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ARIZONA GEOLOGICAL SOCIETY

Fall Field Trip 1983

Field Trip to Northern Plomosa Mountains, Granite Wash Mountains, and western Harquahala Mountains

led by Robert Scarborough, Steve Reynolds, and Jon Spencer
Arizona Bureau of Geology and Mineral Technoloty

organized by Stanley B. Keith and Jan C. Wilt
MAGMACHEM Associates

Interpretations and conclusions in this report are those of the consultant and do not necessarily coincide with those of the staff of the Bureau of Geology and Mineral Technology.

STATE OF ARIZONA
BUREAU OF GEOLOGY
AND MINERAL TECHNOLOGY
OPEN-FILE REPORT

83-24

1983 AGS Fall Field Trip Route

Led by
Bob Scarborough, Steven Reynolds, and Jon Spencer
Arizona Bureau of Geology and Mineral Technology

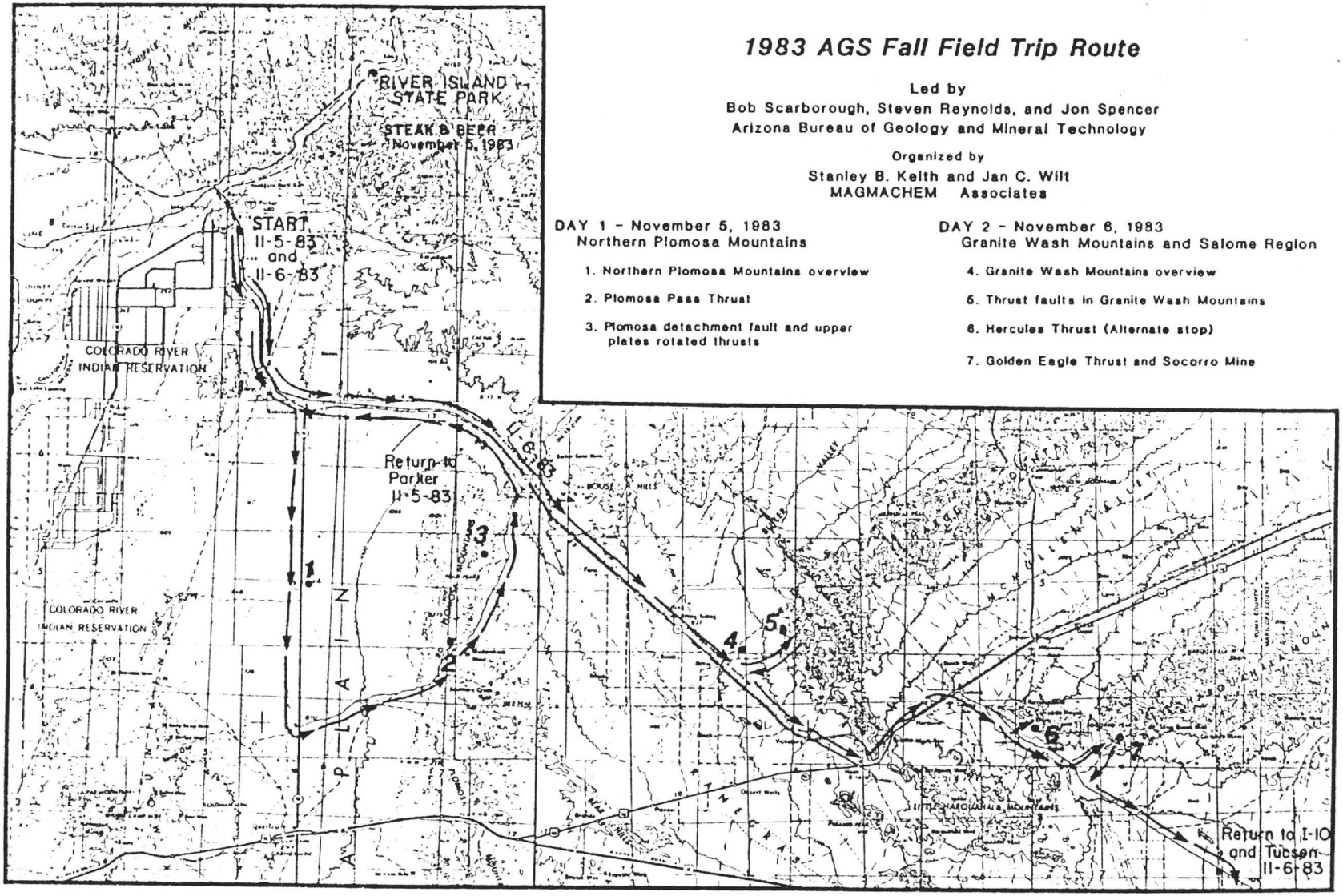
Organized by
Stanley B. Keith and Jan C. Wilt
MAGMACHEM Associates

DAY 1 - November 5, 1983
Northern Plomosa Mountains

1. Northern Plomosa Mountains overview
2. Plomosa Pass Thrust
3. Plomosa detachment fault and upper plates rotated thrusts

DAY 2 - November 6, 1983
Granite Wash Mountains and Salome Region

4. Granite Wash Mountains overview
5. Thrust faults in Granite Wash Mountains
6. Hercules Thrust (Alternate stop)
7. Golden Eagle Thrust and Socorro Mine



RECONNAISSANCE GEOLOGY OF THE

NORTHERN PLOMOSA MOUNTAINS

by Robert Scarborough and Norman Meader

with assistance by Jan C. Wilt and Stanley B. Keith

November 1983

STATE OF ARIZONA
BUREAU OF GEOLOGY
AND MINERAL TECHNOLOGY
OPEN-FILE REPORT

83-24

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RECONNAISSANCE GEOLOGY OF THE NORTHERN PLOMOSA MOUNTAINS, LA PAZ COUNTY, ARIZONA

by Robert Scarborough and Norman Meader, 1983

Previous Work

The northern Plomosa Mountains were actively explored and mined for base and precious metals following the construction of the Arizona and California railroad that passed through Bouse in the very early 1900's. The Little Butte, Malakitt, Hearts Desire, and Old Maid mines at the extreme northern end of the range were producing mines when the U. S. Geological Survey published Willis Lee's "geologic sketch map" (Lee, 1908) of northwestern Arizona. His map only topographically differentiated the Plomosa (his Palomas) mountains from the surrounding desert plains, using only information supplied by railroad engineers.

The first detailed study of the mineral deposits of the northern Plomosa Mountains was by Bancroft (1911). He recognized complex geologic relations between volcanics and limestones in the central Plomosas and recognized that the mineralized host rocks of the Mudersbach copper camp had been affected by the intrusion of a nearby pluton, which is termed the Mudersbach pluton in this report. In the area of this mine he recognized gypsiferous strata that he thought "resulted from the alteration of limestone in place, the alteration being carried on by the sulphuric acid liberated in the oxidation of pyrite, which is found in all stages of decomposition in the deposit." An alternative explanation is offered in this report.

Little more geologic information was known when Clyde Ross made a few observations in the northern Plomosas (Ross, 1922). He noted the presence of limestones at the extreme north end of the Range that he likened in their low metamorphic grade to those of Paleozoic age around Globe, but the lack of fossils in the Plomosa rocks "renders positive correlation impossible." He also noted that they bore undetermined relationship with the underlying crystalline rocks in the area. In this report, the limestones of which he speaks, near the Little Butte mine, are mapped as Miocene age, while some remnants of Paleozoic limestones are found not far south.

A compilation of reconnaissance mapping of the northern Plomosas by Eldred Wilson was published in 1960 by the

Arizona Bureau of Mines and unchanged in 1969 by the U.S.G.S. as the Arizona State Geologic map (scale 1:500,000). In these maps, Wilson showed the east-west bipart geology of the northern Plomosas for the first time.

In 1966, a map and report on the geology and mineral deposits of the northernmost part of the mountains was prepared by Joe Jemmett (Jemmett, 1966). He recognized the faulted character of the contact between the main mountain block and the terrain to the east capped by Tertiary strata. He considered the carbonates that were interleaved with gneisses as Precambrian in age, and recognized what he thought was a landslide mass of schist overriding Tertiary strata in his northerly terrain at Round Mountain. He also recognized repetition of Tertiary strata along northwest striking "thrust" faults, some of which in this report are interpreted as low-angle normal faults (listric faults). Jemmett gave the most up-to-date description of the mines and geology in the northernmost Plomosas that has been written to date.

Acknowledgments

This report is a direct result of a detailed reconnaissance mapping project in the northern Plomosa Mountains funded by Inca Oil and Gas, Inc. of Ft. Worth, Texas. The goal of the study was to evaluate the overthrust belt nature and petroleum potential of the region, following the regional tectonic synthesis paper by Harald Drewes (Drewes, 1978). Mapping was carried on between September and November, 1981 by Robert Scarborough and Norman Meader, with geological and logistical support by Jan C. Wilt and Stanley B. Keith. Thanks go to Alan T. Washburn and Inca Oil and Gas for permission to publish this report.

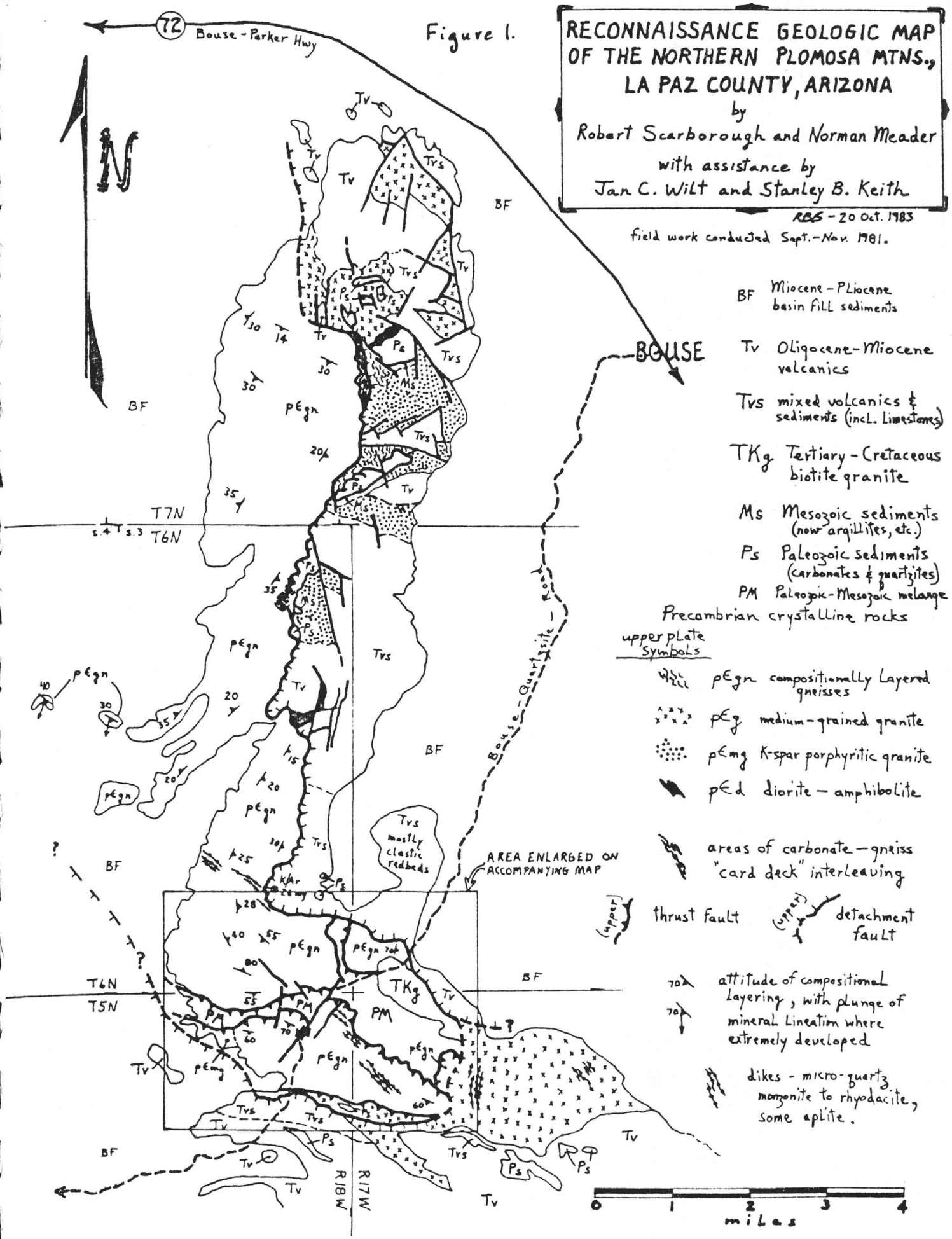
Figure 1.

RECONNAISSANCE GEOLOGIC MAP OF THE NORTHERN PLOMOSA MTNS., LA PAZ COUNTY, ARIZONA

by
Robert Scarborough and Norman Meader
with assistance by
Jan C. Wilt and Stanley B. Keith

RBS - 20 Oct. 1983

field work conducted Sept.-Nov. 1981.



GENERAL STRATIGRAPHY IN THE NORTHERN PLOMOSA MOUNTAINS

Rocks representing Precambrian, Paleozoic, Mesozoic, and Cenozoic eras crop out in the northern Plomosa Mountains and are described here. A schematic section of regional stratigraphy is shown in Figure A.

PRECAMBRIAN

Crystalline rocks of probable Precambrian age dominate the main mountain mass in the northern part of the study area. The predominant lithology in the Precambrian terrain is a medium-grained, gray-colored, foliated, quartzo-feldspathic, gneissic unit. From brief reconnaissance, the foliation is often weak or absent, and when present appears to change attitude in complex ways, probably by both folding and faulting. Other rock types include compositionally layered (banded) quartzo-feldspathic gneisses, a medium-grained biotite and chlorite granite or quartz monzonite that is probably part of a regional 1,700 m.y.o. suite, small amounts of a potash-feldspar granite porphyry (here called a megacrystic granite) that is probably related to a regional 1,400 m.y.o. suite, and various pegmatites, diabase dikes, and aplites. Minor diorite masses may be a dark phase of the 1.7 b.y.o. granite suite.

Three areas display a foliation that can be related to tectonic events of the region. It is assumed that these foliations, of Phanerozoic age, are imposed locally upon Precambrian foliation(s) that are noted elsewhere in the Precambrian terrain on the map. These three areas are (a) extreme westernmost outcrops of the gneiss in sections 15 and 16, T.6N., R.18W., (b) outcrops of the gneiss structurally just beneath the Plomosa fault, extending for about 8 miles in a north-south direction, and (c) outcrops in section 35, T.6N., R.18W., relatable to Phanerozoic faulting near there.

In certain areas such as the NW 1/4, section 26, T.6N., R.18W., the gneiss displays compositional layering with individual laminar bands in places having thicknesses of millimeters and lateral extents of meters. It is possible that these well-layered gneisses have clastic sedimentary protoliths. In other areas, such as NW 1/4, section 30, T.7N., R.18W., a peculiar banded unit crops out and consists of alternating white and apple-green colored, aphanitic, dense, layered material. The individual bands are from one to five feet thick. The protolith of this material may be

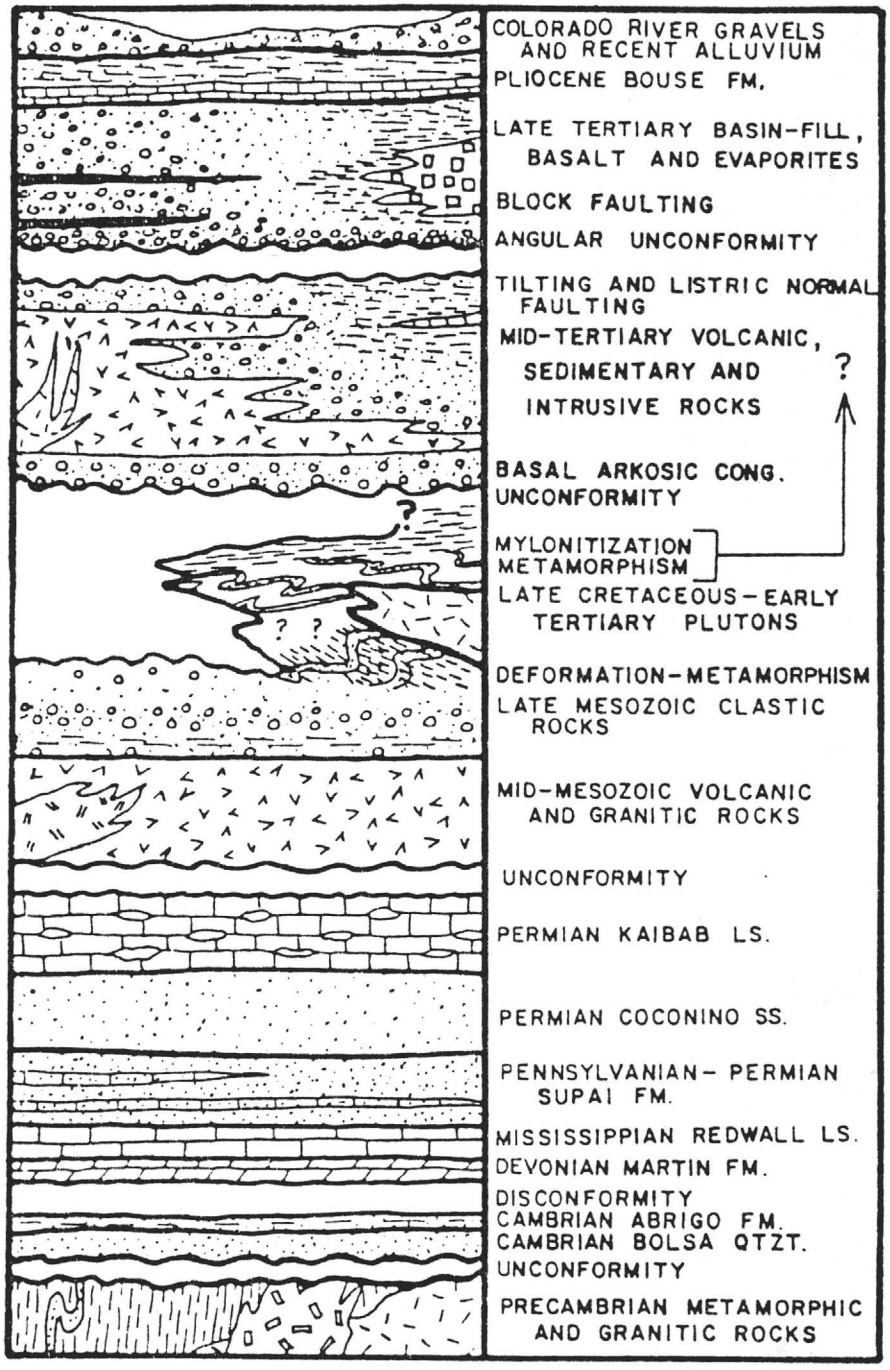


Fig. 1. Chronology of rock units and major events (from Reynolds, 1980).

volcanogenic sediments, possibly subaqueous tuffaceous mudstones.

PALEOZOIC

Paleozoic strata in the northern Plomosa Mountains consist of formations that are lithologically correlatable to those of Paleozoic age in adjacent mountain ranges (Reynolds and others, 1980; Miller, 1970; Richard, 1983; Hamilton, 1963). However, virtually without exception, these formations in the northern Plomosas are bounded by tectonic contacts, making all thicknesses minimal. A few fossil gastropods and crinoid columns, not yet identified as to species, were found in limestones at points identified on the map. The most intact Paleozoic section in the northern Plomosas was seen at Round Mountain (SE 1/4, Section 19, T.7N., R.17W.), where the sequence Bolsa Quartzite through at least Supai Formation, or possibly Kaibab Limestone is present in a southwest-dipping section. Even so, the section is attenuated by numerous bedding plane faults and other internal deformations.

Paleozoic strata in the nearby region consist of the typical cratonic shelf assemblage of southeastern Arizona in the lower part of the section and of the Grand Canyon in the upper part of the section (Miller, 1970). Formations include the Cambrian Bolsa Quartzite and the Abrigo Formation (correlative with the Tapeats Sandstone and Bright Angel Shale of the Grand Canyon, respectively), the Devonian Martin Formation, the Mississippian Escabrosa Formation or Redwall Limestone, the Pennsylvanian-Permian Supai Formation, and the Permian Coconino Sandstone and Kaibab Limestone. A section of massive gypsum mixed with green shaly beds may possibly correlate with the alpha or Harrisburg member of the Kaibab Limestone found in northwestern Arizona or it may be of Mesozoic age, as discussed below.

The Bolsa Quartzite and the Abrigo Formation are both very thin in the area and each consist of 15-20 m. or less. The Bolsa Quartzite consists of a hard, medium-grained quartzite with light pink or maroon colors; it weathers to massive cliffs that are stained very dark by desert varnish. The Abrigo Formation consists of thin interbeds of phyllite, fine-grained quartzite, and thin gray- to tan-colored carbonate beds.

The Martin Formation, which disconformably overlies the Abrigo regionally, is a mixture of medium gray and brown sandy dolomite, dolomite, and dolomitic limestone beds and reaches a thickness of 70 to 100 m. Outcrops of the Martin Formation weather to a yellow-brown color.

The Escabrosa Limestone overlies the Martin Formation disconformably and consists of a massive bedded, cliff-forming, sandy dolomite and cherty limestone that can be 125 m thick in an undisturbed section. Fresh colors are white, buff, and cream. Chert pods do not dominate any units in the Escabrosa. Richard (1983) in the Little Harquahalas recognizes a tripart sequence in the Escabrosa (Redwall) Limestone with the middle part variably dolomitized, and the two lower parts collectively comprising the cliff-forming part of the formation.

Overlying the Escabrosa Limestone is the very colorful and distinctive Supai Formation. It consists of calcareous, fine-grained quartzites that weather to tan, dark reddish-brown, or black colors. The more massive beds, perhaps 2-5 feet thick, weather to the darkest colors and are characterized by a "worm-eaten wood" appearance. The other, more finely interbedded, variably calcareous units weather to tan or red-brown colors. The Supai has a thickness of about 170 m.

Overlying the Supai Formation is the Coconino Sandstone; it consists of about 200 m of fine- to medium-grained, white, pure quartz arenite, now quartzite, that generally lacks any visible internal bedding and is usually highly fractured. The intense fracturing makes rubbly slopes out of even the best Coconino exposures and renders cross-bedding quite difficult to see. Nowhere else in the stratified sequence does a thick, similar-colored, quartzitic unit occur, thus making the Coconino an easily mappable unit.

Above the Coconino is the Kaibab Limestone, which is a very cherty, fetid, gray to blue-gray, fossiliferous series of limestone beds that is up to 205 m thick in the Quartzsite quadrangle of the southern Plomosa Mountains. Richard (1983) discusses a relatively complete Kaibab Limestone section in the Little Harquahala Mountains that is up to 400 meters thick and consists of five units. Further detailed work in the northern Plomosas would probably delineate units of his Kaibab stratigraphy there.

As mentioned above, an evaporite unit is juxtaposed with the Kaibab Limestone and Mesozic clastic strata, as judged from details of stratigraphy in the Plomosa Pass area. It may represent the alpha (Harrisburg) member of the Kaibab that is present in the Basin and Range country south of Las Vegas (Bissell, 1969) or it may be an evaporite unit within the Mesozoic volcanic-sedimentary rocks. Its possible regional importance, discussed later, has thus far been overlooked because of the brief, reconnaissance nature of previous work. The evaporite unit consists of white,

coarsely crystalline (recrystallized) gypsum with perhaps some minor anhydrite and with abundant partings and thin interbeds of light to dark green to dark gray laminated mudstones. In places the mudstones attain thicknesses of several tens of feet. Pure gypsum beds within this sequence are 5 to 25 feet thick. The unit weathers as a slope-former, but is characterized by a peculiar popcorn surface of mottled gray, green, and light gray colors, making it easily mappable.

Richard (1983) mapped a 10-20 m thick evaporite-green mudstone sequence in the Little Harquahala Mountains that is lithologically very similar to the northern Plomosa evaporites. The evaporites in the Little Harquahala Mountains occur at the center of the western edge of section 19, T.4N., R.12W., in a south-dipping Mesozoic volcanic-sedimentary sequence. Richard maps the evaporites as stratigraphically above his Jv unit (lower and upper Jurassic volcanics, including a quartz porphyry unit) and an overlying Jvs unit (volcanoclastic sediments derived from Jv); and the evaporite is beneath his JKau (upper Apache Wash Formation tuffaceous sandstones). A laterally equivalent unit to the evaporites is his JKal unit, (lower conglomerate member) that thins out northward and is replaced by the evaporites. In this stratigraphic context, the gypsum-shales may represent ponded, restricted circulation evaporites formed synchronously with riverine or piedmont gravels, and overlain by some kind of fluvial (braided?) stream deposits.

A gypsiferous unit has been noted in the Harquahala Mountains in the upper reaches of the piedmont, just below the White Marble mine (Peirce, oral communication, 1983). Its stratigraphic position there is not well known, except insofar as it is associated in outcrop pattern with the Kaibab Limestone, as it is in the Plomosa Pass area of the northern Plomosas.

Paleozoic-Mesozoic gypsiferous strata are recognized in adjacent California. In the Riverside Mountains, Lyle (1982, p. 477) notes that a gypsiferous phyllite that directly overlies the Kaibab Limestone "is a very enigmatic unit. In most areas the gypsum does not appear depositional, but rather seems to have been remobilized or generated by later metamorphism and/or hydrothermal activity associated with sulfide mineralization. Sericitic quartzite (Aztec Sandstone?) that overlies the gypsiferous phyllite is locally present in Mesozoic sections." Above the Aztec Sandstone is a section of tuffs, arenites, dolomites, calc-silicate layers, and conglomerates. His only age constraints on the gypsiferous strata are that they are younger than Kaibab and are older than the sericitic quartzite that a few workers are calling the Aztec Sandstone which in its type area is of

early Jurassic age. In the Little Maria Mountains, Emerson (1982) briefly notes that the Kaibab Limestone "plays host to a considerable amount" of gypsum and anhydrite evaporites.

MESOZOIC

A tectonically thinned, fine-grained clastic sequence is here assigned to the Mesozoic; it is most probably correlative with the "continental red beds" of Miller (1970) found in the Quartzsite quadrangle to the south. As in that area, the sequence in the northern Plomosas contains fine- to medium-grained, variably calcareous sandstones and a few quartzite pebble to cobble conglomerates. As with other stratified units, it is of indeterminate thickness because it is found only in a highly attenuated state in a tectonic melange. The section is now metamorphosed to muscovite-bearing, gray- to silver-colored phyllites or phyllitic mudstones. The unit is found in three parts of the study area - the Plomosa Pass area, south of Round Mountain, and intercalated into the southern volcanic terrain.

Robison (1979), in a M.S. thesis on the Mesozoic clastics in the southern Plomosa Mountains, indicates that these conglomerate-bearing red beds underlie or interfinger with the basal part of the thick Livingston Hills Formation. This 5000 m thick formation consists of conglomerate, graywacke, and siltstone, but is not recognized in the northern Plomosas. Volcanics of Mesozoic age were not recognized in the study area.

Other probable Mesozoic units include a pluton of fine- to medium-grained biotite granite that crops out over an area of about 0.4 square miles near Plomosa Pass, and a related series of northwest-trending aplitic and microgranite to micro-quartz monzonite dikes, which range in thickness from 2 to 50 feet. By regional analogy, this granite is probably 70-85 m.y. old and is assigned a Laramide age. In this report, the granite is called the Mudersbach pluton, named for the mine of the same name that is developed in Paleozoic carbonates that were mineralized by fluids related to the intrusion of the pluton.

CENOZOIC

Late Oligocene and early Miocene rocks are represented by a lower section of 1) Artillery Formation sediments and associated basal silicic volcanics, 2) an overlying and locally thick section of volcanic flows with basal red beds and andesite flows and overlying rhyolites to latites, 3) overlain by a section of red bed fanglomerates. The youngest sediments are 4) those that fill the present valleys and are herin called basin fill. These are the only tectonically undisturbed rocks in the area.

The Artillery Formation, defined in the type area of the Artillery Peaks about 45 miles northeast of the Plomosas, consists of three major units in the map area. A basal arkose and arkosic conglomerate, up to 30 m thick north of Round Mountain, was called the Bouse Arkose by Jemmett (1966), and is composed of white, red-brown, and green-colored beds of fluvially sorted stream sediments. Clasts are composed of white vein quartz, megacrystic granite, and quartzo-feldspathic gneiss. The rock was mostly derived from a granitic terrain, presumably the Precambrian granite upon which it is deposited in most areas. North of Round Mountain the arkoses contain interbeds of thin andesite flows that are now extremely weathered. Above the arkose is 20-80 m of very colorful (maroon, pink, red, and red-brown), thin-bedded limestones, limy mudstones, and shales characterized by laminar wavy bedding. The limestones contain several unwelded and welded ash flows that are 2-5 m thick. The fine grained sediments weather to a rather uniform surface with pure limestone units (3 inches to 2 feet thick) standing out in bold relief. The sequence thickness is best measured in the area east or northeast from Round Mountain, but even there is only measured with difficulty since all contacts with other units are faulted. Around Four Peaks and in the southern part of the map area, several thin ash flows underlie the Artillery sediments.

The Artillery Formation is separated by an angular unconformity (commonly 5-15 degrees) from an overlying section of volcanics whose internal stratigraphy varies from place to place. In the northern part of the area, the section consists of about 50-150 m of a mixture of dark-colored red beds, some andesite flow breccias, and a series of andesitic volcanics, some of which contain manganese and barium mineralization (barite, psilomelane, etc.). In the southernmost area of the map the section consists of 5-20 m of basal andesites with a thin, basal fluvial unit of red beds; the andesites are overlain by

200-400 m of predominantly cliff-forming, unwelded ash flows with related domes, pyroclastic vents and dike swarms that trend north-south to northwest-southeast. Both in the southern map area and around Four Peaks, the lower part of the volcanic section (usually near the top of the basal andesites) contains many small, discontinuous, megabreccia slide blocks of Paleozoic limestones, including lithologies from Escabrosa through Kaibab. The carbonates sometimes are associated tectonically with thin slivers or masses of megacrystic Precambrian granite. The slide blocks clearly sit on andesite flows in many places. See the 1:24,000 map for details. The problematic aspect of these units is that although the quartzite units are internally fractured, thicker masses of limestones do not contain the typical "crackle breccia" texture that is so common in other megabreccia slide masses that are well documented in southern Arizona. Yet their interleaving into the Cenozoic section is an unmistakable attribute of a landslide origin. The landslide blocks most likely were derived from exposures of Paleozoics to the north, where outcrops still occur.

North of the Plomosa Pass area, a red bed unit occurs above the volcanics and consists mostly of bright red-brown colored, debris flow-dominated fanglomerates. They contain thin vertical clastic dikes (as in NE 1/4, SE 1/4, section 30, T.6N., R.17W.), and barite veins that are subject to continued prospecting (as in center, N 1/2, section 31, T.6N., R.17W.). In one spot, symmetrical ripple marks with a wavelength of 4 cm were found on a sandstone in this red bed unit. Just south of Four Peaks, the red beds appear to thicken, perhaps up to 100-200 m. Thick red beds were not seen in the southern part of the map area, but may have been present in the volcanic mountains. These red beds are most probably correlative with the Chapin Wash Formation aroung Artillery Peaks and the Copper Basin Formation north of Blythe, both of which have been dated as mid-Miocene (about 14-16 m.y.o.) based on large mammal tracks and age dates on associated volcanics. See Wilt and Scarborough (1981) for a state-wide summary of Cenozoic stratigraphy.

Undeformed basin fill rests with angular discordance upon all older rocks. Exposed parts of this material are probably no older than mid-Pliocene. A strat test hole (Federal La Posa No. 1A) was drilled by El Paso Exploration Company in 1968 in NW1/4, Sec. 24, T.7N., R.19W., about 11 miles due west of Bouse (collar elevation was about 880 feet above sea level). A partial lithologic log indicates that sandstone, gravels, and minor claystone were penetrated in the first 780 feet; followed by claystone and mudstone with gypsum and anhydrite stringers in the interval 780-2020 feet. 'Metamorphic basement complex' was encountered from 2328 to 2815 feet (Total Depth). El Paso geologists identified Bouse

Formation between 850 and 1197 feet, based presumably on differing colors. If this identification is correct, the top of the Bouse Formation is now 30 feet above sea level in this area, indicating that negligable net vertical crustal movements have occurred since the end of Bouse deposition, which was in the late Pliocene or early Pleistocene. This is in contrast to other places along the lower Colorado River trough where the Bouse Formation is now elevated many hundreds of feet above sea level (Lucchitta, 1978).

These basin fill beds are capped by Pleistocene pediment gravels and on the west side of the range on the La Posa Plain are overlain occasionally by light red-brown colored sand dunes, most of which have been arrested by vegetation. The piedmont west of the mountains, the La Posa Plain, is virtually undissected by stream downcutting, except locally in the uppermost reaches of the piedmont. Stream channel bottoms (as in center, section 16, T.6N., R.18W.) are incised perhaps 1-1.5 m. East of the range, near the mountain front, (as in E 1/2, sections 24 and 25,T.6N.,R.18W.) coarse-grained basin fill has been dissected by the north-flowing ephemeral streams as much as 20-25 meters. Farther out into the Ranegras Plain, dissection is minimal, and sheet flooding occurs.

The ages of the Tertiary rocks must be inferred from regional arguments, since only one published age date is known for the volcanics in the northern Plomosas. An ash flow south of Four Peaks (near center, NE 1/4, SE 1/4, section 26, T.6N.,R.18W.) was dated at 26 m.y. by Eberly and Stanley (1978, their number 91). The ash flows beneath the Artillery Formation date at about 20-30 m.y.o. throughout the region (Scarborough and Wilt, 1979; Reynolds, 1980). These volcanics and the Artillery limestones lie beneath an angular unconformity, above which is a younger volcanic pile and red beds that regionally date at about 14-21 m.y.o. Since this unconformity usually caps rocks with 5-15 degree greater dip than the overlying ones, some sort of regionally extensive tilting phenomenon must have been active between 21-25 m.y. ago. It probably took the form of either listric faulting (Reynolds, 1980) or folding.

Where undeformed basin fill has been dated, it is apparently not older than 12-13 m.y. (Eberly and Stanley, 1978; Scarborough and Peirce, 1978) throughout most of southern Arizona; the oldest flat-lying volcanics along the lower Colorado River are also about 11 m.y. old.

GEOLOGIC RELATIONS IN THE NORTHERN PLOMOSA MOUNTAINS

STRUCTURES

The northern Plomosa Mountains are divided on a structural basis into at least six domains or plates that are adjoined by major faults. Very dissimilar rocks have been tectonically juxtaposed during a series of low-angle, probably thrust faulting events and also during a later Cenozoic, gravity-induced, detachment or sliding event. The earlier thrust fault events most likely occurred in the Cretaceous during the Sevier and/or Laramide orogenies and possibly again in the Eocene during an event called the "Eocene underthrusting" by Stanley Keith. Later, during the middle Miocene, a "dislocation" or "detachment" faulting event again juxtaposed terrains, possibly during a gravity sliding event.

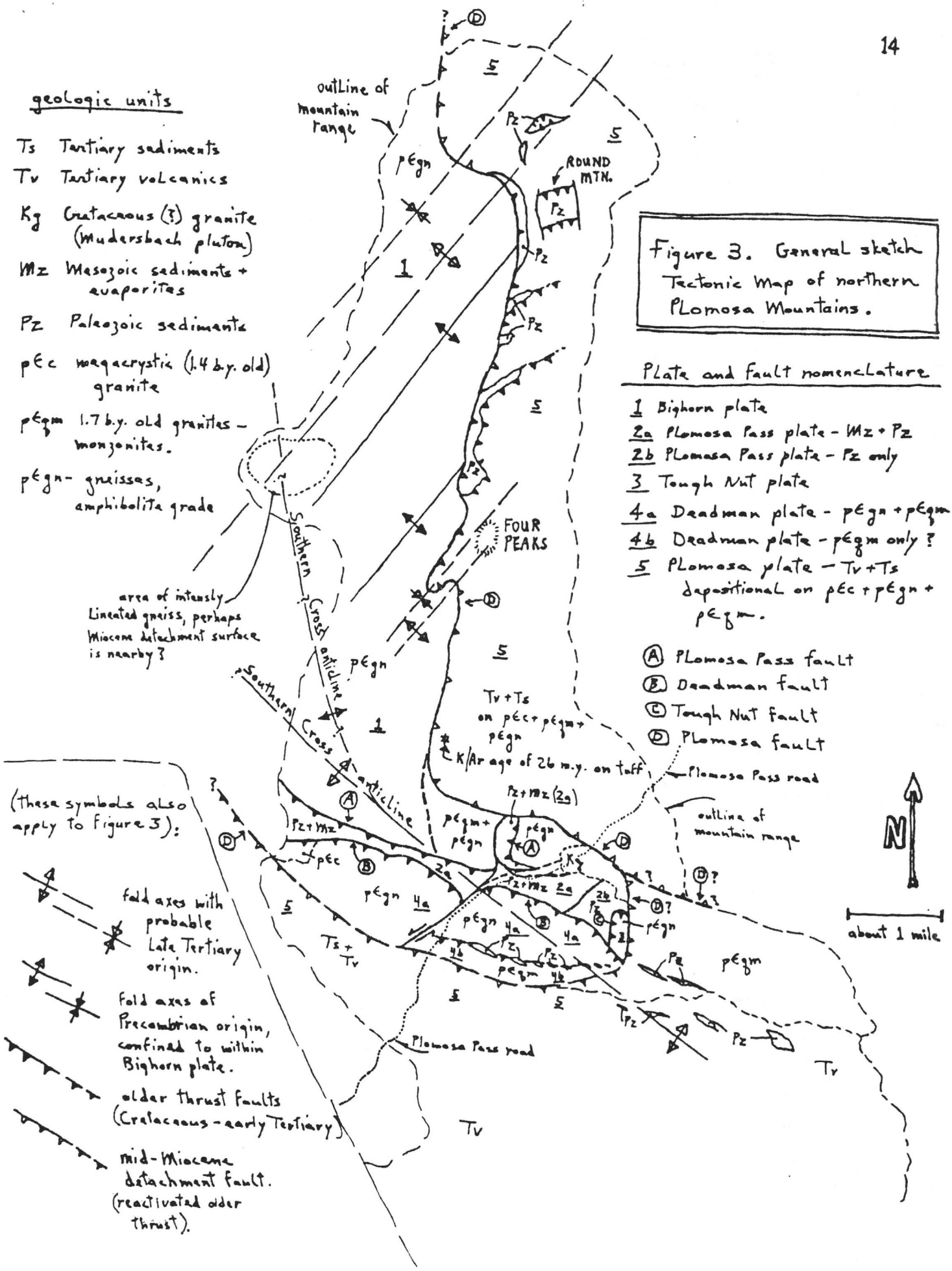
As mapped for this report, the plate above the Miocene fault contains a Cenozoic sedimentary and volcanic series deposited across a tilted and erosionally beveled three-plate melange composed of Precambrian, Paleozoic, and Mesozoic rocks. The plate beneath the Miocene fault contains Precambrian, Paleozoic, and Mesozoic rocks tectonized into a five-plate melange by earlier thrust faults.

Figure 3 is a general tectonic map of the proposed nomenclature for the structural units recognized in the map area. Assuming that none of the plate stratigraphy is overturned, and relying upon dip patterns of plate-bounding faults, the structural sequence from lowest to highest is: Bighorn plate, Plomosa Pass plate, Tough Nut plate, Deadman plate, and Plomosa plate.

GENERAL DESCRIPTIONS OF LITHOLOGIES WITHIN PLATES

1) BIGHORN PLATE

This plate consists mostly of Precambrian gneissic rocks and contains some granites, diorite, pegmatites, and several pods of a possible metasedimentary sequence. The gneisses display complex refolding patterns, but a general NNE-trending compositional layering predominates. The series


geologic units
Ts Tertiary sediments
Tv Tertiary volcanics
Kg Cretaceous (?) granite (Mudersbach pluton)
Mz Mesozoic sediments + evaporites
Pz Paleozoic sediments
p€c megacrystic (1.4 b.y. old) granite
p€gm 1.7 b.y. old granites - monzonites.
p€gn - gneisses, amphibolite grade
outline of mountain range
ROUND MTN.
FOUR PEAKS
Southern Cross anticline
area of intensly Lineated gneiss, perhaps Miocene detachment surface is nearby?
Tv + Ts on p€c + p€gm + p€gn
K/Ar age of 26 m.y. on tuff
Plomosa Pass road
outline of mountain range
Plomosa Pass road
Figure 3. General sketch Tectonic Map of northern Plomosa Mountains.
Plate and fault nomenclature
1 Bighorn plate
2a Plomosa Pass plate - Mz + Pz
2b Plomosa Pass plate - Pz only
3 Tough Nut plate
4a Deadman plate - p€gn + p€gm
4b Deadman plate - p€gm only ?
5 Plomosa plate - Tv + Ts depositional on p€c + p€gn + p€gm.
A Plomosa Pass fault
B Deadman fault
C Tough Nut fault
D Plomosa fault
(these symbols also apply to Figure 3):
fold axes with probable Late Tertiary origin.
fold axes of Precambrian origin, confined to within Bighorn plate.
older thrust faults (Cretaceous - early Tertiary)
mid-Miocene detachment fault. (reactivated older thrust).
N
about 1 mile

is generally metamorphosed to amphibolite grade. Because these are the structurally lowest rocks present in the map area, they could represent autochthonous basement. However, based on evidence in nearby regions that is discussed later, this may not be the case.

2) PLOMOSA PASS PLATE

The Plomosa Pass plate is a tectonic melange containing thin interleaved slices of many sedimentary rock types including Paleozoic limestones and quartzites, massive gypsum beds mixed with green mudstones, and slates and phyllites of Mesozoic age. It has undergone ductile deformation and greenschist grade metamorphism that has destroyed fossil content of the limestones and produced an impressive set of tight folds. In greater detail, and as seen in Figure 2, this plate may be subdivided laterally into two areas, an eastern area containing exclusively Escabrosa, Supai, Coconino, and Kaibab rocks, and a western area contining all the mapped evaporite occurrences, along with many thin slices of Paleozoic carbonates and Mesozoic phyllites. In addition, the Coconino quartzites, which are so thick and extensive in the eastern area, are represented only by a few, thin, small tectonic slices in the western area. The two areas abruptly join each other along what is probably a covered NE-trending fault. The western evaporite-bearing melange is squeezed to extreme thinness (200 m) precisely at the mountain range divide near the Plomosa Pass road.

MUDERSBACH PLUTON. The rocks of the Plomosa Pass and Bighorn plates are mapped as being intruded by the Mudersbach pluton, a biotite granite of probably Laramide age, exposed mostly south of the Bouse-Quartzsite road. This granite is not foliated or deformed, and therefore is younger than the deformation(s) recorded in the rocks of the Plomosa Pass and Bighorn plates. The granite resembles a finer-grained equivalent of the 85 m.y. old Tank Pass Granite that crops out across the valley to the east. The Mudersbach could alternatively be related to the 70 m.y. old granites of the region such as the Granite Wash granite; it could conceivably be related to the granites of the mid-Tertiary volcanic pulse at about 25 m.y.o. An age date on this rock, or on one of the many NW-trending micro-quartz monzonite dikes would help to clarify the minimum age on the time or times of this older tectonization. An interesting, probably reset, age of 16.5 $\pm$ 0.50 m.y. was obtained on the large granite mass shown centered 8 miles east of Bouse on the Arizona state geologic map (Shafiqullah and others, 1980, date number 115). The rock is described as a biotite granodiorite.

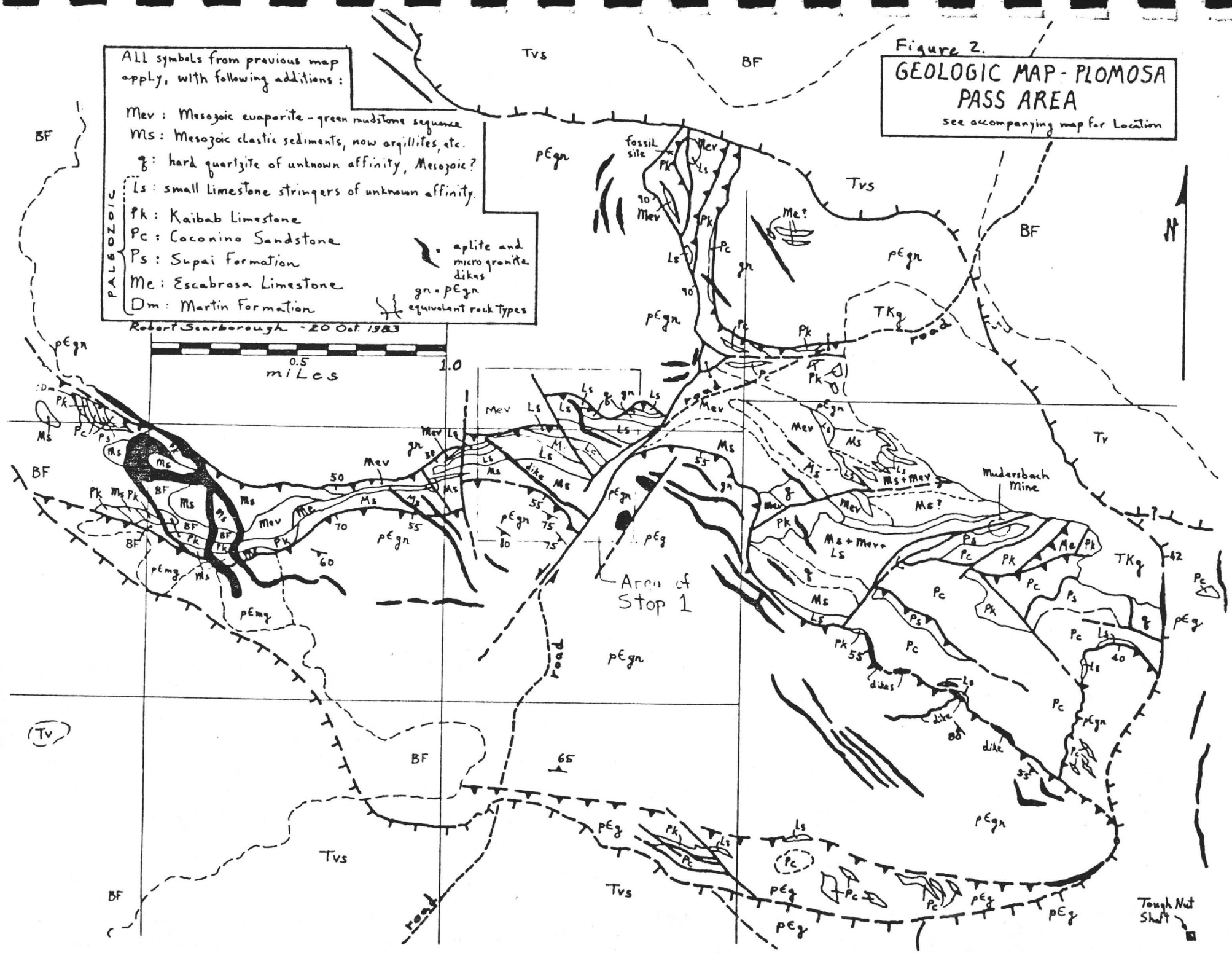


Figure 2.
GEOLOGIC MAP - PLOMOSA PASS AREA
see accompanying map for Location
ALL symbols from previous map apply, with following additions:
Mev : Mesozoic evaporite - green mudstone sequence
Ms : Mesozoic clastic sediments, now argillites, etc.
q : hard quartzite of unknown affinity, Mesozoic?
Ls : small Limestone stringers of unknown affinity.
PALEOZOIC
Pk : Kaibab Limestone
Pc : Coconino Sandstone
Ps : Supai Formation
Me : Escabrosa Limestone
Dm : Martin Formation
aplite and micro granite dikes
gn - pEgn equivalent rock types
Robert Scarborough - 20 Oct. 1983
0.5 miles 1.0
N
Tvs
BF
pEgn
fossil site
Mev
Pk
Ls
Me?
Pc
gn
TKg
road
Tv
Mudersbach Mine
Ms + Mev
Ms + Mev + Ls
Area of Stop 1
dikes
dike
pEg
pEmg
Tough Nut Shaft

3) TOUGH NUT PLATE

This a very small plate-remnant of gneisses that have very similar lithologies to the gneisses of the Bighorn plate. The Tough Nut plate is structurally above the eastern extent of the Plomosa Pass plate, where the latter consists almost exclusively of Coconino quartzites. Interestingly, the Tough Nut gneisses contain small, tectonically interleaved, slices and masses of Coconino rocks, and the tectonic contact between the Tough Nut plate and Plomosa Pass plate is smeared with stretched-out slices of Paleozoic carbonates. An alternative structural interpretation is that possibly because of some ambiguous fault relationships in the area, the Tough Nut plate could be a fragment of the Deadman plate. In such a case the northern boundary of the Tough Nut plate could be an extension of the Deadman fault that had been offset northward along the N-S trending fault mapped as the western boundary of the Tough Nut plate.

4a) and 4b) DEADMAN PLATE

The northern part of the Deadman plate (4a) is a subplate composed of gneissic rocks that display an extreme variety of dark and light lithologies, many of which are meta-igneous. At its western extent, the gneisses grade abruptly into a megacrystic granite terrain. Toward their southern extent, the gneissic rocks appear to be structurally bound to subplate 4b), the southern part of the Deadman plate, which is composed of a medium-grained Precambrian granite or quartz monzonite (probably a 1,700 m.y. old Precambrian rock). Subplates 4a and 4b are structurally bound together along a rehealed tectonic contact that is strewn with small, very discontinuous, sometimes en echelon, tectonic slices of predominantly Supai, Coconino, and Kaibab formations.

5) PLOMOSA PLATE

This plate is defined to include all the rocks above the Plomosa fault, which probably experienced its last movement during the mid-Miocene. This "detachment" phenomenon was probably related to a regional listric faulting (tilting) event which is now recognized to have affected much of the Basin and Range province. As noted later, the Plomosa fault probably had an older movement history.

The rocks in the Plomosa plate consist of a stratified

sequence of Cenozoic rocks deposited on top of a tripart plate assemblage that had been previously thrust-juxtaposed, tilted, and eroded to low relief. The three parts of the plate assemblage consist of a lower plate of 1,700 m.y.o. granite, gneiss and diorite; a middle plate of Paleozoic carbonate and quartzite and minor Mesozoic phyllites; and an upper plate of megacrystic granite with some minor gneisses. After the Cenozoic sediments and volcanics were deposited on the upper megacrystic granite plate, all the rocks above the Plomosa fault were involved in a mid-Miocene detachment faulting event. In this event a series of WNW-trending listric faults homoclinally tilted the Cenozoic rocks of the plate, resulting in south-southwest dips on the strata. The listric faults repeat the Cenozoic-on-crystalline stratigraphy four or five times along the eastern side of the northern Plomosas. In the southern part of the map area the upper silicic volcanic sequence becomes very thick, but still retains south-southwest dips; hence, all pre-basin fill Cenozoic rocks of the Plomosa Mountains that are north of the Interstate 10 freeway must have been listrically rotated and therefore are floored by one or more Miocene detachment surfaces, and numerous listric faults that floor in the detachment.

DIKES

Dikes composed of three different lithologies are represented in the northern Plomosa Mountains. The recognized lithologies are a) microgranite, micro-quartz monzonite, and minor microdiorite, b) rhyodacite, and c) aplite. The dikes generally trend northwest and are concentrated in the area around Plomosa Pass. The micro-quartz monzonite dikes are evenly textured, form vertical dikes 1-15 meters thick, and are found beneath the Plomosa detachment fault in the Bighorn, Plomosa Pass, and Deadman plates (plate nomenclature is shown on Figure 3). The rhyodacite dikes trend northwest to north, are 0.5-3 m thick (thicker in volcanic terrain), and intrude the southern volcanic terrain and the granites upon which the volcanics rest. The aplitic (finely crystalline quartz and feldspar) dikes are vertical, 1-5 meters thick, and trend parallel to, and intrude along, the Deadman and Plomosa faults. The aplitic dikes are concentrated in the terrain beneath the Plomosa fault, but are also found above the Plomosa fault in upper plate granites.

The micro-quartz monzonite dikes attain a 15 meter thickness in the northern half of Sec. 26, T.6N., R.18W. At the west end of that swarm the dikes are the host rocks of the black manganese oxide mineralization controlled by

NNE-trending fractures. The micro-quartz monzonite dikes within the western extreme of the Plomosa Pass Plate flared out into horizontally tabular masses and attain considerable thickness there. A few narrow microdiorite dikes are found cutting the Plomosa Pass plate melange. Judging by their cross-cutting relationship to the structural grain, these dikes are clearly post-kinematic. They compositionally resemble the Mudersbach pluton, but no dikes of any composition were noted to lead away from the pluton, hence an ambiguous relationship of intrusive chronology exists.

Because of poor exposures, it was not possible to ascertain whether or not the aplite dikes were emplaced before or after the last movement on the Plomosa fault, even though they intrude along the fault. They are certainly younger than the Mudersbach pluton because they intrude along the Plomosa fault where the fault truncates the pluton at its southeast corner, two-thirds of a mile southeast of the Mudersbach mine. They consistently intruded along the Deadman fault and parallel to it in the gneisses of the Deadman plate. They maintain a consistent northwest trend even though the general structural grain turns from northwest to an east-west direction going westerly and this suggests the aplite dikes were emplaced post-kinematically.

The rhyodacite dikes are limited in outcrop to a band two miles north of the northern outcrop limit of the southern volcanic terrain. Above the Plomosa fault, the rhyodacite dikes trend north-south in the upper plate granites, parallel to the proposed trend of the conjectural part of the Plomosa fault, and the ones found in the southern volcanic terrain trend generally strike parallel to the rotated blocks of volcanics. Beneath the Plomosa fault, in the gneisses of the Deadman plate, they trend east-west in the eastern half of Sec. 2, T.5N., R.18W.

In conclusion, all the dikes, as well as the Mudersbach pluton are judged to be post-kinematic. The rhyodacite dikes are late-stage and probably are the same age as the mid-Tertiary volcanics, while the micro-quartz monzonite and aplite dikes may be late stage Mudersbach pluton or late Mesozoic or mid-Tertiary in age. Shafiqullah and others (1980, No. 62, p. 249) obtained K-Ar ages of 28.6 $\pm$ 1.9 m.y. and 22.1 $\pm$ 1.3 m.y. on hornblende and biotite, respectively, from a northwest-trending "diorite" dike in the Harquahala Mountains. Logan and Hirsh (1982) obtained an age of 19.0 $\pm$ 1.2 m.y. on a dacite porphyry dike in the Castle Dome Mountains that does not cut a detachment fault nor penetrate upper plate volcanics, while another rhyolite porphyry dike, dated at 20.4 $\pm$ 0.6 m.y., cuts the detachment and upper plate volcanics. Shafiqullah and others (1980) also report two other K-Ar ages from dikes in the region. In

the Cabeza Prieta Mountains, a northeast-trending hornblende andesite dike that cuts the Gunnery Range granite was dated at 17.8 ± 0.6 m.y. (No. 110, p. 254). In the Eagletail Mountains, a biotite latite dike that cuts Precambrian basement and overlying tuffs and vitrophyres was dated at 20.0 ± 0.6 m.y. (No. 93, p. 252). Most likely, the rhyodacite dikes in the northern Plomosas will have an age of 30-15 m.y., based on these dike ages elsewhere.

STRUCTURAL OBSERVATIONS AND INTERPRETATIONS

The nature and timing of structural events within the northern Plomosa Mountains may be discussed using the following salient observations.

1. PLOMOSA FAULT

The general geologic history is best considered by dividing the northern Plomosas into two realms, one above and one below the Plomosa detachment fault. The most important part of the lower plate geology (beneath the Plomosa fault) is exposed in what may be a NW-SE trending anticlinal arch or window, whose axis is shown as the Southern Cross anticline on the 1:24,000 map. Since mapped evidence leads us to hypothesize that the anticline arched the Plomosa fault, the anticline is a very youthful feature, younger than the detachment event, and perhaps 13-15 m.y. in age, based on regional analogs (Reynold, 1980). There are a series of folds and high-angle reverse faults found throughout southern Arizona that were active at about this time, indicating a short-lived, NE-SW directed, compressive pulse just before the initiation of Basin and Range, high-angle, block faulting. It is probable that all the geology observed beneath the Plomosa fault exhibits essentially no trace of the detachment faulting event (except for a small amount of drag of gneissic foliation into parallelism adjacent to the Plomosa fault) and hence is telling us an entirely different story than the Miocene one.

2. ORDER OF STRUCTURAL STACKING

The order of structural stacking beneath the Plomosa fault, and proposed nomenclature for the area, is shown in Figure 3.

3. VERGENCE INDICATORS

In several areas, certain indicators of tectonic vergence were found at or near some of the above faults.

a) Slickenside lineations in the Plomosa Pass fault (structurally the lowest of all the major faults) were found at one locale which indicated an older SE plunge superimposed by a younger SW plunge.

b) Sediments within the Plomosa Pass plate contain small rooted "S" and "Z" fold axes trending S10-55W with indicated vergence of SE to E, and long-axes trends on stretched quartz pebbles of S55E, implying NW-SE transport. A few scattered NE vergent folds were also noted.

c) Paleozoic limestones in an outcrop of tectonic melange above the Plomosa detachment fault (in the Plomosa plate but possibly representing an exotic part of the Plomosa Pass plate) contain a beautiful example of some "S" folds with SSE vergence. This area is very near the center of NW 1/4, section 31, T.7N.,R.17W. in a saddle along the crest of the Paleozoic outcrop there.

d) Along the Deadman fault, limited data (such as a few NE plunging slickenside lineations and a few small folds above and below the fault) indicate NE vergence on this structure. Also, away from the Deadman fault throughout the eastern extent of the Plomosa Pass plate, several NE vergence indicators were noted.

e) Slickenside plunge directions in three areas along the northern part of the Plomosa fault indicate NE - SW movement. Tectonic transport during Miocene detachment of rocks above the fault, however, is more NNE, based on the average SSW dip directions of listrically faulted, stratified Tertiary rocks; transport was more ENE in the extreme northern part of the range, just west of the town of Bouse.

4. MOVEMENT ON PLOMOSA FAULT

The Plomosa fault has experienced at least two periods of movement, probably under very different conditions, based on the following reasoning. A relatively easily mapped, generally east-dipping fault, the Plomosa fault, probably represents brittle failure and regional gravity-induced detachment in Miocene time. However, beneath the detachment fault for a variable distance (0-50 m) exists a tectonic zone that sits structurally on the gneisses of the Bighorn plate

and consists of tectonically interleaved lenses of Paleozoic carbonates and quartzites with gneisses. Individual slices range in thickness from 0.5 to perhaps 3 meters. This phenomenon is well exposed in the SW 1/4, section 19, and adjacent NW 1/4, section 30, T.7N.,R.17W., just west of Round Mountain. The slices are oriented rather parallel to the general trend of the Miocene fault surface, but in some cases they exhibit tight isoclinal folding. The carbonates are clearly interleaved and severely tectonized and stretched, and <u>not</u> simply brecciated. This indicates that this tectonization took place under considerable confining pressure, and not as a near-surface, brittle phenomenon. Sparce vergence indicators, perhaps not enough to be meaningful, suggest SSW vergence for this earlier movement on the Plomosa fault. That the detachment occurs at or near the top of a tectonized zone indicates that the Miocene breakaway occurred along the old zone, which may well represent an older thrust zone, similar to that proposed for the rehealed tectonic contact between the upper and lower Deadman Plate contact.

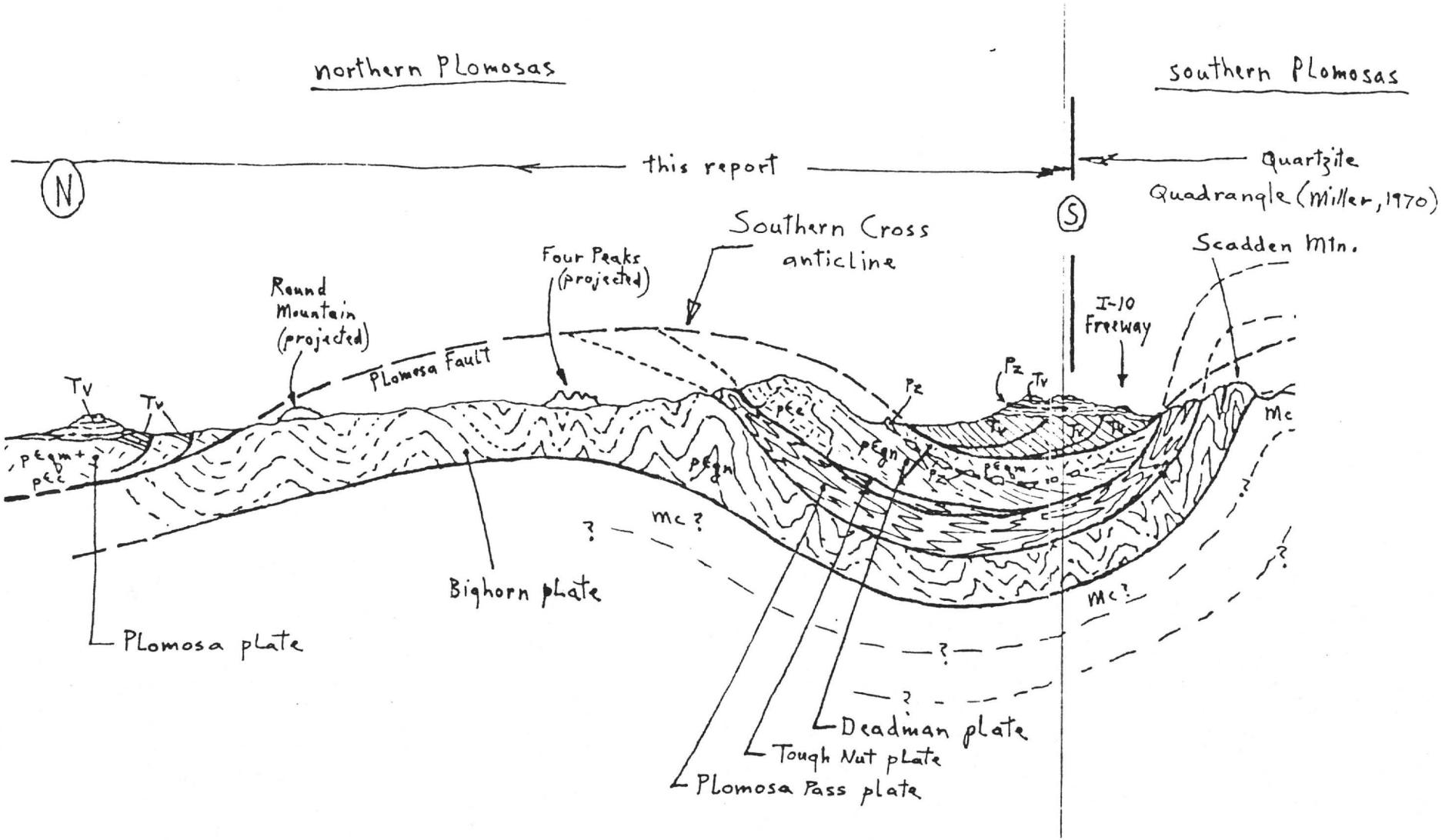


Figure 4. Geologic Cross-Section of the Plomosa Mountains

ECONOMIC GEOLOGY

The northern Plomosas contain two mineralized areas that appear on the Keith and others (1983) map of mineralized areas of Arizona. These are the Northern Plomosa and Central Plomosa mineralized areas. The district total production of these two areas are given in Table 1 and are compared to two other nearby mineralized areas. Serious mining commenced in the region in the very early 1900's following the completion of the Arizona and California Railroad through Bouse (Keith, 1978, p. 67). The route is shown on the geologic map in Lee (1908).

BASE AND PRECIOUS METALS

The northern Plomosa mineralized area is centered about 4 miles northwest of Bouse, and consists of 9 mines with recorded production, operated between 1901 and 1955. Ores were chiefly copper-gold with silver and minor lead; the ores were contained in specular hematite-manganese oxide gangue host, invariably filling faults or shears. Mineralization is confined, with few exceptions, to above the Plomosa detachment fault, in the highly faulted terrain mapped by Jemmett (1966). One small copper-hematite deposit beneath the Plomosa detachment fault is the Sidehill mine of Jemmett, near the center NW 1/4, section 30, T.7N., R.17W.

The largest tonnage mine was the Little Butte mine that produced nearly two-thirds of the district total gold. Mineralization is accompanied by iron-manganese gangue minerals, and consists of pods and stringers along a single major NNE trending fault and several minor NW trending faults that juxtapose Tertiary shales, limestones, and tuffs with Precambrian gneiss (Jemmett, 1966, p. 108). Keith (1978, p. 170) describes severe brecciation and deep oxidation conditions. Gold values in the Northern Plomosa mineralized area are the highest of any in Table 1, reaching 0.68 oz/ton. Silver values district-wide averaged 0.98 oz/ton.

The Central Plomosa mineralized area contains five mines with recorded production, operated between 1907 and 1951. This area is in the four-mile wide zone adjacent to and south of the Bouse-Quartzsite road. The area was mined primarily for lead and zinc with minor silver (2.9 oz/ton). Gold averaged about 0.03 oz/ton. The Southern Cross mine (Lead Camp of Bancroft, 1911) was the largest producer in the area, and was solely responsible for the area's zinc production,

and most of the lead. Mineralization here is along faults and fractures mostly confined within Paleozoic carbonate blocks floating in a mass of mid-Tertiary volcanics, with presumed mid-Tertiary timing on mineralization. The smaller Climax mine group, 2 miles farther southwest, has metal ratios very similar to the Southern Cross mine, as does the Keiser barite mine, farther south yet. The Excelsior (Mudersbach) mine produced copper-silver ore with minor gold between 1910 and 1930. This production came from replacement bodies in Paleozoic carbonate host rocks that are within 300 meters of the edge of the intrusive Mudersbach pluton. This mine is the only one in the Central Plomosa mineralized area whose production is dominated by copper rather than lead-zinc, and may represent a Laramide mineralization system rather than mid-Tertiary. Grossular garnet-specularite-calcite skarns are locally abundant along lithologic or structural boundaries within the carbonate-quarzite masses.

Other scattered areas of base-precious mineralization are known in the northern Plomosas. Traces of copper-lead mineralization with gangue manganese-iron are seen on the south flank of Four Peaks, the south flank of Round Mountain (section 19, T.7N.,R.17W.) along with yellow fluorite, along a northwest trending shear zone (near center, section 15, T.6N.,R.18W), and elsewhere.

FERROUS METALS

Iron

Iron ore was shipped from one property. In 1917, 19 freight cars of 61% iron ore (8% silica, low sulfur, low phosphorus) were shipped from the Phoenix and Yuma mine groups, one-half mile northwest of the Excelsior (Mudersbach) mine (north central part, section 6, T.5N., R.17W.) from what is reported by Keith (1978, p. 170) as "stringers and massive replacement bodies of hematite in a faulted complex of metamorphosed ... limestone, and Precambrian gneiss and schist".

Manganese

Manganese was produced in the northern Plomosas from four properties. The Black Chief and Cindy mines, one mile west of Round Mountain (along the junction between sections 24, T.7N., R.18W., and 19, T.7N., R.17W.) produced collectively about 2100 long tons of ± 20% Mn ore in 1953 from shear zones in the Plomosa detachment fault. The Black Bird mine group, one mle east of Bouse (SE 1/4, section 24, T.7N., R.17W.)

produced about 3470 long tons of ± 20% Mn ore from fracture zones in Miocene andesite porphyry and tuffaceous agglomerates. And in the southern part of the map area, the Black Beauty mine (NE 1/4, section 34, T.5N., R.17W.) produced 490 long tons of ± 20% Mn ore in the early 1950's, from along brecciated shear zones cutting the Tertiary andesite-tuff sequence (Keith, 1978, p. 166-168).

INDUSTRIAL MINERALS

Barite

Barite with admixed fluorite has been mined from veins generally cutting mid-Tertiary andesitic volcanics or redbeds. Three mines with known production are the Black Mountain mines group, 4 miles north of Bouse (center, section 34, T.8N., R.17W.) with 2500 tons produced, the Happy Day No. 3 mine (center, section 31, T.7N., R.17W) with 100 tons produced, and the Keiser barite mine (east central, section 21, T.5N., R.17W.) with small amounts of high grade barite produced (Keith, 1978, p. 167-169). Assays on mined barite concentrates from these deposits indicated between 3 and 14% contained fluorite. Exploration for barite continued into 1982 in and around NE 1/4, section 36, T.6N., R.18W., 1.7 straight line miles northwest of the Mudersbach mine. Vertical veins to 0.3 m thick that cut redbeds were being exposed by bulldozer scraping.

Bentonite

A few hundred tons of swelling type bentonitic clay were mined from a shallow quarry in young altered tuffaceous sediments east of Bouse in west central part of section 25, T.7N., R.17W., for use as a local drilling mud (Keith, 1978, p. 166).

URANIUM POTENTIAL

There are three known areas of anomalous radioactivity in the northern Plomosas. Anomalous radioactivity occurs in the center NE1/4, Sec. 13, T.6N., R.18W., (Rayvern claims, US AEC PRR-AP-348), in a steeply dipping section of limestones and shales of probable Paleozoic age. An incline shaft noted on the 15' quadrangle was sunk probably in search of copper at the site. The radioactive horizon, a very light-colored shale bed about 1 meter thick, has radioactivity characteristic of 0.05-0.10% uranium, but is too limited in extent to warrant further exploration. Nearby in the center

W1/2, Sec. 7, T.6N.,R.17W.) hematized fault gouge in Miocene redbeds rich in granitic debris is locally very radioactive (to 15x). And several thin limestone beds in the Tertiary shale-limestone-tuff sequence, correlative with the Artillery Formation in the Date Creek basin, contain 3x radioactive anomalies in several areas around Round Mountain (Scarborough and Wilt, 1979, p. 61). Judging from the general nature of these anomalies, the overall potential for uranium is judged to be low.

PETROLEUM POTENTIAL

This study was originally funded as an attempt to better understand the oil and gas potential of the Plomosas, in light of the recently hypothesized, regionally important "overthrust belt" concept that has been successfully drilled for oil in Wyoming and Chihuahua, Mexico. The hypothesis states that petroleum traps may exist in sedimentary strata that were buried beneath impermeable crystalline plates during a low-angle thrust-faulting event of Cretaceous or Laramide age. Drewes (1978) and Anschutz (1980) hypothesize that this belt of deformation extends through southern Arizona and connects the more certainly documented areas of thrusting in Wyoming and Chihuahua.

This study has documented the presence of telescoped cratonic Paleozoic and Mesozoic sediments with various crystalline rocks, comprising a stacked thrust assemblage in the northern Plomosa Mountains. However, the metamorphosed character of the sedimentary rocks robably precludes the possibility of any petroleum potential in these rocks. However, because of the stacked nature of the geology extending to an unknown depth, there may be potential for natural gas. Source beds for hydrocarbons are probably limited to various sands and evaporite-rich rocks that are seen in the Mesozoic section. Paleogeography and degree of telescoping are sufficiently unknown to exclude proper source rocks from being present, and perhaps buried beneath exposed structural levels. The best exploration tool is probably seismic profiling, assuming that thrust faults will be good reflectors, and that buried faults and folds will be present to act as traps.

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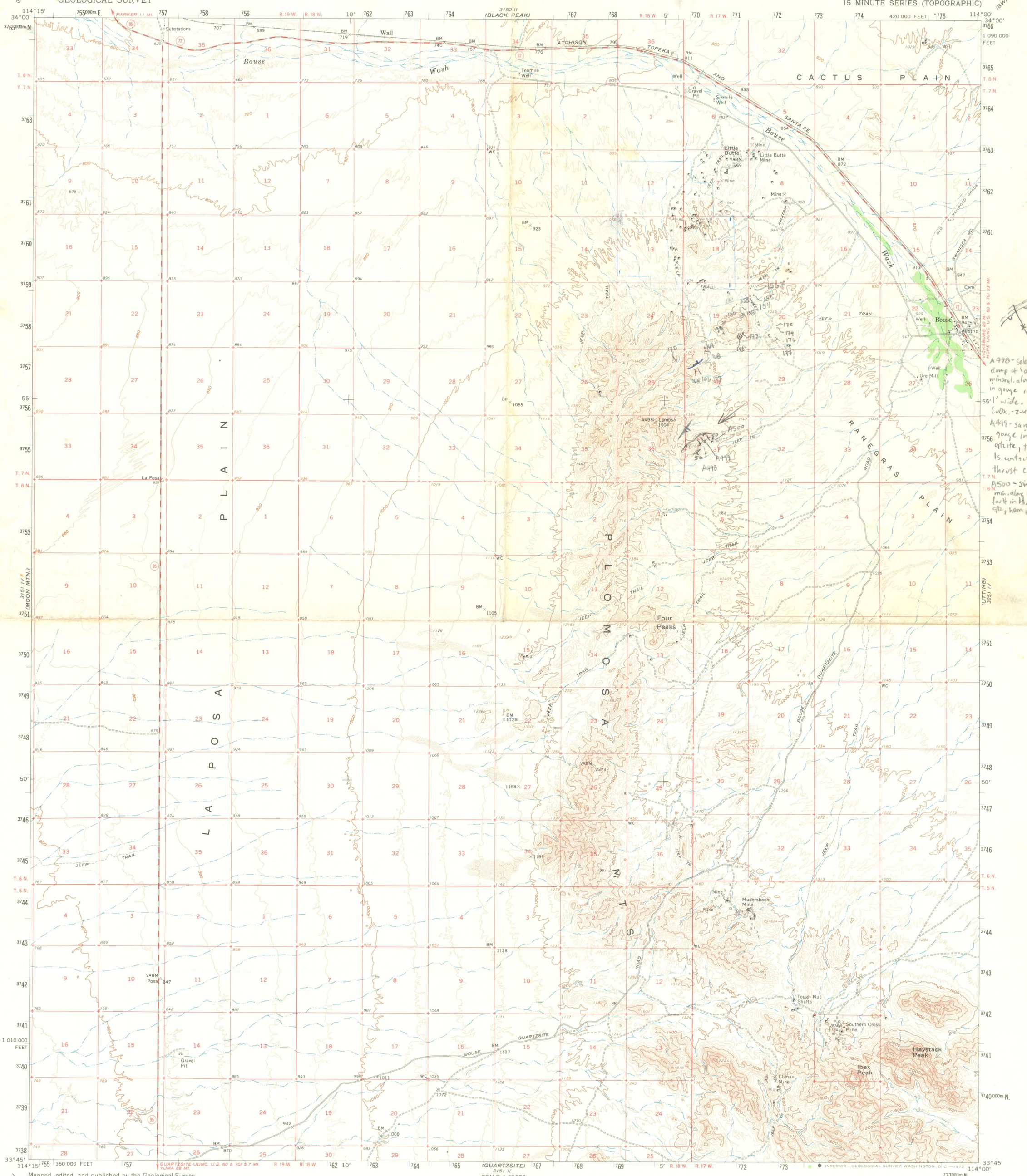
A-497 - Little Butte Mine - largest Au producer. - rip grab from dumps along stoping part of vein. vein trends ~N-S, dips 25-40E., ~2' wide. Spec. hem., w.r. frags, hem., MnOx, CuOx. No silica. Shaly w.r., locally argillized w.r. - trace vein for ~300'

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

BOUSE QUADRANGLE
ARIZONA–YUMA CO.
15 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1951 and 1960. Field checked 1962

Polyconic projection. 1927 North American datum
10,000-foot grid based on Arizona coordinate system, west zone
1000-meter Universal Transverse Mercator grid ticks, zone 11, shown in blue

Where omitted, land lines have not been established

UTM GRID AND 1962 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:62 500

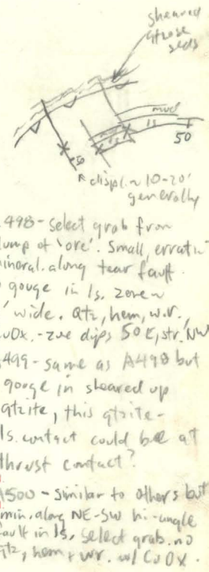
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

ROAD CLASSIFICATION
Medium-duty — Light-duty
Unimproved dirt
State Route

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225 OR WASHINGTON, D. C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

BOUSE, ARIZ.
N3345—W11400/15
1962
AMS 3151 IV—SERIES V798



A498 - Select grab from dump at 'ore'. Small, erratic mineral along tear fault in gouge in ls. zone ~1' wide. Qtz, hem, w.r. CuOx. - zone dips 50E, str. NW

A499 - same as A498 but gouge in sheared up qtzite, this qtzite-ls. contact could be a thrust contact?

A500 - similar to others but min. along NE-SW hi-angle fault in ls, select grab. no qtz, hem + w.r. w/ CuOx.

160

SOUTHERN PLOMOSA DISTRICT

Location:

This district is a southern extension of the northern Plomosa district and occurs in the mountains south of U.S. I-10. The district adjoins the New Water area on the east and includes mineral occurrences in the Livingston Hills to the south. Black Mesa which lies in the central part of the district is the dominant topographic feature. The district is included in Townships 3 and 4 North, Ranges 17 and 18 West of La Paz County and is found on the Quartzite 15' quadrangle.

Geology and History:

The geology of the district appears on the 15' geologic map of the Quartzite Quadrangle by Miller (1970). Generally, it consists of an extremely complex thrust terrain in pre-Tertiary rocks. The various lithologies involved in this interleaved tectonized sequence include: Precambrian plutonic rocks, Paleozoic cratonal facies sedimentary and metamorphic rocks, Mesozoic volcanic and continental sedimentary rocks and their metamorphic equivalents and Mesozoic plutonic rocks including a distinctive, chloritized, megacrystic quartz monzonite porphyry and quartz porphyry of probable Jurassic age. In places, such as just west of Guadalupe Mountain and just south of U.S. I-10, deformation in Paleozoic (?) strata that has been thrust upon Precambrian basement shows extreme plasticity and formational attenuation. Relatively short distances away, such as just north of Black Mesa, the Paleozoic section is intact and only mildly disturbed. A major lithologic unit mapped along the west margin of the southern Plomosa Mountains consists of mildly metamorphosed rhyolitic to dacitic volcanics and tuffaceous rocks resting depositionally on Precambrian quartz monzonite. Miller cites either a Precambrian or Mesozoic age for the unit. We lean toward the Mesozoic age.

Occurring in the southern Plomosas and making up the Livingston Hills to the south is a thick continental sedimentary sequence appropriately named the Livingston Hills Formation. Extensively studied by Harding (1980, 1981), this formation consists of a lowermost conglomerate member, overlain by an intermediate siltstone member and an upper graywacke member. The formation is estimated to be of Jurassic age.

Tertiary rocks consist of andesitic volcanics, minor rhyolite, hypabyssal dike rocks and the <15 m.y. old basalt of Black Mesa. With the exception of Black Mesa basalt, these rocks have been affected by rotational normal faulting (listric) and by strike-dip faulting on a broad zone of northwest-striking structures that trend through the southern part of the area.

Mineral occurrences in the district are commonly gold bearing and of interest for two special reasons: (1) a number exhibit Laramide (?) thrust control like many prospects in the Harquahala and Little Harquahala districts, and (2) at least two, the Bright Star and Night Hawk or Livingston camps, are notable because of the syngenetic or metamorphic associations of tungsten and

tungsten-gold with minor base metals. Like similar occurrences in the Granite Wash Mountains and in southeastern California (i.e. Tumco district), these deposits exhibit stratibound characteristics and display unusual mineralogical associations high in fluorine, boron and alumino-silicate alteration.

The Iron Queen, Gila Monster, and other placer deposits which fringe the western portions of the southern Plomosa Mountains produced a reported cumulative production of 18,000 oz of Au and 1,800 oz silver from 1860 to the 1950's. The extensiveness of these deposits may be an indication of favorability for the source rocks of Mesozoic (?) metavolcanic and metasedimentary lithologies and their thrust dominated contacts.

Mines of Interest:

Gold Nugget mine: (T4N, R18W, Sec. 25) Coarse gold occurs with cerrusite, anglesite, galena and oxidized copper minerals in stringer veins of white quartz and siderite along a N25W fault zone in Paleozoic quartzite cut by diorite dikes. Bancroft (1911) describes horse-tailing and minor veining outward into wallrocks adjacent to the vein. This mine produced 100 tons that averaged about 1 opt Au, 2 opt Ag and 1% Pb. Attention is also called to a gold-copper occurrence about 1 mile northwest of the Gold Nugget workings which lies along the thrust faulted contact of highly deformed Paleozoic rocks with Precambrian quartz monzonite.

Bell of Arizona mine: (T4N, R18W, Sec. 35) Gold-silver with quartz in pods and stringers cutting a fracture zone in Precambrian quartz monzonite. Property produced about 200 tons averaging 0.4 opt Au and 0.1 opt Ag.

Bright Star mine: (T4N, R18W, Sec. 34) Occurrence of tungsten as scheelite, disseminated and in discontinuous quartz veinlets, in fractured Mesozoic calcareous schist at contact with limestone. Siderite and pyrophyllite are reported. The description sounds much like suspected Mesozoic metasedimentary tungsten occurrences in the Granite Wash Mountains, some of which are auriferous. Needs sampling and inspection with gold in mind. Much of the area is covered with overburden and very little work has been done on the deposit.

Iron Queen and Copper Prince mine groups: (T3N, R18W, Sec. 3) Gold, silver and oxidized copper associated with multiple quartz veining in highly silicifed, epidotized Paleozoic (?) and/or Mesozoic metasediments and altered volcanics. Deposit occurs along a major thrust (not shown on Miller's map) between these supracrustal rocks and the quartz monzonite basement. Numerous workings produced about 1,720 tons averaging about 0.3 opt Au, 1 opt Ag and 0.6% Cu.

Apache Chief mine: (T3N, R18W, Sec. 12) Although historic production from this mine was low in gold (0.03 opt), it did recover 12 opt Ag and significant copper (11%). Tonnage mined was relatively large for the district (2,100 tons). Of further interest is the setting of mineralization within a highly thrust faulted section of Paleozoic-Mesozoic rocks intruded by diorite and quartz porphyry dikes.

Poorman and Goodman mines: (T3N, R17W, Sec. 7) Noted for its high grade gold production (3.8 opt), this occurrence is also of interest because of its probable localization along a thrust zone between Precambrian crystalline rocks and overlying deformed Livingston Hills Formation.

Night Hawk, White Dike and Colorado mine groups: (Also known as the Livingston mine group) (T3N, R18W, Secs. 34, 35 & 36) Scheelite with associated precious metals, copper, and lead occurs in disseminated pockets and small masses with bedded (?) tourmaline, quartz and calcite along a contact between calcareous, tourmalinized schist and limey quartzite beds of the Livingston Hills Formation. Gold occurs with small quartz veins and veinlets. Mineralization may be strati-bound and is highlighted because of its resemblance to similar deposits occurring in the Granite Wash Mountains and in southeastern California. The Night Hawk and other occurrences are spread out along the strike of tilted bedding for over two miles. The scheelite-bearing zone is about 1.5 miles long and ranges from 100 to 600 ft wide. Stratigraphically below the mineralized section is found a quartz porphyry that is either a volcanic intrusion or extrusive flow complex.

References:

Arizona Dept. Mineral Resources, file data; Bancroft, 1911; Keith, 1978; Miller, 1970.

Structure - Petrology of S. Plomosa Mtns.
- Fred K. Miller, 1966 PhD. Stanford
- copy at U of A by Univ. Precipitous

Thrust faults do not appear to cut silic vole. rx.

p. 37 - L. Mesozoic clastics - ~~[illegible]~~ Mudstone - where metamorph. by plutonic rocks converted to musc. schist
p. 42 Scadden Mtn. QM intrudes L. Mesozoic seds
p. 50 - Scadden Mtn QM - just east of Elephant Back Mtn, alteration 50-100' into L. Meso. mudstone ie. musc schist
p 51-54 describes alteration of Scadden QM
p. 55-59 - altered Mesozoic qtz porph

— Thesis map extends east of 114° to about E side of Sec. 31, R 16W about 2½ mi E of Pinsey Mtn

p. 88 Simplified structural map

p. 92 Thrusting was after Livingston Hills, before andesite-rhyolite rocks - thrust faults cut by strike slip faults

from USGS - BLM Rept + KNWR

Cu, Pb, Zn, and Ag. More specifically, one drainage contained a Cu-As anomaly, two contained As anomalies, and one drainage each for B-Pb, Ag, and Sb-B-Zn.

Sheep Tank Mine Area

This mining area in the Little Horn Mountains near the eastern boundary of the Refuge showed consistenly strong anomalies in Pb, Zn, Cu, Ag, Mn, and As.

Northern Kofa Mountains

Only the northernmost portion of the Kofa Mountains were sampled on a reconnaissnance basis during the 1984 field season. There seems to be small, but consistent, anomalies in Be and La in the heavy-mineral concentrates.

Interpretation

Southern Plomosa Mountains

Geochemical anomalies in Pb, Zn, Ag, Sn, Mo, W. Bi, Cu, As, and Au found in heavy-mineral concentrates from stream sediments collected from the southern Plomosa Mountains apparently delineate mineralization related to previous mining and prospecting activity. The geology of this region is quite complex with sedimentary, metamorphic, volcanic, and intrusive rocks ranging in age from Precambrian to Quaternary. The region also shows strong local structural deformation.

The mineralization in this region is quite varied (Keith, 1978). The most productive area has been the gold placers located on the western side of the Plomosa Mountains. These placers evidently resulted from the erosion of numerous gold-bearing quartz veins in Precambrian quartz monzonite. Other mineralization found in the southern Plomosa Mountains region includes Cu-Ag with minor Au, Pb, and Zn in shear zones associated with thrust faults (Apache Chief Mine); Pb, Ag, Cu, and Au as replacement deposits in Paleozoic limestone (Black Mesa Mine); W in quartz veinlets (Bright Star Mine); Pb-Ag

mineralization consisting of argentiferous galena in a thrust fault zone (Humdinger, or Picacho, Mine); Ag, Pb, Zn, and Cu mineralization with Mn- and Fe-oxides along a fault contact between Jurassic limestone and Tertiary rhyolite (Ramsey Mine); and W, Au, Ag, Cu, and Pb mineralization associated with quartz veins in Mesozoic sediments (Livingston Mine). Anomalous areas defined by the reconnaissance geochemical survey can be explained by mineralization associated with these and other mines and prospects.

New Water Mountains

The As, Sb, B, Cu, Pb, Zn, and Ag anomalies in heavy-mineral concentrates collected from this region are believed to have their origin in the spotty, scattered, oxidized copper mineralization associated with limonite in joints and fractures in Tertiary volcanic rocks (Keith, 1978). Rock samples from similar Cu occurrences approximately two miles northeast of the New Water Mountains showed an elemental association similar to that found in heavy-mineral concentrates from the New Water Mountains.

Sheep Tank Mine Area

The area near the Sheep Tank Mine is well defined by strong Pb, Mn, Zn, Cu, Ag, and As anomalies in heavy-mineral concentrates. These anomalies are rather obviously related to mineralization at the mine. This consists of Au and Ag mineralization with some Cu, Pb, and Zn occurring in a fualt zone cutting Tertiary volcanics (Keith, 1978).

Northern Kofa Mountains

The Be and la anomalies found in limited samples of heavy-mineral concentrates from the northermost Kofa Mountains are believed to be related to the lithologies present in this region and not directly related to mineralization.

Table 6.--Selected analyses of ore and altered rock samples from mines and prospects in the northern portion of the Kofa National Wildlife Refuge
[All values in parts per million unless indicated otherwise.
N=not detected at the lower limit of determination shown in parenthesis]

APACHE CHIEF MINE -N. Plomosa

Au	Ag	Cu	Pb	Zn	As	Sb	Mo	Hg
0.35	1,000	<2%	50	5	85	140	100	0.42
0.15	30	2%	N(10)	10	15	200	100	0.38

BLACK MESA MINE -N. Plomosa

Au	Ag	As	Sb	Hg	Bi	Cu	Pb	Zn
0.70	100	510	650	>10	100	1,500	5,000	7,000
0.60	20	500	750	6.3	52	3,000	5,000	5,000

HUMDINGER (PICAHO) MINE -N. Plomosa

Au	Ag	As	Sb	Hg	Cu	Pb	Zn	Mo
N(.05)	100	65	32	0.56	5,000	2%	7,000	150
<0.05	100	240	68	3.6	1,500	>2%	1,100	N(5)

RAMSEY MINE -New Water, N. Plomosa

Au	Ag	As	Sb	Hg	Cu	Pb	Zn	Mn	W
0.10	1,000	45	22	3.8	100	5,000	5,000	>5,000	18
<0.05	150	210	150	0.50	700	2,000	1,500	>5,000	45

LIVINGSTON MINE -N. Plomosa

Au	Ag	As	Sb	Cu	B	Bi	Mo	W
0.15	1	20	300	150	1,000	500	100	1,500
1.2	7	520	2,000	1.5%	>2,000	300	700	200

SHEEP TANK MINE

Au	Ag	As	Sb	Hg	Cu	Pb	Zn
0.25	200	240	16	5.0	150	1,000	1,900
0.10	10	50	22	1.3	15	200	220

Structure - Petrology of S. Plomas Mtns.
- Fred K. Miller, 1966 PhD. Stanford
- copy at U of A by Univ. Microfilms

Thrust faults do not appear to cut silic vol rx.

p. 37 - L. Mesozoic clastics - ~~the~~ Mudstone - where metamorph by plutonic rocks converted to musc. schist
p. 42 Scodden Mtn. QM intrude L. Mesozoic seds
p. 50 - Saddle Mtn QM - just east of Elephant Back Mtn, alteration 50-100' into L. Meso. mudstone ie. mica schist
p 51-54 describes alteration of Scaden QM
p. 55-59 - altered Mesozoic qtz porph

— Thesis map extends east of 114° to about E side of Sec 31, R 11E about 2½ mi E of Pansey Mtn

p. 88 Simplified structure map

p. 92 Thrusting was after Livingston Hills, before andesite-rhyolite rocks - thrust faults cut by strike-slip faults

NICOR MINERAL VENTURES

One of the NICOR basic energy companies

MEMORANDUM

To: Clancy Wendt

From: Mike Dennis

Date: August 28, 1985

Subject: Monthly Report - August 1985

ARIZONA
La Paz County
S. Plomosa Mtn. Recon

Mineralization in the Plomosa Mtns, south of I-10 is characterized by Cu-Au occurrences controlled by high-angle structures in Precambrian quartz monzonite and thrust fault contacts involving Paleozoic and Mesozoic sedimentary rocks and plutonic rocks. Most of the production from the district has come from placers on the west side of the range. Auriferous quartz veins in Precambrian quartz monzonite are the probable source for the placers.

Two interesting prospects surfaced from my recon. The Apache Chief occurs at the thrust fault contact between overlying Paleozoic limestones and Mesozoic, fine-grained clastic rocks. Copper oxides occur along fractures in quartz breccia and quartz vein stringers within the thrust fault zone. The structure is exposed for about 1000' and may be an interesting target if geochem results are encouraging.

The Livingston Mine is of interest because of the presence of characteristics associated with exhalative activity. Intercalated tourmaline bearing ~~banded~~ chert and carbonate iron-formation associated with sericite schist (rhyolite?) and chlorite schist (alteration?) with minor Cu-oxides strongly suggest an exhalative origin. Unfortunately, the northern boundary of the Kofa Game Refuse is only 200 feet from the main workings.

CALIFORNIA
Riverside County
Riverside Pass Project

Road work for Phase II drilling has been completed. Drilling should commence on August 25.

APPLIED GEOLOGIC STUDIES, INC.
3375 South Bannock
Suite 210
Englewood, Colorado 80110
(303) 761-5624

August 1, 1985

TO: Subscribers to AGS's Western Arizona Project

FROM: William A. Rehrig - AGS, Inc.

SUBJECT: EXPLORATION RESEARCH PROPOSAL - STRATIFORMAL and/or DYNAMO-THERMAL THRUST-RELATED GOLD MINERALIZATION OF THE ALUMINO-SILICATE TYPE IN WESTERN ARIZONA

Those of you who have received and reviewed data from our Western Arizona Project report are aware of the emphasis we placed on a relatively novel, syn-sedimentary to syn-metamorphic, precious metals deposit model delineated during our work in the Mojave-Sonoran region. As stated in our recommendations, there are many unresolved issues concerning these boron; tungsten rich occurences, the chief being a clarification of syngenetic-exhalative versus structural-metamorphic attributes of the type deposits. For example, many of the aluminous, kyanite-sencite-dumortierite occurrences are spatially related to major, deep-seated thrust zones yet appear stratigraphically controlled. The stratiform, alteration zones may or may not coincide specifically with the gold metallization but generally appear to be favorable environments in which to focus prospecting.

We feel that resolution of the problems and sorting out the multiplicity of processes for these unusual metal occurrences would greatly improve the ability to prospect for them in the southwestern U.S. or elsewhere. As these types of occurrences bear an uncanny resemblance in many lithologic and structural ways to some newly delineated major gold districts in Canada such as Hemlo, and because of their "elephant" size-character (i.e. Cargo Muchacho, Mesquite (?), Hemlo), we assume that any serious exploration company would want to focus on this ore setting.

AGS therefore proposes an applied research project which involves the following procedures: (1) initial field mapping and sampling (2) analytical work (3) interpretation and documentation. This sequence of study is described more fully below along with preliminary cost estimates.

Before this discussion, we should note our association with a first-rate research facility possessing the full array of analytical hardware (XRF, XRD, neutron activation, fluid inclusion apparatus, stable isotopes) for supplementing a study of this type. Most important however, is the fact that our associates at this University of Western Ontario headed by Dr. Robert Kerrich and Robert Hodder have accrued extensive experience working with alumino-silicate alteration and structural problems associated with Archean gold deposits of the shield in Canada. A better research-partner could therefore not be chosen for this particular investigation.

Tentative Sequence of Study

Stage 1: Mapping and Sampling

Several specific areas are known in the Sonoran and Mojave desert provinces which display characteristics suggestive of syngenetic, synmetamorphic, synthrusting, alumino-silicate and tungsten-associated gold mineralization. Best known are the precious metals deposits in the Cargo Muchacho Mtns. of southeastermost California. Other occurences in several ranges of western Arizona were delineated in our Western Arizona regional study. Step 1 of this proposal consists of a careful mapping and geochemical sampling of at least two of these type areas. Mapping would focus on stratigraphic and structural relationships of the alumino-silicate alteration assemblage and its association (spatial or genetic) with metals zonation, particularly that for gold. Sampling and multi-element geochem analysis would establish metals control. Additional sampling would constitute input for petrographic, micro-probe and isotopic analysis.

As a preliminary estimate, we are recommending about 40 man days of field work, which would include a week or so following the analytical stage to follow-up on any remaining questions. The cost on this field work is estimated at from about $14,000 to $18,000.

Stage 2: Analytical Work

Samples would be shipped to the research facilities for geochemical analysis, thin sectioning, etc. Trace and major elements would be monitored along with precious metals and pathfinder elements. Petrographic analysis would focus on, paragenesis, alteration mineralogy and textural or structural relationships. Microprobe data would supplement microscopic evidence. Stable isotopic work would key on identifying fluid regimes. Costs are tentatively estimated at around $10,000 for stage 2.

Stage 3: Final Documentation

Data accumulated from field and laboratory phases of the project would be collected and brought together in maps, tables, figures, and results summarized in report form. The report would additionally emphasize the exploration significance of the research and recommend steps or strategy pertinent for discovery of similar precious metals deposits. Costs for this stage of the project are estimated at $8,000 to $10,000.

Our time-frame for the project would begin in the fall of this year with completion by mid-year, 1986. We would like to offer the benefits of such an endeavor exclusively to initial underwriters of the Western Arizona Project. If you were to share in the research, the cost for each participant would only be $6,000 or $7,000. Your interest in the proposal is therefore solicited prior to

the mid-September termination of our contractural confidentiality. After that time, we would offer the project to outside companies interested in this exploration province.

In conclusion, you may wish to restudy the chapter on gold deposit models and corresponding conclusions and recommendations in our Western Arizona report to appreciate the importance we have placed on this new gold-bearing tectonic environment. Since this writing, added familiarity with large Canadian deposits such as Red Lakes and Hemlo have convinced us of remarkable similarities with environments and occurrences in the Southwestern U.S. Thus regardless of your own ideas regarding the gold model, we feel a systematic structural-stratigraphic-mineralogical-geochemical data base would be most helpful to productive exploration in this environment.

Please call if there are further questions. I will be canvassing initial subscribers within a couple of weeks regarding their interest.

La Paz Pima, Pinal
Maricopa Yuma
Mohave Santa Cruz

	Au ? oz/T	Ag ? oz/T
A 1249	<.005	1.36
1250	.135	10.36
1251	<.005	<1.00 oz/T
1252	.14 ppm Au	16 ppm

~~6964~~
6964 50 ppm Ag
6966 36 Ag
6970 28 Ag, 12000 Cu, 6200 Pb, 2500 Zn

6963 1750 As, 3000 ppm Zn, 1000 Pb, 700 Cu
964 220 As, .32 ppm Hg, 4200 Zn, 16000 Pb,
970 9100 As, >10 ppm Hg
966 .90 ppm Hg, 17000 Cu
967 5000 Cu, 10 Pb, Zn
[redacted]

6951 thru 957, <.02
958 .20
959 .03
960 <.02
961 1.4
962 1.8
963 <.02
964 .04
965 <.02
966 .03
967 .02
968 <
69 <
70 .26
71 <
72 <
73 <
74 <

75 .28
[redacted]

Other Publications

Arthur D. Little, Inc., and Jones, Day, Reavis & Pogue, 1985, Impact of the President's tax reform proposals on the United States mining industry: 72 p.

Cather, S. M., and Johnson, B. D., 1984, Eocene tectonics and depositional setting of west-central New Mexico and eastern Arizona: New Mexico Bureau of Mines and Mineral Resources, Circular 192, 33 p.

Davis, G. M., 1985, Geology of the southern Plomosa Mountains: Tempe, Arizona State University, M.S. Thesis, 158 p., scale 1:24,000.

Dietz, David, and Williams, Charles, 1985, Geophysical investigations of Butler Valley, Arizona: University of Arizona Water Resources Research Center, 22 p.

Goodlin, T. C., and Mark, R. A., 1985, Geologic map of and cross sections through the Hot Springs Canyon area, Cochise County, Arizona: Tucson, University of Arizona, M.S. Thesis maps, scale 1:24,000, 2 sheets.

Myers, I. A., 1984, Geology and mineralization at the Cyclopic mine, Mohave County, Arizona: Las Vegas, University of Nevada, M.S. Thesis, 64 p., 6 sheets.

Owen-Joyce, S. J., 1984, Hydrology of a stream-aquifer system in the Camp Verde area, Yavapai County, Arizona: Arizona Department of Water Resources Bulletin 3, 60 p., scale 1:24,000, 3 plates.

Smith, R. C., 1984, Mineralogic and fluid-inclusion studies of epithermal gold-quartz veins in the Oatman district, northwestern Arizona: Tucson, University of Arizona, M.S. Thesis, 232 p., 1 sheet.

Stoneman, D. A., 1985, Structural geology of the Plomosa Pass area, northern Plomosa Mountains, La Paz County, Arizona: Tucson, University of Arizona, M.S. Thesis, 99 p., 4 plates.

U.S. Bureau of Land Management, 1985, Yuma district resource management plan and environmental impact statement: 310 p., scale 1:250,000.

Yeats, K. J., 1985, Geology and structure of the northern Dome Rock Mountains, La Paz County, Arizona: Tucson, University of Arizona, M.S. Thesis, 123 p., 3 plates.

Spring Symposium on Geology and Ore Deposits

On March 20-21, 1986 at the University of Arizona, Tucson, the Arizona Geological Society will host a symposium entitled, "Frontiers in Geology and Ore Deposits of Arizona and the Southwest." Fourteen separate preconference and postconference field trips, to be held on March 17-19, 22, and 23, will round out the conference.

The symposium will highlight recent advances in tectonics and ore deposits of the Southwest. Papers with a regional focus include overviews of Precambrian tectonics and ore deposits, Mesozoic structure and tectonics in western Arizona and the Southwest, Laramide magmatism and metallogeny, the regional nature of detachment faults in western Arizona, potassium metasomatism in the Southwest, mineralization related to detachment faults, preliminary CALCRUST results, and ore deposits of contiguous Mexico. Papers with a specific focus include mineralization at Picacho mine, Imperial County, Calif.; mineralization of the McCabe-Gladstone deposit, Yavapai County, Ariz.; and mineral deposits associated with topaz rhyolites in the Southwest.

Field trips include topics such as Precambrian evolution of the [illegible]-Mazatzal area, Mesozoic to mid-Tertiary tectonics and [illegible]ization of west-central Arizona, stratigraphy and petroleum [illegible] of the Pedregosa basin in southeastern Arizona, and [illegible] hazards and hydrology of southern Arizona. The fourteen [illegible] will give participants an opportunity for "hands-on" [illegible] to the geology of the Southwest.

[illegible] activities for spouses and guests will feature views of Arizona, from desert flora and fauna to the culture of its people.

For more information, contact AGS Conference, University Conference Dept., 1717 E. Speedway, Suite 3201, Tucson, AZ 85719; (602) 621-1232.

New Bureau Publications

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Chenoweth, W. L., and Learned, E. A., 1985, Historical review of uranium-vanadium production in the northern and western Carrizo Mountains, Apache County, Arizona: Open-File Report 85-13, 35 p., scale 1:126,000; text: $5.75; map: $2.00.

The carnotite deposits of the northern and western Carrizo Mountains have been mined for their radium, vanadium, and uranium content since 1920. This report summarizes uranium and vanadium production in these mountains and provides hard data for a previously confused chapter in the history of uranium mining in Arizona. The report was made possible by the release of heretofore confidential data prepared by the Indian Trust Accounting Division of the General Services Administration for a court hearing in 1983 (Navajo Tribe vs. United States).

Capps, R. C., Reynolds, S. J., Kortemeier, C. P., Stimac, J. A., Scott, E. A., and Allen, G. B., 1985, Preliminary geologic maps of the eastern Big Horn and Belmont Mountains, west-central Arizona: Open-File Report 85-14, 25 p., scale 1:24,000, 2 sheets; text: $4.00; maps: $3.25 each.

This report presents preliminary 1:24,000-scale geologic maps of the eastern Big Horn and Belmont Mountains in west-central Arizona. The mapping, completed between January and April 1985, was jointly funded by the U.S. Geological Survey and the Arizona Bureau of Geology and Mineral Technology as part of the cost-sharing Cooperative Geologic Mapping Program (COGEOMAP). The Big Horn and Belmont Mountains were chosen because neither range had been previously mapped, except in broad reconnaissance for previous State geologic maps, and because both ranges have substantial mineralization and exploration activity.

The Big Horn and Belmont Mountains are composed of a metamorphic-plutonic basement that is overlain by middle Tertiary volcanic and sedimentary rocks. Volcanism was accompanied by low- to high-angle, normal faulting and rotation of the older volcanic units and subjacent crystalline basement. Slight to moderate angular unconformities within the volcanic sequence attest to synvolcanic tilting and faulting. The area contains a number of distinctive types of precious- and base-metal mineralization. Many mineral deposits in this area, including significant occurrences of gold, manganese, and barite-fluorite mineralization, are associated with middle Tertiary faults and intrusive-volcanic centers.

Chenoweth, W. L., 1985, Early vanadium-uranium mining in Monument Valley, Apache and Navajo Counties, Arizona and San Juan County, Utah: Open-File Report 85-15, 13 p.; $2.00.

This report summarizes the history of vanadium and uranium production in the Monument Valley area. The report contains previously confidential data prepared by the Indian Trust Accounting Division that are similar to data released in Open-File Report 85-13.

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(602) 622-4836

REPORT OF ANALYSIS

JOB NO. UGH 087
September 30, 1985
G951-G975

NICOR MINERAL VENTURES
Attn: Mr. Mike Dennis
2341 So. Friebus, Suite 12
Tucson, Arizona 85713

Analysis of 25 Rock Chip Samples

	ITEM	SAMPLE NO.		Au (ppm)	Ag (ppm)	Cu (ppm)	Pb (ppm)	
Blackwater Flt. recon	1	G951		<.02	.15	<5.	5.	
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	3	G953		<.02	<.05	<5.	<5.	
	4	G954		<.02	<.05	<5.	<5.	
	5	G955		<.02	<.05	5.	5.	
	6	G956		<.02	<.05	<5.	10.	
	7	G957		<.02	.15	<5.	15.	
	8	G958		.18	1.10	30.	265.	
	9	G959		.03	.70	10.	80.	
S. Plomosa Mtns	10	G960	Belle of Arizona	<.02	<.05	10.	10.	
	11	G961		<.02	<.05	<5.	<5.	
	12	G962		1.80	.90	10.	85.	-qtz vein rich tails
	13	G963	Dos Picachos	<.02	.65	600.	1000.	
	14	G964		.04	53.00	2800.	16000.	-dump select
	15	G965		<.02	.50	20.	75.	
	16	G966	Apache Chief	.03	40.00	17000.	320.	-dump
	17	G967		.02	4.30	5000.	<5.	
	18	G968		<.02	.10	85.	10.	
	19	G969		<.02	.20	5.	5.	
	20	G970	Rehrig Cu	.29	27.00	12000.	6200.	
	21	G971	Bright Star	<.02	.30	170.	85.	
	22	G972	Livingston Mine	<.02	.40	105.	25.	
	23	G973		<.02	.10	25.	<5.	
	24	G974		<.02	<.05	55.	5.	
	25	G975		.29	1.50	620.	30.	-dump

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4	G954	25.	30.	<2.	.02
5	G955	20.	<5.	<2.	<.01
6	G956	30.	<5.	<2.	.02
7	G957	30.	<5.	<2.	.01
8	G958	490.	10.	6.	.09
9	G959	85.	10.	4.	.20
10	G960	10.	<5.	<2.	<.01
11	G961	5.	<5.	<2.	<.01
12	G962	40.	<5.	<2.	.12
13	G963	3000.	1750.	10.	.02
14	G964	4200.	220.	80.	>1.00*
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18	G968	45.	20.	<2.	.03
19	G969	15.	15.	<2.	.04
20	G970	2500.	910.	4350.	>1.00*
21	G971	45.	20.	60.	>1.00*
22	G972	15.	45.	20.	.37
23	G973	30.	10.	2.	.02
24	G974	5.	<5.	4.	.04
25	G975	10.	100.	100.	.03

*NOTE: Greater than normal geochemical range.
Please advise if further assay is needed.

REGISTERED ASSAYER
CERTIFICATE NO. 9425
WILLIAM L. LEHMBECK
DATE SIGNED
Arizona U.S.A.

William L. Lehmbeck
Manager

8/21/85 Plomosa Mtns

Belle of Arizona mine or "The snake pit"

- 4 to 5 opencuts & stopes driven on shear zone trending N45°E.

N30W Milky qtz veins seen on north hillside are not cut by shear but continue across it.

G-960 dump grab — silicified granite from shear zone, trace lim. aft. pyrite, mod qtz veining + veinlets, trace specularite on fracture surfaces. Mafics → chl & fe-ox, no sericite or clay

G-961 dump — selectively sampled qtz vein material, ~1/2% specularite as clots + along partings in qtz

G-962 mill tails — qtz vein rich mill tails

Dos Picachos

Working along thrust fault; rocks grade up to sericite schist w/ milky qtz along thrust; appeared to be qtzite qtz

G-963 OC — shallow workings ~~at~~ driven on qtz pods in thrust fault gouge, wk to mod fe-ox stain

G-964 comp select — adit at least 200' long, driven along eastward dipping thrust; offsite overlying lo. from greywacke-siltstone. Much recrystallized calcite + qtz vein stringers 1-2% galena + cerussite, 1/2% chalco or cu-ox. 15% pyrite locally. Very strong fe-ox in pods along vein structures

Adit is ≈100' from diorite dike

G-965 OC — in 30' cut, fault gouge, mostly sericite + clay, east dipping

Apache Chief

G 966 dump — decline following thrust N10E 40E 4 to 5' thick quartz breccia overlain by 1-2' thick zone of sil gouge w/ malachite, azurite, fe-ox after pyrite. Total Cu content ≈ 2%

G 967 OC — at adit driven along strike of thrust (N-S) 35°E dip. Brecciated limestone forms footwall. Thrust marked by 1"-1' thick pale yellow gouge zone containing discontinuous ½" thick qtz stringers. Cu-oxides occur along qtz stringers & along fractures in underlying ls.
Hangingwall is hematite-stained carbonate-rich sericite-chl schist displaying wavy foliation. Foliation probably imparted structurally since 2' blocks of fe-ox stained rock are present in hangwall underground. Sample mostly hangingwall w/ 10% gouge zone.
It's cool + shady here. I could write for days

8/22/85 Plomosa Mts

G 968 OC — sheared + brecciated Pe quartz monzonite, abundant sericite + chlorite, approx 100' from ls exposure. Thrust fault is concealed in alluvium; no sil or veining, rsh fe-ox stain locally.

G 969 — quartzite, locally brecciated then recrystalized, sericite rich zones, well foliated, small x 2-3' long, 1" thick to lenses, weak fe-ox stain on fractures, adjacent to mafic dike intruded along thrust. Dike is not foliated but appears(?) folded about fold axis paralleling thrust

G 970 — Cu prospect a la Rehing dug on structure oriented N55E, 65° NW. Thrust contact is 150' south.
Cu-oxides in sericite bearing ls: minor silty zones. Weak SiO_2 veining, weak to mod. fe-ox stain (to mod. spotty). Total Cu x 1%

Bright Star

small pit dug on milky qtz sweat out of Mesozoic? felsic schist

G971 mod to strong chlorite altered felsic (metarhy?) tuff, 1-2% very dark green chlorite pods, milky qtz worms through schist showing no control stratigraphically or structurally, weak fe-ox stain. Old boys stockpiles qtz material (tungsten/scheelite?)

Pit is ≈ 50', structurally above Pc qtz monzonite; thrust contact

Livingston Mine

Mesozoic sed. rocks

- large areas of white milky qtz semi-concordant w/ foliation, often w/ dark green bladed mineral

G972 OC — dark gray green carbonate (iron fm?) very fine grained, well foliated where sericite occurs, adjacent to white qtz

G973 OC — 50' long trench ⊥ to foliation. sample is channel along bench. Dominantly calcareous qtz-sericite schists w/ variable amounts of limonite. Interbedded is white qtz (vein?). Seems confined to one schist unit, w/ abundant dark green chlorite

G974 OC — lt green sericite schist w/ ~1% py, pods of black micaceous mineral + banded w/ siderite locally, qtz generally follows foliation + in places looks like variably fe-stained chert. Could white qtz be remobilized SiO_2 w/o fe?

6-925 main adit + shaft
dump

- Chert, fractured, wk to mod Fe-ox
~1/2% lim. aff pyrite, 1% Cu-ox,
occasionally banded, pods
of black mica. mineral

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Plomosa Mtns

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SOUTHERN PLOMOSA DISTRICT

Location:

This district is a southern extension of the northern Plomosa district and occurs in the mountains south of U.S. I-10. The district adjoins the New Water area on the east and includes mineral occurrences in the Livingston Hills to the south. Black Mesa which lies in the central part of the district is the dominant topographic feature. The district is included in Townships 3 and 4 North, Ranges 17 and 18 West of La Paz County and is found on the Quartzite 15' quadrangle.

Geology and History:

The geology of the district appears on the 15' geologic map of the Quartzite Quadrangle by Miller (1970). Generally, it consists of an extremely complex thrust terrain in pre-Tertiary rocks. The various lithologies involved in this interleaved tectonized sequence include: Precambrian plutonic rocks, Paleozoic cratonal facies sedimentary and metamorphic rocks, Mesozoic volcanic and continental sedimentary rocks and their metamorphic equivalents and Mesozoic plutonic rocks including a distinctive, chloritized, megacrystic quartz monzonite porphyry and quartz porphyry of probable Jurassic age. In places, such as just west of Guadalupe Mountain and just south of U.S. I-10, deformation in Paleozoic (?) strata that has been thrust upon Precambrian basement shows extreme plasticity and formational attenuation. Relatively short distances away, such as just north of Black Mesa, the Paleozoic section is intact and only mildly disturbed. A major lithologic unit mapped along the west margin of the southern Plomosa Mountains consists of mildly metamorphosed rhyolitic to dacitic volcanics and tuffaceous rocks resting depositionally on Precambrian quartz monzonite. Miller cites either a Precambrian or Mesozoic age for the unit. We lean toward the Mesozoic age.

Occurring in the southern Plomosas and making up the Livingston Hills to the south is a thick continental sedimentary sequence appropriately named the Livingston Hills Formation. Extensively studied by Harding (1980, 1981), this formation consists of a lowermost conglomerate member, overlain by an intermediate siltstone member and an upper graywacke member. The formation is estimated to be of Jurassic age.

Tertiary rocks consist of andesitic volcanics, minor rhyolite, hypabyssal dike rocks and the <15 m.y. old basalt of Black Mesa. With the exception of Black Mesa basalt, these rocks have been affected by rotational normal faulting (listric) and by strike-dip faulting on a broad zone of northwest-striking structures that trend through the southern part of the area.

Mineral occurrences in the district are commonly gold bearing and of interest for two special reasons: (1) a number exhibit Laramide (?) thrust control like many prospects in the Harquahala and Little Harquahala districts, and (2) at least two, the Bright Star and Night Hawk or Livingston camps, are notable because of the syngenetic or metamorphic associations of tungsten and

tungsten-gold with minor base metals. Like similar occurrences in the Granite Wash Mountains and in southeastern California (i.e. Tumco district), these deposits exhibit stratibound characteristics and display unusual mineralogical associations high in fluorine, boron and alumino-silicate alteration.

The Iron Queen, Gila Monster, and other placer deposits which fringe the western portions of the southern Plomosa Mountains produced a reported cumulative production of 18,000 oz of Au and 1,800 oz silver from 1860 to the 1950's. The extensiveness of these deposits may be an indication of favorability for the source rocks of Mesozoic (?) metavolcanic and metasedimentary lithologies and their thrust dominated contacts.

Mines of Interest:

Gold Nugget mine: (T4N, R18W, Sec. 25) Coarse gold occurs with cerrusite, anglesite, galena and oxidized copper minerals in stringer veins of white quartz and siderite along a N25W fault zone in Paleozoic quartzite cut by diorite dikes. Bancroft (1911) describes horse-tailing and minor veining outward into wallrocks adjacent to the vein. This mine produced 100 tons that averaged about 1 opt Au, 2 opt Ag and 1% Pb. Attention is also called to a gold-copper occurrence about 1 mile northwest of the Gold Nugget workings which lies along the thrust faulted contact of highly deformed Paleozoic rocks with Precambrian quartz monzonite.

Bell of Arizona mine: (T4N, R18W, Sec. 35) Gold-silver with quartz in pods and stringers cutting a fracture zone in Precambrian quartz monzonite. Property produced about 200 tons averaging 0.4 opt Au and 0.1 opt Ag.

Bright Star mine: (T4N, R18W, Sec. 34) Occurrence of tungsten as scheelite, disseminated and in discontinuous quartz veinlets, in fractured Mesozoic calcareous schist at contact with limestone. Siderite and pyrophyllite are reported. The description sounds much like suspected Mesozoic metasedimentary tungsten occurrences in the Granite Wash Mountains, some of which are auriferous. Needs sampling and inspection with gold in mind. Much of the area is covered with overburden and very little work has been done on the deposit.

Iron Queen and Copper Prince mine groups: (T3N, R18W, Sec. 3) Gold, silver and oxidized copper associated with multiple quartz veining in highly silicifed, epidotized Paleozoic (?) and/or Mesozoic metasediments and altered volcanics. Deposit occurs along a major thrust (not shown on Miller's map) between these supracrustal rocks and the quartz monzonite basement. Numerous workings produced about 1,720 tons averaging about 0.3 opt Au, 1 opt Ag and 0.6% Cu.

Apache Chief mine: (T3N, R18W, Sec. 12) Although historic production from this mine was low in gold (0.03 opt), it did recover 12 opt Ag and significant copper (11%). Tonnage mined was relatively large for the district (2,100 tons). Of further interest is the setting of mineralization within a highly thrust faulted section of Paleozoic-Mesozoic rocks intruded by diorite and quartz porphyry dikes.

Poorman and Goodman mines: (T3N, R17W, Sec. 7) Noted for its high grade gold production (3.8 opt), this occurrence is also of interest because of its probable localization along a thrust zone between Precambrian crystalline rocks and overlying deformed Livingston Hills Formation.

Night Hawk, White Dike and Colorado mine groups: (Also known as the Livingston mine group) (T3N, R18W, Secs. 34, 35 & 36) Scheelite with associated precious metals, copper, and lead occurs in disseminated pockets and small masses with bedded (?) tourmaline, quartz and calcite along a contact between calcareous, tourmalinized schist and limey quartzite beds of the Livingston Hills Formation. Gold occurs with small quartz veins and veinlets. Mineralization may be strati-bound and is highlighted because of its resemblance to similar deposits occurring in the Granite Wash Mountains and in southeastern California. The Night Hawk and other occurrences are spread out along the strike of tilted bedding for over two miles. The scheelite-bearing zone is about 1.5 miles long and ranges from 100 to 600 ft wide. Stratigraphically below the mineralized section is found a quartz porphyry that is either a volcanic intrusion or extrusive flow complex.

References:

Arizona Dept. Mineral Resources, file data; Bancroft, 1911; Keith, 1978; Miller, 1970.

STRUCTURAL ANALYSIS OF MESOZOIC THRUSTING IN THE NORTHERN PLOMOSA MOUNTAINS, SOUTHWESTERN ARIZONA

Deborah Stoneman

A major north-vergent thrust zone of Mesozoic age is exposed in the Plomosa Pass area of the Northern Plomosa Mountains, La Paz County, Arizona. The thrust zone contains imbricated Paleozoic and Mesozoic metasedimentary rocks, sandwiched between structurally higher and lower blocks of Precambrian granite and gneiss. The whole sequence has been metamorphosed to greenschist facies. The fault zone is crosscut by an 85m.y. old granodiorite pluton and associated microdiorite dike swarms. The east-west trending thrust zone is truncated by an east-dipping Tertiary detachment fault which parallels the eastern flank of the Plomosa Range. The granite-metasediment-gneiss tectonic stacking order is repeated in several places within the upper plate of the detachment fault.

The thrust fault zone consists of two approximately parallel south-dipping faults bounding the medial imbricated wedge. The upper Deadman Fault appears to show ductile northeast-directed thrusting. The Lower Plomosa Pass Fault is much more ambiguous in character, appearing to show both ductile and brittle behavior.

The imbricated metasediment wedge varies along strike in width, composition, and structural complexity. Large quartzite, phyllite, marble, and conglomerate lenses are structurally interleaved. These blocks are internally deformed, as well as externally shear-bounded and rotated. Most rock types contain well-developed foliation and lineation, and many exhibit intrafolia folds, stretched clasts, and many other features indicative of ductile shearing.

In summary, deformation in this area is characterized by Mesozoic large-scale, ductile thrusting, involving basement rocks and chaotic metasediment assemblages, overprinted by Tertiary detachment faulting.

'84 Bosscieria Dore

from USGS - BLM Rept. + RNWR

Cu, Pb, Zn, and Ag. More specifically, one drainage contained a Cu-As anomaly, two contained As anomalies, and one drainage each for B-Pb, Ag, and Sb-B-Zn.

Sheep Tank Mine Area

This mining area in the Little Horn Mountains near the eastern boundary of the Refuge showed consistenly strong anomalies in Pb, Zn, Cu, Ag, Mn, and As.

Northern Kofa Mountains

Only the northernmost portion of the Kofa Mountains were sampled on a reconnaissnance basis during the 1984 field season. There seems to be small, but consistent, anomalies in Be and La in the heavy-mineral concentrates.

Interpretation

Southern Plomosa Mountains

Geochemical anomalies in Pb, Zn, Ag, Sn, Mo, W. Bi, Cu, As, and Au found in heavy-mineral concentrates from stream sediments collected from the southern Plomosa Mountains apparently delineate mineralization related to previous mining and prospecting activity. The geology of this region is quite complex with sedimentary, metamorphic, volcanic, and intrusive rocks ranging in age from Precambrian to Quaternary. The region also shows strong local structural deformation.

The mineralization in this region is quite varied (Keith, 1978). The most productive area has been the gold placers located on the western side of the Plomosa Mountains. These placers evidently resulted from the erosion of numerous gold-bearing quartz veins in Precambrian quartz monzonite. Other mineralization found in the southern Plomosa Mountains region includes Cu-Ag with minor Au, Pb, and Zn in shear zones associated with thrust faults (Apache Chief Mine); Pb, Ag, Cu, and Au as replacement deposits in Paleozoic limestone (Black Mesa Mine); W in quartz veinlets (Bright Star Mine); Pb-Ag

mineralization consisting of argentiferous galena in a thrust fault zone (Humdinger, or Picacho, Mine); Ag, Pb, Zn, and Cu mineralization with Mn- and Fe-oxides along a fault contact between Jurassic limestone and Tertiary rhyolite (Ramsey Mine); and W, Au, Ag, Cu, and Pb mineralization associated with quartz veins in Mesozoic sediments (Livingston Mine). Anomalous areas defined by the reconnaissance geochemical survey can be explained by mineralization associated with these and other mines and prospects.

New Water Mountains

The As, Sb, B, Cu, Pb, Zn, and Ag anomalies in heavy-mineral concentrates collected from this region are believed to have their origin in the spotty, scattered, oxidized copper mineralization associated with limonite in joints and fractures in Tertiary volcanic rocks (Keith, 1978). Rock samples from similar Cu occurrences approximately two miles northeast of the New Water Mountains showed an elemental association similar to that found in heavy-mineral concentrates from the New Water Mountains.

Sheep Tank Mine Area

The area near the Sheep Tank Mine is well defined by strong Pb, Mn, Zn, Cu, Ag, and As anomalies in heavy-mineral concentrates. These anomalies are rather obviously related to mineralization at the mine. This consists of Au and Ag mineralization with some Cu, Pb, and Zn occurring in a fualt zone cutting Tertiary volcanics (Keith, 1978).

Northern Kofa Mountains

The Be and la anomalies found in limited samples of heavy-mineral concentrates from the northermost Kofa Mountains are believed to be related to the lithologies present in this region and not directly related to mineralization.

Table 6.--Selected analyses of ore and altered rock samples from mines and prospects in the northern portion of the Kofa National Wildlife Refuge
[All values in parts per million unless indicated otherwise.
N=not detected at the lower limit of determination shown in parenthesis]

APACHE CHIEF MINE -N. Plomosa

Au	Ag	Cu	Pb	Zn	As	Sb	Mo	Hg
0.35	1,000	<2%	50	5	85	140	100	0.42
0.15	30	2%	N(10)	10	15	200	100	0.38

BLACK MESA MINE -N. Plomosa

Au	Ag	As	Sb	Hg	Bi	Cu	Pb	Zn
0.70	100	510	650	>10	100	1,500	5,000	7,000
0.60	20	500	750	6.3	52	3,000	5,000	5,000

HUMDINGER (PICAHO) MINE -N. Plomosa

Au	Ag	As	Sb	Hg	Cu	Pb	Zn	Mo
N(.05)	100	65	32	0.56	5,000	2%	7,000	150
<0.05	100	240	68	3.6	1,500	>2%	1,100	N(5)

RAMSEY MINE -New Water, N. Plomosa

Au	Ag	As	Sb	Hg	Cu	Pb	Zn	Mn	W
0.10	1,000	45	22	3.8	100	5,000	5,000	>5,000	18
<0.05	150	210	150	0.50	700	2,000	1,500	>5,000	45

LIVINGSTON MINE -N. Plomosa

Au	Ag	As	Sb	Cu	B	Bi	Mo	W
0.15	1	20	300	150	1,000	500	100	1,500
1.2	7	520	2,000	1.5%	>2,000	300	700	200

SHEEP TANK MINE

Au	Ag	As	Sb	Hg	Cu	Pb	Zn
0.25	200	240	16	5.0	150	1,000	1,900
0.10	10	50	22	1.3	15	200	220

CONCLUSIONS

The Livingston Hills Formation is a thick (3600 m) clastic sequence deposited on continental crust. Its age is presently constrained only by the Paleozoic rocks it overlies with angular unconformity and middle Tertiary volcanic rocks which cap it, leaving a time span of over 200 m.y. Potentially correlative dated and undated Mesozoic sequences in southwestern North America are numerous. Radiometric ages or fossil evidence will be needed for secure correlation of sequences, since petrographic work in the two Livingston Hills Formation sequences, easily correlated megascopically, raises questions as to whether the Plomosa Mountains and the Livingston Hills sections have the same provenance. Characteristics of the Livingston Hills Formation which should fit a tectonic setting chosen for it include its 1) cratonic setting, 2) 3600 m thickness, 3) subaerial-shallow water depositional environment, 4) north to south (Livingston Hills) and northeast and southwest (Plomosa Mountains) paleocurrent directions, 5) sudden supracrustal to igneous conglomerate clast lithology change, 6) nonidentical volcanic-volcanic-plutonic provenances for the two sections, and 7) stratigraphic relationships with Paleozoic rocks, continental red bed deposits, Jurassic(?) metavolcanics, and the intrusive-extrusive quartz porphyry.

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PETROLOGY AND TECTONIC SETTING OF THE LIVINGSTON HILLS FORMATION, YUMA COUNTY, ARIZONA

by

Lucy Elizabeth Harding

A Thesis Submitted to the Faculty of the

DEPARTMENT OF GEOSCIENCES

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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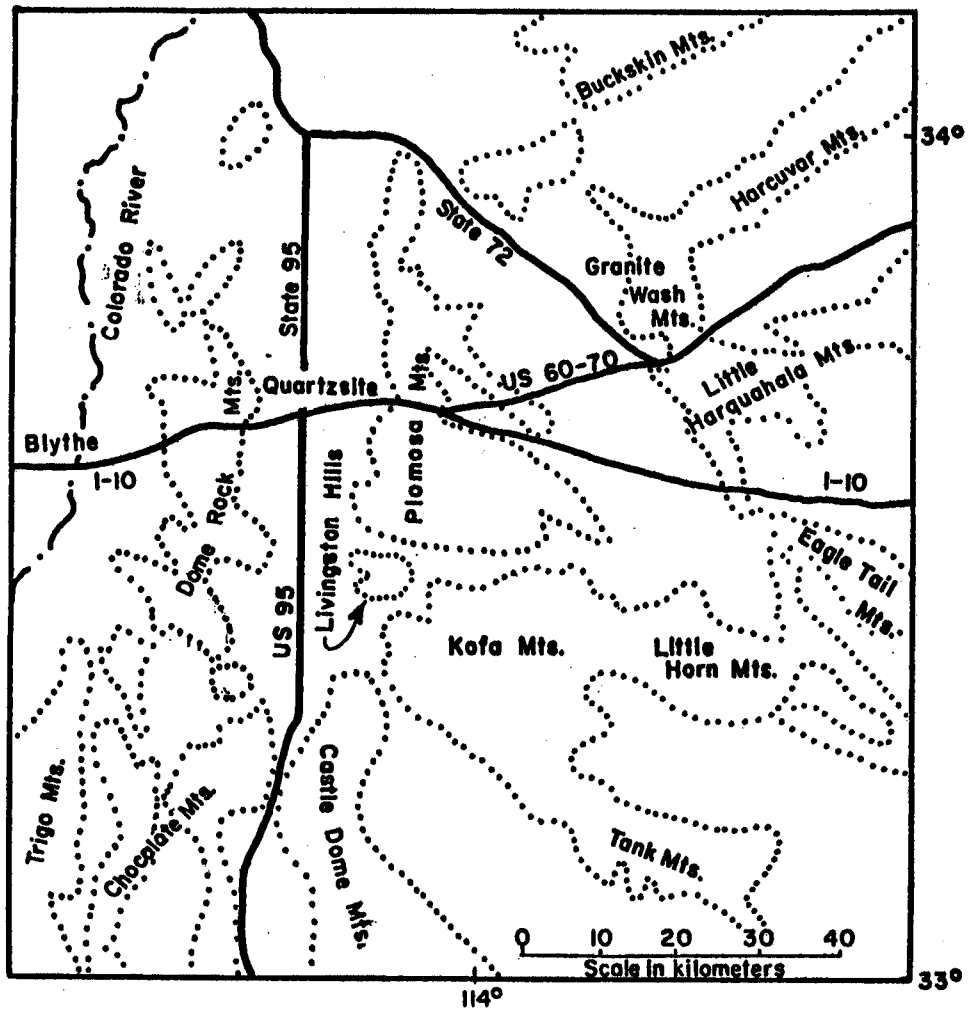
ABSTRACT

Great thicknesses of Mesozoic sedimentary rocks are exposed throughout southwestern Arizona, southeastern California, and northern Sonora. One of these sequences, the Livingston Hills Formation, was studied in an attempt to answer questions concerning age, depositional environment, and tectonic setting. The Livingston Hills Formation is a 3600 m clastic sequence divided into conglomerate, graywacke, and siltstone members. It was deposited as a series of debris flows and shallow water sediments. Livingston Hills Formation sediment transport direction is north to south in the Livingston Hills and northeast and southwest in the Plomosa Mountains. Conglomerate member clast lithologies change abruptly from supracrustal to igneous. Petrographic point counts from the two sections of the Livingston Hills Formation plot in different fields in Q-F-L and Qp-Lv-Ls diagrams, suggesting nonidentical but not mutually exclusive provenance for the two sections. Specific parameters Q, F, L, P/F, V/L, and C/Q suggest a plutonic-volcanic provenance. Since the age of the Livingston Hills Formation is unknown, its tectonic significance cannot be determined. Possible tectonic settings include 1) intra-arc basin for the Jurassic magmatic arc, 2) synorogenic deposits from a Cretaceous fold and thrust belt, and 3) distal shoreline facies of an Orocopia Schist protolith back-arc basin.

INTRODUCTION

Throughout southwestern Arizona, southeastern California, and northern Sonora, Mexico, there are extremely thick sequences of sedimentary and volcanic rocks exposed in isolated mountain ranges. These rocks are found stratigraphically above Paleozoic rocks and below mid-Tertiary volcanic rocks. Most of the sequences have been assigned a Mesozoic age. Sparse fossil evidence from Sonora, California, and Arizona suggests the age could range from the Permian through Paleocene. The sedimentary rocks, being monotonous in lithology, unfossiliferous, and exceedingly thick, are very different from the classic Mesozoic sequence exposed on the Colorado Plateau. Lithologic types include conglomerate containing sedimentary and igneous clasts, feldspathic and quartz-rich sandstone, siltstone, and minor limestone, pyroclastic, and volcanic rocks. Thicknesses range up to 3600 m. All the sequences show effects of metamorphism, ranging from minor mineralogic changes in matrix to complete recrystallization into high-grade gneisses. Perhaps most indicative of the enigmatic nature of these sedimentary rocks is the fact that they have not been included in any paleotectonic or paleogeographic reconstructions of the Mesozoic in southwestern North America.

In an attempt to answer questions about the age, depositional environment, and tectonic setting of these Mesozoic sedimentary rocks, two relatively unmetamorphosed sections were chosen for detailed study: a section in the southern Plomosa Mountains, and a section in the Livingston Hills, both in Yuma County, Arizona (Figure 1).



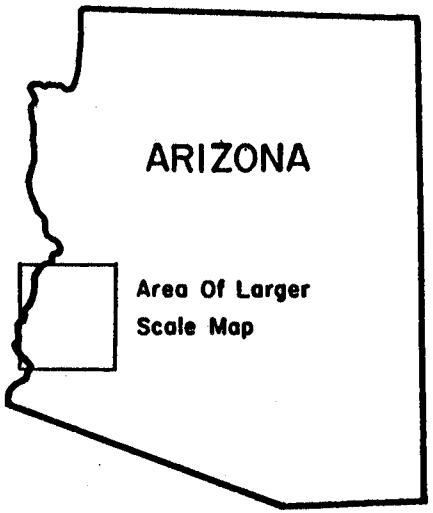


Figure 1. Index Map. -- The map shows the location of the Livingston Hills, Plomosa Mountains, and surrounding mountain ranges.

Previous work on Mesozoic sedimentary rocks in the Livingston Hills and southern Plomosa Mountains includes a brief description by Wilson (1933) and a map of Yuma County (Wilson, 1960) showing the broad extent of Mesozoic sedimentary rocks throughout the county. E. D. McKee (1947) detailed the stratigraphy of a section of Mesozoic sedimentary rocks about 1½ miles northeast of Crystal Hill. Miller (1966) mapped the southern Plomosa Mountains and Livingston Hills, described the geology of the region, and gave the name Livingston Hills Formation to the Mesozoic sedimentary rocks exposed in the area. A geologic map of the Quartzsite Quadrangle by Miller (1970) duplicates his earlier work with minor modifications.

GEOLOGIC SETTING OF THE LIVINGSTON HILLS FORMATION

The Livingston Hills Formation is exposed in highly complex structural relationships with a variety of rocks. These rocks include fossiliferous Paleozoic rocks, probable Jurassic metavolcanic rocks, other Mesozoic sedimentary rocks, Tertiary volcanic rocks, and plutonic rocks of unknown age. Thrust faults are numerous, as are other types of faults. Many rock sequences are completely fault-bounded. The following discussion of geologic setting of the Livingston Hills Formation is largely based on the geologic map of the Quartzsite Quadrangle by Miller (1970) and reconnaissance mapping and observations by the author.

Three separate sections of fossiliferous Paleozoic sedimentary rocks are exposed in the Plomosa Mountains. All are cratonic sequences of mixed southeastern Arizona-Grand Canyon affinity. Formations present include the Bolsa Quartzite, the Abrigo and Martin Formations, the Escabrosa Limestone, the Supai Group, the Coconino Sandstone, and the Kaibab Formation. Thickness of the Paleozoic section totals 857 m. The depositional base of the Paleozoic rocks is nowhere exposed. In addition to the more complete sections, low-angle fault-bounded "slices" of metamorphosed Paleozoic sedimentary rocks are exposed throughout the southern Plomosa Mountains. The Plomosa Mountains section of the Livingston Hills Formation is in depositional contact with one of these "slices."

Thick (3300 m) metavolcanic sequences of Precambrian or Jurassic age crop out in the western Plomosa Mountains. The Precambrian age

assignment by Miller (1966) is based on lithologic similarity of the metavolcanic rocks with the Yavapai Series of known Precambrian age exposed south of the Mogollon Rim. Miller's Jurassic age is based on lithologic similarity to rocks exposed in the Dome Rock Mountains 16 km to the west dated by Leon T. Silver (Miller, 1970). Thick sequences of metavolcaniclastic and metavolcanic rocks are found in the Dome Rock Mountains. Due to the proximity, thickness, and lithologic similarities between the sections in the western Plomosa Mountains and in the Dome Rock Mountains, a correlation between the sections should be considered. A metavolcaniclastic boulder containing a Permian sponge, Actinocoelia, was found in alluvium at the top of Copper Bottom Pass at the base of Cunningham Mountain in the Dome Rock Mountains. Therefore, Precambrian, Permian, and Jurassic ages must be considered for the metavolcanic and metavolcaniclastic sequences.

Exposed in the southern Plomosa Mountains in fault-bounded blocks and isolated hills is a sequence of interbedded maroon siltstone, quartzite, sandstone, and conglomerate which Miller (1970) calls continental red bed deposits. Structural complications have made it difficult to establish a stratigraphic sequence and thickness of this unit, but it is at least 305 m thick. In the western Plomosa Mountains the base of the section rests on a quartz porphyry. It is overlain by the Livingston Hills Formation, with angular discordance in the northeastern Livingston Hills. The contact is covered and may be either depositional or tectonic. Miller (1966) suggests a correlation between the continental red bed deposits and the Triassic Moenkopi Formation of southern Utah and northern

Arizona because of lithologic similarities. Stewart, Poole, and Wilson (1972), in their sedimentary facies and isopach map of the Moenkopi Formation, have a 241 m thick section at the southern edge of their map area which they correlate with the Moenkopi Formation. The section is in Sycamore Canyon, about 250 km northeast of the southern Plomosa Mountains. This section consists of conglomerate and cross-stratified sandstone and siltstone interpreted as channel deposits. The section is anomalous in that to the north into Utah and to the east to Holbrook, the Moenkopi Formation is characterized by quiet water and current deposits of parallel ripple-laminated siltstone and interstratified siltstone, carbonate, shale, and gypsum. Although the Sycamore Canyon section is not unusually thick, the thickness and possible southern source areas implied by the lithofacies relationships suggest that more undiscovered Moenkopi Formation may be present to the south of its known extent. On the other hand, if the metavolcanic rocks are Jurassic and if the continental red bed deposits are younger than the metavolcanic rocks, the correlation between the Moenkopi Formation and the continental red bed deposits is not possible.

An intrusive and extrusive quartz porphyry (Miller, 1970) crops out at several localities in the central Plomosa Mountains along the contact between Paleozoic marbles and the Plomosa Mountains section of the Livingston Hills Formation. The same quartz porphyry is exposed in the western Plomosa Mountains with continental red bed deposits interstratified with it and resting above it, and with metavolcanic rocks in discordant contact below it. In Apache Wash in the central Plomosa

Mountains, the quartz porphyry is interstratified with the basal 10 m of the conglomerate member of the Livingston Hills Formation. Contact relationships described above suggest that the quartz porphyry is post-metavolcanic rocks and Paleozoic marbles in age and is probably close to contemporaneous with initial deposition of the conglomerate exposed in Apache Wash and the continental red bed deposits exposed in the western Plomosa Mountains. The interstratified nature of the quartz porphyry with both the Plomosa Mountains section conglomerate member of the Livingston Hills Formation and the continental red bed deposits suggests that they may be lateral facies equivalents.

At least three separate undated quartz monzonite intrusions are mapped in the southern Plomosa Mountains. They have been assigned a Mesozoic or early Tertiary age because they intrude Paleozoic carbonates.

The Livingston Hills Formation, as exposed in the central Plomosa Mountains, is a nearly complete homoclinal sequence 2000 m thick deposited on Paleozoic carbonates and an extrusive-intrusive quartz porphyry unit with slight angular discordance. The top of the sequence is truncated by a low-dipping fault placing granitic rocks and continental red bed deposits on the Livingston Hills Formation. In the Livingston Hills, the Livingston Hills Formation rests with considerable angular discordance on continental red bed deposits. The top of the sequence is not exposed. The section there is 3572 m thick and also homoclinally exposed. Probable mid-Tertiary volcanic rocks overlie the sequence with pronounced angular unconformity. Age of the Livingston Hills Formation is constrained only by the Paleozoic section on which it

was deposited and the mid-Tertiary volcanic rocks that overlie it. Furthermore, it has been thrust faulted and must predate the last major compressive deformation of the region.

Subhorizontal rhyolites and andesites capped in some places by basalts make up the section of presumed mid-Tertiary volcanic rocks exposed in the southern Plomosa Mountains and Livingston Hills.

THE LIVINGSTON HILLS FORMATION

The Livingston Hills Formation is an extensive sequence of conglomerate, quartzofeldspatholithic sandstone (terminology from Crook, 1960), and siltstone that crops out in the Livingston Hills and southern Plomosa Mountains. Miller (1966) divided the formation into conglomerate, graywacke, and siltstone members. The conglomerate member forms roughly the lower third of the section, the graywacke member the middle third, and the siltstone member the upper third of the section. The most complete section of the Livingston Hills Formation is exposed in the Livingston Hills, where the thickness is 3572 m. In the Apache Wash region in the southern Plomosa Mountains, the section totals 1996 m. Both sections were measured by Jacob staff, described in detail (Figure 2, in pocket) and sampled at close intervals for petrographic analysis. Both sections contain all three members of the formation. Conglomerate, which Miller correlated with the Livingston Hills Formation conglomerate member, crops out near Crystal Hill in the southernmost Plomosa Mountains, where it overlies Miller's (1970) continental red bed deposits.

Petrography of the
Siltstone Member

The siliceous siltstone of the Livingston Hills section is highly altered. Rare angular fragments of quartz and feldspar occur in a very fine grained 5-15μ siliceous matrix laced with stringers of iron oxide and clouded with a coating of sericite. Matrix, probably mostly recrystallized pseudomatrix, makes up to 95% of the rock.

THE LIVINGSTON HILLS SECTION OF THE LIVINGSTON HILLS FORMATION

Distribution

The type section of the Livingston Hills Formation is exposed in the Livingston Hills as a homoclinal sequence dipping 30-45° to the south. Conglomerate similar in lithology to the Livingston Hills section conglomerate member is exposed in the northwestern and west-central Plomosa Mountains as well.

Contact Relationships

At the type section in the north-central Livingston Hills, the base of the Livingston Hills Formation is in high-angle fault contact with continental red bed deposits. The upper contact is nowhere exposed. Volcanic rocks of probable mid-Tertiary age overlie parts of the section with pronounced angular unconformity. In the northeastern Livingston Hills, the Livingston Hills conglomerate member is exposed structurally above continental red bed deposits along a contact which, if depositional, would represent the base of the section. The continental red bed deposits are badly faulted, sheared, and foliated in several directions right up to the contact. The conglomerate member exposed above the contact is massive, only locally foliated, and contains dominantly igneous clasts. Lowest exposures of the conglomerate member at the type section are well-bedded, show a penetrative near-horizontal foliation, and contain dominantly supracrustal (quartzite and marble) clasts. The lithologic and structural differences between the exposures

THE PLOMOSA MOUNTAINS SECTION OF THE LIVINGSTON HILLS FORMATION

Distribution

The Plomosa Mountains section of the Livingston Hills Formation is exposed in a 15 square kilometer area around Apache Wash in the south-central Plomosa Mountains and in an isolated hill in the southwestern Plomosa Mountains. Conglomerate possibly correlative with the conglomerate of the Plomosa Mountains section is exposed in low hills near Crystal Hill in the southernmost Plomosa Mountains. Siltstone correlative with the siltstone member of the Plomosa Mountains section crops out in the west-central Plomosa Mountains. Throughout the Quartzsite Quadrangle (Miller, 1970) isolated patches of conglomerate and siltstone members of the Livingston Hills Formation are mapped, but lithologies vary from one outcrop to the next. Some outcrops have an affinity with either the Livingston Hills or Plomosa Mountains section of the Livingston Hills Formation and others look quite different from either section.

Contact Relationships

In the Apache Wash region of the Plomosa Mountains the Livingston Hills Formation is exposed as a generally east-dipping, locally overturned homoclinal sequence that rests with slight angular unconformity in depositional contact with cliff-forming Paleozoic marbles. The top of the section is truncated by low-angle faults that place granitic rocks of unknown age and continental red bed deposits above the siltstone

member. West of Crystal Hill in the southwestern Plomosa Mountains, conglomerate very similar in appearance to that in Apache Wash is in depositional contact with Paleozoic marbles.

Complicating the basal contact of the Livingston Hills Formation in the Plomosa Mountains is a unit that Miller (1970) calls both an intrusive and extrusive quartz porphyry. The quartz porphyry is mapped by Miller as intruding the basal contact of the Livingston Hills Formation. Further mapping by the author confirms that the quartz porphyry is in intrusive and extrusive contact with the Paleozoic marbles and that it is interstratified with the lowest 10 m of the conglomerate member of the Livingston Hills Formation in Apache Wash. In the western Plomosa Mountains, mapping by the author suggests that the quartz porphyry overlies a Jurassic(?) metavolcanic sequence and is overlain by continental red bed deposits in depositional contact. This relationship with the quartz porphyry, along with lithologic similarities between the continental red bed deposits and the conglomerate member of the Livingston Hills Formation exposed in Apache Wash, suggests a possible correlation between the continental red bed deposits and the conglomerate exposed in Apache Wash.

The Conglomerate Member

The conglomerate member of the Livingston Hills Formation exposed in Apache Wash is about 372 m thick. Most of it is overturned and dips 50-85° to the west. It is composed of light pink to orange-red medium- to coarse-grained quartzofeldspatholithic interbedded

DEPOSITIONAL ENVIRONMENT OF THE LIVINGSTON HILLS FORMATION

The conglomerate member of the Livingston Hills Formation exhibits extreme variation in sorting of clasts and matrix, grain size of matrix, and thickness of beds from bed to bed. The conglomerate is always matrix-supported and clasts are not imbricated or found in preferred orientations. Beds thicken and thin along strike, suggesting wedge-shaped depositional units, and are continuous in outcrop over at least 100 m. Bedding in the conglomerate ranges between 1 cm and 10 m thick. The feldspathic sandstone interbeds within the conglomerate commonly show graded bedding and are between 1 cm and 1 m thick. The conglomerate exposed in Apache Wash and near Crystal Hill in the Plomosa Mountains is orange-red to pink and contains large amounts of iron oxide in interstitial material. The conglomerate exposed in the Livingston Hills is blue-gray to gray and contains mainly sericite and calcite in interstitial material. The limestone lenses exposed near the base of the conglomerate section in Apache Wash contain oncolites suggestive of hot spring activity (N. J. Silberling, written communication, 1978). Stromatolites and one example of fluvial cross-bedding suggest a shallow water environment. In thin section all samples from the conglomerate member contain large volumes of secondary micas which may be alteration products of an original clay-rich matrix.

Criteria diagnostic of alluvial fan deposits described by Bull (1972) and seen in the Livingston Hills Formation include the oxidized

nature of the sedimentary rocks in the Plomosa Mountains section, the variability between beds in thickness, particle size and sorting, and the presence of clay matrix. Debris flows are defined by Bull (1972) as being high viscosity, high density flows with entrapped sediment grains that act more like a plastic mass than a Newtonian fluid. These flows are commonly poorly sorted and are deposited as a continuous sheet. They generally have sufficient matrix strength to transport very large boulders. Conglomeratic debris flows are matrix-supported. Conditions leading to their formation include steep slopes with little vegetation, a source for the mud found in the matrix of the flows, and abundant rainfall for short infrequent periods of time. The term mudflow, Bull (1972) suggests, should be reserved for fine-grained (sand, silt, and clay) debris flows. The term debris flow should be reserved for flows consisting of coarse-grained sediments and clasts.

The above evidence suggests that the conglomerate of the Livingston Hills Formation was deposited as a series of debris flows and mudflows in a subaerial or shallow water fan-type environment.

Oxidation of some of the conglomerate and reduction of other conglomerate is possibly due either to differences in ground water chemistry following deposition or subaerial deposition for the oxidized conglomerate in the Plomosa Mountains, and shallow water deposition for the blue-gray conglomerate in the Livingston Hills. Geologic processes involved in debris and mudflow deposition are indistinguishable for subaerial and shallow water environments. Paucity of fossils and difficulties in creating a deep marine environment on continental crust

suggest that the fans were not deposited as submarine canyon and channel deposits.

The variability in grain size, sorting, and bedding thickness within the graywacke member, the presence of clasts and mudchips floating in a sand matrix, graded beds, lack of fossils, and continuous bedding over long distances are all characteristics found in subaerial fan deposits. The presence of these characteristics suggests that the graywacke member may also have been deposited as a series of mudflows and debris flows. As with the conglomerate member, no criteria are available to distinguish between subaerial and shallow water (lacustrine or marine) deposition.

Tidal flat environments are characterized by fine-grained sediment deposition, interlamination of sand and silt, both massive and laminated beds, asymmetric oscillation ripples, and bidirectional current indicators (Reineck, 1972). The siltstone member of the Livingston Hills Formation contains interlaminated sand and silt, massive sand and silt and laminated silt beds, and slightly asymmetric transverse ripples that indicate (Figure 10) bidirectional current flow. Evidence from Potter and Pettijohn (1977) that the current rose pattern obtained from the transverse ripples is typical of tidal flat environments plus similarity of characteristics listed above suggest that the siltstone member of the Livingston Hills Formation was deposited in a tidal flat environment.

Feldspathic sandstone beds within the siltstone member are all internally structureless, massive, and not continuous in outcrop. They

could be either debris flow and mudflow deposits as discussed earlier for the feldspathic sandstone in the graywacke member, or were deposited in tidal channels.

In Apache Wash, the siltstone member of the Livingston Hills Formation is typified by laminated silt beds 1-6 cm thick interbedded with graded sandstone beds less than 4 cm thick. Lunate and transverse ripples occur on bedding plane surfaces but do not indicate highly preferred directions of sediment transport (Figure 11). Fossil wood was found at one locality. Siltstone in Apache Wash contains a high percentage of sericitized micas indicating an original clay-rich matrix. Environment of deposition could be tidal flat, as for the Livingston Hills section siltstone member, or lacustrine, suggested by the periodically present graded sandstone interbeds.

STRATIGRAPHY AND PETROLOGY OF SOME MESOZOIC ROCKS IN WESTERN ARIZONA

by

Brad Alan Robison

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A Thesis Submitted to the Faculty of the

DEPARTMENT OF GEOSCIENCES

In Partial Fulfillment of the Requirements
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ABSTRACT

Continental red-bed deposits, the "Red Beds," exposed in the Plomosa Mountains, western Arizona, consist of a complex assemblage of coarse- to fine-grained, quartz-rich clastic and finely crystalline, gypsiferous carbonate rock. Lithologic types are arranged stratigraphically as a succession of fining-upward cyclothems.

The "Red Beds" nonconformably overlie a Mesozoic rhyodacite porphyry, and conformably overlie volcanic arenite derived in part from the porphyry. The Livingston Hills Formation conformably overlies the "Red Beds."

The "Red Beds" represent channel, pointbar and floodplain deposits of a meandering stream system. The source was located to the north or northwest and consisted primarily of a Paleozoic cratonic sequence.

The "Red Beds" are lithologically equivalent to member one of the McCoy Mountains Formation, southeastern California, and are time equivalent to the basal portion of the Livingston Hills Formation. All may be Early Cretaceous in age.

Mesozoic strata in western Arizona and southeastern California were deposited in a west- to northwest-trending, block fault basin system.

Spatially associated with the "Red Beds" are Precambrian igneous, Paleozoic sedimentary, Mesozoic igneous, volcanic and

sedimentary and Cenozoic igneous, volcanic and sedimentary lithologic units. Structural events include Cretaceous-Tertiary thrust faulting and Late Tertiary strike-slip faulting.

CHAPTER 1

INTRODUCTION

The Problem

The stratigraphy of western Arizona is poorly understood. Consequently, the geologic and tectonic histories of the area are speculative.

Since the reconnaissance mapping by Wilson (1933, 1960), sedimentary and metasedimentary rocks have been known to crop out in western Arizona. Wilson (1960) and the Geologic Map of Arizona (Wilson, Moore and Cooper, 1969) portray exposures of Paleozoic, Mesozoic and Mesozoic/Paleozoic undifferentiated strata in many of the mountain ranges.

McKee (1947) described a conglomeratic unit near Quartzsite, Arizona, that contains Paleozoic clasts.

Miller (1966) mapped the southern half of the Plomosa Mountains located south and east of Quartzsite. He recognized several distinct stratigraphic units. These included Precambrian(?) metavolcanic rocks; Precambrian(?) metasedimentary rocks; a relatively thin Paleozoic sequence consisting of fossiliferous limestone, mature sandstone and minor shale; a Lower Mesozoic(?) clastic sequence and a very thick Upper Mesozoic or Lower Tertiary sequence.

The area mapped by Miller (1966) was revised and published as the Geologic Map of the Quartzsite Quadrangle, Yuma County, Arizona (Miller, 1970). On this map the metavolcanic rocks were assigned a Precambrian or Mesozoic age. Marble, quartzite and schist comprising the metasedimentary rocks were recognized by Miller (1970) as plastically deformed Paleozoic sediments. Lithologic correlation of undeformed Paleozoic rocks with formations on the Colorado Plateau and in southeastern Arizona allowed adoption of existing terminology to name stratigraphic units. The Lower Mesozoic(?) clastic sequence was informally named and interpreted as continental red-bed deposits. And lastly, the Upper Mesozoic or Lower Tertiary sequence was formally defined as the Livingston Hills Formation (Miller, 1970).

The Livingston Hills Formation is the only unit to have received further study (Harding, 1978). It consists of matrix-supported conglomerate, graded arkosic sandstone and siltstone that represent alluvial fan and tidal flat(?) sedimentation. Complex facies relationships with the continental red-bed deposits of Miller (1970) were suggested (Harding, 1978).

Although Miller (1966, 1970) previously correlated these red-bed deposits with redbeds of the Moenkopi Formation of the Colorado Plateau, they are lithologically dissimilar. In fact, the red-bed deposits of Miller (1970) consist of a complex sequence of interbedded mudstone, siltstone, sandstone, conglomerate and carbonate rock that is not even red. Actually, like the Livingston Hills Formation, the

red-bed deposits seem to have no previously described lithological equivalent in Arizona.

Therefore, a study of these continental red-bed deposits, (hereafter referred to as the "Red Beds"), was undertaken in hopes of clarifying at least certain aspects of local and regional stratigraphy. Specifically, an attempt is made to accurately describe the sequence, define the lower and upper contacts, interpret the environment(s) of deposition, determine provenance, refine the age, make local and regional correlations and to characterize the tectonic setting.

Methods of Study

This study concentrates primarily on outcrops in the southernmost Plomosa Mountains, Yuma County, Arizona, where the "Red Beds" are best exposed and mapped (Figure 1). However, outcrops were also studied to the north and east in Arizona, and to the west in Arizona and California, to aid in regional interpretations.

Extensive faulting and folding in the Plomosa Mountains, and the nature of the sedimentary sequence, inhibit attempts at reconstruction of a complete stratigraphic succession. Therefore, several partial sections were measured where contact relationships were observable and where continuous successions were best exposed. Virtually every exposure of the "Red Beds" in the Plomosa Mountains was observed and sampled to insure that no significant data gaps occurred.

Stratigraphic sections were measured with a Jacob staff and Brunton compass. Every observable change in lithology was noted.

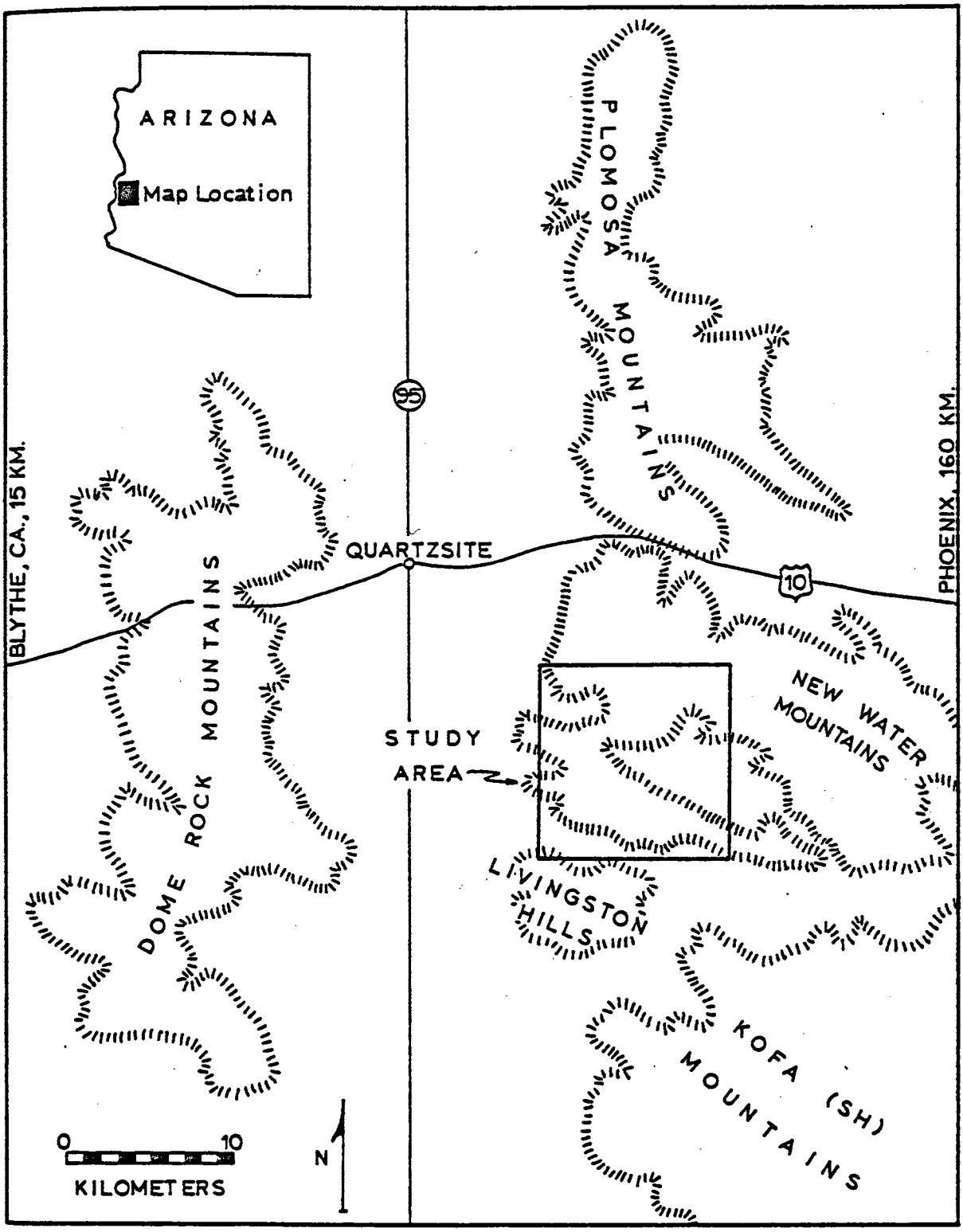


Figure 1. Map of Western Arizona Showing Location of Primary Study Area

CHAPTER 2

DESCRIPTIVE STRATIGRAPHY AND PETROGRAPHY

Introduction to the "Red Beds"

The "Red Beds" in the southern Plomosa Mountains consist of a complex assemblage of coarse- to fine-grained clastic and finely crystalline carbonate rock. The various rock types are not separable into distinct members, but rather they occur in an interbedded fashion. All rock types occur within a very short stratigraphic interval.

A compilation of 99 point counts of rock units from a single stratigraphic succession within the "Red Beds" is presented in Figure 2. Conglomerates are not included. The poles of the triangle are detrital grains, matrix and carbonate plus gypsum. All grains larger than medium silt are included as detrital grains, and matrix is defined as all non-chemical components finer than 0.03 mm in size (Pettijohn, 1975).

In order to discuss the characteristics of these rocks in a coherent manner, the points have been divided into groups. One natural group is clearly visible near the carbonate plus gypsum pole. These are microsparites. Essentially, they represent slightly recrystallized calcareous mudstones.

CHAPTER 4

GEOLOGIC MAP

Description and Interpretation of Map Units

Detailed stratigraphic study of the "Red Beds" and associated rock units allows significant refinement of a portion of the Quartzsite Quadrangle originally mapped by Miller (1966, 1970). The following is a brief description and interpretation of map units portrayed on the revised map (Figure 16, in pocket).

A thin sequence of poorly dated lithic arkose, mapped by Miller (1970) as a latite dike, nonconformably overlies Precambrian or Mesozoic metavolcanic rock. Extrusive, Mesozoic rhyodacite porphyry depositionally(?) overlies the lithic arkose. Although the porphyry and the arkose are progressively sheared toward the contact, lack of slickensides and cataclasis suggests that the contact is essentially sedimentary in origin. Poor stratigraphic control does not allow valid age assignment to the arkose.

The basal portion of the sequence is very conglomeratic, and contains clasts derived from the underlying metavolcanic rock. The top of the unit is characterized by interbedded very fine grained sandstone to matrix-supported gritstone.

The lithic arkose consists of plagioclase, potassium feldspar, volcanic rock fragments, quartz, epidotized and chloritized grains

and magnetite. Grain size, rounding and sorting are variable. Matrix consists of micro-crystalline quartz, chlorite, sericite, sparry calcite and abundant disseminated hematite and opaque minerals. Feldspar and quartz are partially replaced by calcite. In addition, feldspar is intensely sericitized. Magnetite is partially altered to hematite.

The lithic arkose probably represents debris flow and alluvial deposits derived primarily from the underlying metavolcanic rock.

The oldest rock unit in the map area may be Precambrian quartz monzonite. The rock has not been dated, but it is nonconformably overlain by Cambrian(?) strata. The monzonite is coarse grained, and consists of quartz, highly altered feldspar and chloritized biotite and hornblende (Miller, 1970).

Slightly metamorphosed, Precambrian or Mesozoic metavolcanic rock is exposed in the northwest corner of the map area. The sequence is comprised of approximately 3500 m of rhyolitic to dacitic flow and tuffaceous rock (Miller, 1970).

Sparse quartz and albite/oligoclase phenocrysts occur in an aphanitic groundmass of quartz, plagioclase, chlorite and muscovite. Calcite, epidote, biotite and magnetite also occur. Phenocrysts are euhedral; quartz commonly is embayed.

Age assignment is tenuous. North of the map area, the metavolcanic sequence may be intruded by a quartz monzonite pluton

(Miller, 1966). L. T. Silver calculated an age of 1730 to 1750 my, (U-Pb, zircon), for the pluton. In addition, the metavolcanic rock is lithologically similar to lower Precambrian rock exposed in central Arizona. Therefore, a Precambrian age is suggested (Miller, 1970).

Re-evaluation of map relationships suggests the possibility that the contact with the pluton may be depositional. Furthermore, the pluton dated by Silver may not be the one in contact with the metavolcanic sequence (Miller, 1970). Since the metavolcanic rock is lithologically similar to lower Mesozoic rock described by Grose (1959) exposed to the west in California, a Mesozoic age can also be suggested.

Approximately 900 m (Miller, 1970) of undifferentiated Paleozoic limestone, dolomite, quartzite and minor shale crop out in the northern part of the study area. The sequence rests nonconformably on coarse-grained quartz monzonite. Composition and thickness are characteristic of stable shelf sedimentation (Stewart and Poole, 1974).

Locally, this sequence is divisible into formational units, but because of the distance to documented Paleozoic sections, correlations are tentative. Hayes and Poole recognized that the lower four units resemble the Bolsa Quartzite and Abrigo Formation of Cambrian age, the Martin Formation of Devonian age and the Escabrosa Limestone of Mississippian age in southeastern Arizona. The upper three units are similar to the Supai Formation of Pennsylvanian-Permian age and the Coconino Sandstone and Kaibab Limestone of Permian age on the Colorado Plateau (Miller, 1970).

A thick, monotonous sequence of sheared volcaniclastic rock, (metamorphosed porphyry of Miller, 1966), crops out on the western edge of the map area. The sequence is surrounded by alluvium except on the southeast side of the outcrop, where the unit is contact with rhyodacite porphyry and the Livingston Hills Formation. Due to intense shearing and alteration, the nature of the contacts is not known.

The volcaniclastic rock consists of medium to very coarse, subrounded to euhedral grains of plagioclase, (oligoclase?), orthoclase and minor quartz. Feldspar commonly is zoned; quartz is embayed. Biotite and magnetite occur in trace amounts. Approximately one-half of the rock consists of microcrystalline matrix.

Alteration is extensive. Much feldspar is so intensely sericitized that it can be distinguished from matrix only with difficulty. Some feldspar has been saussuritized. Biotite is partially altered to chlorite and opaque minerals. The matrix has been recrystallized to microcrystalline quartz, chlorite and abundant epidote group minerals.

Sedimentary origin is indicated by the bedded character, rounded nature of some detrital grains and by megascopic sedimentary fabric.

Compositionally and texturally similar and possibly correlative rock is exposed in the Dome Rock Mountains, located 20 km to the west. A piece of float derived from the Dome Rock exposure contains a Permian sponge, Actinocoelia, preserved in chert. It cannot be

determined if the chert is interstratified with the volcanic material or if it is exotic.

The occurrence of the sponge in correlative(?) strata may indicate that the volcaniclastic rock is Permian or younger in age. A Mesozoic age may be suggested based upon the possible association with arc-related sedimentation that began in Late Triassic time along the western margin of North American (Davis, Monger and Burchfiel, 1978). If the volcaniclastic rock is related to volcanic activity associated with the lower Mesozoic Mogollon highland, central and southern Arizona (Stewart and others, 1972a, 1972b), an early Mesozoic age is indicated.

The origin of the volcaniclastic rock is not clear. It is compositionally similar to the Mesozoic rhyodacite porphyry, but it is distinctly different from conglomeratic, volcanic arenite derived in part from the porphyry.

Because Permian volcanism is not known in Arizona, it is possible that the volcaniclastic rock represents a portion of a "suspect" terrane. These late Paleozoic terranes accreted to the western continental margin during Mesozoic time (Coney, 1979), and are recognized by fossil content representing disjunct paleobiogeographical provinces (Hamilton, 1978). Since Actinocoelia is widespread in the western United States (Finks, Yochelson and Sheldon, 1961), it offers little evidence for this hypothesis.

If the volcaniclastic rock is Mesozoic in age, it may represent a portion of the lower Mesozoic arc terrane that probably extended

from the terrane in southeastern California described by Grose (1959) to the lower Mesozoic volcanic terrane in the Canelo Hills, southeastern Arizona, described by Hayes, Simons and Raup (1965). Upper Triassic strata in New Mexico and west Texas were derived from an igneous source to the south suggesting that this lower Mesozoic arc terrane may have extended as far as southwest Texas (McKee and others, 1959).

Mesozoic quartz monzonite porphyry intrudes Precambrian quartz monzonite and undifferentiated Paleozoic rock west and northwest of Black Mesa. Miocene rhyodacite and Tertiary and/or Quaternary basalt unconformably overlie the quartz monzonite porphyry (Miller, 1970).

The quartz monzonite porphyry consists of feldspar and quartz phenocrysts in a groundmass of quartz, plagioclase and potassium feldspar. Chloritized biotite and amphibole also occur (Miller, 1970).

Mesozoic rhyodacite porphyry, (quartz porphyry of Miller, 1966 and 1970), is exposed in several regions within the map area. The porphyry may be both intrusive and extrusive in origin. It intrudes undifferentiated Paleozoic rock (Miller, 1970) and depositionally(?) overlies lithic arkose of unknown age. The rhyodacite porphyry is nonconformably overlain by upper Mesozoic conglomeratic volcanic arenite and by the "Red Beds." A hypabyssal rhyodacite porphyry exhibiting similar field relationships occurs in the McCoy and Palen Mountains, California. D. Krummenacher determined an age of 175.8 $\pm$ 2.7 my, (K-Ar, plagioclase), for the porphyry in California (Pelka, 1973).

The rhyodacite porphyry consists of euhedral to subhedral oligoclase, potassium feldspar and quartz phenocrysts in an aphanitic groundmass of quartz, plagioclase, (albite?), chlorite, sericite and epidote group minerals. Rarely, calcite, magnetite, biotite, muscovite and piedmontite occur. Apatite and hornblende(?) have also been reported (Miller, 1966). Much feldspar is altered to sericite and epidote group minerals. Some feldspar is zoned. Quartz phenocrysts commonly are embayed. Intensity of alteration and phenocryst to matrix ratio are highly variable.

Poorly stratified, conglomeratic volcanic arenite nonconformably overlies Mesozoic rhyodacite porphyry. Where cobbles and boulders are absent, the arenite is very difficult to distinguish from the porphyry. The sequence becomes finer grained upward. Thickness is variable, but nowhere is it greater than 100 m.

The volcanic arenite consists primarily of very finely crystalline, siliceous and chloritic, volcanic rock fragments. Pebble- to boulder-sized clasts strongly resemble Precambrian or Mesozoic metavolcanic rock and Mesozoic rhyodacite porphyry. Quartz, plagioclase, potassium feldspar and chert account for a relatively small proportion of the detrital component. Trace amounts of epidote and biotite also occur.

Grains are subrounded and moderately to poorly sorted. Siliceous, chloritic and sericitic matrix is extremely abundant, and is gradational with volcanic fragments. Matrix may represent in part alteration of volcanic material.

Volcanic arenite is interbedded with and conformably overlain by the Livingston Hills Formation, the "Red Beds," (Harding, 1978) and the "Green Beds." This suggests a late Mesozoic, (Early Cretaceous?), age. Composition, structure and areal distribution suggest that the volcanic arenite represents debris flow and alluvial deposits of local derivation.

Although compositionally distinct, the Glance Conglomerate Member of the Bisbee Group, southeastern Arizona, is similar to the conglomeratic, volcanic arenite. Like the volcanic arenite, the Glance Conglomerate unconformably overlies a relict Mesozoic topographic surface, is of local derivation, is highly variable in thickness and occurs at the base of a thick conformable Lower Cretaceous sequence (Hayes, 1970). The volcanic arenite and the Glance essentially may represent equivalent deposits.

Three distinct map units are of probable Early Cretaceous age. They include the "Red Beds," the "Green Beds" and the Livingston Hills Formation. The basal portion of all three is interstratified with the locally derived volcanic arenite and lithologies identical to those found in the "Green Beds" and the Livingston Hills Formation occur as tongues in the Red Beds."

The "Red Beds" crop out primarily in the southern half of the map area. The sequence is composed of fining-upward cyclothems representing deposits of a meandering stream system. The unit has been described previously and needs no further discussion here.

Approximately 1200 m of the "Green Beds" is exposed in the central part of the map area near the Livingston Mine. Although compositionally and physically distinct from the "Red Beds," the two units were previously mapped as one (Miller, 1966, 1970).

The "Green Beds" are interstratified with and conformably overlie the conglomeratic, volcanic arenite. In addition, the unit is conformably overlain by the Livingston Hills Formation. Therefore, the "Green Beds" are time equivalent with the "Red Beds" and are Early Cretaceous in age.

The "Green Beds" consist primarily of coarse- to very fine-grained sandstone and phyllitic siltstone and mudstone. Lithologies show no obvious preferred stratigraphic arrangement. Color is characteristically light greenish gray. Phyllitic units generally have a silvery sheen. Thick to thin beds are very continuous laterally and are structureless.

Sandstone from the "Green Beds" consists of well- to poorly-sorted, subrounded to angular, coarse to very fine grains. Near the base of the section, intensely sericitized and partially recrystallized volcanic(?) rock fragments are most abundant. Quartz, plagioclase, potassium feldspar(?), epidote and epidotized grains also are common. Euhedral, unaltered magnetite, chloritized biotite and leucoxene occur in trace amounts. Quartz commonly is embayed suggesting a volcanic origin. Plagioclase may be zoned. Sandstone rapidly becomes much more quartz rich up section.

Abundant matrix occurs in sandstone from the "Green Beds." It consists of microcrystalline quartz, sericite, chlorite and minor epidote. Much of the matrix appears to have originated by alteration and deformation of unstable rock fragments.

Conglomerate comprises less than 1% of the "Green Beds." Conglomerate is matrix supported and internally structureless. Angular to subangular, granule- to pebble-sized clasts, (average diameter approximately 1 cm), consist of slightly recrystallized and altered volcanic rock, chert, quartz-rich sandstone and other unidentifiable lithologies. Origin of the "Green Beds" and nature of the facies relationship with the "Red Beds" are not clear. Sandstone composition and texture are similar to the conglomeratic, volcanic arenite and may reflect derivation from the same or similar source. However, much of the section appears too quartz rich to be primarily volcanically derived. Continuity of bedding, sand-sized grains and association with matrix-supported conglomerate are characteristics of sheetflood deposits (Bull, 1972). The "Green Beds" may represent distal alluvial fan deposits that are time equivalent with fluvial deposits of the "Red Beds."

The Livingston Hills Formation was named for a thick sequence of conglomerate, sandstone and siltstone exposed in the Livingston HIlls just south of the map area. A correlative sequence occurs in the southernmost Plomosa Mountains (Miller, 1970).

The formation is divided into three memebers (Miller, 1970). The lowermost conglomerate member is interbedded with and conformably

overlies the conglomeratic, volcanic arenite (Harding, 1978). The conglomerate member also is interstratified with and conformably overlies the "Red Beds" and the "Green Beds." All three are time equivalent and are of probable Early Cretaceous age.

In the Plomosa Mountains, the conglomerate member is approximately 350 m in thickness and consists of interbedded arkose, lithic arkose and matrix-supported, pebble conglomerate. Clast lithology changes from quartzite, limestone and granitic rock in the lower part of the section to granitic and volcanic in the upper possibly suggesting unroofing of an igneous terrane. The conglomerate member probably represents debris and mudflow deposits (Harding, 1978).

The graywacke member, named by Miller (1970), conformably overlies the conglomerate member. It consists of over 700 m of massive arkose and lithic arkose. Angular, poorly sorted grains of quartz, feldspar and lithic fragments occur in a sericitic and hematitic matrix. The graywacke member in the Plomosa Mountains is less feldspathic and volcanic rich than correlative strata in the Livingston Hills. The graywacke member is thought to represent debris and mudflow deposits (Harding, 1978).

Approximately 900 m of laminated siltstone and minor graded sandstone comprise the siltstone member of the Livingston Hills Formation. Laterally continuous beds are thin to very thin and may contain lunate or transverse ripples. Rarely, fossil plant stems(?) occur in the siltstone. Sedimentary structures and bidirectional orientation

of the current indicators may indicate that the siltstone member represents tidal flat deposits (Harding, 1978).

Mesozoic or Tertiary mafic dikes intrude the "Red Beds" in the northern part of the map area. Dikes range in thickness from approximately 1 to 60 m (Miller, 1970). The dikes are composed of epidotized and chloritized phenocrysts in a groundmass of albite, tremolite, quartz, sericite, chlorite, calcite and leucoxene.

Extrusive rhyodacite of Miocene age (Miller and McKee, 1971) unconformably overlies the Livingston Hills Formation. The rhyodacite consists primarily of hornblende, biotite and plagioclase phenocrysts in a microcrystalline matrix of plagioclase, glass and opaque minerals. The mass near Dripping Spring lacks hornblende and is intrusive in part (Miller, 1970). The rhyodacite is dated as 19.1 $\pm$ 0.6, (K-Ar, hornblende) and 20.2 $\pm$ 0.6 my, (K-Ar, biotite) (Miller and McKee, 1971).

Tertiary and/or Quaternary basalt crops out on Black Mesa in the northeastern part of the map area. The unit consists of a series of flows and tuffaceous rock amounting to nearly 400 m in thickness. The basalt is composed of labradorite, diopsidic augite and minor olivine, (forsterite), and opaque minerals (Miller, 1970).

South of Black Mesa, large areas are underlain by Tertiary and/or Quaternary older alluvium. The older alluvium consists of unconsolidated to poorly consolidated debris derived from all older rock units. Stratification is obscure. Older alluvium probably

represents a fanglomerate deposit derived from the Black Mesa region (Miller, 1970).

The youngest rock unit is represented by Quaternary alluvium. It includes all unconsolidated surficial debris presently accumulating in stream channels and on talus slopes, alluvial fans and desert pavement. Alluvium can be distinguished from older alluvium only by topographic expression and appearance on aerial photographs (Miller, 1970).

Structure

Two distinct, major phases of faulting are recognized in the map area. These include both a thrust faulting and a strike-slip faulting phase.

A series of northward-striking, shallowly dipping, imbricate thrust faults are exposed in the northern part of the map region west of Black Mesa. The lower plate contains a plastically deformed Paleozoic sequence in which individual units are tectonically thickened and thinned. Highly deformed and correlative Paleozoic rock crops out in the Big Maria Mountains, California, 65 km to the northwest. Similar style and degree of deformation across this region suggests a widespread tectonic event (Miller and McKee, 1971).

Paleozoic rock in the upper plate is relatively undeformed. The juxtaposition of the plastically deformed and undeformed Paleozoic strata suggests that a large amount of telescoping has occurred between the thrust faults. Because the faults dip eastward, east to west movement is inferred (Miller and Mckee, 1971).

Thrust faults cut the Livingston Hills Formation and are unconformably overlain by middle Miocene rhyodacite (Miller and McKee, 1971). If the Livingston Hills Formation is Early Cretaceous in age, these relationships suggest that thrust faulting is late Cretaceous or early Tertiary in age.

A zone of west-northwest trending, near-vertical, strike-slip faults is exposed in the southern portion of the map area. These faults can be recognized by local bleaching of rock color, intensive shearing and by the formation of distinct topographic lineaments (Miller, 1966).

Contacts, dikes and other faults are all offset in a right-lateral sense across the strike-slip faults. Apparent offset across the zone is in excess of 5 km (Miller and McKee, 1971).

The strike-slip faults cut the rhyodacite unit and thus, are post-middle Miocene in age. Although the faults commonly control drainage within the area, no offset can be detected in Quaternary alluvial units. Therefore, the strike-slip faults are believed to be late Miocene and/or Pliocene in age (Miller and McKee, 1971).

A northwestward projection of the zone of strike-slip faulting in the southernmost Plomosa Mountains passes through a fault zone in the Dome Rock Mountains and into a right-lateral, strike-slip system in the Big Maria Mountains, California, mapped by W. B. Hamilton (Miller and McKee, 1971). Stewart (1970) has portrayed this system as

a possible extension of the Death Valley-Furnace Creek fault complex. This complex may have a right-laterial offset as much as 80 km (Stewart, 1967).

Northwest-trending, right-lateral, strike-slip faults are common in the western Great Basin (Stewart, Albers and Poole, 1968). These faults may have developed in response to right-lateral slip between the North American and Pacific plates (Atwater, 1970).

Spatially associated with and probably related to the strike-slip faults in the map area are several large-scale, overturned folds. The largest of these folds is represented by approximately 2.5 km^2 of overturned section. Widespread, pervasive cleavage in the southern part of the map area strikes northeast and dips shallowly to the northwest. It parallels the axial plane of existing folds and may represent axial plane cleavage.

CHAPTER 5

CONCLUSIONS

The geologic and tectonic history of western Arizona and southeastern California are poorly understood due to the lack of accurate descriptive and documented interpretive information. Primary focus of this study has been upon a single lithologic unit that crops out in this region. Assuming that these strata are autochthonous, collection and interpretation of stratigraphic and petrographic data result in the following conclusions.

1. The "Red Beds" exposed in the Plomosa Mountains, western Arizona, consist of pebble-supported conglomerate, sandstone, matrix-rich sandstone, siltstone, mudstone and gypsiferous carbonate rock.

2. Lithologic types are arranged stratigraphically as a series of fining-upward cyclothems.

3. The "Red Beds" conformably overlie a locally derived, conglomeratic, volcanic arenite and nonconformably overlie a Mesozoic rhyodacite porphyry.

4. The Livingston Hills Formation conformably overlies the "Red Beds."

5. The "Red Beds" represent deposits of a meandering stream system.

6. The source area consisted primarily of Paleozoic sedimentary and Precambrian metasedimentary rock and was located in west-central Arizona and east-central, southeastern California.

7. The "Red Beds" are lithologically equivalent to the basal member of the McCoy Mountains Formation, and are time equivalent to the basal portion of the Livingston Hills Formation and the "Green Beds."

8. The "Red Beds" and correlative strata are Mesozoic, possibly Early Cretaceous in age.

9. The "Red Beds" and correlative strata were deposited in a west-northwest trending block fault basin that was bounded on the north by a cratonic terrane and on the southwest by an inactive arc terrane.

10. Deposition of Mesozoic strata in western Arizona and southeastern California may be genetically related to deposition of the Bisbee Group in southeastern Arizona.

MAP GQ-841

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

DEKALB Mining, Inc.
390 Freeport Blvd., #12
Sparks, Nevada 89431

GEOLOGIC QUADRANGLE MAPS OF THE UNITED STATES

GEOLOGIC MAP OF THE QUARTZSITE QUADRANGLE YUMA COUNTY, ARIZONA

By
Fred K. Miller

Look at unit 3 - qtz-alb-schist -

QUADRANGLE LOCATION

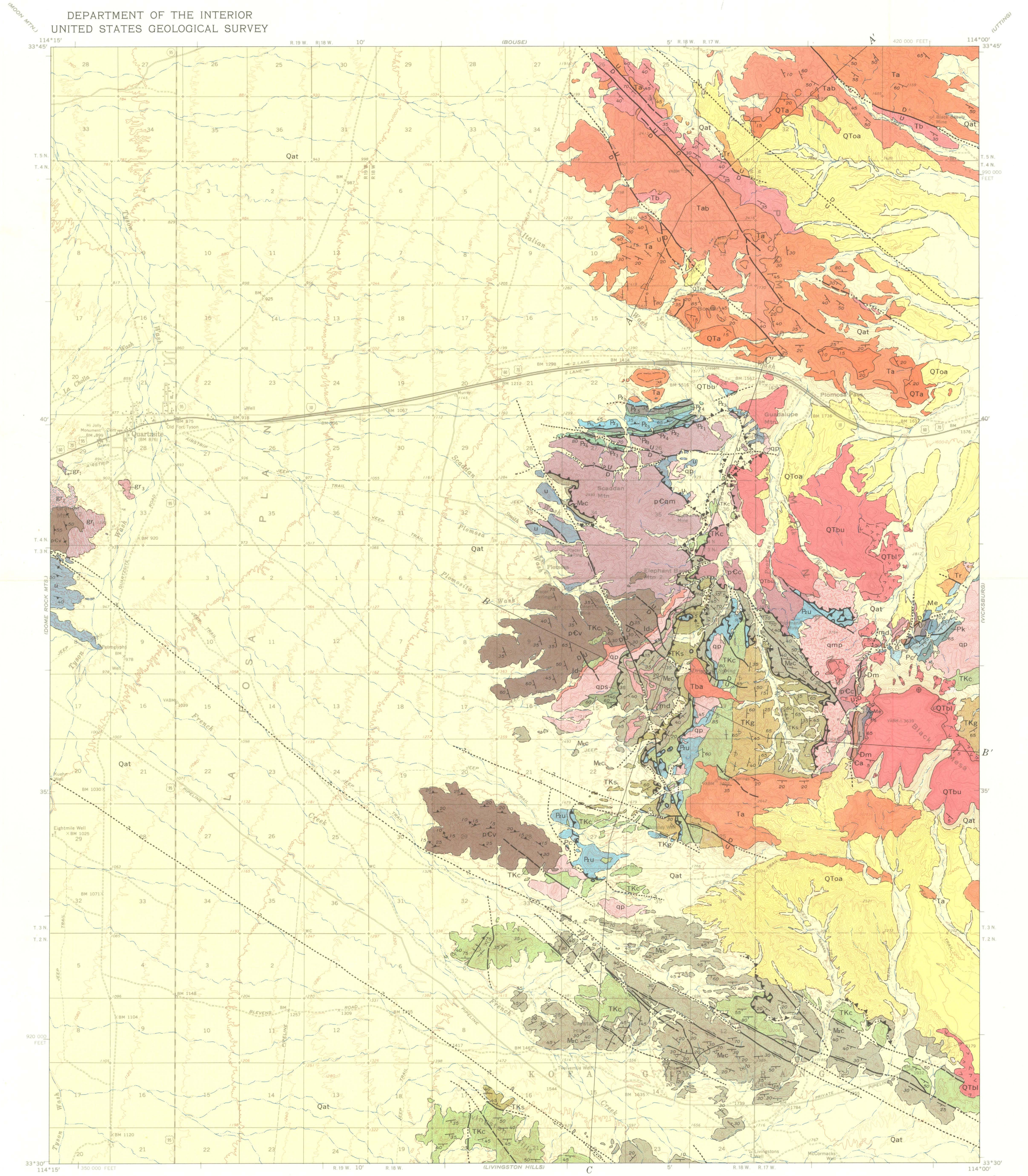
PUBLISHED BY THE U. S. GEOLOGICAL SURVEY
WASHINGTON, D. C.
1970

DEKALB Mining, Inc.
390 Freeport Blvd., #12
Sparks, Nevada 89431

MAP GQ-841

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEOLOGIC QUADRANGLE MAP
QUARTZSITE QUADRANGLE, ARIZONA
GQ-841



Base by U.S. Geological Survey, 1962

TRUE NORTH
MAGNETIC NORTH
14°
APPROXIMATE MEAN DECLINATION, 1969

SCALE 1:62 500

1 ½ 0 1 2 3 MILES

1 .5 0 1 2 3 KILOMETERS

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

QUADRANGLE LOCATION

Geology mapped 1963–66

EXPLANATION

STRATIFIED ROCKS

Qat
Alluvium and talus
Includes all unconsolidated surficial debris except older alluvium

QUATERNARY

QToa
Older alluvium
Unconsolidated to poorly consolidated alluvium. Forms dissected hills at elevations higher than areas of present alluvial accumulation

UNCONFORMITY

QTbu
QTbl
Basalt of Black Mesa
QTbu, *upper unit; olivine-bearing basalt*
QTbl, *lower unit; olivine-bearing basalt interbedded with tuffaceous sedimentary rocks*

UNCONFORMITY

QTa
Hornblende-biotite andesite
Dark-gray to black andesite; abundant glass in matrix

TERTIARY OR QUATERNARY

UNCONFORMITY

Tba
Biotite andesite
In part intrusive and part extrusive

Ta
Older hornblende-biotite andesite
Pink, gray, and brown andesite and minor tuffaceous sedimentary rocks

Tab
Andesite breccia
Angular unsorted andesite breccia with interbedded andesite flows

Tb
Older basalt
Amygdaloidal and massive basalt flows

Tr
Rhyolite
Light-pink to light-gray rhyolite or rhyodacite flows and tuff

TERTIARY(?)

UNCONFORMITY

TKg
TKs
TKg
TKc
Livingston Hills Formation
TKg, *graywacke member with minor siltstone and conglomerate*
TKs, *siltstone member with minor thin-bedded graywacke*
TKc, *conglomerate member with interbedded graywacke*

qps
Sedimentary rocks derived from quartz porphyry
Arkose and conglomerate; occurs only southwest of Dripping Spring

CRETACEOUS OR TERTIARY

ld
Latite dike
Purple dike bordering porphyry mass west of Dos Picachos

qmp
Quartz monzonite porphyry
Microcline phenocrysts partially replaced by albite in a fine-grained matrix of quartz, albite, and microcline. Mafic minerals are all altered

md
Mafic dikes
Altered to epidote, chlorite, tremolite, albite, and quartz

qp
Quartz porphyry
Quartz and altered plagioclase phenocrysts in an altered matrix of quartz, plagioclase, sericite, and epidote-group minerals

MESOZOIC OR CENOZOIC

u
Paleozoic(?) rocks and Precambrian or Mesozoic rocks, undifferentiated
Highly deformed. Includes metavolcanic rocks and parts of units Pz_1 *to* Pz_5

Pz_5
Unit 5
Dolomite, tan, cherty, massively bedded

Pz_4
Unit 4
Vitreous quartzite, medium to massively bedded

Pz_3
Unit 3
Quartz-albite-muscovite-chlorite schist, in part metaclastic, in part metaigneous

Pz_2
Unit 2
Thinly interbedded carbonate, carbonate-bearing quartzite, and quartzite

Pz_1
Unit 1
Dolomite and dolomitic limestone, gray to tan

PALEOZOIC(?)*

UNCONFORMITY

Mzc
Continental red-bed deposits
Maroon mudstone with interbedded sandstone and pebble conglomerate

MESOZOIC(?)

DISCONFORMITY

Pk
Kaibab Limestone
Light-gray and dark-gray cherty limestone, abundantly fossiliferous

Pc
Coconino Sandstone
Vitreous quartzite, medium to massively bedded; in part crossbedded

Ps
Supai Formation
Maroon quartzite with interbedded limestone and mudstone

PERMIAN

DISCONFORMITY

Me
Escabrosa Limestone
Limestone and dolomite, white, gray, and tan, thick bedded; some chert

MISSISSIPPIAN

DISCONFORMITY(?)

Dm
Martin(?) Formation
Dolomitic limestone, dolomite, and sandy dolomite; light gray to almost black

DEVONIAN

DISCONFORMITY

Єa
Abrigo(?) Formation
Sandy shale and thinly interbedded quartzite; multicolored

Єb
Bolsa(?) Quartzite
Quartzite, coarse-grained, well-rounded, relatively pure

CAMBRIAN

Pzu
Paleozoic rocks, undifferentiated

PALEOZOIC

NON CONFORMABLE ON COARSE-GRAINED QUARTZ MONZONITE

pЄv
Metavolcanic rocks
Flows of intermediate composition, with interbedded metatuffaceous rocks. Mass northwest of Livingstone mine is probably intrusive

PRECAMBRIAN OR MESOZOIC**

pЄqm
Quartz monzonite
Medium- to coarse-grained biotite quartz monzonite

pЄc
Coarse-grained quartz monzonite
Very coarse grained biotite quartz monzonite

PRE-CAMBRIAN

gr_2
gr_1
gr_3
Granitic rocks of the Dome Rock Mountains
gr_1, *highly sheared, pink quartz monzonite*
gr_2, *porphyritic biotite quartz monzonite*
gr_3, *slightly sheared, biotite-rich quartz monzonite*

AGE UNKNOWN

*Part of this section is probably the same as the fossiliferous Paleozoic section north and west of Black Mesa. However, these units have undergone such extreme plastic deformation that correlation is not positive. This section also resembles parts of the younger Precambrian Grand Canyon Series, and the younger Precambrian of southeastern California, although a formation-by-formation correlation is not possible.

**This unit may be correlative with similar metavolcanic rocks of Late Triassic or Early Jurassic age (L. T. Silver, oral commun., 1967) in the Dome Rock Mountains 10 miles to the west.

Contact
Dashed where approximately located

U
D
?
Fault
Dashed where approximately located; dotted where concealed; queried where uncertain. U, *upthrown side;* D, *downthrown side. Arrows indicate relative direction of lateral movement*

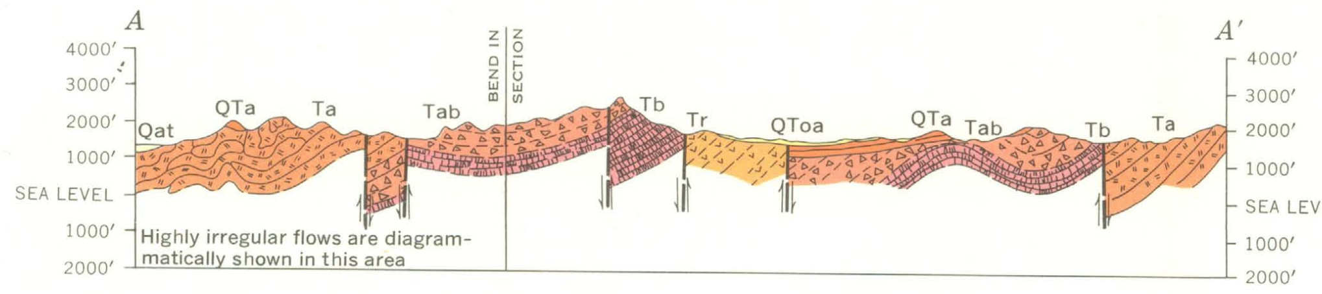
?
Thrust fault
Dashed where approximately located; dotted where concealed; queried where position uncertain. Sawteeth on upper plate

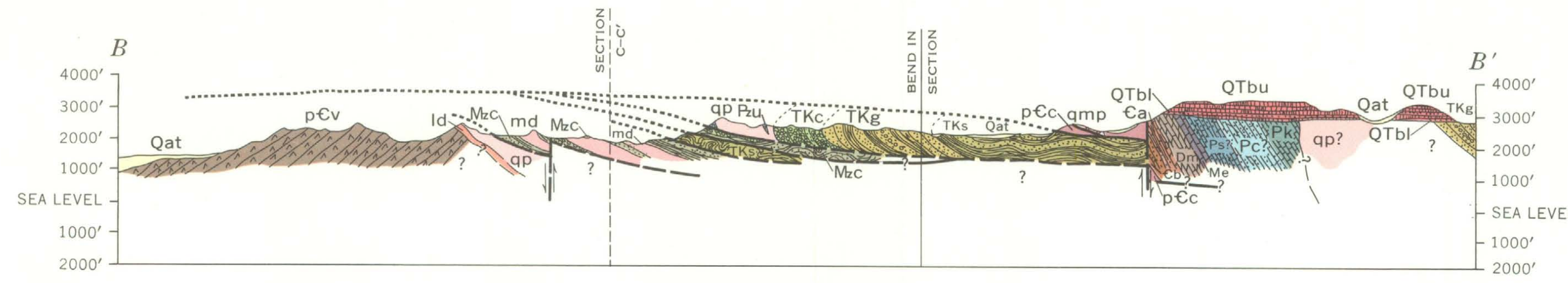
Anticline
Plunging overturned syncline
Overturned anticline
Folds, showing trace of axial plane

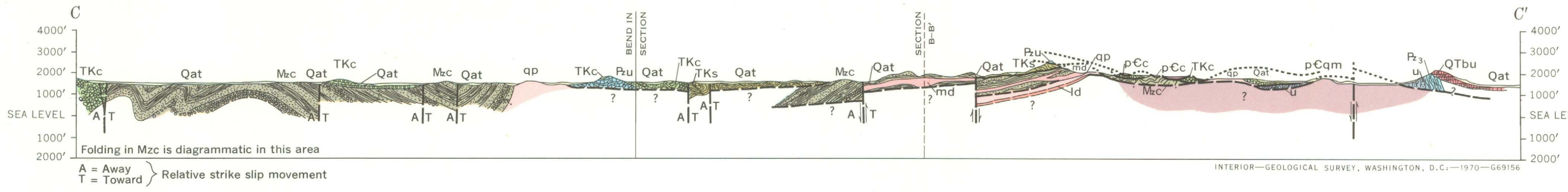
FA 5
Bearing and plunge of minor fold axes

⊕ Horizontal
70 Inclined
Vertical
70 Overturned
Strike and dip of beds

70 Inclined
10 15 Plunge
Vertical
Strike and dip of schistosity







A = Away
T = Toward
Relative strike slip movement

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1970—G69156

GEOLOGIC MAP OF THE QUARTZSITE QUADRANGLE, YUMA COUNTY, ARIZONA

By
Fred K. Miller
1970

For sale by the U.S. Geological Survey, price $1.00
Explanatory pamphlet accompanies map

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GQ 841
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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

TO ACCOMPANY MAP GQ-841

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PRECAMBRIAN ROCKS

Quartz monzonite.—An area of about 4 square miles in the central part of the quadrangle is underlain by an even-grained biotite quartz monzonite. The pluton is in fault contact with all rocks except the Precambrian or Mesozoic metavolcanic sequence to the south.

Both feldspars in the rock are highly altered. Biotite is in various stages of chloritization and has probably been recrystallized at least once. The south half of the body is more leucocratic than the north half and may in fact be a separate intrusion.

Leon T. Silver, using lead-isotope methods on zircon, has calculated an age of 1730 to 1750 m.y. for the quartz monzonite.

Coarse-grained quartz monzonite. Very coarse grained biotite quartz monzonite underlies the low hills near the juncture of Italian Wash and Apache Wash. North and west of Black Mesa, Cambrian sedimentary rocks nonconformably overlie the same body. Other contacts are faulted. West of Apache Wash some of the rock is medium to coarse grained and contains hornblende. All feldspar is highly altered, and biotite and hornblende chloritized.

PRECAMBRIAN OR MESOZOIC ROCKS

Metavolcanic rocks.—An area of about 5 square miles in the central and south-central part of the quadrangle is underlain by mildly metamorphosed rhyolitic to dacitic intrusive, flow, and tuffaceous rocks. Although the section is probably repeated by undetected faulting, a maximum thickness of 11,000 feet for the stratified part of unit was calculated from outcrop width. Some of the rock is sheared and in places is schistose. Color is variable from dark green to light gray. Quartz and plagioclase phenocrysts occur in an aphanitic matrix of quartz, plagioclase, chlorite, muscovite, and opaque minerals. The tentative age assignment of Precambrian or Mesozoic is based on lithologic similarities with both older Precambrian rocks of central Arizona, and rocks to the west that are thought to be of Mesozoic age.

PALEOZOIC(?) ROCKS

Five lithologic units found only in a one-square-mile area just south of U.S. Highway 60 70 have undergone a style and degree of deformation unique among the rocks in the Quartzsite quadrangle. These rocks have undergone extreme plastic deformation as contrasted to brittle deformation common in all other rocks in the quadrangle. Although highly deformed, some of the units in the Paleozoic(?) rocks are similar to, and probably correlative with, formations in the fossiliferous Paleozoic section north and west of Black Mesa. Unit 1 is possibly equivalent to parts of the Martin(?) Formation and Escabrosa Limestone, unit 2 to the Supai Formation, and unit 4 to the Coconino Sandstone. Unit 3 is not represented in the fossiliferous Paleozoic section, and unit 5 is probably part of the Escabrosa Limestone faulted up against unit 4.

However, because of differences in stratigraphy and deformational history, correlation between the Paleozoic(?) rocks and the Paleozoic section north of Black Mesa, although considered reasonable, is not regarded as positive.

Unit 1. About 150 to 300 feet of dolomite and dolomitic limestone is faulted against Precambrian quartz monzonite. The rock is gray and tan, and in places chert bearing. Most stratification has been destroyed by deformation, but where recognizable, the rock appears to be thick to massively bedded.

Unit 2.—About 400 feet of thinly interbedded carbonate, calcareous quartzite, and quartzite structurally, and probably stratigraphically, overlie unit 1. Although most beds are less than an inch thick, some quartzite beds are as thick as 10 feet. The rock is cream colored to pink. Near the top, the unit becomes increasingly chloritic and grades upward into the schist of the overlying unit.

Unit 3.—Unit 3 is about 450 feet thick, predominantly quartz-albite-muscovite-chlorite schist with interbeds up to 10 feet thick which resemble unit 2. Primary features preserved in the schist suggest that the rock was predominantly a fine-grained sedimentary clastic rock with either interbeds of extrusive volcanic flows or intrusive hypabyssal sills.

Unit 4.—About 400 feet of medium- to massively bedded vitreous quartzite overlie unit 3. The contact appears to be gradational. The quartzite is light tan to white, well sorted, and quite pure.

Unit 5.—Unit 5 is a tan, massively bedded carbonate rock. Part of the carbonate contains irregularly distributed chert masses, but much of the unit is free of chert. As near as can be estimated, owing to its poorly bedded character, about 400 feet of the unit is preserved. The contact between unit 4 and unit 5 appears to be a fault. The upper contact is a fault which places unit 5 against unit 3.

Paleozoic(?) rocks and Precambrian or Mesozoic rocks, undifferentiated. Rocks probably belonging to the Precambrian or Mesozoic metavolcanic unit, and the Paleozoic(?) numbered units are found east and west of Scadden Mountain and south of Granite Mountain. These rocks are highly deformed dolomite and sheared metavolcanic rock. For various reasons, it was not possible to reliably assign these rocks to any of the other units.

PALEOZOIC ROCKS

North of Black Mesa, a section of limestone, dolomite, and quartzite is divisible into seven formations. Because of the distances to known Paleozoic sections, correlation is a major problem. There are no well-documented Paleozoic rocks within 100 miles of the Plomosa Mountains. A partial section, similar to that in the Plomosa Mountains, but presenting the same correlation problems, is present in the Little Harquahala Mountains 25 miles to the east.

The upper three formations of the section north of Black Mesa are similar to the Supai Formation, Coconino Sandstone, and Kaibab Limestone of the Grand Canyon section. P. T. Hayes and F. G. Poole first recognized that the lower four formations appear to more closely resemble the Bolsa Quartzite, Abrigo Formation, Martin Limestone, and Escabrosa Limestone of southeastern Arizona (written commun., 1966).

Bolsa(?) Quartzite. About 65 feet of quartzite rests nonconformably on coarse-grained Precambrian quartz monzonite in the wash immediately north of the Six Price mine. This rock strongly resembles the Cambrian Bolsa Quartzite (Ransome, 1904, p. 28) in southeastern Arizona. Bedding thickness ranges from an inch to about 3 feet, and color from light tan to white. Grain size varies from less than 0.1 mm to over 10 mm. Almost all clasts are well rounded. Crossbedding and minor graded bedding are present, but rare.

Abrigo(?) Formation. Dark-purple, green, and black sandy shale with thin interbeds of fine-grained impure quartzite overlies the Bolsa(?) Quartzite and is tentatively correlated with the lower member of the Cambrian Abrigo Formation as used by Cooper and Silver (1964, p. 47). No fossils were found in this

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unit except for what appeared to be animal tracks or worm trails along the interfaces between quartzite and shale beds. Thickness of the formation is about 150 feet.

Martin(?) Formation.—About 325 feet of dolomitic limestone, dolomite, and sandy dolomite, tentatively correlated with the Devonian Martin Formation as used by Cooper and Silver (1964, p. 53), overlie the Abrigo(?) Formation. The time hiatus between the deposition of these two formations is not reflected in any apparent unconformity. Bedding ranges in thickness from about 6 inches to 3 feet. Color is various shades of gray, although a number of tan, brown, and almost black beds are present. No fossils were found in this unit.

Escabrosa Limestone.—Overlying the Martin(?) Formation is about 415 feet of dolomite, limestone, and cherty limestone which is correlated with the Mississippian Escabrosa Limestone of southeastern Arizona (Ransome, 1904, p. 42; and Hayes and Landis, 1965, p. F20). The lower half of the Escabrosa Limestone in the Quartzsite quadrangle is massively bedded, light-gray, tan-weathering, sandy dolomite. The upper half is cherty limestone and limestone conglomerate with only small amounts of interbedded dolomite. Fossils collected by F. G. Poole from these beds and identified by W. J. Sando and Helen Duncan include *Syringopora surcularia* Girty and *Vesiculophyllum* cf. *V. incrassatum* (Easton and Gutschick). Both are common to the Mississippian Escabrosa and Redwall Limestones.

Supai Formation.—Rocks closely resembling the Supai Formation of Permian age overlie the Escabrosa Limestone disconformably. Above the contact is 1 inch to 1 foot of lenticular basal conglomerate. The lower half of the formation is white, pink, and maroon quartzite with some interbedded limestone and sandy red mudstone. The upper half of the unit contains only minor amounts of limestone. The formation is 550 feet thick and unfossiliferous in the Plomosa Mountains.

Coconino Sandstone.—The Coconino Sandstone is 660 feet thick in the Plomosa Mountains and consists of medium- to massively bedded, white to gray vitreous quartzite. Thin laminations are visible on some weathered surfaces. The clasts are medium grained, well sorted, and fairly well rounded. In the upper half of the formation, large-scale crossbedding is found locally. The quartzite rests with apparent conformity on the Supai Formation.

Kaibab Limestone.—About 670 feet of chert-bearing limestone correlated with the type Kaibab Limestone overlie the Coconino Sandstone in apparent conformity. The top of the formation is removed by an intrusive dacite porphyry. The lower part of the formation is light tan and gray and contains irregular-shaped chert masses. The upper third of the preserved Kaibab is dark-blue-gray limestone enclosing large numbers of brown-weathering chert lenses. The limestone is fine grained, extremely fetid, and contains large numbers of Permian brachiopods, corals, and bryozoans. R. E. Grant identified the brachiopods as a species of *Peniculauris* that is similar to, but not the same as, *P. bassi* (McKee). Helen Duncan examined the bryozoans and identified one as *Timanodictya* and found another suggestive of *Bicorbis arizonica*. Both are diagnostic of the Kaibab and Kaibab equivalents in the Great Basin.

Paleozoic rocks, undifferentiated.—Paleozoic rocks mapped as undifferentiated occur primarily in an almost linear belt west of Apache Wash. These rocks include parts of the Paleozoic section already described, with one exception. Near Dripping Spring is 500+ feet of mottled gray-and-gold-colored dolomitic limestone that contains small, round structures resembling *Girvanella*. This dolomitic limestone is very similar to the Cambrian Muav Limestone found in the Grand Canyon. An unconformity bounds the top of the unit and a fault the bottom. The carbonate has not been recognized in the section north of Black Mesa, the lower part of which is more like the southeastern Arizona Paleozoic than the Grand Canyon section.

MESOZOIC(?) ROCKS

Continental red beds.—Several square miles in the south and central parts of the quadrangle are underlain by continental red-bed deposits. The unit is cut by many faults, and the lower contact is nowhere depositional. Sandy maroon mudstone makes up about 50 percent of the unit, sandstone about 40 percent, and pebble conglomerate about 10 percent. Mudstone layers, separated by sandstone or conglomerate beds, range in thickness from a foot to about 100 feet. Sandstone beds are from 1 to 15 feet thick and are white, tan, or pink. Conglomerate beds up to 15 feet in thickness are composed of chert, quartzite, and limestone clasts that average about 1 inch in diameter. The greatest nonfaulted section preserved in the quadrangle is about 500 feet thick. As shown on the map and cross-section C–C′, some areas are apparently underlain by greater thicknesses of this unit. These areas, however, are cut by numerous small faults which are not shown.

MESOZOIC OR CENOZOIC ROCKS

Quartz monzonite porphyry.—An area of about 2 square miles west and northwest of Black Mesa is underlain by a distinctive light-gray quartz monzonite porphyry. The pluton is fault bounded, except on the southeast, and at localities where it is overlain by younger volcanic rocks. The porphyry has a uniform texture and mineralogy. Conspicuous feldspar phenocrysts up to 2 cm long occur throughout, and smaller phenocrysts of quartz are even more numerous. The groundmass is quartz, plagioclase, and potassium feldspar averaging between 0.2 mm and 1 mm in size. Biotite and possibly amphibole were present in small amounts, but are now completely altered to chlorite.

Quartz porphyry.—Light-gray quartz porphyry intrudes older rocks at several places in the quadrangle. Three of the intrusions are elongate in outcrop pattern and have a definite northeast trend. The porphyry has an aphanitic groundmass, which encloses euhedral phenocrysts of quartz and plagioclase averaging about 2 mm in size. All plagioclase is altered to sericite and epidote group minerals. Small crystals of biotite and possibly hornblende have been altered to magnetite, chlorite, piedmontite, and epidote. Potassium feldspar is microcline and in most cases makes up less than 10 percent of the rock. The altered groundmass consists of sericite, quartz, albite, and epidote group minerals. Composition of the rock is probably dacite.

Mafic dikes.—Dark-green, highly altered dikes intrude the continental red beds west of Dripping Spring and the coarse-grained quartz monzonite north of Black Mesa. They range in thickness from about 5 feet to 200 feet. Epidote, albite, tremolite, chlorite, quartz, sericite, and opaque minerals now compose the rock. Original textures are crudely preserved. Grain size is medium to coarse. The dikes are younger than the continental red beds but older than the Tertiary(?) volcanic rocks.

Latite dike.—A dark-purple-gray latite dike is intruded along the entire west side of the quartz porphyry mass southwest of Dos Picachos. The dike rock has an aphanitic groundmass which contains abundant, highly altered feldspar phenocrysts. This dike may have been emplaced along a preexisting fault separating the quartz porphyry and metavolcanic rocks.

Sedimentary rocks derived from quartz porphyry.—Several hundred feet of arkose and conglomeratic arkose appear to rest nonconformably on quartz porphyry about 2 miles southwest of Dos Picachos. The clastic rock appears to be derived almost entirely from the porphyry, and where stratification is not obvious, strongly resembles the porphyry. The rock is light gray and consists of poorly rounded but moderately well sorted clasts of feldspar, quartz, epidote, and lithic fragments. Beds are a few inches to about 5 feet thick. The original thickness of the unit is not known because the upper contact is a thrust fault.

LIVINGSTON HILLS FORMATION

The name Livingston Hills Formation is here introduced for the interbedded sequence of conglomerate, graywacke, and siltstone found in several mountain ranges in Yuma County. At the type locality in the Livingston Hills, most of which lies just outside the southern boundary of the quadrangle, a homoclinal section almost 12,000 feet thick is well exposed. Here, almost the entire Livingston Hills is underlain by the type section which rests unconformably on the continental red beds of Mesozoic(?) age. At other places in the quadrangle, however, it rests on Paleozoic carbonate and hypabyssal intrusive rocks. The upper contact is hidden beneath alluvium. The formation is divided into three members.

The conglomerate member forming the base of the formation is about 4,700 feet thick at the type locality and is composed of massively bedded heterogeneous boulder conglomerate. Conglomerate beds average about 25 feet thick and are separated by thinner, lensoidal beds of arkose or graywacke. Boulders are derived from all older units and range in size from a few inches to over 5 feet; almost all are angular. The conglomerate grades upward into the graywacke member through increasing numbers of graywacke beds.

The graywacke member at the type locality is composed of about 5,500 feet of well-lithified medium- to coarse-grained graywacke and conglomeratic graywacke. It is dark to medium gray. Bedding thickness ranges from a few inches to several tens of feet. Quartz, plagioclase, and rock fragments are the most abundant clasts. Sericitic and calcareous material makes up the bulk of the matrix, which constitutes 20 to 60 percent of the rock.

About 3,300 feet above the top of the conglomerate member is approximately 2,000 feet of siltstone and fine-grained graywacke which intertongues with the graywacke member. About 2,200 feet more graywacke overlies the siltstone. Both the upper and lower contacts of the siltstone member are gradational with the graywacke. Bedding in the siltstone member averages from 1 to 3 inches in thickness, and color is most commonly light gray.

Algae, plant remains, poorly preserved gastropods, and a stomatopod have been found in the Livingston Hills Formation, but none are preserved well enough to be of use in determining the age of the rock. The unit is younger than the continental red bed deposits, but older than the Tertiary(?) volcanic rocks. It is therefore assigned a Cretaceous or Tertiary age.

TERTIARY(?) ROCKS

Rhyolite.—Light-pink to light-gray rhyolite or rhyodacite flows and tuff crop out a mile north of Lazarus Tanks and about 2 miles north of Black Mesa. The rock contains quartz and altered biotite phenocrysts in an altered pink groundmass. Small spherulites and quartz-lined vugs are common. Some of the rhyolite shows banding, but most is massive. It appears to be the oldest rock in the exposed Tertiary(?) volcanic series.

Older basalt.—Amygdaloidal and massive basalt about 1,200 feet thick overlies the rhyolite near the north border of the quadrangle. Flows range in thickness from a few feet to about 50 feet. "Iddingsite" after olivine forms the only phenocrysts visible. Most of the rock is highly altered.

Andesite breccia.—An area of several square miles in the northeast part of the quadrangle is underlain by angular unsorted breccia and interlayered andesite flows. The rock is light pink to gray. Andesite similar to the interlayered flows forms clasts up to 50 feet in diameter in the breccia. Stratification within the deposit is obscure. Thickness calculated from width of outcrop using the attitude of bounding units is about 2,500 feet.

Older hornblende-biotite andesite.—Overlying, and possibly interfingering with, the andesite breccia is a section up to several thousand feet thick composed of pink, gray, and red-brown hornblende-biotite andesite flow rock. Tuffaceous material is interbedded locally with the andesite flows, especially near the base. Hornblende, biotite, and plagioclase crystals averaging 1 or 2 mm in size are common in most of the andesite and are easily seen in hand specimen. In most cases the groundmass is a microcrystalline mixture of plagioclase, glass, and opaque minerals. Textures range from trachytic to hyalopilitic.

Biotite andesite.—A small mass of biotite andesite is present just east of Dripping Spring. The andesite is in part intrusive and in part extrusive. Small biotite and plagioclase phenocrysts are set in a light-tan to light-gray groundmass of plagioclase, with lesser amounts of opaque minerals and glass. Pyroxene crystals intermediate in size between the groundmass and phenocrysts are common but not abundant. Texture is trachytic to pilotaxitic.

Hornblende-biotite andesite.—Between 200 and 400 feet of dark-gray to black hornblende-biotite andesite unconformably overlies the andesite breccia and the older hornblende-biotite andesite. Individual flows appear to be about 50 feet thick and have glassy borders. Small phenocrysts of hornblende, biotite, and plagioclase are present in most of the rock. Plagioclase, glass, and opaque minerals make up the groundmass. The present topography was developed, at least in part, at the time of extrusion, for the lavas are found at very different elevations and appear to buttress against the older volcanic rocks.

TERTIARY OR QUATERNARY ROCKS

Basalt of Black Mesa.—Black Mesa, in the east central part of the quadrangle, is underlain by Tertiary or Quaternary olivine-bearing basalt. The basalt is divisible into two parts: a lower unit containing interbedded tuffaceous rocks and an upper unit of basalt flows only. In the lower unit the tuff beds average about 10 feet thick, but some are as much as 50 feet thick. Thickness of individual flows is from 20 to 50 feet in both units. Basalt of the two units appears to be identical. Labradorite constitutes 50 to 60 percent of the rock; diopsidic augite, 35 to 45 percent; olivine (Fo_{78-82}), 5 percent; and opaque minerals about 1 percent. Thickness of the lower unit is estimated at 400 to 500 feet, that of the upper unit at about 700 feet.

Older alluvium.—Fifteen to 20 square miles along the eastern edge of the quadrangle is underlain by unconsolidated to poorly consolidated older alluvium. It consists of completely unsorted blocks of all bedrock units in a matrix of arkose and lithic arkose. Stratification within the deposit is obscure. The older alluvium is distinguished from the recent alluvium only by its topographic expression and appearance on aerial photographs.

Alluvium and talus.—Alluvium and talus are not separated in the Quartzsite quadrangle. Included in the undifferentiated unit is all surficial debris in present drainage channels, on talus slopes, on alluvial fans, on the broad areas of desert pavement, and on the La Posa Plain. Most of the material consists of a heterogeneous mixture of angular, unsorted boulders, cobbles, sand, and smaller sized material.

ROCKS OF UNKNOWN AGE

Granitic rocks of the Dome Rock Mountains.—Granite Mountain, the easternmost part of the Dome Rock Mountains, is underlain by at least three different plutonic rocks. Probably the oldest is a pervasively sheared pink quartz monzonite. This rock is intruded by an essentially unsheared biotite quartz monzonite. Forming a small outlier from the main mountain is a dark-colored, slightly sheared biotite-rich quartz monzonite. The age of these rocks and their extent beyond the quadrangle are unknown.

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Algae, plant remains, poorly preserved gastropods, and a stomatopod have been found in the Livingston Hills Formation, but none are preserved well enough to be of use in determining the age of the rock. The unit is younger than the continental red bed deposits, but older than the Tertiary(?) volcanic rocks. It is therefore assigned a Cretaceous or Tertiary age.

TERTIARY(?) ROCKS

Rhyolite.—Light-pink to light-gray rhyolite or rhyodacite flows and tuff crop out a mile north of Lazarus Tanks and about 2 miles north of Black Mesa. The rock contains quartz and altered biotite phenocrysts in an altered pink groundmass. Small spherulites and quartz-lined vugs are common. Some of the rhyolite shows banding, but most is massive. It appears to be the oldest rock in the exposed Tertiary(?) volcanic series.

Older basalt.—Amygdaloidal and massive basalt about 1,200 feet thick overlies the rhyolite near the north border of the quadrangle. Flows range in thickness from a few feet to about 50 feet. "Iddingsite" after olivine forms the only phenocrysts visible. Most of the rock is highly altered.

Andesite breccia.—An area of several square miles in the northeast part of the quadrangle is underlain by angular unsorted breccia and interlayered andesite flows. The rock is light pink to gray. Andesite similar to the interlayered flows forms clasts up to 50 feet in diameter in the breccia. Stratification within the deposit is obscure. Thickness calculated from width of outcrop using the attitude of bounding units is about 2,500 feet.

Older hornblende-biotite andesite.—Overlying, and possibly interfingering with, the andesite breccia is a section up to several thousand feet thick composed of pink, gray, and red-brown hornblende-biotite andesite flow rock. Tuffaceous material is interbedded locally with the andesite flows, especially near the base. Hornblende, biotite, and plagioclase crystals averaging 1 or 2 mm in size are common in most of the andesite and are easily seen in hand specimen. In most cases the groundmass is a microcrystalline mixture of plagioclase, glass, and opaque minerals. Textures range from trachytic to hyalopilitic.

Biotite andesite.—A small mass of biotite andesite is present just east of Dripping Spring. The andesite is in part intrusive and in part extrusive. Small biotite and plagioclase phenocrysts are set in a light-tan to light-gray groundmass of plagioclase, with lesser amounts of opaque minerals and glass. Pyroxene crystals intermediate in size between the groundmass and phenocrysts are common but not abundant. Texture is trachytic to pilotaxitic.

Hornblende-biotite andesite.—Between 200 and 400 feet of dark-gray to black hornblende-biotite andesite unconformably overlies the andesite breccia and the older hornblende-biotite andesite. Individual flows appear to be about 50 feet thick and have glassy borders. Small phenocrysts of hornblende, biotite, and plagioclase are present in most of the rock. Plagioclase, glass, and opaque minerals make up the groundmass. The present topography was developed, at least in part, at the time of extrusion, for the lavas are found at very different elevations and appear to buttress against the older volcanic rocks.

TERTIARY OR QUATERNARY ROCKS

Basalt of Black Mesa.—Black Mesa, in the east central part of the quadrangle, is underlain by Tertiary or Quaternary olivine-bearing basalt. The basalt is divisible into two parts: a lower unit containing interbedded tuffaceous rocks and an upper unit of basalt flows only. In the lower unit the tuff beds average about 10 feet thick, but some are as much as 50 feet thick. Thickness of individual flows is from 20 to 50 feet in both units. Basalt of the two units appears to be identical. Labradorite constitutes 50 to 60 percent of the rock; diopsidic augite, 35 to 45 percent; olivine (Fo_{78-82}), 5 percent; and opaque minerals about 1 percent. Thickness of the lower unit is estimated at 400 to 500 feet, that of the upper unit at about 700 feet.

Older alluvium.—Fifteen to 20 square miles along the eastern edge of the quadrangle is underlain by unconsolidated to poorly consolidated older alluvium. It consists of completely unsorted blocks of all bedrock units in a matrix of arkose and lithic arkose. Stratification within the deposit is obscure. The older alluvium is distinguished from the recent alluvium only by its topographic expression and appearance on aerial photographs.

Alluvium and talus.—Alluvium and talus are not separated in the Quartzsite quadrangle. Included in the undifferentiated unit is all surficial debris in present drainage channels, on talus slopes, on alluvial fans, on the broad areas of desert pavement, and on the La Posa Plain. Most of the material consists of a heterogeneous mixture of angular, unsorted boulders, cobbles, sand, and smaller sized material.

ROCKS OF UNKNOWN AGE

Granitic rocks of the Dome Rock Mountains.—Granite Mountain, the easternmost part of the Dome Rock Mountains, is underlain by at least three different plutonic rocks. Probably the oldest is a pervasively sheared pink quartz monzonite. This rock is intruded by an essentially unsheared biotite quartz monzonite. Forming a small outlier from the main mountain is a dark-colored, slightly sheared biotite-rich quartz monzonite. The age of these rocks and their extent beyond the quadrangle are unknown.

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