REPORT ON THE GENERAL GEOLOGIC HISTORY OF THE MESA NTMS QUADRANGLE WITH ACCOMPANYING 1:250,000 COMPILATION MAPS OF GEOLOGY AND METALLIC MINERAL OCCURRENCES

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>PHYSIOGRAPHY</td>
<td>2</td>
</tr>
<tr>
<td>GEOLOGIC HISTORY</td>
<td>4</td>
</tr>
<tr>
<td>Older Precambrian</td>
<td>4</td>
</tr>
<tr>
<td>Mazatzal Orogeny</td>
<td>6</td>
</tr>
<tr>
<td>Younger Precambrian</td>
<td>7</td>
</tr>
<tr>
<td>Paleozoic Era</td>
<td>9</td>
</tr>
<tr>
<td>Regional Statement</td>
<td>9</td>
</tr>
<tr>
<td>Paleozoics in Mesa Quad</td>
<td>10</td>
</tr>
<tr>
<td>Mesozoic, pre-Laramide History</td>
<td>12</td>
</tr>
<tr>
<td>Laramide Orogeny</td>
<td>13</td>
</tr>
<tr>
<td>Cenozoic (Pre-Basin and Range Time)</td>
<td>17</td>
</tr>
<tr>
<td>Metamorphic Core Complexes</td>
<td>22</td>
</tr>
<tr>
<td>Basin and Range Disturbance</td>
<td>23</td>
</tr>
<tr>
<td>Basin and Range Volcanism</td>
<td>26</td>
</tr>
<tr>
<td>Pleistocene</td>
<td>26</td>
</tr>
<tr>
<td>Globe-Miami Example</td>
<td>27</td>
</tr>
<tr>
<td>STRONTIUM ISOTOPE GEOCHEMISTRY</td>
<td>27</td>
</tr>
<tr>
<td>POTASH-SILICA RELATIONSHIPS</td>
<td>29</td>
</tr>
<tr>
<td>CURRENT MINING IN THE MESA QUAD</td>
<td>30</td>
</tr>
<tr>
<td>URANIUM EXPLORATION IN THE MESA QUAD</td>
<td>32</td>
</tr>
<tr>
<td>REGIONAL CROSS SECTIONS</td>
<td>35</td>
</tr>
<tr>
<td>FIGURES</td>
<td>37</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>68</td>
</tr>
<tr>
<td>General References</td>
<td>74</td>
</tr>
<tr>
<td>Relevant MS and Ph.D. Theses</td>
<td>74</td>
</tr>
<tr>
<td>Uranium Related References</td>
<td>76</td>
</tr>
</tbody>
</table>
1. Physiographic provinces and post-10 m.y. volcanic rocks in Arizona. 37

**PRECAMBRIAN**

2. Precambrian stratigraphic relations, central Arizona. 38
2a General stratigraphic sections, central Arizona. 39
3. Columnar section, Apache Group sediments. 40
4. Statewide outcrop map of Apache Group sediments. 41
5a Post-Troy N-S cross section through central Arizona. 42
5b Late Devonian N-S cross section through central Arizona. 42
6. Outcrops of Apache Group sediments and diabase. 43

**PALEOZOIC**

7. Total Paleozoic isopach map of Arizona. 44
8. Thickness profiles of Arizona Paleozoic strata. 45
9. Permian isopach map of Arizona. 46
10. Paleozoic nomenclature of central Arizona. 47
11. Apache Group - lower Paleozoic relations, central Arizona. 48
12. Karst sinkholes in Redwall Limestone, Gila County. 49

**MESOZOIC**

13. Jurassic evaporites and Laramide overthrusts, western U.S. 50
14. Laramide plutons in southern Mesa quad. 51
15. Laramide dike orientations. 52
16. Histogram for Laramide and mid-Tertiary K/Ar dates. 53

**CENOZOIC**

17. Volcanics of the Superstition volcanic field. 54
18. Three cauldrons, Superstition volcanic field. 54
18a Volcanic stratigraphy, Superstition volcanic field. 55
FIGURES (Cont.)

18b Trends of Cenozoic K/Ar dates, Arizona. 56
19. Mid-Tertiary dike orientations. 57
20. Attitudes of Oligocene and Miocene layered rocks. 58
21a Arizona metamorphic core complexes. 59
21b Details of metamorphic core complex stratigraphy. 59
22. General relationship of rocks, Globe-Miami area. 60

GEOCHEMISTRY

23. Strontium initial ratios, tabular data. 61
24. Strontium initial ratio growth diagram, central Arizona. 63
25. Strontium initial ratios for mid-Tertiary rocks. 64
26. Paleozoic stratigraphy along Mogollon Rim. 65
27. Potash-Silica diagram for Arizona igneous rocks. 66
28. General Cenozoic stratigraphy, southern Arizona. 67
INTRODUCTION

This report is a brief compilation of the general geologic history of the Mesa $1^\circ \times 2^\circ$ NTMS quadrangle of east-central Arizona (33 - 34$^\circ$ N. latitude, 110-112$^\circ$ W. longitude). References listed at the end of the report are divided into a general geology section, an MS and PhD thesis section, listing only works of broad scope or interest, and a section at the end dealing with uranium occurrences. This report accompanies a 1:250,000 map of the general geology of the quadrangle which has an accompanying legend. A separate map shows known mineral occurrences in the quadrangle. Eight regional cross sections oriented NE-SW and extending through the Mesa quad are included with the map.

The 1:250,000 scale geologic map has been abstracted from the 1:500,000 scale geologic map of Arizona, published in 1969 by Eldred Wilson, Richard Moore, and John Cooper, with additional data from post-1969 USGS mapping and other published and unpublished sources. In particular, one may note contact revisions pertaining to Laramide intrusives, Oligocene and Miocene sediments, and inclusion of larger Laramide and Late Tertiary dike swarms.

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PHYSIOGRAPHY

Arizona may be divided into three provinces based upon physiography, as illustrated in Figure 1. The northeastern third of the state is part of the southwestern Colorado Plateau, which consists of gently warped and arched Paleozoic and Mesozoic sediments. The Plateau is elevated to 6,000-7,500 feet above sea level at its southern and western margins, and gently slopes towards the northeast so that elevations in the Four Corners region range from 4,000-6,000 feet.

The southwestern half of the state is part of the southern Basin and Range province, which consists of broad, flat valleys broken only by a series of disconnected, generally N-S elongated mountain ranges. Valley floor elevations rise in all directions from near sea level at Yuma to 1,500 ± feet near Phoenix, 2,000 ± feet near Lake Mead (just below the Grand Canyon gorge) and up to 4,500-5,000 feet in parts of southeastern Arizona. Mountain "islands" rise above the adjacent valley floors by 1-2,000 feet in southwestern Arizona, by 2-4,000 feet in the northwestern part of the state and 4-6,000 feet in the southeastern part of the state.

Separating the Colorado Plateau and Basin and Range provinces is the Transition Zone, so named because of its pronounced transitional physiography, Phanerozoic stratigraphy and tectonic involvement, when compared to its neighbors. The Mesa quadrangle in this scheme spans the Basin and Range/Transition Zone interface, as seen in Figure 1. The Mogollon Rim (Figure 1) is a sharply defined south- to west-facing escarpment which defines the southern boundary of the Colorado Plateau.
The Rim is best developed on the cliff-forming Permian Coconino Sandstone and Kaibab Limestone. The Rim boundary passes in an east-west direction, 15-30 miles north of the northern boundary of the Mesa quadrangle.
GEOLOGIC HISTORY

Older Precambrian

The major features of the Precambrian history of central Arizona are discussed by Livingston and Damon (1968), Gastil (1958), Ludwig (1974), and Conway (1976). Refer to figures 2 and 2a for a geological column of the Precambrian of the area.

The oldest rocks in central Arizona are termed the Yavapai Schist or the Yavapai Group (Wilson, 1939). These are several discontinuous sequences of volcanic-sedimentary rocks, unmetamorphosed in some areas, and severely deformed in others. A composite thickness of the Yavapai Group, perhaps only a poor estimate, is 40-50,000 feet. The Yavapai rocks include volcanics of andesitic-to-mafic composition with massive rhyolite flows in a few areas, intercalated fanglomerates (submarine?), greenstones, shales, mudstones, and some clean quartzites. Wilson (1939) divided the Yavapai Group into (oldest to youngest) the Yeager Greenstone, now the Ash Creek Group (altered mafic flows and sediments, greater than 2,000 feet thick), the Red Rock Rhyolite (flows, breccias, agglomerates, and minor intrusives, greater than 1,000 feet thick), and the Alder Series (shales, mudstones, quartzites and conglomerates, locally metamorphosed to slates through schists, and greater than 5000 feet thick). These three units are found only in tectonic contact with each other. See Ludwig (1974) and Conway (1976) for recent revisions of stratigraphy based upon their PhD fieldwork.

A series of age dates have been run on Older Precambrian rocks in the central part of the state (Anderson and Silver, 1976). Most are U-Pb discordia dates; other Rb-Sr dates are usually in agreement with these assignments. The Red Rock Rhyolite is dated at 1715 m.y.
The Yavapai Group rocks of Wilson are intruded by a series of plutons ranging from 1,670 to 1,770 m.y. Dates in the west-central part of the state on volcanics intercalated into Yavapai rocks range from 1,770 to 1,820 m.y. Farther east and south, initiation of volcanism, as in the Mazatzal Range, was at about 1,720 m.y. Only one rock in the state has been dated to be older than the above mentioned rocks; and that is a gneiss in the Grand Canyon with a Rb-Sr whole rock date of about 2,000 m.y. (Clark, et. al., in press). Ages of 1,730 m.y. or younger on older Precambrian rocks extend through the Globe-Miami area and southward. There is a hint in the U-Pb zircon data of a general younging trend from about 1,800 m.y. to 1,650 m.y. in terrains extending from the northwest part of the state to the southeast.

These Older Precambrian layered rocks, where deformed, are tightly-to-openly folded in a series of NE-SW trending, NE plunging (20 - 60) upright folds (Gasti1, 1958).

Anderson and Silver (1976) describe Arizona's "Yavapai Series" as resembling "many of the Older Precambrian greenstone belts, characteristically occurring as scattered remnants in silicic cratons." They suggest that the "Yavapai Series" may represent either island arc accumulations or else deposits formed on locally downwarped and/or thermally extended thinned sialic crust. They indicate that the very low potash content of some of the Yavapai mafic volcanics suggests an oceanic basalt and island arc origin for these rock series.

In central Arizona, the following sediments were deposited, in ascending order, above the eroded Red Rock Rhyolite: 100-800 feet of Deadman Quartzite (medium-grained, cross-bedded); 500-1000 feet of Maverick Shale (gray fissile shale with some quartzite interbeds); and 1,000-3,800 feet of Mazatzal Quartzite (cliff-forming, fine-to-
-medium grained, cross-bedded and ripple-marked). These sediments are clearly intruded by 1,400 m.y. granites, but are only in fault contact with the older, 1,600-1,700 m.y. granites. L. Silver of Cal. Tech. has a 1,720 m.y. zircon age on a rhyolite flow (or reworked rhyolite detritus), intercalated into the lower Mazatzal Quartzite near Pine. Livingston (1969) correlates a sedimentary section of Older Precambrian sandstones and shales just south of the Salt River, 20 miles north of Globe with the above sedimentary section of the Mazatzal Mountains. Here, the sediments rest disconformably on the Redmon Rhyolite, a flow mass dated at 1510 m.y. (Rb/Sr by Livingston) and at 1720 m.y. (U/Pb, in Conway, 1976?), which resembles the Red Rock Rhyolite beneath the Older Precambrian sediments of the Mazatzal Mountains. The U/Pb date is probably the more trustworthy of the two in this case.

The City Creek Series is a 2,000 foot thick pile of gray and red shales and minor quartzites which are judged by degree of deformation to be younger than the Mazatzal Quartzite, and older than the Apache Group. These rocks are found in the northern Mazatzal Mountains, and have no known equivalents. Livingston (1969) has an unpublished 1300 m.y. age on a thin diabase sill cutting the City Creek Series.

**Mazatzal Revolution**

The Mazatzal orogeny or revolution of Wilson (1939) is defined as that tectonic event that follows the deposition of the Mazatzal Quartzite and precedes the deposition of the Apache Group sediments. As defined, it only loosely coincides with the intrusion of massive amounts of quartz monzonite to granite intrusives and related stocks and dikes of diorite, pyroxenite and rhyolite porphyry. The Oracle and Ruin granites (included in "pg" on the map) are of this group. Structurally, the
orogeny in its type area in the Mazatzal Mountains was characterized by "subparallel folds, thrust faults and imbricate, steeply dipping reverse faults, generally of northeastward to northward trend" (Wilson, 1939, p. 1161). Precambrian granites of the Mesa quadrangle contain age dates ranging from 1,450 to 1,350 m.y.; this age range dates the culmination of Wilson's Mazatzal Revolution as originally defined (Livingston, 1969). In addition, at least two earlier locally-recognized and unnamed deformations (Gastil, 1958) have affected some of the Older Precambrian rocks of the region.

**Younger Precambrian**

All Older Precambrian rocks, including the 1,400 m.y. granites were attacked by an extensive period of erosion, with the resultant surface becoming the depositional base of the Younger Precambrian Apache Group sediments and Troy Quartzite. These sediments, found in the north central and south central Mesa quad, were extensively intruded by large masses of diabase, which, in many areas, were concordantly intruded as sill masses, and vertically inflated the Apache Group section by a large amount. Chemically, the diabase contains $K_2O = 0.3$ to $2.2\%$; $SiO_2 = 43.8$ to $47.2\%$, according to Granger and Raup (1969). Figure 3 gives a columnar description of the Apache Group sediments and their approximate thicknesses in the Mesa Quad.

The Apache Group sediments consist of the Pioneer Shale with basal Scanlon Conglomerate, overlain in turn by the Dripping Spring Quartzite with basal Barnes Conglomerate, the Mescal Limestone and uppermost basalts. Throughout most of the Mesa quad, the Apache Group sediments were deposited on Pinal Schist and 1400 m.y. granites.
In the northwest corner, they were deposited on granites and Older Pre-cambrian metasediments of Wilson's Yavapai Group. Williams (1957) suggests flow directions for the Sierra Ancha Mountains region for these times as toward the SW, W and NW. Other imbrication directions for the Barnes Conglomerate at Canyon Creek suggest flow toward the south (H.W. Peirce, pers. comm). Preserved patches of Apache Group sediments are only recognized in parts of southern Arizona, as sketched in Figure 4. Considerable attention, mentioned later, has been given to certain Apache Group sediments because of their uranium potential.

The Troy Quartzite rests disconformably upon the upper Apache Group sediments, but is best preserved where protected in post-Troy, pre-Paleozoic grabens (Krieger, 1961). Radiometric ages on the extensive diabase sills, which intrude all these sediments, range from 1,050 to 1,200 m.y., averaging perhaps 1,150 m.y. In the Mesa quad, the Younger Precambrian sediments are generally not found west of a north-south line through Roosevelt Lake, and are eroded away or covered in the eastern quarter of the quadrangle (except for a small patch preserved near Mt. Turnbull). The younger Precambrian sediments may be related in age to the Unkar Group sediments the Grand Canyon region.

Figure 5 is a pair of NNW-SSE cross-sections from Shride (1967) which illustrates the kinds of events that were interpreted to have occurred in central Arizona in post-Troy, pre-diabase time (Figure 5a) and in latest Devonian time (Figure 5b). These cross-sections emphasize a gentle Apache-Troy disconformity, the extensive nature of the diabase intrusions, and a hypothesized pre-Devonian, post-Troy horst and graben terrain of the Mesa quad. Abrupt thickness variations of Cambrian rocks in the region indicate the presence of a very ir-
regular surface of Cambrian deposition (Hammer and others, 1962).

Figure 6 is a map from Shride (1967) which shows the relative proportions of Apache Group sediments and diabase where they outcrop together.

Paleozoic Era

Regional Statement

Figures and ideas for this section are taken from Peirce (1976), and USGS quadrangle maps in the area.

The general geometry of Paleozoic rocks in Arizona is shown in Figure 7 (map) and Figure 8 (several statewide cross-sections) (Peirce, 1976). These figures display a statewide thickness differential of at least 5,000 feet for Paleozoic rocks. "The maximum contrast occurs between the thicker sections of both the northwest and southeast corners and the thinner sections preserved in eastern Arizona between Canyon de Chelly and Springerville in Apache County. An analysis of this thinning suggests that only half, and perhaps more, should be attributed to Paleozoic tectonic manifestations. The remainder is the result of various combinations of thinning by onlap onto elements inherited from Precambrian events and erosion in late Paleozoic to Early Triassic time."

"The larger regional Paleozoic tectonic framework includes: (1) the Cordilleran miogeosyncline in Nevada; (2) an adjacent shelf zone in northern Arizona; (3) a positive region in central and eastern Arizona, and (4) a basining tendency in southeastern Arizona extending northward from the Sonoran geosyncline and limited to the north and northeast by the shoaling and positive tendencies mentioned above."

"In northwestern Arizona, the locale of more rapid thickening toward the miogeosyncline is often called a hinge line. The persistence of this feature, as well as its near-coincident position with the present
boundary zone between the Basin and Range and Colorado Plateau provinces, is of fundamental tectonic significance (Moore, 1972. p. 58). The positive and shoal region of northern, central and eastern Arizona is frequently depicted as being a southwestward extension of the Transcontinental Arch" (Peirce, 1976).

And Peirce notes that the "regional characteristics of the Paleozoic sedimentary rocks indicate that they were affected and controlled by movements broadly classed as epeirogenic which includes mild tilting, arching and sagging. Movements tended to be repetitious in space often reflecting similar directional components, especially northeast, northwest and northerly trends. The definable tectonic elements approximate the spatial distribution of younger, regionally prominent Laramide structures shown on contemporary geologic maps. Even Cenozoic trends reflected in the present physiographic margins of the Colorado Plateau province in Arizona are parallel to tectonic elements active during Paleozoic time."

Paleozoics in Mesa Quad

Figure 8 cross-section D-G hypothesizes that Paleozoic sediments once blanketed southern Arizona, in contrast to the remnants of today, which are visible in the Mesa quadrangle only as a flat-lying, Colorado Plateau-type sequence in the northeast corner, and as tectonically disturbed and eroded patches in the southern Mountain blocks.

The explanation of today's pattern of Paleozoic outcrops is not a simple one because of several regionally-based denudational events which will be discussed later. But their influences is still apparent on such particular matters as the absence of Permian strata throughout most of the Mesa quad (Figure 9), which may be explained by pre-late Cretaceous erosion of the area.
Figure 10 shows thicknesses of identified Paleozoic strata from USGS quadrangle mapping done both north and somewhat south of the Mesa quad, and in the Globe-Superior-Christmas area in the south central part of the quad. A problem remains concerning the differentiation of the Precambrian Troy Quartzite and the Cambrian Bolsa and Abrigo Formations, as noted by Krieger (1961, 1968) and Hammer and others, (1962). Older literature contains various nomenclature problems for these units. Cambrian rocks consist of the middle Cambrian Bolsa Quartzite and the late Cambrian Abrigo Formation. Both are found throughout southern Arizona but are missing in generally the northern half of the Mesa quad under Devonian cover rocks. The Bolsa Quartzite rather resembles the Troy Quartzite, even though they are separated in time by at least 550 m.y., with the result that proper assignments on geologic maps, given this choice, cannot be guaranteed outside of the areas where the two are seen together.

Lower Ordovician El Paso Limestone is found in the southeastern part of the state as far northwest as Morenci. However, the Ordovician and Silurian rocks are entirely missing from the rest of Arizona, due to erosion or non-deposition prior to the widespread Devonian sedimentation event.

The Cambrian units are variously preserved or missing, and frequently upper Devonian Martin beds are seen depositional on Precambrian terrain of considerable relief (Figure 11). Recent work at the University of Arizona has suggested the naming of the uppermost Devonian rocks seen in this region the Percha Formation after similar rocks in New Mexico (Schumacher and others, 1976).

The Mississippian section is predominantly composed of carbonates, and commonly displays an upper subaerially eroded contact with karst
sinkholes and solution cavity phenomena (Figure 21). These rocks are the Escabrosa Limestone of southeastern Arizona and the Redwall Limestone of the Colorado Plateau region.

Pennsylvanian-Permian stratigraphy in the Mesa quad is a complex mixture because of two different sets of nomenclature for the Colorado Plateau (mostly clastic rocks) and SE Arizona (mostly carbonate rocks). See Figure 10. In the region of the Mesa quad, Pennsylvanian rocks are usually called the Naco Limestone, equivalent to the Horquilla Limestone to the south and the lower Supai Formation to the north. Permian rocks are missing in the Mesa quad except for the typical Colorado Plateau assemblage of Supai-Coconino-Kaibab rocks of the extreme northeast corner of the quad. Reasons for this follow.

Mesozoic, Pre-Laramide History

If one defines Laramide time as beginning at about 80 m.y. ago, then the pre-Laramide Mesozoic record of the Mesa quad is represented by very thin, only locally-preserved patches of clastic sediments in the extreme south central part of the quad (noted by Willden, 1964) and similar upper Cretaceous sediments in the northeast part (noted by Finnell in USGS quads GQ-544 and 545, and McKay in USGS quad GQ-973). See Miller (1962) for Upper Turonian age assignments on marine Cretaceous deposits exposed in the Deer Creek area (near Winkelman) and the Morenci area. These non-spectacular remnants are in contrast to the voluminous, earlier Mesozoic volcanics and sediments of southern Arizona and the famous Triassic-Jurassic-Cretaceous deposits of the central Colorado Plateau. Similarly-aged rocks in central Arizona were either eroded by Turonian time or else not deposited because of the presence of a Mesozoic "Mogollon Highland" situated in this region. In the eastern Mesa quad, Cretaceous volcanics and sediments
sit on or are in fault contact with Precambrian granite and/or Paleozoic sediments. South of Tucson, preservation of Paleozoic and Mesozoic strata increases notably. In the Morenci-Clifton area, Paleozoic strata with overlying Cretaceous Pinkard Formation clastics are preserved in places under an Oligocene volcanic cover; however, in fully half of the Morenci area, the Oligocene volcanics are deposited directly upon Precambrian granite. The general picture for the east-central part of Arizona is one of both late Mesozoic and early to middle Cenozoic erosion which has left the Mesozoic rocks essentially unrepresented in the Mesa quad. 

Laramide Orogeny

The Laramide orogeny, which so profoundly readjusted the Cordilleran landscape by east-west compressive crustal shortening and intense plutonism and volcanism, may have had different kinematic expressions in different areas of the West. The beautiful low angle thrust faults and broad folds (Coney, 1976) of areas north of Las Vegas appear to be replaced in southern Arizona by moderately-to-steeply dipping northwest trending thrust faults and faulted closed folds, described by some as "basement-cored uplifts" (for example, Keith and Barrett, 1976). Others, such as Drewes (1976), have suggested that the extensive low-angle foreland thrust systems of Utah-Idaho-Wyoming and those of Chihuahua, Mexico are also present in Arizona by invoking a regionality argument and connecting together various Laramide-aged thrust segments found in southern Arizona's isolated mountain blocks. Figure 13 graphically portrays this hypothesis. However, the field expression of large-scale overthrust belts in Arizona is entirely lacking from this writer's viewpoint, and thus, individual Laramide structures appear to be confined to areas on the scale of one or two adjacent mountain blocks.
Much of the folding and faulting exposed in the mountains of the Mesa quad involving Paleozoic and Mesozoic rocks is of Laramide age, and, according to Keith (1975), is bracketed between roughly 90 and 50 m.y. The entire interval, Superior-Globe-San Carlos-Winkelman, contains a wide variety of structural features which occurred in late Cretaceous time and can be grouped into phenomena created by ENE directed compression on a regional scale.

Laramide plutons are represented on the Mesa quad in the Santa Teresa mountains and in the Granite Basin laccolith (both in the SE corner), in the plutons of the Globe-Miami area, and many smaller plutons extending throughout the southern part of the quad, including the Sacaton mountains in the SW corner of the quad. These igneous rocks (K-Ar dated at 55-70 m.y. in central Arizona; Damon and Mauger, 1966; Banks, et. al., 1972) are noted for their Cu and Mo contents. Economic deposits of this age are known at Globe and Miami, at Ray, along the southside of the Sacaton Mountains, and many smaller deposits such as at the Christmas mine near Winkelman. Titley and Hicks (1966) and Jenny and Hauck (1978) have devoted volumes to the characteristics and geologic setting of these important metaliferous deposits in Arizona and adjacent areas.

Detailed geochronologic data on Laramide rocks do not everywhere exist, especially for non-mineralized stocks. Figure 14, however, indicates their minimal distribution in the southeastern Mesa quad. Most Laramide plutons usually fall into the quartz diorite to quartz monzonite compositional range (SiO₂=60-70\%, K₅7.₅= 1.5 to 2.2, hence calc-alkaline according to Keith, 1975) with more minor quantities of mafic plutons and dike masses usually lurking around. Granite as a rock type is not common compared to granodiorite.
Livingston and others (1968) discuss the geochronology of the Laramide porphyry copper deposits of Arizona, and also suggest a Cenozoic history relating to their preservation or removal depending upon whether or not Cenozoic volcanic flows covered and protected the Laramide plutons.

Laramide-aged volcanics are found on the Mesa quad associated with the Laramide plutons and in the south-central portion in the Deer Creek area, and are described by Willden (1964). Here, a thick pile of andesite-to-basalt flows are intermixed with flow breccias, and overlie a Cretaceous coal-bearing sedimentary sequence. Together, they disconformably overlie the Naco Formation. The entire Paleozoic and Cretaceous section is folded into an asymmetric shallow E-W trending syncline. These Cretaceous volcanics are termed the Williamson Canyon volcanics in the USGS nomenclature (see Krieger MH, USGS map GQ-1106, Winkelman quad map). Some would classify these volcanics, dated by K/Ar at 75-80 m.y., and chemically belonging to the basalt clan (Koski, 1979), as pre-Laramide in age.

Laramide dikes, mineralized joints, veins and elongate stocks in central Arizona show a marked preference towards a N 50-70°E orientation, according to Rehrig and Heidrick (1976). See example of Figure 14. They suggest that this direction is consistent with ENE-WSW-oriented maximum principal stress, and NNW-SSE-oriented minimum principal stress for Laramide times (75-50 m.y. ago). Further, they cite references which suggest up to 6-14% of N-S crustal expansion in the Tortilla mountains due to dilatational dike emplacement, and up to 25% expansion in the Morenci area (p. 208). Figure 15 illustrates these data graphically. Clearly, in this diagram, all other orientations in these areas are subordinate.
A Laramide event not as well-defined, is the apparent left-lateral motion along N70°W faults mainly in SE Arizona. There is some evidence that deep crustal zones of weakness oriented in this direction (the "Texas Zone") helped in a broad sense to localize Laramide deposits in their current distribution (Keith, 1978). Many faults in the south and central Mesa quad have this approximate orientation and have complex movement histories which include both normal and reverse movement.

The Canyon Creek fault zone of the north central part of the quad, and extending another 15 miles northward, is a N-S probable dip-slip fault with at least two opposing times of movement (Finnell, 1962). He suggests a probable Laramide east-side-down movement of at least 1,800 feet, and a younger motion (post 21 m.y. according to Peirce and others, in press) west-side-down at least 1,300 feet, with a net resultant throw of east-side-down 500 feet. Throw on the fault decreases in a northerly direction, where the fault becomes a monocline. However, more regional arguments based upon erosional conditions suggest that larger amounts of throw, perhaps in excess of 5,000 feet in the central Mesa quad have been masked by the fact that net throw is very small. These arguments are based upon sources, flow directions, and gradients of Oligocene or older Cenozoic stream systems which deposited the "rim gravels," discussed in next section.

The Laramide interval is a likely candidate for the time of uplift in an undefined parcel of the Western U.S., including part or all of Arizona. The late Turonian marine sandstones of the Mogollon Rim region just north of the Mesa quad are now found at elevations of 7,000-7,500 feet and their time of elevation, although not known, can probably be more easily modeled as having occurred pre-rim gravel time. This elevation
phenomenon appears more likely to be an epeirogenic event than an orogenic one; its effects however, are still apparent in such phenomena as the extreme elevation of Eocene deposits in SW Utah, now found at 9,000–11,000 foot elevations.

Finally, the main pulse of Laramide magmatism, as noted previously, dates at 75–50 m.y. It appears very separate and distinct from younger Cenozoic magmatism, as is seen in Figure 16. Igneous rocks in Arizona with dates of 50–40 m.y. are quite rare, but occur on a series of WNW trending basalt dikes in the Dos Cabezas Mountains of Cochise Co., and in some enigmatic two-mica granites found associated with some of the Arizona "metamorphic core complexes."

**Cenozoic (pre Basin-and-Range time)**

Following the Laramide orogeny in Arizona and preceding the Mid-Tertiary volcanic cycle, the history of central Arizona seems to be one of erosion and only limited deposition. The only documented pre-Miocene Cenozoic deposits in the Mesa quad are the Whitetail Conglomerate near Ray (Cornwall and others, USGS map GQ-1021), some red clastic floodplain deposits in the Tempe area of pre 17 m.y. (and pre-22 m.y.) age, a thick tilted redbed assemblage in the Hayden area (south-central part of quad), and the "rim gravels" in the northeast corner of the quadrangle, which are dated as pre-28 m.y. by Peirce and others (in press). These "rim gravels" blanketed much of the southern margin of the Colorado Plateau, contain flow direction indications of southwest to northeast, and contain clasts of Precambrian crystalline rocks which logically could have only come from south of the Plateau edge. The picture, then, for this Eocene–early Oligocene time is one of a topographic high in central Arizona shedding debris to the northeast onto what is today the southern Colorado Plateau.
Beginning some time in the Oligocene, there appears to have been an erosive carving out of central Arizona, at which time much of the pre-existent Phanerozoic section was stripped from a 100 mile-wide NW-SE elongate swath through the central part of the State, producing among other features an ancestral Mogollon Rim (majority of the escarpment of Figure 1). This topographic break acted as a northeastward limit of deposition to the subsequent voluminous Cenozoic volcanics and sediments of the southwestern region, including those of the Mesa quad.

A late Oligocene 10,000 + feet thick redbed sequence about 10 miles west of Hayden, in the south-central part of the Mesa quad deserves particular interest. The sequence was termed the Hackberry Formation by Schmidt, (1971), but later called the San Manuel Formation by USGS workers in the area, such as Krieger, (1977). This writer prefers the first applied name. The sequence dips eastward at 20-40° and is composed of fanglomerates, fluvial overbank deposits and playa-like muds. This package encloses "megabreccia" slide deposits, the largest of which is 2.5 miles long and 800 feet thick (Krieger, 1977). The presence of these megabreccias hints at rapid tectonic-sedimentation rates, and local relief comparable to that of today. Tectonic rotation of this sequence apparently does not involve younger fanglomerates of the Big Dome Formation in the area which are dated at 14-17 m.y. (Krieger and others, 1974) and also appears to not involve the 20 m.y. old Apache Leap tuff found just NW of here. This deformation can be modeled as either monoclinal (compressional) or listric fault (tensional) produced, east side down, and appears to involve similarly aged sediment-volcanic assemblages of the San Pedro valley at least 90 miles farther south.
In the Superior-Globe area, the pre-mid-Tertiary volcanic, post-Cretaceous Whitetail Conglomerate has been involved in complex faulting tectonics, with major movements on NW and N-S fault sets and subsequent erosion vastly affecting the present outcrop distribution of all rocks as young as Whitetail. Near Ray and the Superior area, Whitetail beds are 3-5,000 feet thick and rest upon Paleozoic sediments on the west side of a N-S to NNW-trending high angle fault, but are very thin (0-200 feet) across this fault to the east, where they rest on Precambrian rocks and Laramide Schultze granite. Apache Leap tuff thicknesses across this fault are 1,000 ± feet on both sides (S.B. Keith, pers. comm.). From this geometry, one can postulate pre-Whitetail (Laramide?) stripping of the Paleozoic section on the east side of the fault and a presumed syn- or post-Whitetail fault reactivation which controls present-day location of Whitetail outcrops. By 20 m.y. ago, (Apache Leap tuff time) faulting on this structure had ceased. See comments on the Canyon Creek fault zone for a possible analogous movement history.

Several outcrops of Oligocene-Miocene coarse clastic redbeds are seen in the extreme west-central part of the Mesa quad (labeled "OM" on the map), and occur as isolated remnants which dip in various directions. These contain reddish brown coarse fanglomerates, mudflows and fluvial floodplain deposits as the dominant lithologies, and contain clasts of Precambrian granites exposed in the area. In certain areas (10 miles NE of Scottsdale), there are andesite flows and agglomerates interbedded or underlying the redbeds, which have yielded 15 to 20 m.y. age dates elsewhere to the west.

The dominant magmatic action in southern Arizona in the 30 to 13 m.y. time slot is the eruption of voluminous ignimbrites with associated andesites and plutonic phases (Shafiquullah and others, 1978). In the Mesa quad, the Superstition volcanic field (described by Sheridan, 1978) embraced this time and in its main bulk may be composed of at least three "cauldrons" (Figs. 17 and 18) of differing ages. Figure 17 outlines the
minimal, original extent of this volcanic field as defined by Sheridan, which encompasses very nearly the entire southwestern quarter of the Mesa quad. Figure 18, from Sheridan (1978) hypothesizes three "cauldrons" of 25-15 m.y. ages (shown on the figure) which underwent some of the normal caldera evolutionary steps including at least central collapse. Figure 18a presents the currently recognized stratigraphy and ages of the volcanic phenomena of the Superstition field. And Figure 18b indicates regional trends of K/Ar ages of Cenozoic volcanics in Arizona (the breakdown of basalts - silicic rocks here are not based upon the strictest chemical definition).

In the Superior area and points north and east from it, the 20 m.y. old Apache Leap tuff blankets the landscape. In several areas, this flow angularly truncates Cenozoic structures, as near Ray where it unconformably overlies a beveled homocline composed of Whitetail Conglomerate. Peterson (1968) suggests that it originally covered in excess of 1500 mi$^2$ with a volume of about 150 mi$^3$ of dacitic material. In time it matches with the initiation of the Goldfield cauldron in the Superstition volcanic field (20-21 m.y., Sheridan, 1978). Peterson was not able to confirm a source area for this sheet. On Figure 17, the Apache Leap tuff forms most of the outcrops of the southeast and east edge of the Superstition field, and appears to have flowed to the NE down some paleo-topographic lows coincident with portions of the Salt River Canyon. Apparently, there has been a post-20 m.y. drainage reversal in the Salt River Canyon area, since the river now flows towards the SW in this same region.
In the Northwest corner of the Mesa quad, Cenozoic rocks are found as a series of basalt-capped mesas which have been dissected by a set of southerly-flowing streams such as Cave Creek, Tonto Creek and the lower Verde River. Reconnaissance geologic work suggests at least three periods of sedimentation and volcanism in the time span 27-11 m.y. separated by variable amounts of tectonism. The last volcanics of this group are the "Hickey basalts" which have been dated at several places in central Arizona as 15-11 m.y. in age, and still cap mesas from the area of Bartlett Reservoir northwestward at least to the Jerome region. Under the "Hickey basalts" in the NW Mesa quad are an older set of altered flows of andesite to rhyolite composition (seen along Cave Creek) and an overlying 500-1000 foot thick set of basalt flows, altered air-fall tuff beds, and minor fluvial conglomerates and mudstones. These beds were gently folded and erosionally truncated before they were capped by the Hickey basalts which, in this area, date at 13-15 m.y. This geology is summarized by Scarborough and Wilt (1979).

No plutons of middle Cenozoic age are known in the Mesa quadrangle. Rehrig and Heidrick (1976) note that the direction of elongation of "late Tertiary dikes, veins and elongate stocks" is generally NNW in southern Arizona (Figure 19), including measurements taken at Klondyke and Mineral Mountain in the Mesa quad. This indicates, then, a direction of tension oriented ENE-WSW during their Late Tertiary (22-15 m.y.) interval.

Layered Rocks as young as middle Miocene in the Basin and Range country can be grouped into domains with a characteristic NW strike and unidirectional NE or SW dip direction (Figure 20). Rehrig and Heidrick (1976) explain this regionally based pattern by rotation of sedimentary blocks along listric faults which represented gravitational sliding directed towards thermally distended and collapsed crests of regional NW-SE elongate domes or arches (anticlinal axes of Figure 20).
which had formed previously during mid-Tertiary time by "widespread heat ingress into the crust". Fieldwork continues in areas affected by this enigmatic phenomena.

**Metamorphic Core Complexes**

The Mesa quad contains one small outcrop of rocks now generally accepted as belonging to the "metamorphic core complex" assemblage. These Tertiary phenomena are being increasingly recognized as important elements of the Cenozoic evolution of the Cordillera (Davis and Coney, 1979; and a GSA memoir, in press). The Mesa quad outcrop ("Tm" of map) is along the west central edge, and is also the eastern extreme of South Mountain, just south of Phoenix (Figure 21). This complex, described by Reynolds and Rehrig (above memoir, in press) is composed of, from west to east, Precambrian gneiss, a young granite (K/Ar = 19.2 m.y., Rb/Sr = 25 m.y.) in the center of the range and a granodiorite (K/Ar = 20.2 m.y., Rb/Sr = 25 m.y.) in the eastern two-fifths of the range. The eastern end of the range contains an upper layer of cataclastically deformed and lineated "gneiss" which can be seen to grade downward into undeformed granodiorite (Figure 21), with the mylonitic rocks now deformed into a "N60°E - elongate dome which has gently dipping NW and SE flanks, and plunges gently NE. The mylonite fabric runs across the roof of the range and plunges rather more steeply SW, disappearing into the Precambrian terrain at the west end of the range. The uppermost levels of the mylonitic rocks are overprinted by a peneconcordant layer of chlorite breccia which quickly grades upward into a "dislocation surface," upon which, in other areas of Arizona where such relationships are better defined, some undefined amount of movement of "upper plate" rocks (a wide assortment of rocks of ages as young as middle Miocene) has occurred in response to an unknown local stress field. "Upper plate" rocks related to the South Mountain complex may well include the redbeds ("OM"
of map) in the Phoenix-Tempe area. In this model, the listric faults responsible for the tilting of the "upper plate" rocks gradually merge at depth with the dislocation surface.

The history of this complex appears as follows: (A) 25 m.y. intrusion of granodiorite followed by granite; (b) some kind of regionally-based (Figure 21a) thermal and/or stress field which followed these intrusions and overprinted a cataclastic mylonite fabric on the rocks; and (c) a warping along NE-SW fold axes, and movement along the dislocation surface, producing a chlorite breccia in the mylonitic rocks beneath the surface and rotational sliding along listric faults of the upper plate rocks. Fundamental remaining questions are: (1) the nature and magnitude of the supposed thermal/stress pulse which forms the mylonite fabric; (2) the regional tectonic setting of these complexes, including their relationship to the intrusion of some two-mica granites which often lurk nearby; and (3) the magnitude and parent local stress field of the listric faulting event.

**Basin and Range Disturbance**

The Mesa quadrangle in Arizona is unique in that it encompasses the southern boundary of the relatively flat-lying Colorado Plateau-type sediments in the northeast, and at the other corner expresses the geology of the southern Basin and Range province. The Transition Zone (Figure 1) which can be outlined to the northwest in the Wickenburg-Verde Valley interval loses some coherence as one approaches the Mesa quadrangle because, this author believes, another zone of relatively active tectonism, defined by the line of the present San Pedro - Tonto - Verde - Chino valleys, disrupts the geology and topography of the Transition Zone. This tectonic zone is that which warps the Hackberry Formation, already mentioned.
Through this complex meeting of differing tectonic styles, the event referred to by this author as the Basin and Range disturbance can still be discerned. One may confine this event to that which has blocked out the essence of the present topography of southern Arizona with its broad flat valleys interrupted by NW elongate discontinuous mountain ranges. Gathering evidence suggests that this event is best represented in southern Arizona by a series of NNW trending high angle faults produced under E-W tension with perhaps a San Andreas style right-lateral shear component, along which alternating graben blocks dropped and were subsequently filled with sedimentary debris, called basin fill. That the graben blocks more actively collapsed than the mountain blocks actively rose during this action is evidenced by thick marine Late Miocene beds deposited in the grabens near Yuma, the surface of which is near sea level today, while such time stratigraphic horizons as the base of the Palaeozoic in the isolated mountain blocks of central Arizona, when joined together into a continuous surface, defines a gently bowed arch which appears more genetically related to Laramide-early Tertiary tectonics than to Basin and Range events. The main pulse of Basin and Range rifting in Arizona appears bracketed in time between 12 and 6 m.y. See Eberly and Stanley (1978) for a discussion of SW Arizona Basin and Range tectonic effects.

Basin fill varies lithologically from place to place, ranging from coarse fanglomerates to fluvial mudstones to claystones to thick accumulation in some of the lower elevation basins of anhydrite (as in the Picacho basin), gypsum (Safford, lower San Pedro valleys), or halite (Red Lake near Lake Mead, Luke basin under Glendale). See Peirce (1976 b) and Scarborough and Peirce (1978) for detailed discussions.
In the Mesa quad, the thickest, most extensive basin fill deposits are in the extreme southeast corner toward Safford, and in the elongate valley-trough extending through Mesa and Florence. Two deep drill holes exist which indicate minimum basin fill thickness (Peirce and Scurlock, 1972). The first hole is located in the Paradise Valley midway between Scottsdale and Cave Creek (T4N, R4E, SW\(^1\), Sec 8) and penetrates 4,500 feet of conglomerates, sandstones and minor shales and bentonitic tuffs, then 80 feet of limestone (fresh water?), and below that 300 feet of dark volcanics dated at 22 m.y. by Eberly and Stanley (1978). The hole bottomed in "quartz diorite" at 5,400 feet. The second drill hole, 12 miles southeast of Mesa near Higley (T2S, R6E, SE\(^1\), Sec 1) penetrated 5,600 feet of sandstone, mudstone, thick bedded anhydrite and claystones beneath 1,000 feet of gravels, and then 2,600 feet of tuffs and sandstones (Superstition volcanic field?) before hitting "igneous rock," possibly gabbro at a depth of 9,200 feet. The basin fill materials here are interpreted to be the 5,600 feet of upper sediments.

Coincident with Basin and Range faulting, sedimentation in the basins was proceeding along with backwearing of the mountain fronts adjacent to the valleys. This mountain front retreat back from the Basin and Range faults has produced a buried bedrock shoulder strip (pediment) at the edge of most valleys averaging 1-5 miles wide. This concept must be kept in mind when engaging in exploration for water and mineral resources. However, the real distribution of these buried landforms must remain speculative in any area until confirmed or denied by drill-hole and/or geophysical data. See Summer and others (1976) for a free-air gravity map of Arizona which outlines the deep basins of Arizona.
The lower Tonto Basin of the north-central part of the Mesa quad has a poorly defined origin. It is a member of a set of relatively small NW-SE elongate valleys in the Transition Zone, but as well it shows up on State geologic maps as topographically aligned with the San Pedro and Dripping Spring Valleys to the south, and the upper Verde and Chino Valleys to the north. These valleys, collectively, share certain atypical features such as Quaternary vertical tectonics and relatively active Pliocene-Recent stream downcutting histories, and hence are suspect of having tectonic histories different from most other areas of southern Arizona. Geology of the mountains adjacent to and thus defining the Tonto Valley consists, to the west in the Mazatzal Mountains, of Precambrian granite overlain by Mazatzal Quartzite at elevations above 5000 feet, and, to the east in the Sierra Anchas, a flat-lying terrain of relatively flat-lying Apache Group sediments over tilted Older Precambrian sediments with elevation of the contact between them of about 2500 feet. The Roosevelt Dam region contains an eroded remnant Apache Group section which in part dips strongly NE. Hence, the Apache Group is eroded away but most certainly was above 5000 feet to the west of Tonto Basin, undergoes an east-side-down warping around Roosevelt Dam, and is found at 2500 foot elevations on the east side of the basin. This monoclinal (?) structure pervades the geology farther south in the San Pedro Valley in a very similar manner, and there, can be modeled as having perhaps the predominate period of movement involving Oligocene-early Miocene sediments such as the Hackberry Formation. But in that same area, the structure does not involve the middle Miocene (14-17 m.y.) Big Dome Formation. Basin and Range grabens (post 12 m.y.) contain 10-25 mg residual negative gravity anomalies centered under many southern Arizona valleys, but such anomalies are missing, or at best of minor magnitude in these aligned valleys, such as the Tonto Basin.
Basin and Range Volcanism

Volcanism in Arizona during Basin and Range times (last 10 m.y. or so) has been limited in extent. The major eruptive centers in Arizona are shown on Figure 1, and are associated with the southern edge of the Colorado Plateau, as well as a few scattered areas in southern Arizona. Rock types include extensive flood basalts, with some andesite-rhyolite masses present in the major eruptive centers. In the Mesa quad, these volcanics are limited to some mesa-capping basalt flows in the San Carlos area, and a few flow remnants NW and NE of Florence. Flows in the San Carlos area consist of higher elevation late Miocene flows and lower elevation flows of Pleistocene age. See section on Geochemistry for petrological terms. These flows are intercalated into basin fill sediments and have erupted out of presently-hidden vent sources. Curiously, the location of Quaternary volcanic centers coincides closely with neither a zone of Quaternary surface rupturing (Figure 1) nor the distribution of modern seismicity in Arizona as measured by seismograph records.

Pleistocene

The last geologic event that has helped to shape the landscape has been a regional stream downcutting episode which has been most intense along the major streams of the region. This episode has left paired terraces perched as far as 400 feet above present river channels. Dating by paleomagnetic means farther south, near Tucson, suggests that this episode is less than one million years old. The general Phoenix region has acted in the near past as sump for materials transported in by the streams coming from the east, north and south, where relative downcutting as measured by height of Quaternary terraces above stream level has been greater than in the western Mesa quad.
**Globe-Miami Example**

Figure 22 is a sketch cross-section through the general Globe-Miami region illustrating the general geology of that area, except for the Laramide plutonism and mineralization. Essentially, the only undeformed materials here is the "QTg," basin fill. The tectonic disturbances responsible for tilting of all older rocks (including Tw) are mostly distributed between Laramide and mid-Tertiary events, as outlined above.

**STRONTIUM ISOTOPE GEOCHEMISTRY OF IGNEOUS ROCKS**

The data on strontium isotope initial ratios for central and southern Arizona are summarized in Figure 23 for individual rock units. Figure 24, from Livingston (1969) is a Sr isotope evolutionary diagram for central Arizona Precambrian rocks, upon which other data for Phanerozoic rocks have been superimposed. Figure 25 is a histogram of Sr initial ratios for some Oligocene and Miocene igneous rocks in the Mesa quad and points south.

Figure 24 shows that Sr initial ratios for Precambrian rocks appear to follow a growth curve (line B on the figure) for materials derived from crustal material having a Rb/Sr ratio of about 0.25 and original formation age of 1800 m.y. However, as Livingston notes, younger rocks do not follow this trend, starting apparently with the 1100 m.y. old diabases, but oscillate in time between line A (growth curve of Sr isotope ratios for mantle-like material with Rb/Sr ratio of 0.21) and some undefined envelope curve such as Line B.

No Sr isotope data for Triassic-Jurassic volcanics of southern Arizona are known to this writer. The Williamson Canyon volcanics (K/Ar ages of 75-80 m.y.) lithologically resemble andesites but by
whole rock chemistry more resemble basalts. They have Sr initial ratios of .7043-.7047. Laramide volcanics of southern Arizona (K/Ar ages of 70-50 m.y.) in general have Sr initial ratios of .708-.710; none have been lithologically classified as basalts. Mid-Cenozoic volcanics (K/Ar ages of 30-13 m.y.) are mostly bracketed in the range .706-.710, with some silicic units displaying reported ratios of up to .715. Some of these very silicic, highly potassic volcanics are known for a variety of Cenozoic volcanics in Arizona. However, none of these are known to occur in the Mesa quad.

Although data are sparse, a series of two-mica granites, possibly formed by anatexis of upper crustal material during the time range 50-40 m.y., and which are associated with some of the Arizona metamorphic core complexes, apparently have high Sr initial ratios (.710 and higher? Keith and others, in press). None of these anatetic rocks are found in the Mesa quad. The rocks of Arizona with K/Ar ages less than about 15 m.y. (with only very few exceptions) are petrologically basalts with minor rhyolite to andesite differentiates and have Sr initial ratios of .703-.705.

Generally, then, the Sr isotope pattern oscillates between basaltic events, as with the Basin and Range volcanics, and the masses of Laramide and mid-Tertiary volcanics. The ultimate explanation for the Sr isotope variation must reside in the mechanism and depth of magma formation and character of source material. However, it is common to suggest that the high Sr initial ratio materials are derived by partial melting of mantle-crust material just above perhaps a descending slab of ocean lithosphere, while the low Sr initial ratio
materials are created at other times where the colder continental crust is pervaded by deep seated fractures which tap lower crust to upper mantle materials. This general pattern is quite consistent with the geology of Arizona as it is presently understood.

POTASH-SILICA RELATIONSHIPS FOR CENTRAL ARIZONA ROCKS

Figure 27 is a compilation of Arizona igneous rock chemistry by Stanley B. Keith of the Arizona Bureau of Geology using available published standard rock data on potash-silica ratios. The figure shows perhaps as well as any the tendency for igneous rocks formed during a particular space-time interval to display rather well-defined chemical variation trends. These trends can, of course, be rationalized using global tectonic arguments.

If one accepts the tendency of uranium to associate with potassium in igneous rocks, then Figure 27 assumes some importance in defining potentially favorable uranium-bearing environments. It can be seen that in general, the more alkaline suites are (1) the younger Precambrian granites, (2) Jurassic volcanics of southernmost Arizona, and (3) certain suites within the mid-Tertiary volcanics, particularly some volumetrically minor high-potash rocks including some "ultrapotassic trachytes" (Shafiqullah and others, 1976). These latter rocks are found in a SE-NW zone across all of central Arizona with decreasing ages from 20 to 15 m.y. going from SE to NW. The most studied of these rocks lie outside the Mesa quad, to the south around Picacho Peak, and to the west around Wickenburg. To this author's knowledge, none have been documented in the Mesa quad.
The Basin and Range basalts lie at the low-silica apex of Figure 27. These appear to be alkali-rich relatives of the ocean ridge tholeiitic basalts, as seen along the East Pacific Rise near southern Baja California.

The rocks which lie in the subalkaline field of Figure 27 are the older Precambrian igneous rocks (except perhaps some of the rhyolitic masses of the central part of the state), the Laramide volcanics, and some of the early Laramide volcanics. There is data in Laine (1974) which may allow placement of the uraniferous Laramide rocks of the Globe-Miami district onto Figure 27.

CURRENT MINING IN THE MESA QUADRANGLE

The main current mining activity in the Mesa quadrangle is a series of medium-to-large scale copper mines developed in Laramide-aged porphyry copper pluton systems. These are Kennecott's Ray Mine, Magma Copper Company's mine at Superior, Cities Service Company's Copper Cities and Pinto Valley mines at Miami, Ranchers Exploration and Development Company's Bluebird mine one mile west of Miami, and Inspiration Consolidated Copper Company's Thornton pit, Live Oak pit, and Oxide pit (Globe-Miami district) and Christmas pit/underground operation. 1978 production figures for all operations in the Mesa quadrangle include 418.5 million pounds of copper, 1.2 million pounds of 50% molybdenum concentrate, 509,000 troy ounces of silver, and 5,200 troy ounces of gold. Lead, zinc and tungsten production is negligible. Cumulative production figures show that about 33% of all copper produced in Arizona porphyry copper deposits has come from mines in the Mesa quadrangle (16.3 billion pounds compared to the total of 50.3 billion pounds).
In the past, the region around the Salt River in Gila County has been a significant producer of long-fiber asbestos, associated with serpentine as hydrothermal replacements in Mescal Limestone by the Precambrian diabase sill intrusions. See Shride (1952). Shipments by one producer for the past two years have probably been less than 1000 short tons per year.

Small quantities of gem-grade peridot have been mined and marketed by the San Carlos Apache Tribe from a dunite-bearing Quaternary basalt flow exposed just SW of the town of San Carlos.

Limestone is being quarried at two places in the Mesa quad for use as a copper smelter flux, near the Hayden smelter, and just east of the Ray Mine.

Pegmatites are generally associated with Precambrian granite terrain of northwestern Arizona, as far east as Phoenix (Jahns, 1952). However, few are recognized in the Mesa quad. Production minerals have included feldspar, amblygonite, spodumene, beryl, bismutute, muscovite and columbite-tantalite. Production from areas NW of the Mesa quad is only occasional. Any current production records are kept only by the U.S. Bureau of Mines.

Lausen and Gardner (1927) and Bailey (1969) summarize mercury deposits of Arizona. Roughly 95% of Arizona mercury production (7400 flasks of about 8000 flasks total as of 1969) has come from metamorphosed older Precambrian "schistose" metasediments and metavolcanics of the central Mazatzal Range, where the mercury, as cinnabar, occurs as veinlets cutting the schistosity or as thin films on fracture planes.
As well, some minor amount of cinnabar has been reported from limonite - cinnabar veins paralleling schistosity in Precambrian metamorphic rocks from the Squaw Peak area just north of Phoenix, just off the west edge of the Mesa quad, but production is negligible.

URANIUM EXPLORATION IN THE MESA QUADRANGLE

Potential exploration targets for uranium in the Mesa quadrangle may be classified into five geologic settings. There is continued interest in the Dripping Spring Quartzite member of the Apache Group in areas east of Roosevelt Lake in the Sierra Ancha Mountains, and some current drilling in this area is being done by Wyoming Minerals. Much literature exists for this potential target, and is summarized by Granger and Raup (1969), and Schwartz (1978). The uranium here appears stratabound in certain units of the Dripping Spring Quartzite, but apparently localized near diabase intrusive masses. It is not obvious whether the uranium is related to the diabase intrusives or whether it was deposited along with the clastic sediments.

Uraniferous horizons consisting of channel-fill conglomerates with carbonaceous plant trash are described in beds of the upper Naco Formation and lower Supai Formation along generally the southern boundary of the Colorado Plateau in central Arizona by Peirce and others (1977). Figure 26 indicates the "zone of interest" in an area along the Mogollon Rim and south from it, generally between Payson and the westward limit of the White Mountain volcanic field. This mineralization is thought to be related to diagenesis of the sediments and Paleozoic in age. These authors suggest that small targets at near-surface conditions may exist near the contact between the Naco and Supai Formations in the extreme NE corner of the Mesa quad (PPn and PPs contact on the map).
Several copper-bearing pluton systems in the State are known to have some associated uranium, such as the Twin Buttes mine of Anamax south of Tucson, portions of Phelps Dodge's mines at Bisbee and Morenci, and portions of the Pinto Valley (Castle Dome) and Copper Cities mines belonging to Cities Service Company in the Globe-Miami district. All these deposits are Laramide in age except for the Bisbee deposit which is thought to be Jurassic (180 m.y.). Uranium in the Copper Cities and Pinto Valley copper systems was the subject of Still's (1962) PhD thesis, who noted that the uranium distribution in the pluton systems there closely parallels that of hypogene copper insofar as both show a "vertical hypogene zoning and both are slightly concentrated along a granite porphyry - quartz monzonite contact." He notes also that "the Copper Cities deposit contains an average of 11 times, and up to a maximum of 38 times..........., the quantity of uranium that usually occurs in normal igneous rocks of this general composition." Uranium recovery is now being engineered or attempted at tailings at Twin Buttes and Bisbee, and in leach solutions at Morenci. To this author's knowledge, no uranium is currently being extracted from any deposits of this nature in the Mesa quadrangle.

Some limited exploratory drilling has taken place in basin fill sediments occurring in various parts of the state, including the Big Sandy Valley around Wikieup and the Lake Pleasant area just north of Phoenix. In the Mesa quadrangle, some drilling has just been completed in the Tonto Basin north of Roosevelt Lake, with unknown results. Thus far, however, uranium found in sediments of this age group has proven to be only locally and subeconomically concentrated. This is not surprising in light of the sparcity of seemingly favorable host
sediments or environments to act as concentrates of uranium. A recent report by Texas Instruments, Inc. deals with aerial radioactivity traverses through roughly the SE third of the Mesa quad, and lists 110 "possible uranium prospects" in the quad, including some basin fill-aged marls just SE from San Carlos.

The last recognized potential uranium source rock for the Mesa quad is contained in a series of lower to middle Miocene floodplain, paludal, lacustrine sediments which outcrop discontinuously throughout central and west-central Arizona (Scarborough and Wilt, 1979). See Figure 28. There are many uraniferous outcrops known for these sediments in the state, and the Anderson mine of westermost Yavapai county owned by Minerals Exploration Company and Urangesellschaft USA is the foremost of these, having uranium reserves probably in excess of 20 million pounds of \( \text{U}_3\text{O}_8 \), and potential uranium resources of 60 million pounds. The uranium here is bound to black carbonaceous and silica-bearing paludal(?) sediments. Sediments of this age are found in the northwestern Mesa quad as noted in the geology section but here are light-colored tuffs, marls, limestones and mudstones and are only known to contain isolated and low grade uranium occurrences. However, the full uranium potential for these sediments in the Mesa quad (or elsewhere) is unknown since they occupy the hills under the "Tbo" cover basalts of several parts of the NW Mesa quad. Near the town of New River, 5 miles west of the Mesa quad, preliminary drillings by the Univex Mining Company has uncovered a potential uranium reserve in some sediments of this age near the surface of a small valley. Here, no carbonaceous sediments are known; rather, the uranium is associated with a series of thin dolomite beds which outcrop at the surface in places.
REGIONAL CROSS SECTIONS

Included with the map are eight regional cross sections drawn by Mr. Carl B. Richardson of Tucson, Arizona. The cross sections are drawn parallel to each other, oriented generally N 60° E, and have a horizontal scale of 4 miles per inch, a vertical scale of 2000 feet per inch, and a vertical exaggeration of about ten to one. Their general orientation is shown in the figure on the following page. Numbers on this index figure refer to circled numbers found on the individual cross sections. In each case except 53 and 54, they cover the entire Mesa quadrangle. Geology on the cross sections coincide with that on the enclosed 1:250,000 scale map only insofar as the state and county geologic maps served as starting points for the cross sections, and some differences in interpretations are to be expected.
Index map to regional cross sections.
Figure 1. Physiographic Provinces and post 10 m.y. volcanic rocks in Arizona.
<table>
<thead>
<tr>
<th>Designation on Arizona Bureau of Mines County Geologic Maps</th>
<th>CENTRAL ARIZONA</th>
<th>SOUTHERN AND SOUTHEASTERN ARIZONA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabase (db)</td>
<td>Grand Canyon Disturbance with Intrusion by diabase dikes, sills, and irregular bodies</td>
<td>Grand Canyon Disturbance with Intrusion by diabase dikes, sills, and irregular bodies</td>
</tr>
<tr>
<td>Sandstone and quartzite (sq)</td>
<td>Sandstone and quartzite, Troy quartzite north and northwest of Coolidge Dam (Figure 7)</td>
<td>Lower portion of the Troy quartzite between Latitudes 32°30' and 33°30', approximately (Figure 7)</td>
</tr>
<tr>
<td>Apache group (Ag)</td>
<td>Apache group</td>
<td>Apache group</td>
</tr>
<tr>
<td>Mescal limestone (Am)</td>
<td>Basalt ...</td>
<td>Basalt ...</td>
</tr>
<tr>
<td>Lower Apache group (Aq)</td>
<td>Mescal limestone ...</td>
<td>Mescal limestone ...</td>
</tr>
<tr>
<td></td>
<td>Dripping Spring quartzite</td>
<td>Dripping Spring quartzite</td>
</tr>
<tr>
<td></td>
<td>Barnes conglomerate ...</td>
<td>Barnes conglomerate ...</td>
</tr>
<tr>
<td></td>
<td>Pioneer shale ...</td>
<td>Pioneer shale ...</td>
</tr>
<tr>
<td></td>
<td>Sanilin conglomerate ...</td>
<td>Sanilin conglomerate ...</td>
</tr>
<tr>
<td></td>
<td>Total (local maximum)</td>
<td>Total (local maximum)</td>
</tr>
<tr>
<td></td>
<td>0 - 1,250</td>
<td>800 to 1,500</td>
</tr>
</tbody>
</table>

**GREAT UNCONFORMITY**

Granite and related crystalline rocks (gp), diorite porphyry (dp), pyroxenite (py), and granite gneiss (gr)

Mazatzal Revolution, culminating with intrusions ranging from granitic to gabbroic in composition

<table>
<thead>
<tr>
<th>Mazatzal quartzite (mq)</th>
<th>Mazatzal quartzite, Maverick shale, and Deadman quartzite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5,400</td>
</tr>
<tr>
<td>Schist (sch), rhyolite (rh), and greenstone (gst)</td>
<td>Alder group: Foliated volcanics and slate</td>
</tr>
<tr>
<td></td>
<td>20,000 to 30,000</td>
</tr>
<tr>
<td></td>
<td>Red Rock rhyolite, 4,000+ feet</td>
</tr>
<tr>
<td></td>
<td>Ash Creek group:</td>
</tr>
<tr>
<td></td>
<td>Basaltic, andesitic, rhyolitic, and dacitic flows and pyroclastic rocks and tuffaceous sedimentary rocks. Locally foliated.</td>
</tr>
<tr>
<td></td>
<td>Total Yavapai</td>
</tr>
<tr>
<td></td>
<td>20,000 to 23,500</td>
</tr>
<tr>
<td></td>
<td>40,000 to 54,000</td>
</tr>
<tr>
<td></td>
<td>20,000-</td>
</tr>
</tbody>
</table>

Granite gneiss (gp)                                           | Granite gneiss                                           |
|                                                            |                                                            |

Tentative correlation of Arizona Precambrian units.

**FIG. 2.** General stratigraphic relations of the Precambrian rocks of central and southeastern Arizona. (Reproduced from Wilson, 1962, by permission of the Director of the Arizona Bureau of Mines.)

_from Livingston and Damon (1968)._
Figure 2a. Sketch geologic cross-section of central and southern Arizona.
Troy Quartzite

Predominantly light-colored quartzite and sandstone; conglomerate horizons; cross-stratified.

UNCONFORMITY

Vesicular basaltic lava, not everywhere present

Upper member: 0–110 feet; cherty and novaculitic siltstone and shaly mudstone; thin-bedded; predominantly red to brown.

Basalt (less than 52 feet)

Algal member: 10–150 feet massive dolomitic limestone containing algal structures.

Lower member: 150–269 feet; thin-bedded impure limestone and dolomite; intercalated chert layers.

UNCONFORMITY

Vesicular basaltic lava. not everywhere present

Upper member: 0–110 feet; cherty and novaculitic siltstone and shaly mudstone; thin-bedded; predominantly red to brown.

Basalt (less than 52 feet)

Algal member: 10–150 feet massive dolomitic limestone containing algal structures.

Lower member: 150–269 feet; thin-bedded impure limestone and dolomite; intercalated chert layers.

EROSIONAL DISCONFORMITY

Dripping Spring Quartzite

Middle member: 0–370 feet; very fine grained to medium-grained feldspathic to arkosic sandstone and orthoquartzite, reddish orange to grayish pink, cross-stratified, slabby to massive.

Barnes Conglomerate Member: 0–50 feet; well-rounded quartzite pebbles and cobbles in arkose sandstone or quartzite matrix.

EROSIONAL DISCONFORMITY

Predominantly maroon to purple tuff and pink to gray siltstone and sandstone; arkosic and quartzitic at bottom.

Subangular to well-rounded quartzite pebbles and cobbles in a largely arkosic matrix.

UNCONFORMITY

Metasedimentary and metavolcanic rocks intruded by granite

Figure 3—Generalized columnar section of the Apache Group, Gila County, Ariz. From Granger and Raup (1964).
Figure 4. Presently known outcrops (black color) and Limits of deposition (---) of younger Precambrian Apache Group sediments in southern Arizona, and outcrops of possibly equivalent Unkar Group in northern Arizona in the Grand Canyon.
Figure 5b.—North-south geologic section at the end of Devonian time. Structures are diagrammatic, but the positions of the Troy Quartzite and the Apache Group relative to the pre-Bola and pre-Martin unconformities are probably representative.

Figure 5a.—North-south geologic section after the Troy Quartzite was deposited. Vertical exaggeration overemphasizes pre-Troy folding and angularity between Troy and Apache strata. Contacts dashed where there are no remnants to confirm interpretation.

both from Shride (1967)
Figure 6—Outcrops of younger Precambrian strata and coextensive diabase intrusions in southeastern Arizona. Modified from county geologic maps published by Arizona Bureau of Mines, 1958–60.

from Shride (1967).
Figure 7. Total Paleozoic isopach map and index to thickness sections shown in Figure 8, from Prince (1976a).
Figure 7. Thickness profiles of the Paleozoic strata of Arizona.
Figure 9. Generalized isopach of the Permian System.
from Peirce (1976 a).
Figure 10. Nomenclature and approximate thicknesses of Paleozoic strata in the Mesa quadrangle.
Figure 11—Stratigraphic relations between the Sierra Ancha and Bisbee, Arizona
FIGURE 12.—Sketch showing the contact of the Redwall limestones and the Naco formation near the confluence of Horton and Tonto Creeks, Gila County, Ariz. (locality 13, fig. 9). from Huddle and Dobrovolsky (1952).
Figure 13. The large Laramide overthrust belts of the American Cordillera and Jurassic evaporite basins. The question becomes whether or not these thrust belts are present in southern Arizona, perhaps in the subsurface.
Belt of Laramide Intrusive rocks in SE Arizona
E. A. Schmidt, 1970

Data from Schmidt (1970) PhD, Univ. of Arizona.

Figure 14. Laramide plutons in the general Hayden-Ray area, southern Mesa quad.
Figure 15. Strike-histogram rosettes for Laramide dikes, elongate stocks, and veins (in that order of abundance). Rosette bars are constructed for 10° strike segments of bearing angle from NS to EW. Lengths of strike bars are proportional to percentages of total strike measurements. The total measurements are shown by numbers beneath each plot.

From Rehriq and Heidrick (1976).
Figure 16. Histogram of Late Cretaceous–Cenozoic K-Ar dates for hypabyssal plutons and volcanic rocks of the Basin and Range Province.

Figure 17. Distribution of volcanic rocks associated with the Superstition-Superior field. Superstition caldron (S), Goldfield caldron (G), and Tortilla caldera (T) are indicated by the line pattern.

Both figures from Sheridan (1978).

Figure 18. Detail of the three principal caldrons. Main faults shown with the ball on the down-dropped side.

Figures illustrating extent of Superstition volcanic field, and hypothesized limits of the three caldrons proposed by Sheridan.
<table>
<thead>
<tr>
<th>Age (m.y.)</th>
<th>Thickness (m)</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200</td>
<td>Rhyolite conglomerate</td>
</tr>
<tr>
<td>15.2 ± 1.0</td>
<td>0 - 15</td>
<td>Basalt</td>
</tr>
<tr>
<td>16.1 ± 1.0</td>
<td>20 - 170</td>
<td>Canyon Lake member of the Superstition Fm.</td>
</tr>
<tr>
<td>16.3 ± 0.5</td>
<td>0 - 100</td>
<td>Rhyolite and rhyodacite domes and lavas</td>
</tr>
<tr>
<td>18.4 ± 0.5</td>
<td>0 - 200</td>
<td>Geronimo Head Fm. ash flows and lahars</td>
</tr>
<tr>
<td>17.8 ± 3.1</td>
<td>15 - 25</td>
<td>Dogie Spring member of the Superstition Fm.</td>
</tr>
<tr>
<td></td>
<td>30 - 430</td>
<td>Basanite</td>
</tr>
<tr>
<td></td>
<td>20 - 100</td>
<td>Geronimo Head Formation ash flows and lahars</td>
</tr>
<tr>
<td>21.3 ± 1.0</td>
<td>10 - 15</td>
<td>Rhyodacite domes and lavas</td>
</tr>
<tr>
<td></td>
<td>0 - 100</td>
<td>Geronimo Head Formation ash flows and lahars</td>
</tr>
<tr>
<td>24.4 ± 0.7</td>
<td>0 - 670</td>
<td>Siphon Draw member of the Superstition Formation</td>
</tr>
<tr>
<td>29.0 ± 0.6</td>
<td>330 - 450</td>
<td>Latite of Government Well</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>Older Basalt</td>
</tr>
<tr>
<td>Oligocene?</td>
<td>75</td>
<td>Arkosic conglomerate</td>
</tr>
<tr>
<td>1395 ± 45</td>
<td></td>
<td>Granitcit basement</td>
</tr>
<tr>
<td>1540 ± 84</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 18a.** Idealized stratigraphic section for the Superstition Mountain region. Diagram from Stuckless (1971); rock unit ages determined by Damon (1969), Stuckless (1971), Stuckless and Sheridan (1971), and Stuckless and Naeser (1972).
Figure 4. Histograms showing K-Ar ages of volcanic rocks from various physiographic regions of Arizona. Histograms based on both published data from literature and unpublished data from Laboratory of Isotope Geochemistry. Data for samples from the Arizona Strip are not included in the histograms.

Figure 18b. Regional trends of K/Ar dates in Arizona for Cenozoic igneous rocks, from Shafiqullah, et al. (1978).
Figure 19. Strike-histogram rosette plots for late Tertiary dikes, veins, and elongate stocks. Some mid-Tertiary (>30 m.y.) data are included in the Dos Cabezas plot. Rosette bars are constructed for 10° strike segments of bearing angle from NS to EW. Lengths of strike bars are proportional to percentages of total strike measurements. Total measurements are shown by numbers beneath each plot.
Figure 2o. Attitudes of tilted, late Oligocene to Miocene volcanic rocks in the Basin and Range portion of Arizona. Two major arch-like structures are defined. Central or crestal segments are preserved in certain areas (see text); However, elsewhere the position of crest axis is approximate and inferred. Map's construction is based on data from county geologic maps, Cooley's tectonic map of Arizona, and the authors' own field observations. In a few cases, attitudes on pre-volcanic conglomerates were used.
Figure 21a. Metamorphic core complexes in Arizona (in black) that are presently recognized.

Figure 21b. Hypothetical cross-section of upper core complex rocks. The mylonite at South Mountain contains well-developed cataclastic lineation oriented N60°E in most areas.

all data from Reynolds and Rebriq (in press, GSA Memoir on Cordillera metamorphic core complexes).
FIGURE 3.—Diagram showing the hypothetical general relationships of the sedimentary and volcanic rocks and the intruded diabase.


Apparantly, both Precambrian and Laramide-aged diabases are present in this area (since Paleozoic beds are disrupted); however, only the Precambrian event has been confirmed by age dating.

Later note: personal communication from S. B. Keith suggests that the diabase—Paleozoic contact above is a faulted one, and in fact the diabase is Precambrian. Hence no post-Paleozoic diabase is confirmed in the Globe-Miami district.
Figure 23. Some data on Sr isotopic initial ratios for central and southern Arizona. Data from Damon et al., 1964-1970 reports to A.E.C. and Ph.D. theses by Bickerman, Eastwood, and Livingston, M.S. thesis by Fer concise; and papers by Stuckless and O'Neil (1973) and Moorabth et al. (1967).

<table>
<thead>
<tr>
<th>Modern materials for comparison</th>
<th>.701 - .703</th>
</tr>
</thead>
<tbody>
<tr>
<td>ocean ridge tholeiites (Pliocene-recent)</td>
<td>modern = .7027</td>
</tr>
<tr>
<td>Lower continental crust</td>
<td>.7045</td>
</tr>
<tr>
<td>average continental crust</td>
<td>.7090</td>
</tr>
</tbody>
</table>

**Precambrian rocks**

- Madera diorite of Ransome, Pinal Mts.
  - 1730 m.y. | .7009 |
  - Ruin Granite | 1440 ± 25 m.y. | .7015 |
  - 1300 m.y. old diabases | .7050 |
  - 1100 m.y. old diabases | .7042 - .704 |
  - Redmond Fm. 1510 m.y. (Salt River Canyon) | .705 |
  - mafic/ultramafic in Pinal schists, Tortilla Mts.
    (max 1650 m.y. old) | .7043 |
  - granitic rocks, southern Mazatzal Mnts.
    - Salt River area, 1630 ± 90 m.y. | .7117 |
    - Four Peaks area, 1570 ± 60 m.y. | .7052 |

**Laramide Rocks**

- Granite Mountain porphyry (Ray) plagioclase | .7082 |
- Leatherwood quartz diorite, Santa Catalinas | .7083 - .7097 |
- Williamson Canyon volcanics near Winkelman
  - 75-80 m.y. old, (pre-Laramide?) | .7043 - .7047 |

**Mid-Tertiary rocks**

- Superstition volcanic field | .7056 - .7139 |
  - 25-5 ash flows | .7055 - .7131 |
  - 15m.y. several mafic to silicic domes | .7093 - .7103 |
  - Apache Leap Tuff (20 m.y.) | (cont) |

| 61 |
Figure 23 (cont).

Roskruge Mtn. volcancics (west of Tucson)
basaltic andesites to granite dikes
30-20 m.y. old.
Recortado Butte welded tuff (13 m.y.)

Tucson area volcanics

\[ \begin{align*}
\text{rhyolites} \\
\text{andesites} \\
\text{basaltic andesites} \\
\text{Rillito andesite (33 m.y.)} \\
\text{(30-24 m.y.) "turkey track" andesite porphyries}
\end{align*} \]

Basin and Range basalts

Brawley Wash basalt, Roskruge Mtns.
San Francisco volcanic field

\[ \begin{align*}
.708 & - .713 \\
.712 & - .715 \\
.7085 & - .7095 \\
.7078 & - .7086 \\
.7069 & - .7096 \\
.7086 & - .7090 - .7095 \\
& .7038 \\
.7030 & - .7035
\end{align*} \]
Figure 24. Initial Strontium Isotope Ratios and Ages of Rocks in Central Arizona.

1. Redmond formation
2. Ruin Granite
3. Madera Diorite (North side of the Pinal Mountains)
4. Madera Diorite (Mt. Madera and Signal Peak)
5. Mazatzal Mountains (Salt River region)
6. Mazatzal Mountains (Four Peaks region)
7. Tortilla Mountains (Metarhyolite)
8. Diabase (Sierra Ancha)

A. Evolution line for mantle-like material, Rb/Sr = 0.021
B. Evolution line for average crustal material, Rb/Sr = 0.25

(Phanerozoic rock data modified from Shafiqullah et al., 1978, and several unpublished Ph.D. Theses, including Bickerman, Eastwood, Percious).
From Shafqullah, and others, (1978).

Figure 25. $^{87}\text{Sr} / ^{86}\text{Sr}$ initial ratios for some Oligocene and lower Miocene volcanic rocks (40 to 20 m.y. old) occurring between $31^\circ 30'\ N$ to $33^\circ 30'\ N$ latitude, and $110^\circ$ to $112^\circ$ longitude. Data from Laboratory of Isotope Geochemistry, University of Arizona. R=rhyolite, A=andesite and D=doreite (i.e., potassic basaltic andesite).
Figure 26. Diagrammatic representation of the regional general geologic setting showing some nomenclatural variations.

"Zones of interest" relate to uranium mineralization.

From Price and others, 1977.
1. Precambrian (1750–1600 m.y.) plutonic and volcanics
2. Laramide (70–50 m.y.) plutonic + volcanics
3. Early Laramide (80–70 m.y.) plus some mid-Tertiary (35–15 m.y.) volcanics
4. Jurassic (220–150 m.y.) volcanics
5. Younger Precambrian (1450–1350 m.y.) granites
6. mid-Tertiary (22–13 m.y.) volcanics
7. Basin and Range basaltic (15–0 m.y.)
8. mid Tertiary high-potash volcanics (22–15 m.y.)

Figure 27. Potash-silica diagrams for plutonic and volcanic rocks of southern Arizona. Data compilation and proposed rock clan names from unpublished work of Stanley B. Keith, 1978–79.
Figure 28. Space-Time frame of Arizona Basin & Range Cenozoic deposits projected to a general NW-SE cross-section line.

From Scarborough and Wilt (1979).

Note uranium occurrences (*)
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Ransome, RL (1923), Ray Quadrangle: USGS Geol. Folio 217. Map, 1:62,500 (Map, 1:12,000, same area as No. 43c).

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General References (Cont.)


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Reynolds, SJ (in progress) (Metamorphic Core complexes at South Mountain and White Tank Mountains) Univ. of Arizona Ph.D. Thesis in progress.


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<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Type of Rock/Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 2 m.y.</td>
<td>Qb - quaternary basalts</td>
</tr>
<tr>
<td></td>
<td>Tb - basalts</td>
</tr>
<tr>
<td>10 - 15 m.y.</td>
<td>Tbo- &quot;Hickey&quot; basalts</td>
</tr>
<tr>
<td></td>
<td>Tvs - silicic volcanics</td>
</tr>
<tr>
<td></td>
<td>Tv - volcanics</td>
</tr>
<tr>
<td>15 - 20 m.y.</td>
<td>Ta - andesites</td>
</tr>
<tr>
<td>20 - 30 m.y.</td>
<td>Ti - plugs, intrusive masses</td>
</tr>
<tr>
<td>30 - 50 m.y.</td>
<td>Tm - recrystallized rocks of metamorphic core complexes</td>
</tr>
</tbody>
</table>

- **Q**: valley fill material capped by Pleistocene sediments.
- **Ms**: Miocene sediments
- **Ts**: Tertiary sediments - unk age
- **OM**: Oligocene-Miocene clastic sediments, including Eocene(?)
- **Qb**: quaternary basalts
- **Tb**: basalts
- **Tbo**: "Hickey" basalts
- **Tvs**: silicic volcanics
- **Tv**: volcanics
- **Ta**: andesites
- **Ti**: plugs, intrusive masses
- **Tm**: recrystallized rocks of metamorphic core complexes

**CENozoIC**

<table>
<thead>
<tr>
<th>Time Interval</th>
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<tr>
<td>50 m.y.</td>
<td>La - andesite</td>
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<tr>
<td></td>
<td>Lv - volcanics</td>
</tr>
<tr>
<td></td>
<td>Ldi - diorite</td>
</tr>
<tr>
<td></td>
<td>Lg - granite</td>
</tr>
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</table>

**LARAMIDE**

<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>80 - 50 m.y.</td>
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<tr>
<td>60 m.y.</td>
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</tbody>
</table>

**MESOZOIC**

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Type of Rock/Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>224 m.y.</td>
<td>PP - Pennsylvanian - Permian sediments</td>
</tr>
<tr>
<td></td>
<td>DM - Devonian - Mississippian sediments</td>
</tr>
</tbody>
</table>

**PALEOZOIC**

<table>
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<tr>
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<th>Type of Rock/Formation</th>
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</thead>
<tbody>
<tr>
<td>570 m.y.</td>
<td>T - Troy Quartzite</td>
</tr>
<tr>
<td></td>
<td>d - 1100 m.y. old diabase sills-gabbro complex</td>
</tr>
<tr>
<td></td>
<td>A - Apache Group sediments (Pioneer Shale, Dripping Spring Quartzite, Mescal Limestone)</td>
</tr>
<tr>
<td></td>
<td>pdi - diorite and related intrusives</td>
</tr>
<tr>
<td></td>
<td>pg - granite</td>
</tr>
<tr>
<td></td>
<td>pmp - metamorphosed sediments, volcanics</td>
</tr>
<tr>
<td></td>
<td>pry - rhyolite flows, pyroclastics</td>
</tr>
<tr>
<td></td>
<td>pm - Mazatzal Quartzite and related sediments</td>
</tr>
<tr>
<td></td>
<td>ps - schist and other metamorphics</td>
</tr>
</tbody>
</table>

**PRECAMBRIAN**

- high angle faults, dot on downthrown side
- thrust faults, pattern on upper plate
- same geologic unit

**Major Streams**

- Laramide and Tertiary dikes
2 - 0 m.y. Qb - quarternary basalts
10 - 2 m.y. Tb - basalts
15 -10 m.y. Tbo-"Hickey" basalts
30 -15 m.y. Tvs- silicic volcanics
Tvi- intermediate volcanics
Tv - volcanics
Ta - andesites
Ti - plugs, intrusive masses
Tm - recrystallized rocks of
metamorphic core complexes

Q - valley fill material
capped by Pleistocene
sediments.
Ms- Miocene sediments
Ts- Tertiary seds. - unk age
OM- Oligocene - Miocene clastic
sediments, including Eocene(?) -
Oligocene rim gravels

50 m.y.
La - andesite
Lv - volcanics
Ldi- diorite
Lg - granite

Dikes, Laramide and
Tertiary Age.

80 m.y.
Ks Cretaceous clastic sediments

224 m.y.
PP - Pennsylvanian - Permian sediments.
PPs - Supai Formation
PPn - Naco Formation
DM - Devonian - Mississippian sediments.

COS- Cambrian - Ordovician Silurian sediments.

570 m.y.
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d - 1100 m.y. old diabase sills-gabbro complex
A - Apache Group sediments (Pioneer Shale, Dripping Spring Quartzite,
Mescal Limestone)
pdi- diorite and related intrusives
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pm- Mazatzal Quartzite and related sediments
ps- schist and other metamorphics

high angle faults, dot on
dowthrown side
major streams
thrust faults, pattern on
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Laramide and
Tertiary dikes
same geologic unit

78