in published maps [see, for example, discussion in map text of Banks and others (1977) in the Tortolita Mountains and Davis (this volume) versus Drewes (1977) in the Tanque Verde Ridge area] regarding which exposures in the complex are indeed Pinal Schist and which are mylonitic schists derived from probable igneous protoliths. Exposures of unequivocal Pinal Schist in the complex are few and probably largely restricted to the northwestern Santa Catalina Mountains and the central Tortolita Mountains. As further support for these contentions, the Rb-Sr abundances and Sr-isotope ratios (Damon and others, 1980) from the schistose bands north and south of Chirreon Wash granodiorite in the Tortolita Mountains are similar to those for unequivocal Pinal Schist outside the complex (Fig. 10). The data do not support the proposal of Banks (this volume) that the schistose bands are mylonite schist derived entirely from the Chirreon Wash pluton and Oracle Granite (in the case of the northern band). Rb-Sr abundances in all of the other samples we have collected are unlike those of Pinal Schist.

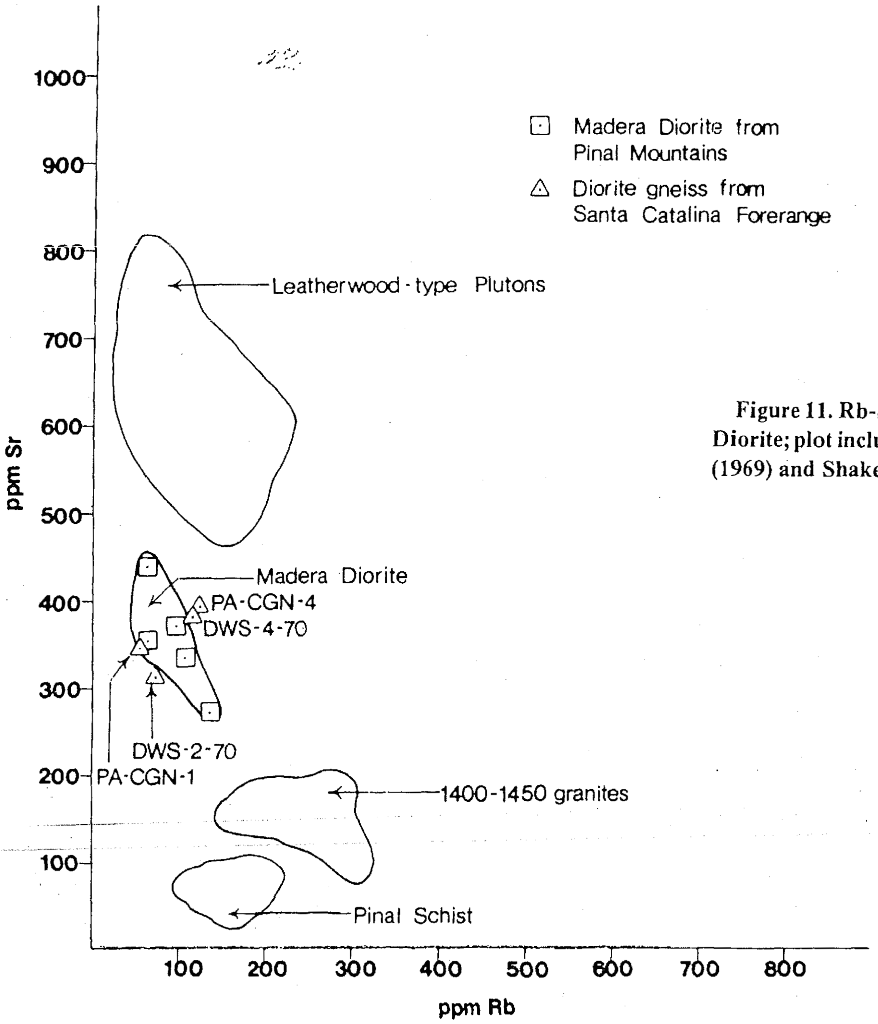


Figure 11. Rb-Sr abundances in Madera Diorite; plot includes data from Livingston (1969) and Shakel (1974).

Precambrian Diorite

Some exposures of foliated diorite (Fig. 3) *may* represent the next oldest rocks in the complex. These diorites lack the abundant epidote and Rb-Sr abundances (Fig. 11) characteristic of the Leatherwood quartz diorite of Late Cretaceous–early Tertiary age. Instead, the Rb-Sr data suggest similarities to 1.65-b.y.-old Madera Diorite of the Pinal Mountains (Ransome, 1903; Livingston and Damon, 1968; Livingston, 1969). This similarity is supported by isotopic data (Fig. 12) for the diorite that plots near a 1.65-b.y. reference isochron through Madera Diorite (Livingston, 1969) at the type locality in the Pinal Mountains. Although the data are somewhat equivocal, the possibility that a Maderalike protolith may constitute part of the dark, mylonitic augen gneisses should not be ignored.

Oracle Granite and Equivalent Granitic Rocks

Creasey and others (1977) suggested that dark augen gneisses of the Catalina forerange are mylonitic equivalents of 1.44-b.y.-old Oracle Granite, a contention which was confirmed by U-Pb systematics in zircons reported by Shakel and others (1977). Rb-Sr abundances (Fig. 13) strongly support this and further indicate that porphyritic varieties of Rincon Valley and Continental Granodiorites (Drewes, 1974, 1977) in the Rincon Mountains and rocks mapped as Oracle Granite in the Tortolita Mountains

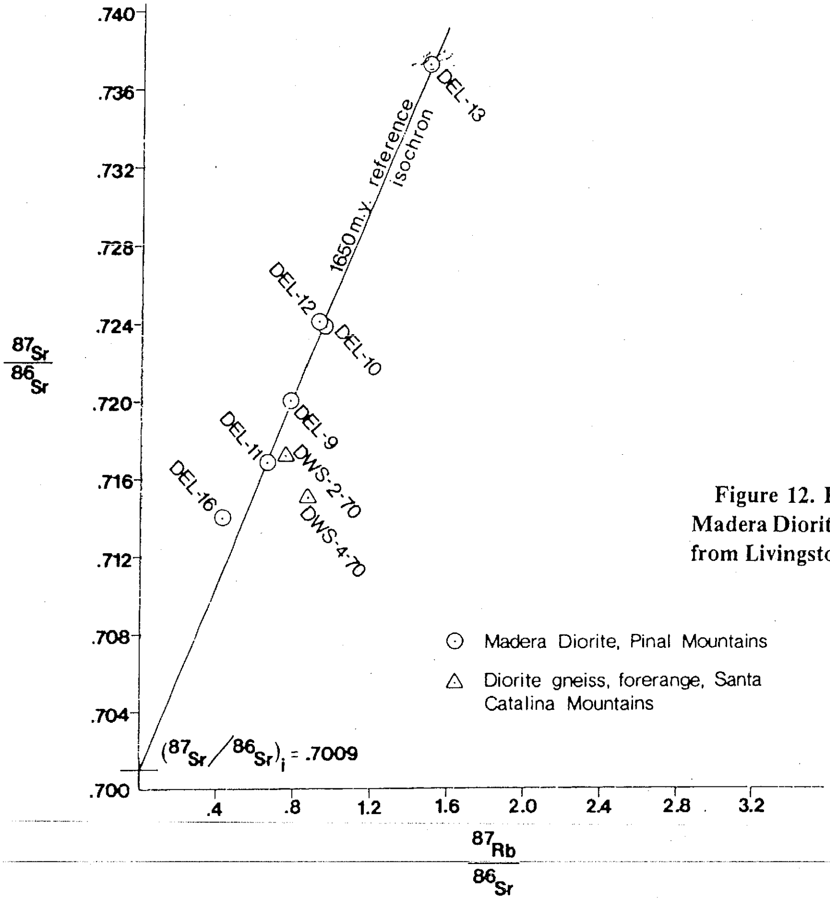


Figure 12. Rb-Sr isochron diagram for Madera Diorite samples; plot includes data from Livingston (1969) and Shakel (1974).

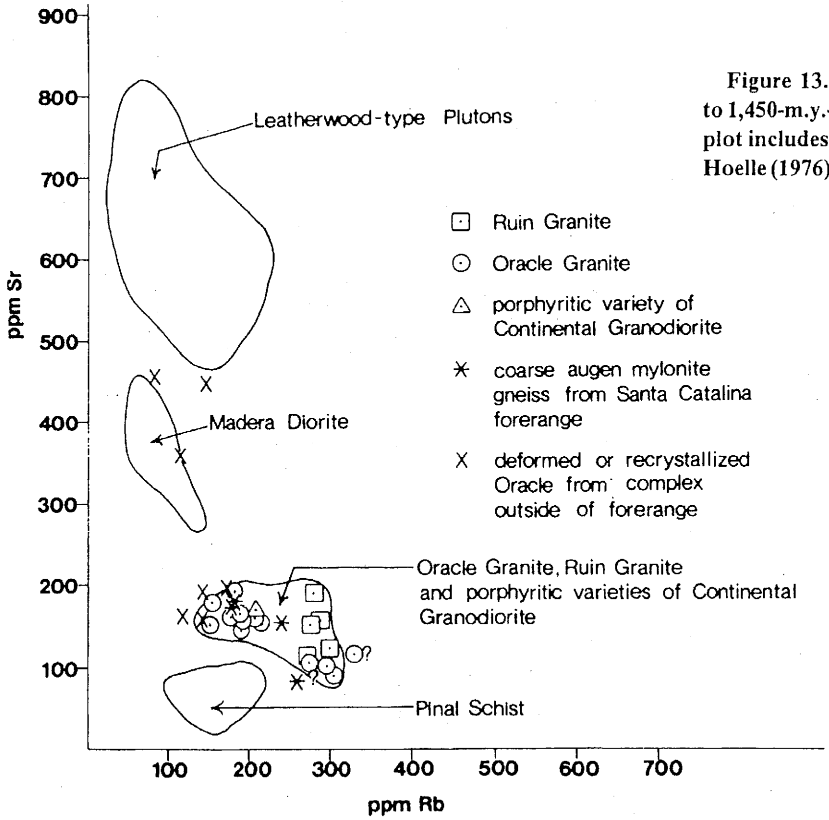


Figure 13. Rb-Sr abundances in 1,400- to 1,450-m.y.-old porphyritic granitic rocks; plot includes data from Livingston (1969), Hoelle (1976), and Marvin and Cole (1978).

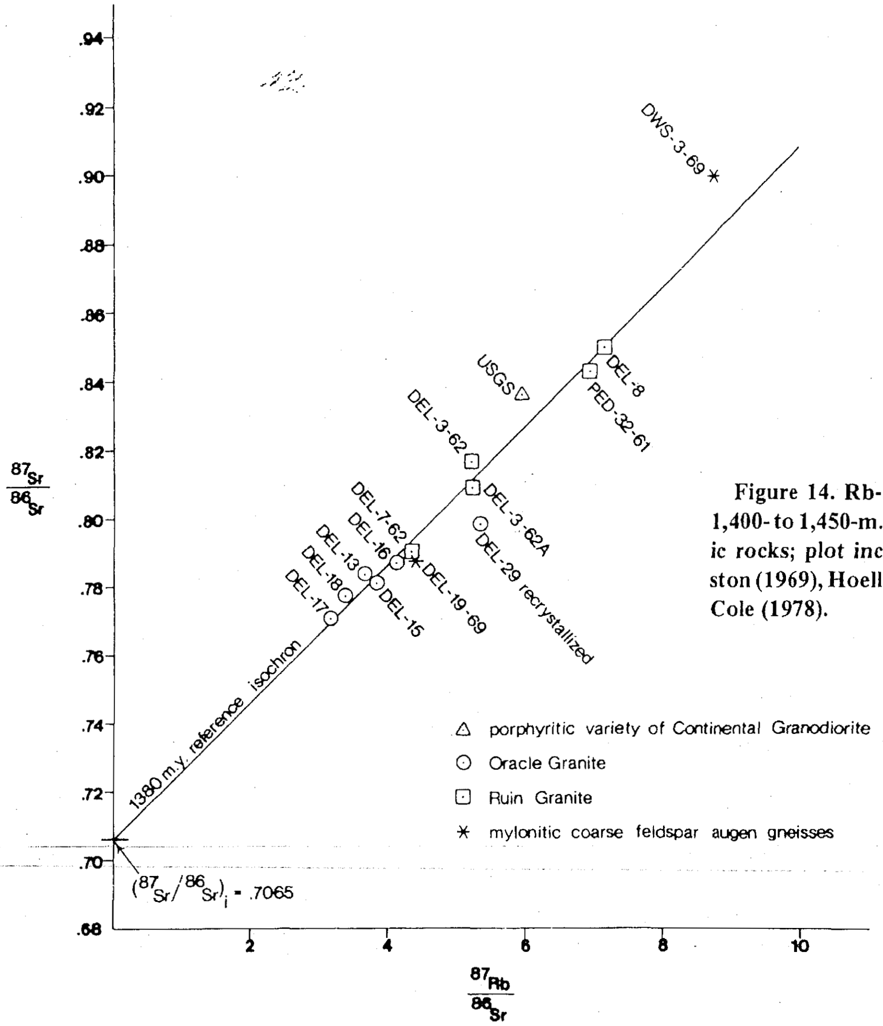


Figure 14. Rb-Sr isochron diagram for 1,400- to 1,450-m.y.-old porphyritic granitic rocks; plot includes data from Livingston (1969), Hoelle (1976), and Marvin and Cole (1978).

(Banks and others, 1977) are members of the 1.4- to 1.45-b.y.-old generation of porphyritic granitic plutons (Damon and Giletti, 1961; Giletti and Damon, 1961; Livingston and Damon, 1968; Silver, 1968, 1978). Isotopic data (Fig. 14) for these rocks, when compared to data for undeformed 1.4-b.y.-old Oracle and Ruin Granites (Livingston, 1969), strengthen the correlation. All available data, therefore, indicate that a *majority* of dark augen gneisses in the complex are deformed 1.4- to 1.45-b.y.old plutons (see App. 1 for further discussion).

Younger Precambrian Apache Group, Diabase, and Paleozoic Rocks

Younger Precambrian Apache Group, diabase, and Paleozoic strata (Fig. 3) occur within the complex and are variably metamorphosed and deformed (Waag, 1968; Budden, 1975; Frost, 1977). Although we have no Rb-Sr data on these rocks, we concur with most of the recent mapping in the Tortolita (Banks and others, 1977) and Santa Catalina Mountains (Creasey and Theodore, 1975; Banks, 1976) about the map position of Apache Group, diabase, and Paleozoic strata. Also, on lithologic grounds, we would add that parts of the southern Santa Catalina forerange rocks (Shakel, 1974, 1978) between Pontatoc and Ventana Canyons (Fig. 5) may equate to metadiabase (amphibolite lenses) or metamorphosed Apache Group strata (quartzite and schist lenses).

Post-Paleozoic Batholithic Rocks

The post-Paleozoic intrusive bodies in the Santa Catalina–Rincon–Tortolita complex can be divided into three suites with plutons of each suite possessing distinctive rock types, field relationships, trace-element and isotopic compositions, and age. The suites are as follows: (1) Late Cretaceous–early Tertiary quartz diorite–granodiorite (Leatherwood suite); (2) Eocene muscovite granite–pegmatite–alaskite with high $^{87}Sr/^{86}Sr$ initial ratios (Wilderness suite); and (3) middle Tertiary quartz monzonite (Catalina suite). The history of nomenclature for each pluton is discussed in Appendix 1, and a summary of the various published radiometric determinations on each pluton is presented in Table 1. Representative modes for plutons of each suite are given in Tables 2 through 5. Analytical data and sample descriptions for new Rb-Sr and K-Ar data will appear in Damon and others (1980).

Late Cretaceous–Early Tertiary (Laramide) Quartz Diorite–Granodiorite (Leatherwood) Suite. Three plutons of quartz dioritic to granodioritic compositions are currently assigned to the Leatherwood suite: the Chirreon Wash granodiorite, an east-elongated, ~40-km² pluton in the east-central Tortolita Mountains; the Rice Peak granodiorite, two probably interconnected stock and sill-like masses, about 12 km², in the northern Santa Catalina Mountains; and the Leatherwood quartz diorite, a 40-km² body in the northeast part of the Santa Catalina Mountains.

Leatherwood suite plutons are characterized by abundant biotite (15% to 25%) in more mafic phases and are mainly quartz dioritic to granodioritic in composition. Epidote is a characteristic accessory mineral of all Leatherwood suite plutons and occurs as several textural varieties (Hanson, 1966; Creasey, 1967; Banks and others, 1978). Representative modes of Leatherwood suite plutons are given in Table 2.

Crosscutting relationships with adjacent plutons indicate that plutons of the Leatherwood suite are the oldest post-Paleozoic intrusions in the complex. Leatherwood quartz diorite and Chirreon Wash granodiorite are both clearly cut by muscovite granite and related aplite, alaskite, and pegmatite apophyses of the Eocene Wilderness suite. In the Tortolita Mountains, Chirreon Wash granodiorite is cut by hundreds of pegmatite dikes and sheets that extend eastward from and grade into or cut the Derrio Canyon muscovite-garnet granite. The Derrio Canyon granite cuts across the Chirreon Wash granodiorite as a north-northeast–trending dikelike mass. The Chirreon Wash granodiorite is older than the middle Tertiary Catalina quartz monzonite, as shown by indirect relationships. The Catalina quartz monzonite occurs in a 2- to 3-km-wide east-northeast– to due-east–trending arcuate belt parallel to and south of the southern contact of the Chirreon Wash granodiorite (Fig. 3). The Chirreon Wash granodiorite is generally separated from the Catalina quartz monzonite by a narrow, arcuate, east-northeast–trending screen of schist tentatively correlated here with the Pinal Schist (see previous

TABLE 2. MODAL MINERALOGY OF LEATHERWOOD SUITE PLUTONS

	1	2	3	4	5	6
Quartz	22	21.0	28	16	19	2-20
K-feldspar	5	7.5	8	6	12	tr.-20
Plagioclase	42 (An_{30-45})	47.0 (An_{38})	31	41	51	36-65 (An_{35-45})
Biotite	19	20.0	18	9	9	10-26
Hornblende	1	3.5	5	..	..	6-18
Epidote	1	..	4	9	4	1-2
Sphene	<1	tr.	..	1	1	1-4
Other	10	..	6	18	3	..
Opaque grains	..	2.0	..	tr.	1	1-4
Apatite	..	tr.	..	tr.	tr.	tr.

Note: Columns as follows: (1) average of 26 thin sections reported by Hanson (1966); (2) sample BR2 from Banks (this volume); (3) sample 5-2-1 from Suemnicht (1977); (4) sample AZ-LWQ-3 from Tom Heidrick (1979, written commun.); (5) sample AZ-LWD-1 from Tom Heidrick (1979, written commun.); (6) range in composition of Chirreon Wash pluton reported by Banks and others (1977). Trace = tr.

TABLE 3. CHEMICAL DATA FOR LEATHERWOOD QUARTZ DIORITE

	BR-2	AZ-LWD-1	AZ-LWD-3
SiO_2	62.7	64.8	62.1
Al_2O_3	16.1	16.3	16.6
Fe_2O_3	2.1	4.3*	4.9*
FeO	2.1	..	..
MgO	2.9	n.d.	n.d.
CaO	4.7	2.38	3.08
Na_2O	3.7	3.94	3.48
K_2O	2.8	2.40	2.28
P_2O_5	0.22	0.13	0.28
TiO_2	0.60	0.61	0.72
L.O.I.	..	0.52	1.0

Note: Samples AZ-LWD-1 and AZ-LWD-3 from Tom Heidrick (1979, written commun.). Sample BR 2 from Banks (this volume). Analysis of AZ samples by Rocky Mountain Geochemical Corp., Midvale, Utah. Loss on ignition (L.O.I.) determined gravimetrically. Other data determined by atomic absorption, except TiO_2 and P_2O_5, which were determined colorimetrically. Not determined = n.d.

*Total Fe expressed as Fe_2O_3.

discussion). Numerous pegmatites related to the Derrio Canyon granite of the Wilderness suite extend eastward across the Chirreon Wash granodiorite, intrude the schistose screen, and are truncated by the Catalina quartz monzonite. Also, large, partially metasomatized inclusions of epidote-bearing biotite quartz diorite are common within the Catalina quartz monzonite. Many of these inclusions bear a strong resemblance to an epidote-bearing biotite quartz diorite phase locally present along the northwest border of the Chirreon Wash granodiorite. If the quartz diorite inclusions correlate with the border phase, the Chirreon Wash granodiorite is older than the Catalina quartz monzonite.

Within the north-central Santa Catalina Mountains, the Leatherwood quartz diorite intrudes upper Paleozoic rocks (Creasey and Theodore, 1975; Banks, 1976) and is, thus, at least a young as Mesozoic. The Leatherwood quartz diorite sill sequence in the Apache Group is abruptly truncated for some 20

TABLE 4. MODAL MINERALOGY OF WILDERNESS GRANITE

	Quartz	Plagioclase	K-Feldspar*	Biotite	Muscovite	Opaque grains	Garnet	Others	Reference
Marshall Gulch pegmatite (part of Lemmon Rock leucogranite)	25	35 (An$_{7-12}$)	37 (m)	Minor	Minor	Minor	Minor	Minor	Matter (1969)
Control Road pegmatite (part of Lemmon Rock leucogranite)	35	31 (An$_{7-12}$)	29 (m)	Minor	More than above	Minor	Minor	Minor	Matter (1969)
Caseco pegmatite—about 30 m below upper contact between Wilderness Granite and metamorphosed Apache Groups	20	42 (An$_{7-13}$)	27	Trace	6	..	4	..	Matter (1969)
Aplite—same location as above	19	32 (An$_{7-13}$)	43	Minor	4	..	1	..	Matter (1969)
Wilderness Granite—various locations within upper half of main sill; average of 10 analyses	28	29 (An$_{20-25}$)	27 (m)	4	7	1 (magnetite)	1-2[†]	..	Pilkington (1962)
East Fork gneiss[#]—layer just below base of main Wilderness Granite sill; average of 7 analyses	31.3	26.6 (An$_{20-25}$)[§]	29.7 (o)	7.4	4.5	0.2	..	0.4	Sherwonit (1974)
Thimble Peak gneiss[#]—average of 16 analyses	32.9	33.6 (An$_{20-25}$)[§]	26.6	4.1	2.4	0.2	..	0.2	Sherwonit (1974)
Sabino Narrows gneiss[#]—light bands; average of 8 analyses	31.6	36.8 (An$_{20-25}$)[§]	28.2	1.7	1.6	0.1	..	..	Sherwonit (1974)
Gibbons Mountain gneiss[#]—average of 7 analyses	29.9	35.5 (An$_{20-25}$)[§]	26.0	7.7	0.3	0.4	..	0.2	Sherwonit (1974)
Soldier Canyon gneiss[#]—light bands; average of 15 analyses	30.4	37.8 (An$_{25-30}$)[§]	25.7	4.2	0.6	0.3	..	0.2	Sherwonit (1974)
Seven Falls gneiss[#]—average of 7 analyses	29.1	41.3 (An$_{25-30}$)[§]	21.8	7.2	0.1	0.3	..	0.3	Sherwonit (1974)

*Microcline = m; orthoclase = o.

[†] Included under "others" by Pilkington (1962).

[§] These An values are from Peterson (1968).

[#] Terminology for gneiss units in Santa Catalina forerange is from Peterson (1968). These units are interpreted by us as injection sheets on lower levels of the Wilderness sill complex.

TABLE 5. AVERAGE MODAL ANALYSES OF CATALINA SUITE PLUTONS AND ORACLE GRANITE

	1	2	3	4	5	6
Quartz	33	26.8	35.0	39.2	42.2	29.5
K-feldspar	28	34.3	40.2	31.2	41.0	29.8
Plagioclase	28	26.7 (An$_{26-35}$)	16.2 (An$_{29}$)	26.4 (An$_{20}$)	10.4 (An$_{25}$)	35.6 (An$_{30-35}$)
Biotite	9	7.5	7.4	3.2	3.2	0.6
Hornblende	..	0.8	0.2	..	..	..
Opaque grains	..	1.3	2.0	Trace	..	1.0
Sphene	..	0.6	0.6	..	..	..
Apatite	..	0.4	0.1	..	..	Trace
Muscovite	..	..	..	..	..	3.2

Note: Columns as follows:

1. Oracle granite (Banerjee, 1957), average of 38 samples reported under sample 50 by Hoelle (1976, Table 1).
2. Catalina quartz monzonite, main porphyritic phase; average of 11 samples as follows: one sample (48) from Erickson (1962), two samples (BR-21 and ML-61) from Creasey and others (1977), five samples (nos. 6, 9, 10, 11, and 12) from Hoelle (1976), 3 samples (5-3-2, 5-4-2, 5-4-3) from Suemnicht (1977).
3. Catalina quartz monzonite, border phase; average of one sample (BR-16) from Creasey and others (1977) and one sample from Suemnicht (1977).
4. Tortolita quartz monzonite; one sample (ML-105) from Creasey and others (1977).
5. Reef of Rock granite; average of four samples as follows: one sample (53) from Peirce (1958); three samples (5-6-3, 5-6-4, 5-6-5) from Suemnicht (1977).
6. Northern body of Happy Valley quartz monzonite; average of eight samples (A through G) from Miles (1965); the body is questionably assigned to Catalina suite.

km along its west-northwest–trending southern margin by Eocene Wilderness granite and related Lemmon Rock leucogranite. Aplites and pegmatites of the Lemmon Rock leucogranite abundantly intrude Leatherwood quartz diorite in the Mount Lemmon area as originally pointed out by Peirce (1958) and Hanson (1966). Similarly, pegmatite apophyses of presumed Wilderness granite intrude Leatherwood in the Korn Kob mine area 20 km east-southeast of Mount Lemmon (Wilson, 1977; Ted Theodore, 1979, oral commun.).

From the work of Banks (1976) and Suemnicht (1977), Leatherwood quartz diorite is intruded by middle Tertiary Catalina quartz monzonite 5 km north of Mount Lemmon. Here, numerous finer-grained apophyses and the coarse-grained main phase of Catalina quartz monzonite intrude Leatherwood, and large inclusions of Leatherwood are contained in Catalina quartz monzonite (Suemnicht, 1977). Also, the Leatherwood quartz diorite is intruded along its western contact by a large north-northeast–trending dikelike mass of the Catalina suite named Reef of Rock granite (Suemnicht, 1977). Numerous xenoliths of Leatherwood occur in Reef of Rock granite, according to Suemnicht (1977).

In summary, geologic relationships suggest that plutons of the Leatherwood suite are post-Paleozoic but predate granites of the Wilderness suite, which will be shown in the next section to be of Eocene age (44 to 50 m.y. old). The Leatherwood suite is therefore restricted to Mesozoic or earliest Tertiary.

We have Rb-Sr geochemistry for Leatherwood quartz diorite and Chirreon Wash granodiorite. High Sr abundances for both plutons are unique in the Santa Catalina–Rincon–Tortolita crystalline complex (Fig. 15). Poor spread in $^{87}Sr/^{86}Sr$ ratios prohibits a conclusive isochron for either pluton (Fig. 16). However, if the plutons are *assumed* to be comagmatic—a permissible assumption considering their impressively similar rock types, position in the intrusive sequence, and Rb-Sr geochemistry—the data for both plutons approximately conform to a Late Cretaceous (73 m.y. B.P.) reference

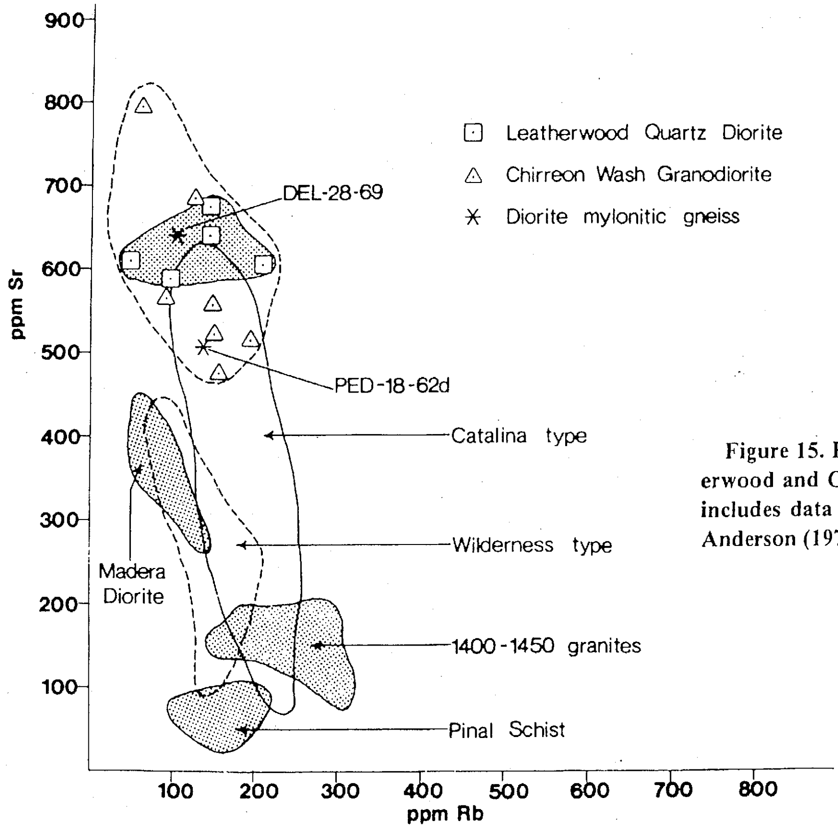


Figure 15. Rb-Sr abundances in Leatherwood and Chirreon Wash plutons; plot includes data from Matter (1969) and P. Anderson (1978, oral commun.).

isochron. The reference isochron, although not rigorously defensible, does not violate any independent geologic age constraints for either or both plutons.

Additional isotopic support for the Laramide age of the Leatherwood quartz diorite was generously provided to us by S. C. Creasey (1979, written commun.) of the U.S. Geological Survey, who has determined K-Ar isotopic ages of two hornblende-biotite mineral pairs. One sample of hornblende-biotite quartz monzonite (Leatherwood) came from Red Ridge about 5 km north of Mount Lemmon and about 150 m (500 ft) east of the contact with the Catalina quartz monzonite. The K-Ar isotopic ages are 38.4 ± 0.7 m.y. on hornblende and 26.1 ± 0.6 m.y. on biotite. These ages agree reasonably well with the K-Ar ages of hornblende (36.8 ± 1.0 m.y.) and biotite (23.5 ± 0.7 m.y.) from an inclusion of Leatherwood in the Catalina quartz monzonite near Cargodera Canyon (location IV in Fig. 2 of Creasey and others, 1977).

The second sample of hornblende-biotite quartz diorite came from near Lombar Hill about 10 km northeast of Mount Lemmon and about 3,960 m (13,000 ft) from the nearest known outcrop of Catalina quartz monzonite. K-Ar isotopic ages are 64.4 ± 1.0 m.y. on hornblende and 27.1 ± 0.5 m.y. on biotite. Creasey (1979, written commun.) indicated that the discordant ages of the mineral pairs are due to the differential Ar loss of the hornblende and biotite from reheating by the Catalina quartz monzonite and that the 64.4-m.y. age of the hornblende from the sample near Lombar Hill approximates the intrusion age of the Leatherwood. He concurred with our interpretation that the age of the Leatherwood is Laramide.

Creasey's K-Ar biotite data are similar to other K-Ar biotite ages of 30.2 (Damon and others, 1969) and 31.7 m.y. (this paper). These ages are complemented by 29.6, 32.2, 28.9, and 28.5 m.y. K-Ar biotite ages for probable Leatherwood sills in the Control mine area about 10 km northeast of Mount Lemmon (S. M. Soderman, 1979, written commun.). A whole-rock determination on one of these sills is 24.9 m.y., a hornblende concentrate yielded a discordant 36.7-m.y. K-Ar apparent age (S. M. Soderman, 1979, written commun.). Additionally, a Rb-Sr whole-rock–mineral isochron on

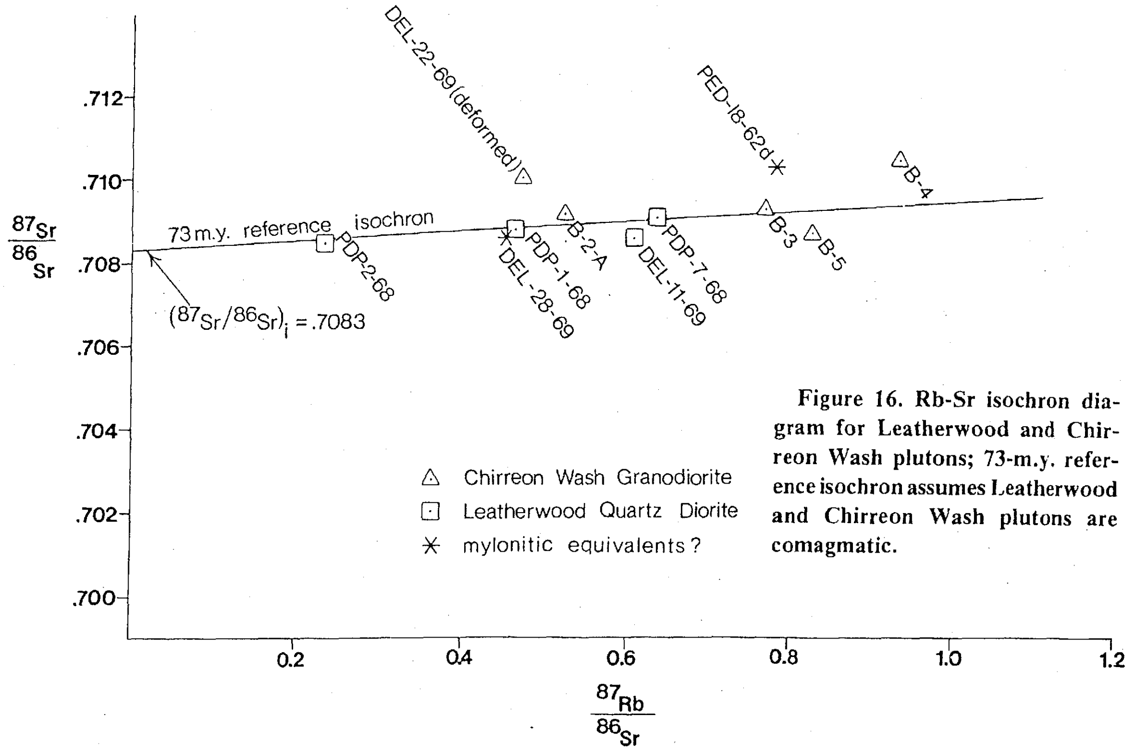


Figure 16. Rb-Sr isochron diagram for Leatherwood and Chirreon Wash plutons; 73-m.y. reference isochron assumes Leatherwood and Chirreon Wash plutons are comagmatic.

biotite, K-feldspar, plagioclase, epidote, and whole-rock from a single sample is 25.7 ± 7.1 m.y. (Damon and others, 1980). We interpret the 32- to 26-m.y. K-Ar biotite ages and Rb-Sr whole-rock–mineral isochron as reduced ages that reflect thermal resetting by Catalina suite plutons or uplift cooling of the complex between 30 and 20 m.y. B.P. The older hornblende ages are less reset because of their higher retentivity. With the exception of the 64-m.y. hornblende age, all K-Ar ages and the Rb-Sr whole-rock–mineral isochron age are reduced because they are all younger than 44 to 51 m.y., the age of Wilderness plutons that clearly intrude the Leatherwood (see next section). The 25-m.y. K-Ar biotite age reported by Banks and others (1978) for the Chirreon Wash pluton is similarly a reduced age.

Attempts to date the Leatherwood quartz diorite by U-Th-Pb techniques on zircons were unsuccessful and gave very discordant U-Th-Pb ages (Shakel, 1978). According to Shakel (1978), the discordant zircons indicated a "high degree of zircon inheritance," possibly from 1,440-m.y.-old Precambrian terrane.

Several additional indirect geologic relationships support the Laramide (75 to 50 m.y. B.P.) age for the Leatherwood suite. The Rice Peak granodiorite has been correlated on petrographic grounds with the Leatherwood quartz diorite by Waag (1968) and Creasey and Theodore (1975). If this correlation is valid, several intriguing implications arise for the age of the Leatherwood suite. The Rice Peak granodiorite clearly intrudes the lower part of the American Flag Formation from which Bromfield (1950) reported the freshwater pelecypod *Unio* (Triassic to Holocene) and the gastropod *Viviparus* (probably Cretaceous to Holocene). The rock type of the lower American Flag Formation is very suggestive of a correlation with the Cretaceous Fort Crittenden Formation (Hayes, 1970). Fort Crittenden equivalents are older than 75 to 72 m.y. on the basis of numerous radiometric ages for widespread overlying volcanic rocks, but are no older than 85 m.y. on the basis of the fossil assemblages contained within those equivalents (see Hayes and Drewes, 1978). *Assuming that all the correlations are valid,* Rice Peak granodiorite (and Leatherwood suite in general) is younger than ~72 m.y., the presumed minimum age of the lower American Flag Formation. Also of interest is the fact that Rice Peak granodiorite has been correlated with a petrographic analogue at San Manuel by Creasey (1967). Two samples of hydrothermal biotite from the granodiorite porphyry at San Manuel gave ages of 65 and 69 m.y. (Creasey, 1965; Rose and Cook, 1965).

Leatherwood quartz diorite is associated with significant porphyry copper–type skarn mineralization at Marble Peak (Braun, 1969) and possibly the Korn Kob mine farther southeast (Wilson, 1977). The time of most porphyry copper–type mineralization in southeast Arizona is essentially coeval with dates from various igneous minerals in spatially and temporally associated intrusions (Creasey and Kistler, 1962; Creasey, 1965; Rose and Cook, 1965; Livingston and others, 1967; Johnson, 1972). With the exception of Bisbee, Arizona, all porphyry copper mineralization is 70 to 50 m.y. old. A K-Ar age of 37.7 ± 0.8 m.y. (Damon and others, 1980) on sericite from a quartz vein that cuts Leatherwood indicates that Leatherwood is at least 38 m .y. old.

Another correlative device is chemical in nature. Three sets of major-element chemical analyses are now available for the Leatherwood quartz diorite (Table 3); K_2O/SiO_2 ratios indicate that the Leatherwood is calc-alkalic in the sense of Keith (1978). Data in the form of hundreds of chemical analyses suggest that true calc-alkalic plutons were emplaced in southeast Arizona only between 70 and 50 m.y. B.P. All other Arizona Phanerozoic plutonic rocks are more alkalic, according to the classification in Keith (1978).

A minimum age of about 50 m.y. for Leatherwood suite plutons is provided by the radiometric age of the Wilderness suite (next section), which clearly intrudes the Leatherwood suite in the Tortolita and Santa Catalina Mountains. Although no technique alone conclusively dates the Leatherwood suite, consideration of all available data converges on a 75- to 64-m.y. age for it.

Eocene Muscovite Granite (Wilderness) Suite. About 65% of the area of the Santa Catalina–Rincon–Tortolita complex is underlain by large sheetlike and laccolith-shaped muscovite granite plutons. Five asymmetric, laccolithic granitic intrusions are currently assigned to the Wilderness suite. They include the Derrio Canyon granite, a group of irregularly stacked sills in the northwestern Tortolita Mountains (Fig. 4); the Wilderness granite (and associated Lemmon Rock leucogranite), a west-northwest–trending batholith-sized laccolith in the main range of the central Santa Catalina Mountains, and several sills or injection sheets in the Santa Catalina forerange (Figs. 5 and 6); the Youtcy granite, an irregular stocklike mass that may be the east end of the Wilderness pluton in the Redington Pass area, between the Santa Catalina and Rincon Mountains; the Espiritu Canyon granite, an east-northeast–elongated pluton having diffuse contacts with the Wrong Mountain granite 2 km northeast of Mica Mountain in the Tanque Verde Mountains; and the Wrong Mountain granite, a batholith-sized laccolithic mass widespread throughout the Rincon and Tanque Verde Mountains. Previous nomenclature is summarized in Appendix 1. The Wilderness-Youtcy plutons are coextensive with Tolman's original batholith (Moore and others, 1949).

Wilderness-type plutons occupy a distinct mineralogic nitch in the Arizona Phanerozoic magmatic framework. For this reason, we affix the term "granite" to plutons of this suite to emphasize their unique mineralogy, even though some phases are technically quartz monzonites (Peterson, 1961) or monzogranites (Streckeisen, 1976). All Wilderness suite plutons contain muscovite with biotite and garnet as common accessories. Average modes for the Wilderness granite, the best-documented pluton of the suite, are listed in Table 4. The data are listed in ascending structural order so that pegmatites at the top of the mountain represent the top of the ~4.5-km-thick section of granitic rocks, much of which contains low-angle mylonitic deformation. The data seem to suggest several mineralogic changes within the Wilderness pluton. Structurally low sills are characterized by more biotite relative to muscovite and less K-feldspar relative to plagioclase feldspar than structurally higher phases. Garnet is locally present throughout the pluton but is evidently more abundant in upper structural levels, particularly in the Lemmon Rock leucogranite. A biotite-rich phase of the Wilderness granite is present south of Mount Bigelow 8 km east-southeast of Mount Lemmon.

Crosscutting relationships indicate that Wilderness suite granites occupy an intermediate stage in evolution of the Late Cretaceous–middle Tertiary batholith. Contact relationships were previously discussed between plutons of the Leatherwood suite and Wilderness suite. These indicate overwhelmingly that Wilderness suite granites intrude and are younger than Laramide Leatherwood suite plutons.

Contact relationships between different muscovite granite phases are commonly gradational (Shakel, 1978; Thorman and Drewes, 1978). Undeformed phases of two-mica Wilderness granite pass gradationally upward into Lemmon Rock leucogranite 2 km south of Mount Lemmon (Shakel, 1978). The Lemmon Rock leucogranite is composed of a complex of alaskites, pegmatites, and aplites. Several generations of dikes may be present in a single outcrop. In the northwest Tortolita Mountains, pegmatite phases of the Derrio Canyon granite extend some 10 km eastward from the main mass in the northwestern Tortolita Mountains. Many pegmatites become more granitic in texture and imperceptibly grade into the main Derro Canyon mass to the west. A few pegmatites cut this mass, but most exhibit a gradational relationship.

Wilderness suite plutons are clearly older than middle Tertiary quartz monzonites (Catalina suite). In the central Tortolita Mountains, pegmatite apophyses of the Derrio Canyon granite are truncated by Catalina quartz monzonite. In Cargodera Canyon in the western Santa Catalina Mountains, the foliated Lemmon Rock leucogranite phase of the Wilderness granite is intruded by and occurs as inclusions in the border phase of the Catalina quartz monzonite (see subsequent discussion in Catalina suite section). In the eastern Rincon Mountains, apophyses from the southern mass of Happy Valley quartz monzonite intrude Wrong Mountain granite, according to the mapping of Drewes (1975).

In summary, field relationships suggest approximate contemporaneity between various muscovite granite phases. Contact relationships clearly indicate that the muscovite granite suite intrudes and is younger than the Laramide Leatherwood suite but is intruded by and is therefore older than the middle Tertiary quartz monzonites (Catalina suite).

Most of our Rb-Sr geochemistry (Fig. 17) is on the Wilderness granite and related Lemmon Rock leucogranite and the Derrio Canyon granite. H. Drewes and R. F. Marvin of the U.S. Geological Survey have provided us with one analysis from the Wrong Mountain granite in the Rincon Mountains (1978, written commun.). The Rb and Sr abundances (Fig. 17) define a field for the Wilderness suite granites and their mylonitic equivalents that is offset from all other igneous rock types, a relationship consistent with the suite's unique mineralogy. Pegmatites with low Sr abundances form a distinct field separate from main phases of the Wilderness suite. We interpret these pegmatites to represent a low Sr residuum formed late in the differentiation history of the Wilderness sequence.

Isotopic data for Wilderness suite rocks (Fig. 18) show much scatter that we interpret as being mainly due to large variation in $^{87}Sr/^{86}Sr$ initial ratios and contamination by nearby highly radiogenic host rocks. Samples whose analyses scatter along the 1.44-b.y. reference isochron (Fig. 18) are generally in geologic settings in which they could have been easily contaminated by highly radiogenic Sr from nearby 1.45-b.y.-old Oracle Granite (see Damon and others, 1980). Some samples of pegmatite from the Santa Catalina forerange are anomalously radiogenic (Damon and others, 1980) and could represent radiogenically disturbed pegmatites of original Precambrian ancestry or small pockets of metamorphically differentiated material "sweated out" from Precambrian protoliths during Wilderness intrusion.

An outstanding example of the contamination phenomenon in Wilderness suite rocks occurs in the Lemmon Rock leucogranite phase of the Wilderness granite intrusion east and southeast of Mount

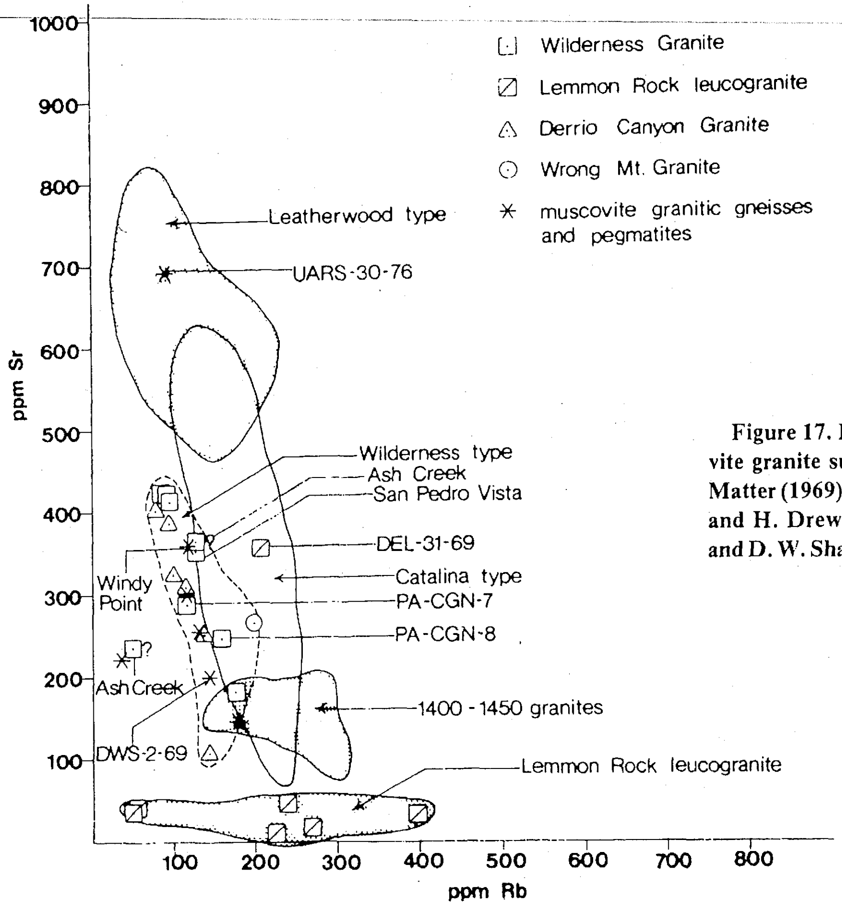


Figure 17. Rb-Sr abundances in muscovite granite suite; plot includes data from Matter (1969), Shakel (1974), R. F. Marvin and H. Drewes (1978, written commun.), and D. W. Shakel (1978, written commun.).

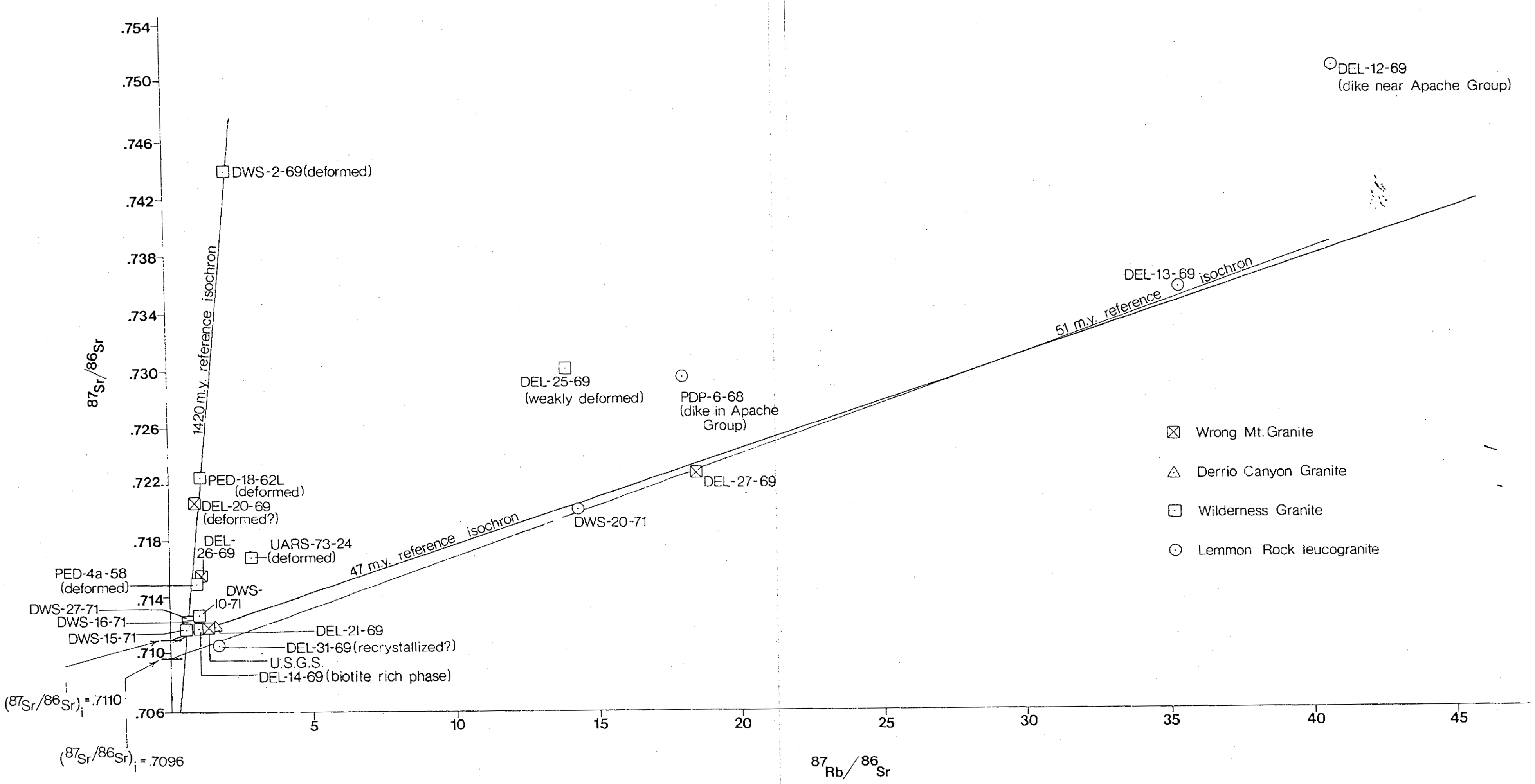


Figure 18. Rb-Sr isochron diagram for muscovite granite suite; plot includes data from Shakel (1974), D. W. Shakel (1978, written commun.), and R. F. Marvin and H. Drewes (1978, written commun.). The 47-m.y. reference isochron is constructed through non-deformed rocks that are sufficient distances from older highly radiogenic host rocks (Damon and others, 1980), and assumes Wilderness granite and Lemmon Rock leucogranite are comagmatic.

Lemmon. A sample of Lemmon Rock leucogranite (DEL-10-69) that contains numerous 1.44-b.y.-old Oracle Granite inclusions about 4 km southeast of Mount Lemmon is anomalously radiogenic ($^{87}Sr/^{86}Sr$ = 0.7772 based on a 49-m.y. assumed age). The Precambrian Oracle Granite host rock in this area (DEL-29-69) is radiogenic enough (0.7936 at 49 m.y. B.P.) to have been a likely source of radiogenic Sr contamination. Also, pegmatite members of Lemmon Rock leucogranite that are near or in Precambrian Apache Group strata (samples PDP-6-68 and DEL-12-69) contain anomalous amounts of radiogenic Sr and plot above the 47-m.y. reference isochron for Wilderness granite. In contrast, samples of Lemmon Rock leucogranite that intrude Leatherwood quartz diorite about 4 km east of Mount Lemmon near Summerhaven (samples DEL-13-69 and DWS-20-71) plot on the 51-m.y. reference isochron (Fig. 18) for the Lemmon Rock leucogranite. Importantly, the Leatherwood quartz diorite is comparatively nonradiogenic (at 49 m.y. measured $^{87}Sr/^{86}Sr$ values for five samples range from 0.7081 to 0.7087). Thus, the only apparent way to explain the large variation in measured ratios from the Lemmon Rock leucogranite in the Mount Lemmon area is by the variable addition of radiogenic Sr to Lemmon Rock leucogranite magma during its intrusion presumably 44 to 50 m.y. ago. Precambrian Oracle Granite and Apache Group hot rocks provided ready sources of radiogenic Sr that was mobilized by hydrothermal metasomatism during emplacement of the water-rich Lemmon Rock leucogranite assemblage of aplites, pegmatites, and alaskites.

Samples of Wilderness suite rocks that were *not* collected near highly radiogenic host rocks and that have only weak or no mylonitic fabric define a 47-m.y. reference isochron which has an initial $^{87}Sr/^{86}Sr$ value of 0.7110. This isochron is based on the assumption that the Wilderness granite and Lemmon Rock leucogranite are comagmatic. The fact that one Derrio Canyon granite analysis and two Wrong Mountain granite analyses fall on the same isochron suggest that these plutons may be comagmatic with Wilderness granite and ~47 m.y. old.

In addition to the Rb-Sr isotope data which indicate a 47-m.y.-age assignment, numerous other radiometric data are concordant with the Rb-Sr data. The first of these data are in the form of K-Ar ages on coarse muscovite (Table 1). Coarse muscovite from the Lemmon Rock leucogranite yielded a 47.9-m.y. K-Ar age. Damon and others (1963) interpreted this age as an incomplete degassing of Ar due to the large dimensions of the mica books. The age in this context was a minimum or inherited age for the pegmatite, which could have had an unknown older age. Within the current radiometric context, however, the 48-m.y. age may date the emplacement of the Lemmon Rock leucogranite. More K-Ar support is found in the Redington Pass area. Marvin and others (1978) reported a 45.8-m.y. K-Ar age for muscovite in a sample of Wrong Mountain granite.

Discordant and relatively old K-Ar ages have been known from the two-mica granitic rocks since the work of Damon and others (1963; Table 1). A coarse muscovite from the Wrong Mountain granite yielded a 33.5-m.y. age. Muscovite from deformed Wilderness granite yielded K-Ar ages of 30.2 m.y. on muscovite versus 25.4 m.y. for biotite (Damon and others, 1963). Rb-Sr dates on the same sample reported by Livingston and others (1967) yielded 36.9 m.y. for muscovite as opposed to 25.4 m.y. for biotite. Another muscovite from deformed Wilderness granite at the same location yielded a 33-m.y. K-Ar age (Catanzaro and Kulp, 1964). Coarse-grained muscovite gave a 31.9-m.y. K-Ar age for a light band (Wilderness equivalent) in the mylonitic forerange gneisses as compared to 26.0 m.y. for fine-grained muscovite and 25.6 m.y. for fine-grained biotite from another sample at the same location. Recently, discordant K-Ar ages from the Wrong Mountain granite in Redington Pass were reported by Marvin and others (1978). Here, biotite gave an age of 21.9 m.y., and muscovite yielded a strongly discordant age of 35.1 m.y.

All of the relatively old and/or discordant ages reported from the Santa Catalina–Rincon–Tortolita complex are on coarse muscovites from Wilderness-type granitic material. Significantly, none of these ages is older than 50 m.y. The ages are distinctly older than the majority of K-Ar and fission-track ages in the complex, which are 20 to 30 m.y. (Table 1). We view these post–45-m.y. and pre–30-m.y.

muscovite ages as reduced ages that probably reflect the relatively retentive nature of coarse muscovites (Damon and others, 1963; Mauger and others, 1968). As a rule, these muscovites have had their ages reduced less than those for finer-grained micas. This is in opposition to the interpretation of Banks (1977 and this volume) that these ages represent contamination of the muscovites by excess Ar during what he considers a middle Tertiary event of batholithic intrusion.

As pointed out by Damon (1970), because all minerals have a measurable solubility for Ar in the presence of an external Ar pressure, excess environmental Ar can be detected by analyzing minerals in which K is a minor or trace component. For such minerals, the presence of significant amounts of excess environmental Ar yields highly discordant ages. Livingston and others (1967) analyzed plagioclase from mylonitic Wilderness granite and concluded that the plagioclase contained no more than 1.5×10^{-11} mol/g of excess Ar relative to muscovite and biotite. This amount of excess Ar would increase the apparent age of the muscovite or biotite by no more than 1.2 m.y. However, in order to place closer limits on the amount of excess environmental Ar, we have analyzed garnet containing only 0.04% K (Damon and others, 1980). This garnet contained only 3.16×10^{-12} mol/g of nonatmospheric ^{40}Ar of which no more than one-half could be excess environmental Ar. This amount would increase the age of muscovite or biotite by only about 0.1 m.y. Therefore, we conclude that the Santa Catalina part of the complex was open to the escape of Ar during the final elevated thermal history. Consequently, the nonatmospheric ^{40}Ar contained within K-bearing minerals of the complex was generated since that time or inherited from older minerals only partially degassed during the middle Tertiary thermal event that preceded final middle Tertiary cooling.

More convincing evidence for the Eocene igneous event is found in U-Th-Pb data recently reported from the Wilderness granite and associated aplite, alaskite, and pegmatite bodies. U-Th-Pb ages of 44 to 47 m.y. on "igneous-looking" monazite from a sample of Wilderness granite in the Santa Catalina main range were reported by Shakel and others (1977). Monazites from foliated two-mica mylonitic gneiss at the west end of the Santa Catalina forerange also yielded 44- to 47-m.y. U-Th-Pb ages (Shakel and others, 1977). It is interesting that the lower-intercept age reported by Catanzaro and Kulp (1964) for the highly discordant zircons from garnet-bearing two-mica mylonite gneiss (deformed Wilderness granite at Windy Point in the Santa Catalina main range) was 50 m.y. Catanzaro and Kulp (1964) emphasized the upper-intercept age of 1,660 m.y. and suggested that the 50-m.y. lower intercept was too old to represent the metamorphic event, which they believed was dated by K-Ar as 30 to 40 m.y. B.P. They thought that middle Tertiary episodic Pb loss from a Precambrian protolith might explain the data. In the context of our work, the 50-m.y. lower intercept probably dates the emplacement of the Wilderness granite. Catanzaro and Kulp included a picture of the zircons they dated. In the picture, there appear to be two populations present. About 10% of the zircons are stubby, opaque, and cloudy and perhaps could be older "inherited" zircons. The other 90% are clear, elongate, and euhedral zircons that might be younger igneous zircons formed during Eocene Wilderness granite crystallization. It is interesting that the actual analysis plots on the discordia line close to the 50-m.y. intercept about nine-tenths of the way down the discordia line toward the 50-m.y. lower intercept. If the source of the zircon contamination was Oracle Granite (as might be predicted by studies of Shakel and others, 1977; Shakel, 1978; and Rb-Sr data in Fig. 18), a discordia cord upper intercept at 1.45 b.y. would require a lower intercept *slightly* younger than 50 m.y. This younger lower-intercept age (interpreted by us to be age of emplacement) would be approximately concordant with our 47-m.y. Rb-Sr reference isochron.

In summary, field relationships require that Wilderness suite granites postdate Late Cretaceous-early Tertiary Leatherwood suite plutons but predate middle Tertiary Catalina suite plutons. Isotopic data from different methods are impressively concordant at 44 to 50 m.y. These include an 11-point whole-rock Rb-Sr isochron, two K-Ar dates of coarse muscovite, two U-Th-Pb dates on monazite, and one zircon sample dated by the U-Pb discordia method. Most of the dates are from the Wilderness granite, Lemmon Rock leucogranite, and related pegmatite phases in the Santa Catalina forerange.

However, one sample from the Derro Canyon granite and two from Wrong Mountain granite fall on our Rb-Sr reference isochron; this suggests that these plutons correlate with Wilderness granite in age as well as mineralogy and relative position within the intrusive sequence of the Santa Catalina–Rincon–Tortolita crystalline complex.

Middle Tertiary Quartz Monzonite (Catalina) Suite. Emplacement of one granite and three quartz monzonite plutons (designated the Catalina suite) in late Oligocene–early Miocene time marked the final event in the growth of the batholith component of the Santa Catalina–Rincon–Tortolita crystalline complex. By far, the greatest volume of magma emplaced during this time was that in the northwestern Santa Catalina Mountains and southern Tortolita Mountains where three coalescing plutons—the Reef of Rock granite and the Catalina and Tortolita quartz monzonites—form a small batholithic mass. The Catalina quartz monzonite forms a large, half-circle–shaped pluton in the northwestern Santa Catalina Mountains and an east-northeast–trending dikelike mass in the south-central Tortolita Mountains. The Tortolita quartz monzonite occupies a rectangular area with an east-northeast–trending long axis in the southern Tortolita Mountains and occurs as north-northwest–striking dikes in the western Santa Catalina Mountains. The Reef of Rock granite forms a jagged north-northeast–trending spine that borders the southeast margin of the Catalina quartz monzonite in the central Santa Catalina Mountains (Suemnicht, 1977). This granite is one of the youngest plutons of the Santa Catalina–Rincon–Tortolita crystalline complex. A fourth pluton, the Happy Valley quartz monzonite, is provisionally placed in the Catalina suite pending further work and appears as two stocklike masses on the eastern slopes of the Rincon Mountains. Together, Catalina suite plutons form about 15% of the batholithic rocks exposed in the complex.

Catalina suite plutons are mineralogically distinct from Wilderness and Leatherwood suites. Average modal analyses are reported in Table 5. Catalina suite plutons contain more quartz and more K-feldspar, less (but more sodic) plagioclase, and much less biotite than Leatherwood suite plutons. Both suites contain hornblende and sphene as important accessories. Catalina suite intrusions have similar quartz content, slightly more K-feldspar, slightly less (but more calcic) plagioclase, and similar amounts of biotite compared with Wilderness type plutons. Catalina plutons (with the exception of the northern mass of Happy Valley quartz monzonite) contain no muscovite compared with 1% to 7% in Wilderness plutons. Catalina suite plutons contain hornblende and sphene as common accessories and *no* garnet. The reverse is true for Wilderness suite plutons.

Upon casual inspection, Catalina quartz monzonite, the largest pluton of the Catalina suite, may easily be confused with Precambrian Oracle Granite. This confusion resulted in an incorrect age assignment for this rock initially by Tolman (1914, unpublished manuscript). This error was continued in many subsequent publications including the recent 1:500,000-scale Arizona State geologic map (Wilson and others, 1969). The mineralogic contrast between the two plutons was first observed by Wallace (1954), who assigned an older Precambrian age to the Oracle Granite on the basis of its intrusive contacts into Pinal Schist of older Precambrian age. A fossil horn coral found in a limestone inclusion by McCullough (1963) and Rb-Sr isotope data published by Hoelle (1976) established a Phanerozoic age for this intrusion. Subsequent isotopic results (Damon and others, 1963; Creasey and others, 1977; Shakel and others, 1977; this paper) firmly establish a late Oligocene age for this pluton. Quartz, plagioclase, K-feldspar, and biotite contents for Oracle Granite and Catalina quartz monzonite are very similar. The important mineralogic difference is in the accessory minerals. Catalina quartz monzonite contains hornblende and sphene in essentially all samples, but these minerals are absent from Oracle Granite.

Published modes of Catalina quartz monzonite are all from that part of the pluton in the western Santa Catalina Mountains (Table 5). The presumed analogue in the Tortolita Mountains has about 25% to 30% quartz, 30% to 35% K-feldspar, 25% to 30% plagioclase (An_{25-35}), 6% to 8% biotite, 1% hornblende, and 0.5% to 1% sphene. Fine- to medium-grained nonporphyritic border and coarser-grained porphyritic main phases of Catalina quartz monzonite are present in both the Santa Catalina and Tortolita Mountains. The border phase (Table 5) is commonly present along outer margins of the Catalina intrusion and surrounds many of the larger inclusions within the Catalina pluton.

Within the small batholith of coalescing Catalina suite plutons in the western Santa Catalina and Tortolita Mountains, there is a compositional variation between plutons (Table 5). Catalina quartz monzonite contains less quartz, less (but more calcic) plagioclase, the same amount of K-feldspar, and more mafic minerals than Tortolita quartz monzonite. In turn, Reef of Rock granite contains more quartz, more K-feldspar, and less plagioclase than Tortolita quartz monzonite. Both plutons intrude Catalina quartz monzonite. Their overlapping isotopic ages (see below) suggest a differentiation continuum.

As discussed earlier, the Catalina quartz monzonite intrudes and postdates the Leatherwood quartz diorite (Suemnicht, 1977). The nature of the southern contact of the Catalina quartz monzonite with phases of the Wilderness granite has been much debated. All previously published opinions (McCullough, 1963; Creasey and others, 1977; Banks, 1977 and this volume) regard the contact as some type of metamorphic front. A new interpretation proposed in this paper is that the contact represents an intrusive contact of Catalina quartz monzonite into Lemmon Rock leucogranite border phase of the Wilderness granite. Much of the contact is occupied by a steeply inclined migmatite zone that contains an interleaved assemblage of metasedimentary rocks (quartzites, calc-silicate skarns, siliceous gneiss) and variably foliated intrusive rocks including Leatherwood quartz diorite, Lemmon Rock leucogranite, and Catalina quartz monzonite. The migmatite—which is interpreted by us to represent a screen of metamorphosed and highly *injected,* pre-Catalina intrusive and metasedimentary rocks—thins to the west. Here a fine- to medium-grained border phase of the Catalina quartz monzonite, similar to that described along the eastern margin of the pluton by Hoelle (1976) and Suemnicht (1977), sharply intrudes and contains inclusions of foliated Lemmon Rock leucogranite. This relationship persists for at least a 2-km length of Catalina-Wilderness contact. Both plutons contain numerous metasedimentary inclusions that locally obscure the intrusive relationships along the contact. In contrast to the conclusions of other workers (McCullough, 1963; Banks, this volume), thin sections and field observations along the Catalina-Wilderness contact in Cargodera Canyon indicate that foliated fabric in the metasedimentary inclusions, Catalina quartz monzonite, and Lemmon Rock leucogranite is mostly nonmylonitic. Our observations do not support the contentions of Creasey and others (1977) and Banks (1977 and this volume) that Cargodera Canyon represents a transition zone ("gneiss front") between mylonitic and nonmylonitic parts of a *single* pluton. In the Tortolita Mountains, Catalina quartz monzonite postdates the Leatherwood and Wilderness suites, as discussed above.

The youngest major pluton in the crystalline core of the complex is the Tortolita quartz monzonite. It is easily distinguished from the Catalina quartz monzonite by its finer grain size and nonporphyritic hypidiomorphic-granular texture. Wherever the two plutons are in contact, the Tortolita quartz monzonite clearly cuts the Catalina quartz monzonite (McCullough, 1963; Banks, 1976). In lower Cargodera Canyon, two large north-northwest–striking dikes of Tortolita quartz monzonite clearly crosscut and contain inclusions of Catalina quartz monzonite and Wilderness granite. These dikes were correlated by Banks (1976) with the main Tortolita pluton in the southern Tortolita Mountains 8 km to the west-northwest. We concur with Banks's correlation. In the southern Tortolita Mountains, the main pluton of Tortolita quartz monzonite occupies the entire southern third (about 70 km^2) of the mountain range. The contact between the Tortolita and Catalina plutons in the south-central Tortolitas was mapped by Budden (1975) as a mixed zone with many different phases present. More recent mapping by one of us (Keith) has indicated that the zone represents inclusions of quartz diorite that have been engulfed and injected by Catalina quartz monzonite and subsequently intruded by sheets of Tortolita quartz monzonite from the south (Fig. 4). Keith believes that the presence of K-feldspar porphyroblasts in and near the edges of the dioritic inclusions and the occurrence of biotitic "patches" in the Catalina pluton suggest K metasomatism during intrusion of Catalina quartz monzonite. The Tortolita quartz monzonite and older rocks are locally intruded by pegmatite, lamprophyre, and granodiorite dikes which volumetrically are insignificant. At the southeast corner of the main Tortolita pluton, intrusions of Tortolita quartz monzonite into Catalina quartz monzonite have been recognized by Budden (1975) and Banks (1976, 1977, and this volume).

Another small pluton, the Reef of Rock granite, is exposed in the Santa Catalina Mountains, 2 km north of Mount Lemmon (Suemnicht, 1977). The granite intrudes and contains inclusions of Leatherwood quartz diorite and Catalina quartz monzonite (Suemnicht, 1977). Possible equivalents of the Reef of Rock granite intrude Tortolita quartz monzonite in the Tortolita Mountains where they have been mapped as a phase of the Tortolita pluton.

A possible fourth pluton of the Catalina suite is the Happy Valley quartz monzonite of the eastern Rincon Mountains (Drewes, 1974). Drewes (1974) mapped projections of the southernmost mass of Happy Valley quartz monzonite cutting Wrong Mountain granite (a Wilderness suite pluton). The northernmost mass contains muscovite (Miles, 1965) and may be a Wilderness suite pluton.

Plutons of the Catalina suite are the youngest set of intrusions in the batholithic sequence and mark its final consolidation. Two of the *youngest* plutons are intruded by northwest-striking dike swarms. Early Miocene K-Ar ages have been obtained from some of these dikes (Banks and others, 1978). The eastern part of the Catalina quartz monzonite is crosscut by northwest-striking rhyolite porphyry dikes. Tortolita quartz monzonite is crosscut by northwest-striking quartz latite and granodiorite dikes (Fig. 2). No dikes are known to crosscut the Happy Valley or Reef of Rock intrusions.

We have Rb-Sr geochemistry on two plutons of the Catalina suite, the Catalina and Tortolita quartz monzonites. Rb-Sr abundances for the two plutons (Fig. 19) do not overlap but are aligned along a similar trend, which is permissive of a differentiation continuum.

Isotopic analyses have been determined for main-phase quartz monzonites and correlative dike and aplite samples. We believe that data for both the Catalina and Tortolita plutons (including their dikes and aplites) are best explained by adherence to a reference isochron of ~26 m.y. (Fig. 20). The slope of the isochron is to a large degree governed by analyses of aplites, but we feel confident that the aplites sampled are comagmatic with the enclosing plutons. Samples that plot well above the reference isochron were collected near to and could have been easily contaminated by highly radiogenic wall rocks or inclusions. Rb-Sr abundances of dark inclusions (Fig. 21) in these young quartz monzonites suggest that a majority of the dark inclusions are from the Leatherwood suite of rocks.

The late Oligocene age suggested by the 26-m.y. Rb-Sr isochron is supported by abundant isotopic data. Single biotite K-Ar ages of 25.6 m.y. in the Santa Catalina Mountains and 28.0 m.y. in the Tortolita Mountains (Damon and others, 1963) for the Catalina pluton are semiconcordant with a single K-Ar biotite age of 23.8 m.y. and concordant K-Ar biotite-hornblende pairs of 23.9 m.y. (biotite) and 23.7 m.y. (hornblende), 24.7 m.y. (biotite) and 27.9 m.y. (hornblende), and 21.1 m.y. (biotite) and 21.6 m.y. (hornblende) for the Catalina quartz monzonite reported by Creasey and others (1977). The last concordant pair is from the Catalina quartz monzonite in the Tortolita Mountains. Similarly, biotite K-Ar ages from the Tortolita pluton of 24.5 m.y. in the Santa Catalina Mountains (Damon and others, 1963) and 22.7 m.y. in the Tortolita Mountains (Creasey and others, 1977) strongly overlap with those of the Catalina intrusion and suggest temporal equivalence. The notion of temporal equivalence is further supported by numerous fission-track ages of 30.0, 28.3, and 28.0 m.y. on sphene; 28.9, 27.1, and 25.9 m.y. on zircon; and 23.5, 20.8, and 21.7 m.y. on apatite for the Catalina quartz monzonite and 18.5 and 17.0 m.y. on apatite from the Tortolita quartz monzonite reported by Creasey and others (1977). With the exception of apatite, which represents final cooling of Catalina and Tortolita intrusions, the fission-track ages are all concordant with the K-Ar ages.

Any doubts about the age of the Catalina pluton were removed by the 27-m.y. U-Pb concordant zircon age reported by Shakel and others (1977). The U-Pb data showed that Rb-Sr "isochrons" published earlier by Shakel and others (1972) and Hoelle (1976) probably involved erroneous assumptions regarding sample selection (see comments in Table 1).

In summary, field relationships indicate that plutons of the Catalina suite are younger than rocks of the Late Cretaceous–early Tertiary Leatherwood suite and Eocene Wilderness suite. Concordant K-Ar biotite ages and hornblende-biotite pairs, sphene and zircon fission-track ages, a U-Pb zircon age, and a poorly constrained Rb-Sr whole-rock isochron require a middle Tertiary age for quartz monzonites of the Catalina suite.

IMPLICATIONS OF PLUTONIC EPISODES FOR MYLONITIC DEFORMATION

Previous sections have detailed the emplacement of three suites of plutons from 75 to 20 m.y. ago. Plutons of *each* suite have been deformed to varying degrees by distinctive, gently inclined mylonitic foliation with conspicuous lineation that plunges east-northeast and west-southwest. At least three episodes or events of mylonitization (and probably more) are recorded in relationships where undeformed parts of younger plutons cut deformed parts of older plutons.

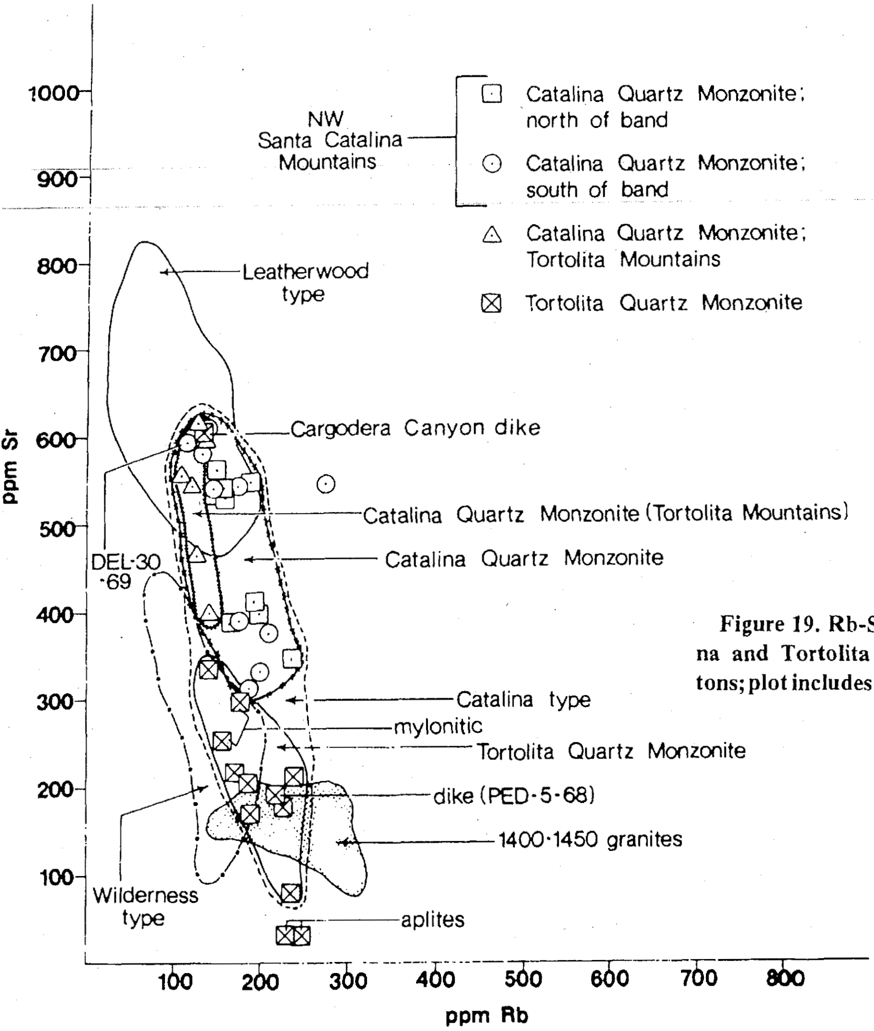


Figure 19. Rb-Sr abundances in Catalina and Tortolita quartz monzonite plutons; plot includes data from Hoelle (1976).

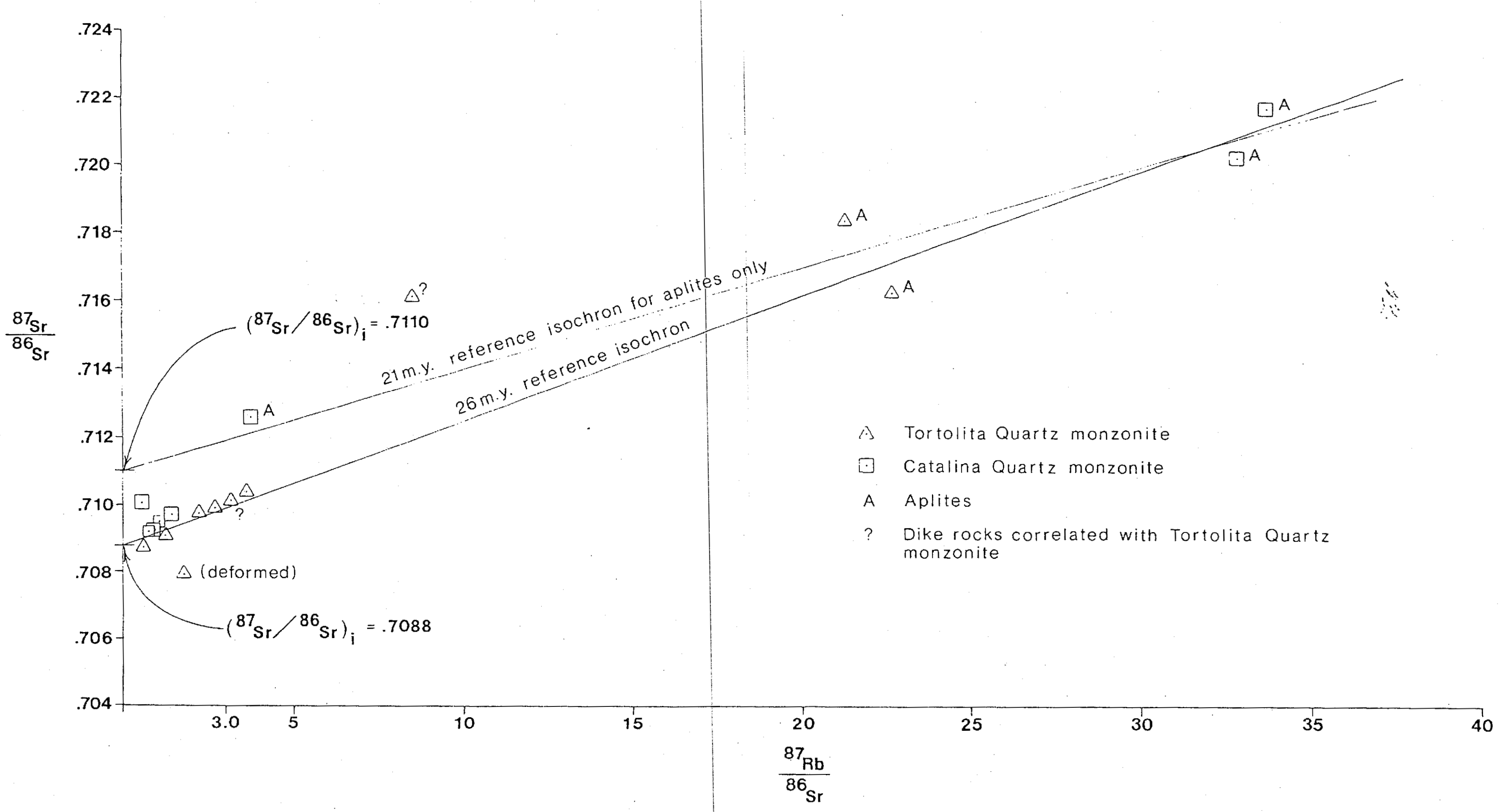


Figure 20. Rb-Sr isochron diagram for Catalina and Tortolita quartz monzonite plutons; plot includes data from Hoelle (1976); 26-m.y. reference isochron assumes Catalina and Tortolita quartz monzonite plutons are comagmatic.

The oldest mylonitic event is post–75 m.y. B.P. because it deforms Leatherwood quartz diorite. This fabric must be pre–50 m.y. because mylonitic foliation in Leatherwood is intruded in many places by dated 44- to 50-m.y.-old undeformed muscovite pegmatites east of Mount Lemmon (Hanson, 1966). In a well-exposed roadcut along the new paved-highway access to the Mount Lemmon ski area 2.5 km east-northeast of Mount Lemmon, several instructive relationships may be observed between mylonitic events in the Leatherwood quartz diorite and muscovite pegmatites of the Lemmon Rock leucogranite. Here, an older, coarser-grained mylonitic foliation is cut at a low angle by a younger, fine-grained, more intense mylonitic foliation. Two generations of pegmatites are present. The older generation consists of shallowly inclined sheets about 0.1 to 0.2 m thick which cut the older, coarser-grained mylonitic foliation but are conspicuously boudined where they cross the younger, fine-grained mylonitic foliation. The two foliation events and the shallowly inclined pegmatites are clearly crosscut by large, steeply inclined, undeformed pegmatite dikes that constitute 90% of the pegmatite exposed in the roadcut.

Similar relationships occur 20 km to the east-southeast of Mount Lemmon (Wilson, 1977; Ted Theodore, 1979, oral commun.) where undeformed pegmatite apophyses of the Wilderness pluton discordantly cut mylonite schist derived from Leatherwood. In addition, equigranular main-phase Wilderness granite may intrude mylonitic Leatherwood quartz diorite east of Green Mountain, about 12 km east-southeast of Mount Lemmon (Pilkington, 1962). The southern part of the Leatherwood pluton is continuously deformed along its east-southeast–trending margin for more than 20 km. As

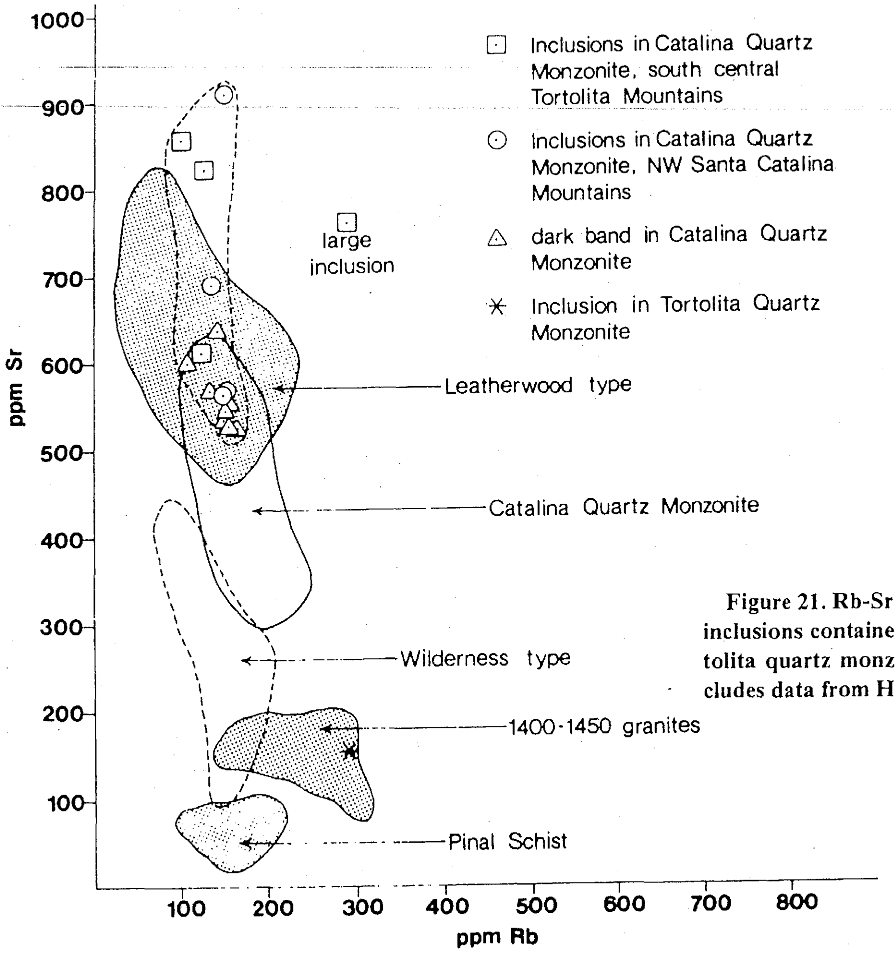


Figure 21. Rb-Sr abundances from dark inclusions contained in Catalina and Tortolita quartz monzonite plutons; plot includes data from Hoelle (1976).

such, mylonitic fabric in the Leatherwood constitutes a major pre–50 m.y. B.P. and post–75 m.y. B.P. mylonitic event in the Santa Catalina–Rincon–Tortolita crystalline complex.

Orientation of mineral lineation in mylonitic Leatherwood quartz diorite is distinct from that in main-range exposures of mylonitic Wilderness granite. Based on 116 measurements, mean lineation in Leatherwood quartz diorite exposures along the Oracle road 3 to 6 km northeast of Mount Lemmon is 16° N85° E (Tom Heidrick, 1979, written commun.). Lineation on low-angle mylonitic surfaces in the deformed Wilderness intrusion in the Windy Point and Spencer Peak areas about 5 and 15 km, respectively, southeast of Mount Lemmon is more northeasterly (about N35°E to N65°E). The difference in lineation orientation suggests that mylonitic foliation in the Leatherwood and Wilderness intrusions may have formed during two distinct episodes of cataclasis.

The next major mylonitic episode deformed the structurally lower parts of the Wilderness granite and its wall rocks in the Santa Catalina forerange. Analogous deformation may be represented by widespread mylonitic fabric in the mineralogically similar Wrong Mountain granite (Drewes, 1977) of the Rincon Mountains. This mylonitization deformed and therefore postdated the 44- to 50-m.y.-old muscovite granites but predated their cooling between 31 and 25 m.y. B.P. as defined by K-Ar and fission-track ages. Keith infers that relationships between deformed and undeformed pegmatites in the Santa Catalina forerange suggest that the mylonitic fabric exposed there formed during the emplacement of Wilderness equivalent pegmatites. Mylonitization in the forerange must have been completely over by the time of intrusion of an undeformed 21-m.y.-old trachyte dike (Shakel, 1974; Damon and others, 1980).

One of the above two episodes may be widespread throughout the northwestern Tortolita Mountains where the Chirreon Wash (Leatherwood suite) and Derrio Canyon (Wilderness suite) intrusions are strongly mylonitized—particularly so in the area of the Derrio Canyon granite sill sequence (Figs. 4 and 7). At least part of this deformation predated emplacement of the Catalina pluton as evidenced by large, strongly deformed and lineated inclusions of quartzite, Pinal Schist, stretched-pebble metaconglomerate, and Oracle Granite in relatively less-deformed Catalina quartz monzonite. Presence of mylonitic inclusions of Leatherwood quartz diorite in Catalina quartz monzonite in the Santa Catalina Mountains (Suemnicht, 1977) also indicates a mylonitic event that predated emplacement of the Catalina quartz monzonite.

In the southwestern Tortolita Mountains, the youngest episode of mylonitization clearly affects to varying degrees the Catalina quartz monzonite and the entire western half of the Tortolita quartz monzonite. This episode must postdate the two ~26-m.y.-old plutons but predate cooling of the mylonitic rocks between 17 and 20 m.y. B.P. as defined by fission-track apatite ages. An additional minimum age for this episode is provided by a series of northwest-trending dikes which discordantly intrude mylonitic foliation. One of these dikes which cuts mylonitic Chirreon Wash granodiorite has yielded a 24-m.y. K-Ar biotite date (Table 1). Thus, a significant mylonitic episode is bracketed very close to 25 m.y. B.P. In the South Mountains near Phoenix, Reynolds and Rehrig (this volume) have documented almost exactly the same age for mylonitic fabric that deforms a pluton which resembles phases of Tortolita quartz monzonite in rock type, texture, and style of mylonitic deformation.

In the Tortolita Mountains, several *events* of mylonitization are recognizable within the youngest *episode* of mylonitization. For example, near the mouth of Wild Burro Canyon, strongly mylonitized inclusions of Oracle Granite that were deformed during an earlier episode are included in the coarsely porphyritic phase of Catalina quartz monzonite. This phase in turn contains a younger, much weaker mylonitic foliation. These are both crosscut by low-dipping sheets of the granitic phase of Tortolita quartz monzonite which has been strongly mylonitized by a still-younger mylonitic event. This youngest mylonitic event may be related to a widespread set of shallow-dipping, relatively wide-spaced shears that cut older, more steeply inclined foliations (some of which are mylonitic) in the Chirreon and Catalina intrusions.

SUMMARY AND CONCLUSIONS

Various rocks within the Santa Catalina–Rincon–Tortolita crystalline complex can be correlated with rocks inside and locally outside of the complex by utilizing field relationships and lithologic, trace-element, and isotopic analyses. Deformed Precambrian, Paleozoic, Mesozoic, and Cenozoic rocks all occur within the complex, but its geology is *dominated* by a series of Late Cretaceous(?) through middle Tertiary plutonic and deformational episodes. Major plutonism was apparently episodic and produced three distinct ages and suites of intrusions. The Laramide (75 to 64 m.y. B.P.) quartz diorite and granodiorite (Leatherwood suite) were emplaced earliest. These were followed by Eocene (44 to 50 m.y. B.P.) muscovite granite, pegmatite, and alaskite (Wilderness suite). Finally, quartz monzonites (Catalina suite) were intruded in middle Tertiary time (27 to 25 m.y. B.P.). At least three episodes of mylonitic deformation occurred between 75 and 20 m.y. B.P. Although the plutonism was episodic, it cannot be definitively demonstrated that the mylonitic deformation was also episodic rather than part of a prolonged continuum. However, the close spatial and temporal association of mylonitization with plutonism suggests a genetic relationship between the two and therefore supports episodicity of mylonitization.

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ADDENDUM

HANDOUTS FROM LEADERS

AT FIELD TRIP

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ORACLE RIDGE MINING PARTNERS
P.O. Box 70, San Manuel, AZ. 85631
Phone: (602) 576-1412 Fax: (602) 576-1539

History

The mining district came into being in 1873 with the founding of the Old Hat Mine. In 1881 a ton per day copper smelter had been erected at Apache Camp approximately 5000' or a mile from the present mill. Ore supplied to the smelter came from numerous small adits located on Marble Peak which includes: Hartman Homestake, Leatherwood, Stratton and Geesaman workings.

In 1937, Catalina Consolidated acquired the property and set up a 100 ton per day flotation mill near the present ORMP Mill Site. Ore was processed from the Geesaman and Daily workings. Records show that 115,000 tons of ore were processed to produce 1081 tons of concentrate averaging 27% copper, 8.6 troy oz./ton silver and 0.015 troy oz./ton gold.

Operations at the property continued intermittently through to 1984. In 1968 Continental Copper leased (to purchase) the property and conducted exploration drilling and underground drifting. By 1974, a total of 106,535 feet of core had been drilled, and 2651 feet of adit had been driven to delineate geological resources estimated at 11 million tons of ore grading 2.25% copper.

In 1977 Union Miniere and Continental Copper entered into a joint venture to evaluate a 2000 ton per day feasibility study with Union Miniere being the operator. Between 1977 and 1979, an office building, maintenance shops and warehouse buildings were constructed. In 1979, a major review of the project suggested that further underground exploration was necessary to define and expand ore reserves, to provide more information for mine planning and to estimate actual mining costs. This resulted in an underground exploration program commencing in April of 1980. By 1981, low copper prices forced work to be suspended. By 1983, the project had stockpiled 85,000 tons of ore grading 2.56% copper, and total development included 28,675 feet of drifting, 125,607 feet of surface diamond drilling and 46,916 feet of underground diamond drill core.

In October 1988, South Atlantic Ventures acquired Union Minere's interest (70%) in the Oracle Ridge Mine and entered into a partnership with Continental Copper to develop the mine. In April 1990, production decision was made and work commenced on the construction of a 750 ton per day concentrator. Milling commenced February 28, 1991, and the first saleable concentrate was shipped on March 4, 1991.

Production has continued to present at intermittent takes with ore being derived from both stopes and development headings. In 1993, South Atlantic Ventures changed it's name to Southern Copper. A production shutdown between August and October 1993 was recorded during which time the mill was expanded to process 1000 tons per day ore. This production rate has remained constant to the present.

Geology

A. Regional

The Oracle Ridge Mining claims are situated in the Santa Catalina Mountains which were formed some 31 million years ago when the ground was uplifted, folded and intruded by the Laramide intrusion. Regionally, the area consists of Precambrian granites found to the north of the Geesaman Fault, meta sediments and quartz diorites. Later intrusions in the form of Lampophyre, Alaskite quartz, and rhyolite dikes and sills have been located. Structurally, the ground had undergone multi stages of folding and faulting.

With the intrusion mineralizing fluids have created ore horizons both as strata bound and contact metamorphic skarn veins.

B. Geology of Mine

Ore horizons in the mine occur both as a stratabound deposit with copper ore occurring in stratigraphically defined sedimentary units as steeply dipping contact metamorphic skarn veins.

1. Stratabound Deposits

These deposits occur in the upper parts of the mine and are the result of mineralizing fluids depositing copper, silver and gold minerals in select sedimentary units located as a roof pendent above the Laramide quartz diorite intrusion. These beds have been folded and faulted with widths varying up to 40 feet thick and strike lengths up to 300 feet long. The angle of dip of the beds vary from 35 degrees to 60 degrees.

2. Contact Metamorphic Skarns Deposits

The contact metamorphic deposits occur in basins and on the flanks of the Laramide intrusion in contact with the limestones and delormitic sediments. Typically ore shoots vary from 10 to 50 feet wide and possess strike lengths from 50 to 500 feet long. The ore shoots are generally steeply dipping.

3. Mineralogy

Ore grade mineralization occurs primarily in the minerals chalcopyrite, chalcocite and bornite. Copper is also found in lesser amounts in the form of covellite, cuprite, native copper, vallurite and other rare copper minerals. Gold and silver are recovered as by products.

ORACLE RIDGE MINING PARTNERS
P.O. Box 70, San Manuel, AZ. 85631
Phone (602) 576-1412 Fax (602) 576-1539

GEOLOGICAL ROCK TYPES TO BE MINED 1995-1997

1995

Mining in 1995 will be derived from the magnesium and garnetiferous skarns of Blocks 1, 6 and 7. Mineralization will be predominately sulfide ore with minor oxide ore bring derived in January from Block 7. Dilutent material found within the ore will be granodiorite to quartz monzonite stock, limestones and dolomites. As Block 6 is mined to completion, the amount of intrusive stock will diminish.

1996

Mining in 1996 will be derived from the magnesium skarns at Block 1. Wall rock diluents will consist of dolomites and siltstones, neither of which is expected to have adverse effects in milling. Little intrusive stock is expected to enter the mill.

1997

Mining in 1997 will be derived from the magnesium skarns of Block 1 and the garnetiferous skarns of Block 8. Diluent material expected in the ores are siltstones and limestones of the Martin Formation with dolomites and siltstones of the Abriego Formation.

The amount of intrusive stock entering the mill will be minimal as only small cross cutting dikes of stock will be encountered in 1997. Where feasible, the intrusive will be mucked as waste to lessen any impact on the mill.

ORACLE RIDGE MINING PARTNERS
P.O. BOX 70, SAN MANUEL, AZ 85631
602-576-1412 fax 602-576-1539

Preliminary assessment of aeromagnetic survey at Oracle Ridge Mine

A brief study of the preliminary survey data allows for the following comments:

Most of the known magnetite rich ore zones are clearly evident. The magnitude of the total field magnetic data pinpoint block1, 2, 3, 6, 7,9,11, and 990 stope. The most intense anomaly lying in the approximate position of block 11.

The anomalies associated with the known ore horizons will be used as guides to anomalous areas within the survey area.

Pertaining to the roof pendant area; the survey has indicated potential targets west of block 3, extending to the Hartman/Homestake Mine and along the western most contact of the intrusive with the Paleozoic sedimentary rocks. The untested southeast quadrant of the pendant contains 2 moderately intense anomalies extending, respectively from B-11 toward the NE and from B-7 to the SW in an essentially straight line between B-7 and B-11. B-7 appears to extend easterly 500-600' and southerly possibly as much as 2000'. B-11 may extend NW for 500' and SE for 600'. B-1 and B-9 appear to be continuous, filling a gap of 600'. The "990" is outlined well, indicating the north extension of B-6. Good, small target 500' NE of B-11. A previous ground magnetic survey has thus been substantiated, and indicates a target worthy of follow-up.

A moderate to strong anomalous zone extends from the NW to SE along the Geesaman fault zone through the Gold Camp claims to the tailings containment pond. The anomaly is apparently associated with the Pre-Cambrian sedimentary rocks to the north of the Geesaman fault, or the fault zone itself.

Several magnetic "highs" are in the area to the south of the pendant around the Lombar Hill claim group. This string of anomalies trends SW to NE and is contained within the most recently claimed area within sections 21 and 22. Favorable Paleozoic sedimentary host rocks in contact with the Leatherwood stock are exposed in Alder Wash in this area

An isolated, rather strong and isolated anomaly occurs outside the claimed area just west of the common section cor of sections 23 and 24. This area will be staked.

In conclusion, the preliminary data indicate a very good potential for increasing the ore reserves at Oracle Ridge by 2 to 3 fold when comparing the anomalous zones in the developed/explored areas with unexplored areas.

3/3/95
Approved by