A STRUCTURAL INVESTIGATION OF THE NORTHERN TORTILLA MOUNTAINS, PINAL COUNTY, ARIZONA

by

Eberhard Adalbert Schmidt

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GRADUATE COLLEGE

I hereby recommend that this dissertation prepared under my direction by Eberhard Adalbert Schmidt

entitled A Structural Investigation of the Northern Tortilla Mountains, Pinal County, Arizona

be accepted as fulfilling the dissertation requirement of the degree of Doctor of Philosophy

Spencer R. Titley — Dissertation Director

April 15, 1971 — Date

After inspection of the final copy of the dissertation, the following members of the Final Examination Committee concur in its approval and recommend its acceptance:*

Spencer R. Titley — April 15, 1971

John W. Anthony — April 15, 1971

Evans B. Mayo — April 15, 1971

[illegible] — April 15, 1971

John M. Guilbert — April 15, 1971

*This approval and acceptance is contingent on the candidate's adequate performance and defense of this dissertation at the final oral examination. The inclusion of this sheet bound into the library copy of the dissertation is evidence of satisfactory performance at the final examination.

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ABSTRACT

The Tortilla Mountains are a discontinuous northwest-trending mountain chain within the mountain region of the Basin and Range province in Pinal County, Arizona. The study area is 60 miles north of Tucson in a deeply eroded older Precambrian basement complex that extends for 55 miles along the west side of the Gila-San Pedro River lineament from Oracle in the south to Superior in the north. The basement complex consists primarily of Oracle Granite and associated aplites which are disconformably overlain by the steeply dipping strata of the younger Precambrian Apache Group. Numerous diabase sills intrude the Apache Group and the granitic basement complex.

No autochthonous Paleozoic sedimentary rocks are exposed, but allochthonous blocks of Devonian and Mississippian limestone occur at several places in this area resting on the Precambrian rocks.

Superimposed upon the Precambrian basement complex is the Laramide magmatic event manifested by Sonora diorite (69 m.y.) and similar-appearing elongate intrusive masses in the Hackberry area, the Grayback granodiorite pluton (63 m.y.), and a cogenetic east-trending porphyry dike system (63 m.y.) which cuts all other rock types.

Crosscutting the Laramide intrusive rocks is a group of systematically oriented, east-northeast- to east-trending fissure veins and mineralized fractures which contain quartz, hematite, magnetite, copper silicates and carbonates, and distinct quartz-sericite alteration envelopes. Associated with the dioritic intrusive masses are well-developed

alteration halos several hundred feet wide in the adjacent Oracle Granite.

The Laramide intrusive rocks and the Precambrian basement complex are disconformably overlain by the steeply eastward dipping mid-Tertiary Ripsey Wash sequence and the Hackberry formation. Plio-Pleistocene Gila Conglomerate in turn unconformably overlies the Hackberry formation.

The Laramide intrusive rocks and fissure veins are of regional extent. Intrusive rocks similar in composition, trend, and age to rocks of the Laramide porphyry dike system occur in the Dripping Spring Mountains, in the Crozier Peak-Copper Hills area, and in the Red Hills, Mineral Hills, and Sacaton Mountains. The geometry and distribution of the intrusions mark a fundamental zone of north-south extension activated during Laramide time. The rocks were passively emplaced in part following the trends of the older Precambrian foliation in Oracle Granite and Pinal Schist.

Deposition of the mid-Tertiary sediments followed in response to the rising Tortilla Mountain block. As a result of this uplift, individual crackle breccia masses composed of younger Precambrian quartzite, diabase, and Paleozoic limestone moved under the force of gravity from the elevated Tortilla Mountains into the adjacent Miocene lake and formed a sequence of intraformational glide sheets several hundred feet wide and 1 to 2 miles long.

The extensive eastward tilting of the mountain range is the result of elongated domal uplift and attendant antithetic rotation during Basin and Range tectonism. This style of deformation is evidenced by the vertically inclined and overturned strata of the Apache Group and the steeply eastward dipping mid-Tertiary sedimentary rocks. Tilting was essentially completed prior to the deposition of the Gila Conglomerate.

INTRODUCTION

Purpose and Scope of Investigation

The Tortilla Mountains are located adjacent to the Gila-San Pedro Valley tectonic lineament. They constitute a Precambrian block that became structurally activated especially during Laramide and mid-Tertiary time. This deformation is indicated by numerous east-northeast-trending dikes and fissure veins as well as by the steeply dipping to overturned attitudes of the younger Precambrian and mid-Tertiary sedimentary rocks.

It was the purpose of this investigation to determine the complex tectonic and igneous history of this area and to place it in the regional tectonic framework. The results will contribute to our understanding of tectonic processes operating in the Basin and Range province of Arizona. For this purpose, a careful analysis of all structural elements in conjunction with petrographic examinations of the rocks is paramount.

It is beyond the scope of this investigation to examine in detail the chemical and petrological variations evident in each of the Precambrian and Laramide intrusive rocks.

Method of Study

The field work was begun in the summer of 1968 and continued intermittently through the fall of 1969. Zones of igneous intrusions, trends of mineralized fissure veins and dikes, and the attitudes of the younger Precambrian and mid-Tertiary sedimentary strata were accurately defined. Great care was taken to plot these data on high-quality maps. Excellent aerial photographs and 7 1/2 minute topographic base maps were available from the U.S. Geological Survey which were enlarged to a scale of 1 inch equals 1,000 feet.

The data were plotted on the photographs using acetate overlays or directly on topographic field sheets, depending on the quality of individual photographs and their contrast level. Usually it proved advantageous to spend a few more hours in each area in order to plot the data directly on topographic maps rather than to speed up the field work by plotting data on distorted margins of photographs for later transfer to the base map. Prominent structural features evident on the photographs were stereoscopically studied prior to the examination in the field.

Several hundred rock specimens were collected from the area for correlation and microscopic identification of the various Laramide intrusive rocks and the older Precambrian basement complex. Each specimen was slabbed and 170 were selected for thin-section analyses to study textural and compositional variations. Photomicrographs of thin sections were prepared by the writer.

The biotite separation from three rocks for K-Ar dating was done by the writer in the laboratory of the Department of Geochronology under the supervision of Drs. D. Livingston and P. E. Damon.

The planar structural elements, such as foliation, mineralized and unmineralized joints, and fissure veins, were treated statistically and plotted on Schmidt equal area nets with the aid of computer (program by Mr. Richard Call, Department of Geological Engineering, The

University of Arizona). For this purpose, the study area was divided into structural domains. Equal area plots of certain structural elements were then prepared for each domain.

A detailed structure map was made of the Kelvin breccia pipe because it is unique in this particular area. A map with a scale of 1 inch equals 200 feet was prepared in order to show in sufficient detail the internal megascopic fabric.

For regional correlation, all available geological data within a radius of 15 to 20 miles around the study area were compiled on an Army Map Service topographic base map of a scale 1:250,000. This aided greatly in viewing the Tortilla Mountains in their proper structural setting.

Location

The Tortilla Mountains are part of a north-northwest-trending discontinuous mountain chain located within the mountain region of the Basin and Range province as defined by Ransome (1903). The Gila and San Pedro Valleys form the eastern boundary. To the north the range extends into the Ray area where it merges with the Dripping Spring Mountains. The western boundary is not well defined because the Tortilla Mountains grade into an extensive pedimentlike erosion surface which slopes a few degrees westward toward the Florence basin 22 miles away.

The specific area of investigation is located in the northern portion of the Tortilla Mountains about 6 miles south of Kennecott's Ray copper deposit and 20 miles east of Florence, in Pinal County, Arizona (Fig. 1). The area comprises about 55 square miles and covers portions

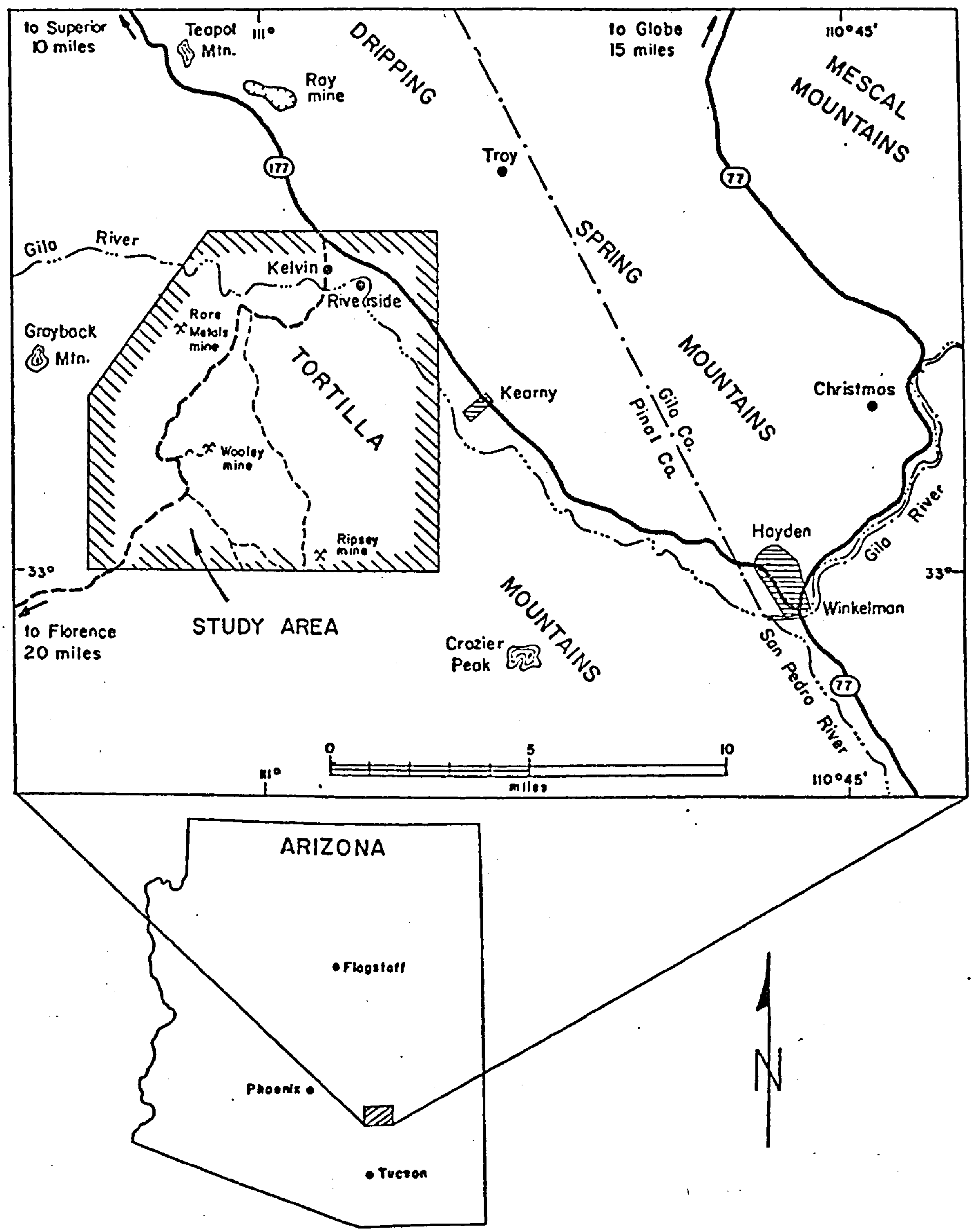


Figure 1. Location Map, Northern Tortilla Mountains

of the U.S. Geological Survey 7 1/2 minute Grayback and Kearny quadrangles, Tps. 4 and 5 S., Rs. 13 and 14 E.

The small settlements of Kelvin and Riverside, near the junction of Gila River and Mineral Creek, are in the northern part of the area. The new town of Kearny lies a few miles east of the map boundary on State Highway 177 across the Gila River. The tracks of the Southern Pacific Company follow the course of the Gila River through the Tortilla Mountains and service the mine at Ray as well as the smelters at Hayden.

The map area is terminated on the north and south by the Grayback and Kearny quadrangle boundaries. To the east the Gila River forms a natural boundary, and to the west the map was terminated where exposures became increasingly poor.

Topography and Accessibility

The Tortilla Mountains range in elevation from 1,800 to 3,600 feet in the investigated area. The mountains form steep canyons where underlain by the younger Precambrian Apache Group and the older Precambrian aplite porphyry complex. Coarsely crystalline Oracle Granite and diabase generally form gentle slopes because of their low resistance to weathering. The high relief of the mountain range can only be appreciated if viewed from the east along the Gila River; from the west on the Florence-Kelvin road, the range appears to extend only slightly above the 3,200-foot high pediment surface (Fig. 2).

The northwest-trending pediment escarpment forms the present drainage divide with deeply incised canyons and washes leading to the north and east into the Gila River. On the pediment a shallow west-southwest-trending dendritic drainage pattern is developed causing

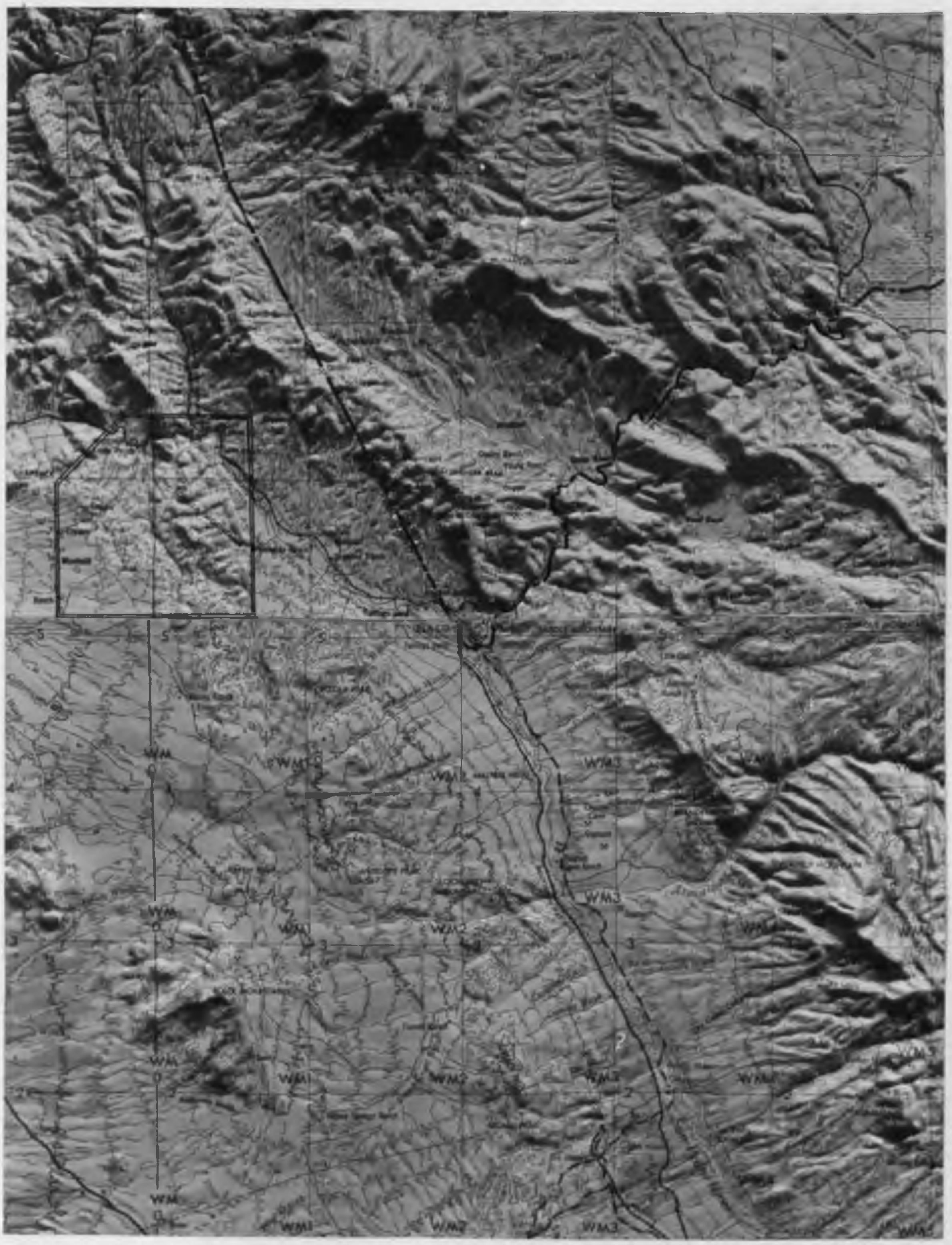


Figure 2. Relief Map of Tortilla Mountains and Vicinity

Study area is outlined by double lines. Photograph taken from U.S. Geol. Survey Plastic Relief Map Series, 1966-1967, Tucson (NI 12-11) and Mesa (NI 12-8) Sheets; scale 1:250,000.

extensive formation of a granitic regolith in this area. This elluvial cover considerably hindered the structural investigation. Generally, however, the lack of heavy underbrush aided greatly in the overall investigation.

The area can be reached via State Route 177 from Winkelman and Superior. A well-maintained gravel road leads into the area from Florence on the west. Access from the east into Hackberry Wash is possible across a privately owned suspension bridge at the DuBois Ranch or a ford across the Gila River at Kearny. Almost no access exists into the central portion of the map area. Ripsey Wash and several tributary washes may be used for vehicular traffic during the dry season; however, the majority of the area can be reached only by foot. Many of the access roads are temporarily impassible after major rainstorms, especially during the summer months. An occasional snowfall during the winter period curtails field work in the higher portions of the area.

Previous Work

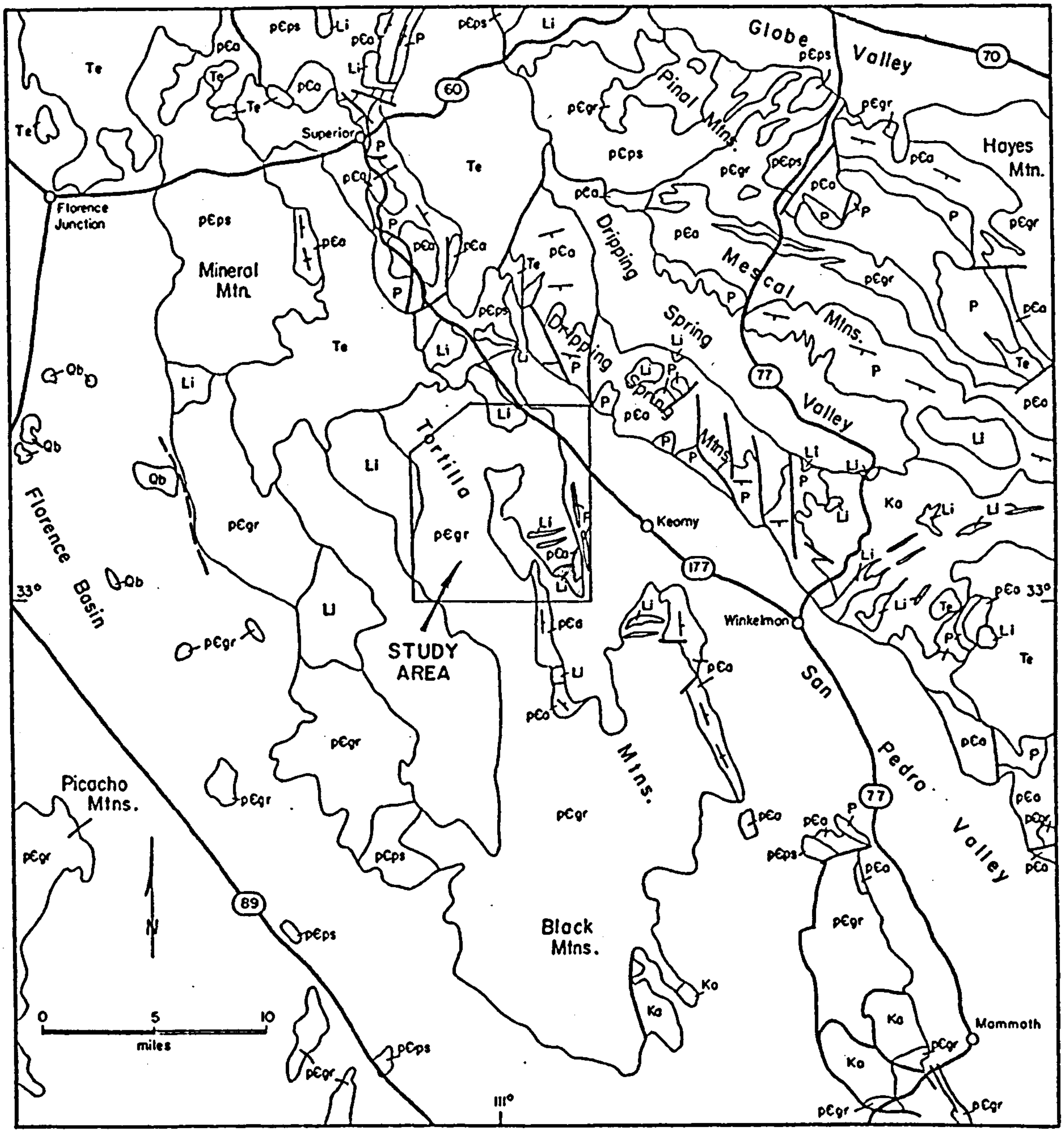
The only published account of the geology and structure of the northern Tortilla Mountains is by Ransome (1919, 1923). In these reports Ransome described the general geologic setting of Ray and Miami in considerable detail, especially with respect to the mineralization. However, the area south of the Gila River (the heart of the present report) is only briefly mentioned in connection with a discussion of the Apache Group and the indurated Tertiary sediments in Hackberry Wash which Ransome regarded as an unusual type of Gila Conglomerate. Several descriptions of the Ray copper deposit (Metz and Rose, 1966; and Metz and Phillips, 1968) discuss the geologic setting of the ore body proper in detail but do not dwell on the regional tectonic framework to any extent.

REGIONAL GEOLOGIC SETTING

The Tortilla Mountains are part of a large Precambrian basement complex that is exposed over a wide region on the southwest side of the Gila and San Pedro Rivers (Fig. 3). The complex crops out near the small settlement of Oracle about 30 miles south of the Tortilla Mountains and extends past the Ray copper deposit to the vicinity of Superior about 18 miles north of Kelvin. From the vicinity of Ray northward, the predominant Precambrian rock is Pinal Schist, whereas a granitic intrusive complex forms the predominant rock type between Ray and Oracle to the south. The dividing line between the two rock groups trends generally east-northeast south of Ray. It is interesting to note that the northwest-flowing Gila River abruptly changes its course near Kelvin and transects the high Tortilla Mountain range in a more or less east-west direction, paralleling the contact trend between the schist and granite provinces.

The Tortilla Mountains are wholly within the older Precambrian intrusive terrane (Fig. 4, in pocket). Remnants of the younger Precambrian Apache Group and Troy Quartzite unconformably overlying the granitic basement are steeply tilted and form narrow ridges on the east flank of the Precambrian block adjacent to the San Pedro Valley. Diabase conformably intrudes the younger Precambrian sedimentary sequence and the granitic basement.

The northwest-trending Dripping Spring Mountains east of the Gila River consist entirely of Paleozoic and younger Precambrian



Geology modified from Geologic Map of Arizona, 1969, Arizona Bureau of Mines and U.S. Geological Survey

EXPLANATION

QUATERNARY	Qb	Basalt flows	PALEOZOIC	P	Undifferentiated limestone
TERTIARY	Te	Extrusive volcanics	YOUNGER PRECAMBRIAN	pЄa	Apache Group, Troy Quartzite and diabase
LARAMIDE	Li	Dikes, stocks, plutons	OLDER PRECAMBRIAN	pЄgr	Oracle granite, Madera diorite and gneiss
CRETACEOUS	Ka	Andesite agglomerate and sediments		pЄps	Pinal Schist

Figure 3. Geologic Sketch Map of the Tortilla Mountains and Vicinity

sedimentary strata that dip gently southeast. The latter are also extensively intruded by diabase. No older Precambrian rocks are exposed.

The Dripping Spring Mountains form a structurally complicated fault block mosaic in which vertical displacements up to several thousand feet occur which bring Paleozoic and younger Precambrian strata together. Nowhere, however, are the strata as steeply tilted as in the Tortilla Mountains to the southwest. In the vicinity of Christmas and Winkelman, the Paleozoic strata of the Dripping Spring Mountains are overlain by an extensive sequence of Cretaceous and Tertiary volcanic rocks.

Thus, on either side of the Gila and San Pedro Rivers rocks are exposed that show different styles of deformation. East of the Gila River, extensive block faulting predominates in the gently dipping sedimentary and volcanic units. West of the river, the Precambrian granite complex indicates extreme eastward tilting evidenced by the steeply dipping younger Precambrian and mid-Tertiary sedimentary rocks.

It is important to realize that any steep contact predating the tilting of The Tortilla range originally had a more or less horizontal attitude. Thus, even though the diabase intrusive bodies appear presently as vertical dikes, they were originally emplaced as flat-lying sheet-like bodies in the younger Precambrian sedimentary strata as well as in the older Precambrian granitic basement complex.

The Mescal Mountains are located 7 miles beyond the Dripping Spring range and are separated from the latter by a broad, northwest-trending gravel-filled valley. They consist of an undisturbed Paleozoic and younger Precambrian sedimentary sequence, which forms conspicuous southwest-facing dip slopes. The Apache Group rests unconformably upon older Precambrian Pinal Schist, Madera Diorite, and Ruin Granite, forming the lofty peaks of the Pinal Mountains near Globe. Coextensive diabase sheets occur throughout the Apache Group of the Mescal Mountains, but very little faulting is recognized. The regular, monotonous arrangement of all the sedimentary units in this range contrasts with the highly disturbed nature of rock units composing the Dripping Spring and Tortilla Mountains.

In the southeast corner of the investigated area, the younger Precambrian rocks underlie two distinct parallel ridges, an eastern ridge at Hackberry Wash and a western ridge near Ripsey Hill. The two exposures are separated by a sequence of conglomeratic sandstones of mid-Tertiary age dipping moderately to the southwest.

Within the study area no autochthonous Paleozoic sedimentary rocks are exposed. Several allochthonous blocks of Mississippian Escabrosa Limestone occur in the Ripsey Hill area where they overlie the steeply dipping Apache sediments with a fault contact. The Escabrosa Limestone dips generally 45°-70° E. The unit is well bedded, very fossiliferous, and non-brecciated. Other Paleozoic limestone units in this area occur as completely brecciated, isolated blocks. These brecciated limestone blocks rest either on the Precambrian basement complex in widely spaced exposures or occur within the steeply dipping mid-Tertiary sedimentary sequence as 1-2-mile long breccia sheets at Hackberry Wash. The latter occurrences will be discussed in more detail in a later chapter.

The Laramide orogeny is manifested by very well defined east-northeast- to west-northwest-trending quartz monzonite and granodiorite porphyry dike swarms that are especially common near the southern and northern map boundary. One of the dikes yielded a biotite K-Ar age of 63 ± 1 million years (Damon, 1970). East-west-trending irregularly shaped quartz diorite bodies are exposed at various places northwest of Hackberry Wash where they intricately intrude the granitic basement complex and the younger Precambrian sedimentary rocks. Gross cutting relationships show that the quartz diorite masses are older than the dike rocks and probably represent the earliest Laramide magmatic pulse. The Sonora diorite exposed northwest of Kelvin and in the Ray mine area (Metz and Rose, 1966) megascopically somewhat resembles the quartz diorite bodies in the Hackberry Wash area, but the rocks in the two areas differ in composition. The different types will be described in a subsequent chapter.

The Laramide dike swarms are of regional extent. Similar rocks with similar orientation are present in the Troy area (Dripping Spring Mountains) to the east, in the South Butte-Red Hills area 10 miles to the west, at various places in the Crozier Peak quadrangle to the south (Medora Krieger, oral communication), and in the Christmas-Deer Creek area 15 to 20 miles to the southeast. The writer believes that this represents a fundamental tensional zone that became activated during Laramide time and was subsequently intruded by a dioritic to quartz monzonitic magma.

A pervasive east-northeast- to east-west-trending fissure vein system is exposed in the northern half of the map area. These mineralized fissures are younger than the hypabyssal rocks but are also considered to be of Laramide age.

West of the map boundary is a quartz monzonite pluton covering at least a 35-square-mile area centered around Grayback Mountain, a prominent landmark in this region. This large intrusive mass has not been previously recognized on any county or state geologic map of Arizona and will here be named Grayback granodiorite. The granodiorite is non-porphyritic, medium grained, and distinctly different from the coarsely crystalline Oracle Granite which surrounds it on all sides. A biotite K-Ar date yielded 63 million years for the granodiorite (Damon, 1970). The east-northeast-trending Laramide dike swarms approach and partly penetrate the Grayback granodiorite pluton from the northeast and southwest but do not completely transect the mass.

The youngest rocks exposed in the report area are sedimentary strata of Eocene(?) to Pliocene-Pleistocene age. The rocks vary considerably in lithology and texture and are found in two separate areas. The Ripsey Wash sequence, a newly named unit, forms a north-trending belt confined to the center of the map and consists of a lower boulder conglomerate unit, a middle tuffaceous sandstone unit, and an upper massive boulder conglomerate unit. The strata generally dip between 20° and 45° E.

The steeply dipping, very well indurated, reddish-brown to light gray conglomeratic sandstone units occurring in the eastern side of the Tortilla Mountains are here named the Hackberry formation. Interbedded shales and sandy layers are common. Usually, a basal massive boulder conglomeratic member immediately overlies the

Precambrian basement. The formation dips steeply to the east where it is in contact with the Precambrian basement complex but flattens gradually as the Gila River is approached. It is this formation that Ransome (1919) considered to be a special type of Gila Conglomerate. In this formation the allochthonous brecciated Paleozoic limestone sheets occur. No isotopic age dates are available from either of the formations in the immediate report area. The high degree of lithification in the Hackberry formation suggests that it is older than the Ripsey Wash sequence.

The northeast portion of the mapped area is underlain by massive cobble and boulder conglomeratic sequences which closely resemble the Gila Conglomerate so widely exposed in Arizona. Aside from local talus debris and alluvial sands, the Gila Conglomerate is the most recent formation; it overlies the sandstones and shales of the Hackberry formation with a marked unconformity.

In the following chapters each major rock types is described in detail sufficient to bring out mineralogical and textural variations as well as the structural peculiarities and complications which proved to be characteristic for the investigated area.

OLDER PRECAMBRIAN ROCKS

The major portion of the investigated area is underlain by a granitic intrusive complex that essentially consists of the coarse-grained porphyritic Oracle Granite, a genetically related aplite porphyry, and a distinctive transitional hybrid phase. Only the granite and the aplite porphyry have been separated on the geologic map (Fig. 5, in pocket). Their mutual contacts are well defined and can be easily distinguished in the field. The transitional hybrid phase, however, is completely gradational with the granite and the aplite porphyry, and its delineation requires painstaking detailed mapping.

No other older Precambrian rock types have been recognized. Pinal Schist is widely exposed in the Ray region, 5 miles north of Kelvin, but no outcrop of schist was found in the study area.

The igneous rock nomenclature used throughout this report is based on Johannsen's (1939) classification. The diagram used to plot modal anlyses is shown in Figure 6.

Oracle Granite

A coarse-grained porphyritic igneous rock resembling, in texture and composition, the Oracle and Ruin Granites crops out over the entire western portion of the study area and forms the backbone of the Tortilla Mountains. Peterson (1938) named the Oracle Granite for exposures in the Mammoth-Oracle area about 30 miles to the south, whereas Ransome (1903) described the Ruin Granite from exposures in Ruin

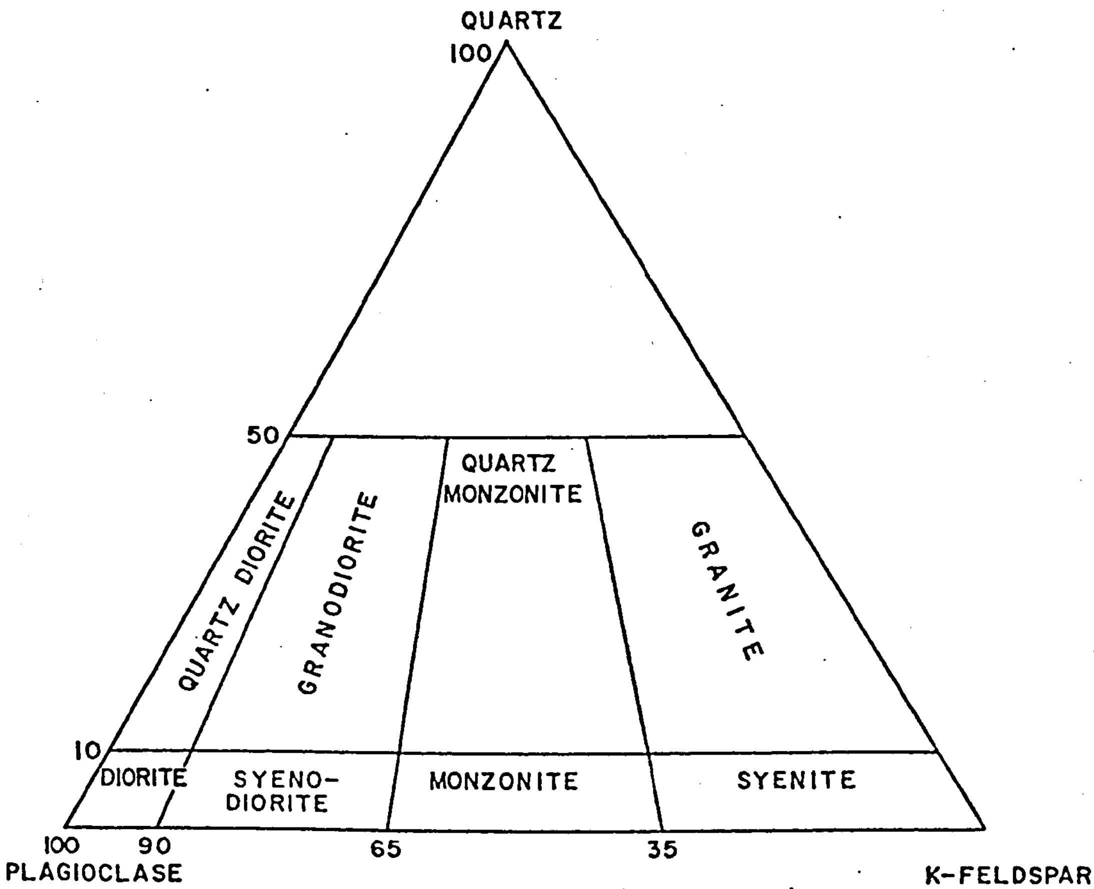


Figure 6. Igneous Rock Classification and Modal Analyses Diagram Used in This Report.--(After Johannsen, 1939; and Ross, 1969)

Basin located a few miles northwest of Miami, Gila County, Arizona. The Oracle and Ruin Granites are nearly indistinguishable in hand specimen. Because the Tortilla Mountains are structurally more closely related to the Mammoth area, the name Oracle Granite is retained here for the older Precambrian granitic rock.

Modal anlyses of the Oracle Granite from different localities are listed in Table 1, and the modal analyses given in Table 1 and other published modes of older Precambrian granitic rocks in central Arizona are plotted on Figure 7. The composition of the Oracle Granite shows considerable variation, but it is confined to the quartz monzonite field. Only two specimens fall on the quartz monzonite-granodiorite boundary and none is present in the granite field.

In hand specimen, the Oracle granite is characterized by numerous pink to red perthitic K-feldspar phenocrysts measuring up to 1 inch in diameter (Figs. 8 and 9). Together with somewhat smaller plagioclase grains they are surrounded by a medium-grained quartz-plagioclase K-feldspar matrix. Because of this large grain size, the Oracle Granite weathers readily into a coarse regolith.

Viewed microscopically, the rock has a holocrystalline, phaneritic, hypidiomorphic granular, very coarse grained porphyritic texture. Microperthite and microcline are the most conspicuous phenocrysts present (Figs. 10 and 11). Locally, microperthite contains individual microcline areas that become evident only upon rotation of the microscope stage. Plagioclase (oligoclase) usually shows weak to moderate sericite alteration confined especially to the central portion of the grains. In detail, the sericite is arranged in an orthogonal pattern within

Table 1.--Modal Compositions of the Oracle Granite

(Values in volume percent)

	1	2	3	4	5	6	7	8
Quartz	28	26	26	31	34	40.5	35	33
K-feldspar	37	31	21	24	21	16	35	30.5
Plagioclase	28	33	38	32	38	38	26	25
Biotite	5	10	15	13	5	--	2	9
Muscovite	--	--	--	--	0.5	0.5	--	--
Chlorite	--	--	--	--	0.5	3	1.5	--
Magnetite	--	--	--	--	1	2	0.5	--
Other	--	--	--	--	--	--	--	2

1. Mammoth mine (Peterson, 1938)
2. Dump of Tar mine (Creasey, 1967)
3. Near Oracle (Creasey, 1967)
4. Near Oracle (Creasey, 1967)
5. K-483B (this study)
6. K-74 (this study)
7. G-47 (this study)
8. Average of 10 analyses, south of Oracle (Banerjee, 1957)

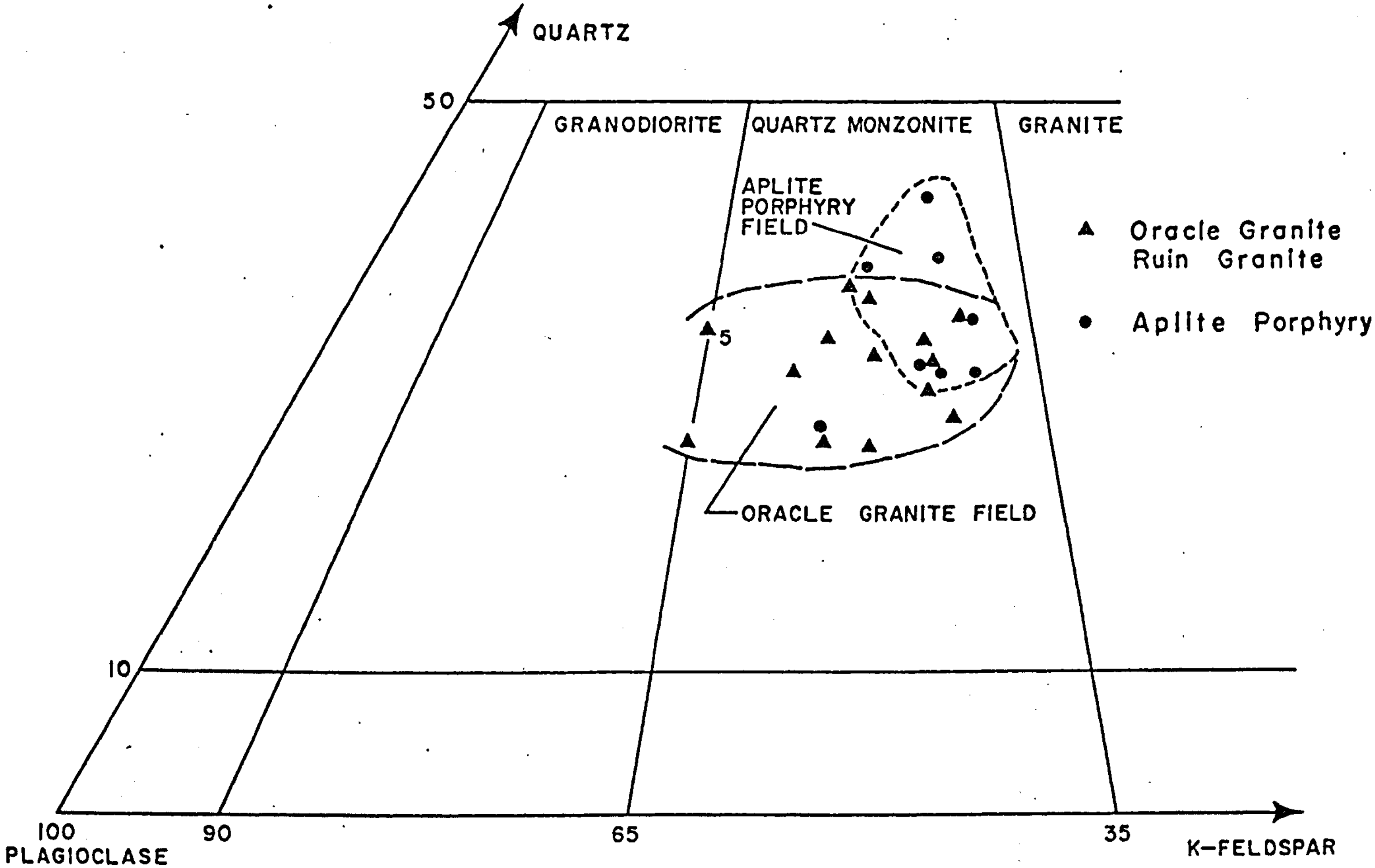


Figure 7. Compositional Plot of Oracle Granite, Ruin Granite, and Aplite Porphyry

The analyses are given in Tables 1 and 2.

Figure 8. Oracle Granite (K-678)

Irregular perthitic K-feldspar phenocrysts are set in a medium-grained quartz-plagioclase-K-feldspar-biotite matrix. Plagioclase is altered to green sericite; K-feldspar phenocrysts show secondary(?) orthoclase overgrowth.

Figure 9. Oracle Granite (K-74)

Subhedral K-feldspar phenocrysts and matrix feldspars contain abundant hematite dust causing the brick-red coloration. Numerous quartz-limonite veinlets are present in the outcrop.

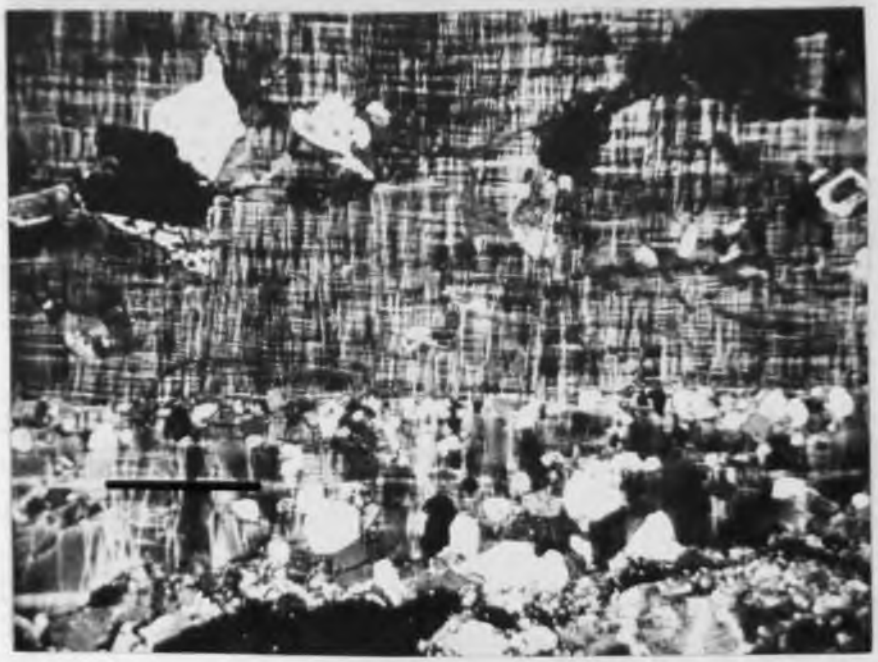


Figure 10. Photomicrograph of Oracle Granite (G-47)

Large microcline phenocrysts (up to 3 cm) in finer grained, holocrystalline matrix composed of undulatory quartz, sericitized plagioclase and irregular orthoclase. Note sharp boundary of quartz penetration into the margin of the microcline phenocrysts. Crossed nicols. Bar is 1 mm.

Figure 11. Photomicrograph of Oracle Granite (G-47) Showing Detail of Figure 10

Microcline phenocryst with typical polysynthetic twinning and quartz inclusions. Crossed nicols. Bar is 0.5 mm.

more or less well defined parallel zones in each grain. This selectivity probably reflects original compositional variations in the plagioclase crystal. Albite-low twin lamellae are usually completely destroyed. Plagioclase grains have generally a 0.25-0.10 mm wide, clear, Na-feldspar-rich(?) margin without any twinning. The rim is present regardless of whether or not the core portion of the plagioclase host is sericitized. The effect is most striking where a completely sericitized plagioclase grain is enveloped by a clear feldspar rim.

Brown biotite occurs either in large individual flakes or in 2-3 mm aggregates consisting of numerous 0.2-0.5 mm biotite flakes (Fig. 12). Magnetite may or may not be associated with the biotite clusters. Anhedral quartz is interstitial to subhedral plagioclase and biotite. Locally, quartz shows serrated edges and undulatory extinction. In general, the Oracle Granite is quite uniform in its appearance throughout the area. There are, however, local variations that merit mention.

A distinct biotite foliation occurs in the granite in the vicinity of Kelvin. The foliation trends N. 50°-80° E., dips steeply to north and south, and appears to be confined to a 1.5-mile-wide zone that roughly follows the course of the Gila River through the Tortilla Mountains.

A much more intense quartz-K-feldspar-biotite foliation occurs in the Oracle Granite southeast of Kelvin in a half-mile-wide zone that parallels the trend of the biotite foliation observed farther to the north. This distinct fabric results from the preferred orientation of spindle-like quartz aggregates up to 10 mm in length and pink K-feldspar phenocrysts up to 20 mm long (Fig. 13). In thin section, the elongate quartz grains have undulatory extinction (Fig. 14). Plagioclase grains are commonly

Figure 12. Photomicrograph of Biotite Aggregate in Oracle Granite (483B)

Rock is very coarse grained, hypidiomorphic granular to porphyritic with abundant 2-4 mm black biotite clusters. The latter consist of extremely fine grained, subhedral biotite flakes and magnetite grains. Parallel nicols. Bar is 0.5 mm.

Figure 13. Foliated Oracle Granite (K-11A)

Foliation is formed by crudely aligned K-feldspar phenocrysts, elongate quartz aggregates, and the parallelism of individual biotite flakes. Scale is in tens of feet.

Figure 14. Photomicrograph of Foliated Oracle Granite (K-418)

Strong foliation caused by preferred orientation of matrix quartz and K-feldspar. Note bending of plagioclase twin lamellae in phenocryst. Crossed nicols. Bar is 1 mm.

corroded and replaced by the foliated quartz matrix. Locally, very fine cataclastic quartz seams cut phenocrysts and foliated matrix alike. In general, the completely sericitized plagioclase grains are not aligned with the quartz foliation but are bent in the direction of foliation giving rise to incipient S-shaped configurations. In some places, plagioclase phenocrysts are displaced along their albit twin lamillae for a fraction of a millimeter. Chloritized biotite (pennine) and muscovite parallel the quartz foliation direction. Some larger chlorite flakes show kink bands. The pervasive foliationtrends almost normal to the granite-diabase contacts. In fact, no preferred mineral orientation is present in the adjacent diabase sheets. The significance and origin of this distinct foliation will be treated in a subsequent chapter.

Locally, the Oracle Granite is completely replaced by epidote with only the K-feldspar phenocrysts and matrix quartz remaining (Fig. 15). In other places, specular hematite and magnetite fill the interstices of brecciated granite. Moderate to strong iron staining after pyrite(?) occurs locally in silicified and sericitized granite giving the rock a brick-red appearance easily discernible from a distance. The east-trending quartz-hematite fissure-vein system in the Kelvin area is attended by only limited alteration of the host rock. Green sericite in the plagioclase and some silicification are the obvious alteration effects extending for 6 to 12 inches into the adjacent granite.

The Oracle Granite is overlain by the sedimentary rocks of the younger Precambrian Apache Group with a smooth depositional contact. Locally, the granite is more intensely iron stained as this contact is

Figure 15. Epidotized Oracle Granite (G-89)

The rock is completely replaced by epidote with only the K-feldspar phenocrysts and quartz matrix remaining.

approached. This phenomenon may reflect oxidation of the old weathering surface prior to the deposition of the Apache Group sediments.

Aplite Porphyry

A large portion of the area west of Ripsey Wash is underlain by irregular intrusive masses of a fine-grained leucocratic granitic phase herein named aplite porphyry. The rock is exposed in secs. 27, 28, 33, 34, T. 4 S., R. 13 E. and secs. 3, 4, 9, 10, T. 5 S., R. 13 E., where it forms prominent topographic features because of its resistance to weathering. A similar aplite porphyry mass is exposed in the vicinity of Kelvin.

The aplite porphyry is light gray to beige depending on the biotite content and has a fine- to medium-grained saccharoidal matrix. Plagioclase and K-feldspar phenocrysts measuring up to 1 inch in diameter constitute about 5 percent of the rock volume (Fig. 16). At some places the aplite contains areas of concentration of biotite 1-2 cm wide surrounded by a distinct 2-3 mm wide biotite-free halo (Fig. 17). These mafic clots show no systematic distribution pattern in the rock.

The aplite porphyry is a holocrystalline, phaneritic, hypidiomorphic granular rock with a very fine grained, nonfoliated interlocking texture. The grain size varies between 0.25 and 1 mm. The matrix consists of anhedral quartz (0.25 mm), subhedral sericitized plagioclase (0.5 mm) and subhedral microcline (0.5-1 mm). Very fine grained biotite is evenly distributed and is commonly altered to chlorite (pennine). The strongly sericitized matrix plagioclase (oligoclase) usually has a clear sodium-rich margin. Modal analyses of aplite porphyry are given in Table 2.

Figure 16. Photomicrograph of Aplite Porphyry (G-25)

Fine-grained, holocrystalline matrix is composed of quartz, microcline and completely sericitized plagioclase. A few microcline and biotite phenocrysts are partly resorbed by the matrix. Crossed nicols. Bar is 1 mm.

Figure 17. Aplite Porphyry (G-213)

Rock is fine grained containing a few K-feldspar phenocrysts and numerous 0.25-inch biotite clots with a narrow biotite-free halo zone. Pencil is 6 inches long.

Table 2.--Modal Compositions of Aplite Porphyry

(Values are volume percent)

	K-43	G-25	G-228	G-241	G-213	K-22
Quartz	27.3	30.8	31.2	32.0	35.1	38.8
Microcline	29.3	19.2	33.3	34.5	27.3	26.7
Microperthite	--	19.4	3.0	0.8	8.0	2.3
Plagioclase	34.9	25.1	28.0	29.2	23.6	28.9
Biotite	6.1	3.6	1.1	0.1	3.0	0.2
Muscovite	2.1	0.1	3.1	0.9	1.7	2.8
Chlorite	--	1.1	0.3	2.0	0.7	0.3
Magnetite	0.3	0.7	--	0.5	0.6	--

The aplite porphyry shows a much more restricted range in composition within the quartz monzonite field than the Oracle Granite (Fig. 7). Most of the values plot closer to the granite boundary. The K-feldspar-plagioclase ratio is slightly increased in favor of orthoclase. Quartz and muscovite are significantly more abundant in the aplite porphyry than in the Oracle Granite. However, biotite shows an inverse relationship by a factor of 2 to 4. Thus, it is evident that the aplite porphyry is enriched in K-feldspar, quartz, and muscovite as compared to the Oracle Granite. Because of the strong sericitization in the plagioclases it was not possible to decide by optical techniques whether the plagioclase phenocrysts in the aplite porphyry differ significantly in composition from the matrix plagioclase. The degree of sericitization is about the same in both.

The present outcrop pattern of the larger aplite porphyry masses suggests enormous sheetlike bodies (Figs. 5 and 18, in pocket). When tilted 90 degrees to the west to their original attitude they attain a nearly vertical position. This pattern suggests that the aplite porphyry bodies originally were dikelike features, several hundred feet thick, which intruded the partly solidified Oracle Granite. The temperature gradient across the contact could not have been very great because the aplite porphyry grades nearly imperceptibly into the Oracle Granite. The transition zone varies from a few to several hundred feet in width.

A strongly foliated variety of aplite porphyry occurs southeast of Kelvin where it appears to be bordered on the north and south by the distinctly foliated Oracle Granite described above. The aplite porphyry contains stretched quartz grains and K-feldspar phenocrysts measuring up to 10 mm and 20 mm in length, respectively. The foliated rock is bounded to the east and west by diabase dikes but no preferred fabric can be recognized in the latter. The foliation generally trends N. 45^{o}-80^{o} E. and dips steeply to north and south. The rock is holocrystalline, phaneritic, allotriomorphic granular with a fine- to medium-grained matrix. The elongate quartz eyes consist of individual anhedral, interlocking, slightly ellipsoidal grains with ragged edges measuring 0.25-0.5 mm in diameter. The quartz grains usually have undulatory extinction. Some elongate phenocrysts are subhedral microperthites and sericitized plagioclase averaging 2-5 mm in length. A modal analysis of foliated aplite porphyry (K-22) is given in Table 2. The composition of the foliated variety does not differ significantly from that of the main aplite porphyry mass and both are therefore considered to be the same rock type.

The foliation in the aplite porphyry as well as in the Oracle Granite must have formed some time before the intrusion of the younger Precambrian diabase for reasons already mentioned. It is believed that the foliation formed during the plastic stage of the solidifying granite and aplite porphyry and that it represents differential movement within the semi-consolidated magma. A similarly foliated aplite porphyry is exposed in sec. 14, T. 4 S., R. 13 E., where it forms a narrow northeast-trending ridge.

Transitional Hybrid Phase

Spatially intermediate between the Oracle Granite and the aplite porphyry there occurs, generally, a medium- to fine-grained rock composed of 50 percent aplite matrix and 50 percent phenocrysts (Fig. 19). The rock is holocrystalline, phaneritic, hypidiomorphic granular and is composed of anhedral quartz, subhedral microcline, clouded plagioclase, and biotite (Fig. 20). Foliation is generally absent.

The phenocrysts are anhedral quartz grains 2-4 mm in diameter, sericitized plagioclase 2-3 mm in diameter, microperthite up to 10 mm in diameter, and fresh biotite with some marginal muscovite flakes and opaque inclusions (Figs. 21, 22, 23, 24). The phenocrysts are completely surrounded by the matrix and show varying degrees of resorption. K—feldspar and plagioclase commonly contain numerous quartz inclusions.

The hybrid phase closely resembles the Oracle Granite and aplite porphyry in mineral composition and therefore indicates similar bulk chemical composition; it differs only in texture. The hybrid phase probably represents a zone of intimate reworking of the partially solidified Oracle Granite by the intruding aplite porphyry.

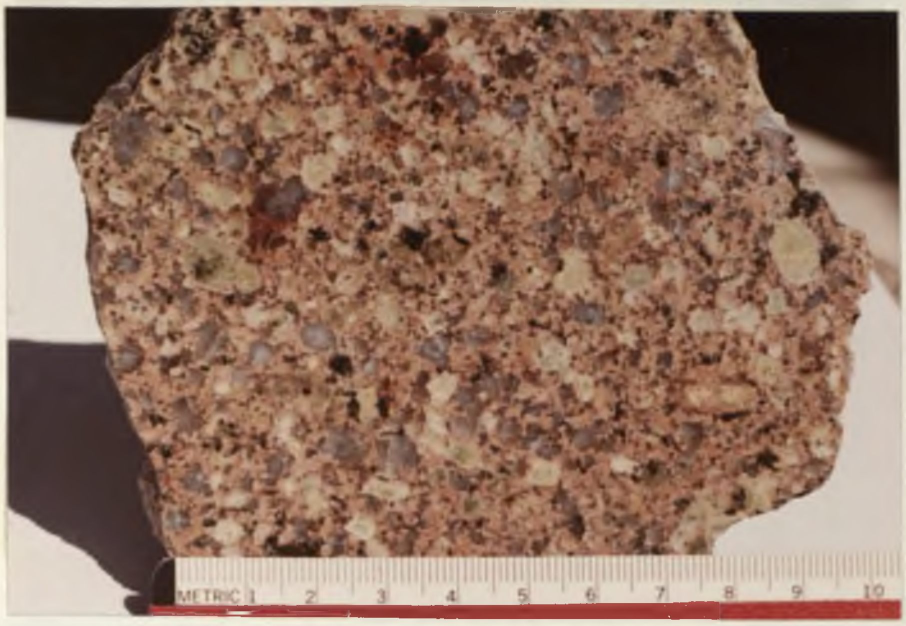


Figure 19. Hybrid Granite

K-feldspar, sericitized plagioclase and quartz phenocrysts are surrounded by an aplitic matrix.

Figure 20. Photomicrograph of Hybrid Granite (K-437)

Rock consists of fine- to medium-grained groundmass (Quartz, microcline, sericitized plagioclase, biotite and muscovite) surrounding larger quartz, sericitized plagioclase, biotite, and poikilitic microperthite grains. Crossed nicols. Bar is 1 mm.

Figure 21. Photomicrograph of Microperthite Phenocrysts in Hybrid Granite (K-437)

K-feldspar microperthite with albite exsolution lamellae. Phenocryst shows faint microcline grid upon rotation of the stage. Note sharp boundary of poikilitic border zone. Crossed nicols. Bar is 1 mm.

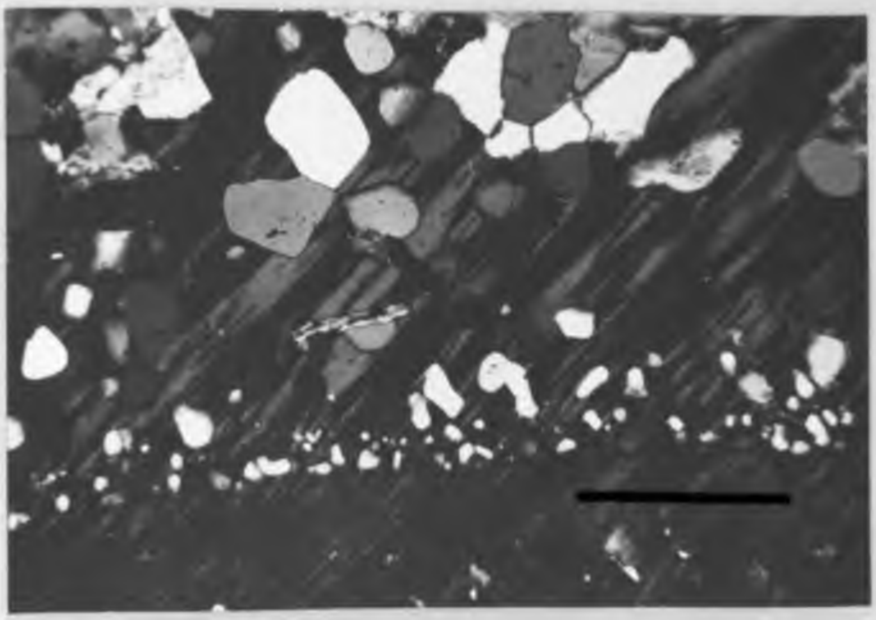


Figure 22. Photomicrograph of Microperthite Phenocryst in Hybrid Granite K-437) Showing Detail of Figure 21

Poikilitic border zone and albite(?) exsolution lamellae in microperthite phenocryst. Crossed nicols. Bar is 0.5 mm.

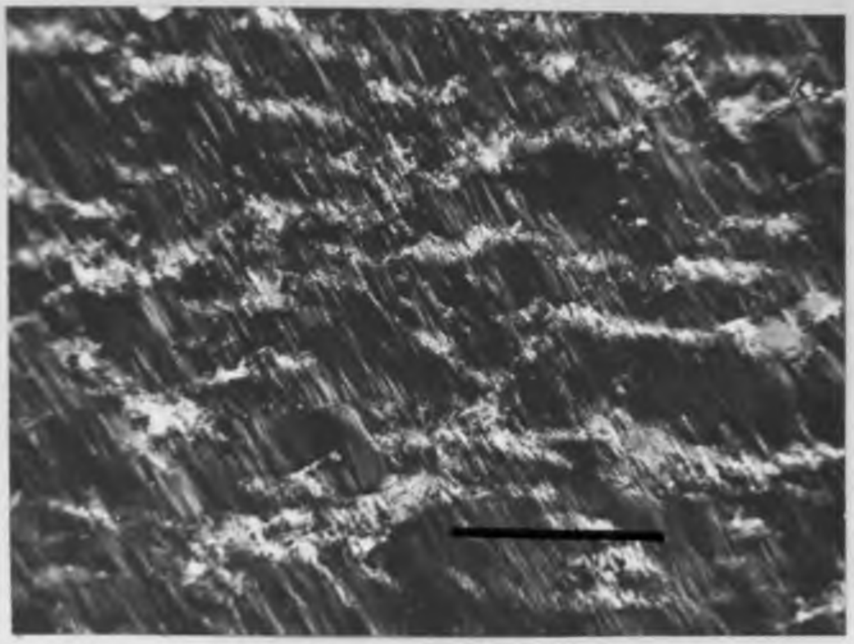


Figure 23. Photomicrograph of Hybrid Granite (K-437) Showing Albite(?) Exsolution Lamellae in K-feldspar Microperthite

Closely spaced, subparallel spindles are cut by larger irregular flame structures. Crossed nicols. Bar is 0.5 mm.

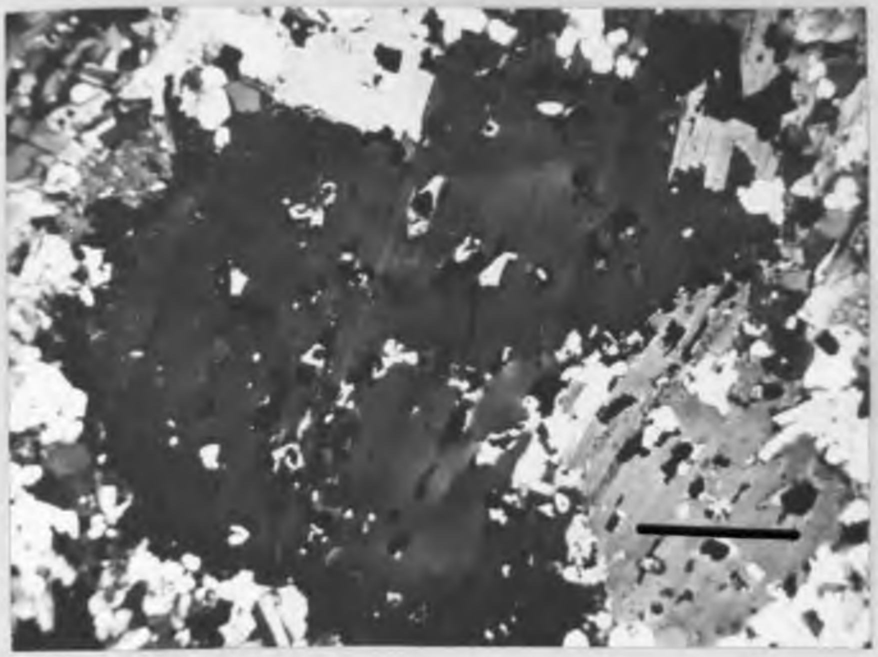


Figure 24. Photomicrograph of Hybrid Granite (K-437) Showing Biotite Phenocryst with Isolated Magnetite Grains

Crossed nicols. Bar is 1 mm.

Wraparound
very tight
Can you make it larger

Aplite Dikes

Many aplite dikes cut the Oracle Granite and transitional hybrid phase, but they have never been observed to cut the aplite porphyry masses. The dikes are a few inches to 100 feet wide and locally develop a pegmatitic texture composed of tourmaline, muscovite, and graphic intergrowths of quartz and K-feldspar. The aplites trend north-northeast and north-northwest, but in detail their path is much more irregular because of their shallow to moderate dip. The dikes differ from the aplite porphyry masses only in that they very seldom contain phenocrysts. The dikes show the typical saccharoidal texture which is identical in composition to the matrix of the aplite porphyry masses.

Because the dikes cut the older Precambrian granitic rocks they are definitely younger than the Oracle granite and the hybrid phase. They are older than the younger Precambrian diabase because the latter cuts the aplite dikes. The writer believes that the aplite dikes are of the same age or slightly younger than the aplite porphyry masses because they generally radiate away from the aplite porphyry bodies.

Jahns and Burnham (1969) recently suggested that a cooling granitic body consolidates in the final stages through crystallization from a silicate melt and coexisting aqueous fluid of lower viscosity. This condition is only realized if one assumes a closed system and an early crystallization of anhydrous mineral phases. A reduction of the confining pressure through newly formed fractures in the already solid upper portions of the granite will cause the escape of the dissolve water and concomitant quenching of the silicate melt to form aplites.

A similar process during the consolidation history of the Oracle Granite may very well have caused the formation of the aplite porphyry masses and associated aplite dikes.

Age and Correlation of the Older Precambrian Rocks

No isotopic age determinations are available for the Precambrian granitic rocks in this particular area. However, rocks of similar composition, texture, and stratigraphic position have been dated near Oracle by Giletti and Damon (1961), Damon, Livingston, and Erickson (1962), Damon, Erickson, and Livingston (1963), and Livingston et al. (1967), using Rb-Sr and K-Ar methods. The dates for the Oracle Granite range between 1,420 and 1,450 m.y. Creasey (1967) obtained an average lead-alpha age of 1,250 $\pm$ 140 m.y. from zircons collected from churn drill cuttings of the San Manuel ore deposit. The writer feels that Creasey's date is too young for what is generally considered to be Oracle Granite. Creasey maintains that a shorter half life for Rb-87 (47×10^9 m.y.) would decrease the Rb-Sr age of Giletti and Damon (1961) to 1,350 m.y., which, according to Creasey, is reasonably close to the average lead-alpha age. In any event, Creasey's date should be considered a minimum age for the Oracle Granite (Livingston, oral commun., 1970).

Livingston (1969) summarized the age relationships of the older Precambrian rocks in central Arizona and concluded that the Ruin Granite (porphyritic biotite quartz monzonite) of the Salt River Canyon, located about 45 miles northeast of Kelvin, gives average K-Ar and Rb-Sr dates of 1,440 $\pm$ 25 and 1,418 $\pm$ 10 m.y., respectively. These dates are in good agreement with the ones obtained from the Oracle Granite. Silver

(1968) reported a U-Pb zircon date of 1,430-1,460 m.y. for the Ruin Granite in Ruin Basin.

Thus, there is convincing evidence from isotope geochronology that the coarse-grained, porphyritic biotite quartz monzonite and associated aplite in central and southeastern Arizona are of older Precambrian age. Stratigraphic evidence in the Tortilla Mountains confirms this conclusion. Wherever exposed, the Apache Group overlies the granitic basement complex with a depositional unconformity. Furthermore, extensive diabase sills and dikes considered to be of younger Precambrian age intrude both the granitic complex and the sedimentary rocks of the Apache Group. Finally, the older Precambrian rocks are systematically cut by hypabyssal rocks of Laramide age.

YOUNGER PRECAMBRIAN ROCKS

In southeast Arizona the younger Precambrian period is represented by the sedimentary rocks of the Apache Group, the Troy Quartzite, and extensive sill and dikelike intrusive bodies of diabase. The main exposures occur in the Sierra Ancha Mountains, Gila County, but isolated outcrops are recognized southward to the latitude of Tucson and westward in the Vekol and Slate Mountains (Shride, 1967).

The younger Precambrian exposures in the Sierra Ancha Mountains and near Globe to the south are relatively undisturbed and flat lying. This attitude contrasts markedly with exposures present west of the Gila-San Pedro River lineament where remnants of the Apache Group and Troy Quartzite are invariably tilted into a vertical position and locally overturned. This deformation is well displayed in the Mineral Mountain area (Schmidt, 1967), Tortilla Mountains (this report), and the Crozier Peak-Putnam Wash area (Krieger, 1969).

The younger Precambrian sedimentary rocks and coextensive diabase sills crop out in two distinct north-trending ridges in the southeast corner of the investigated area. The units are, for the most part, vertical or slightly overturned to the west. Locally, in disturbed areas, the beds dip 30°-60° E. Because of its resistance to weathering, the Apache Group can be followed for the entire exposed strike length without difficulty. The Barnes Conglomerate serves as an excellent marker horizon, especially in faulted areas.

The Apache Group is generally divided into three formations which in ascending order are: Pioneer Formation with the basal Scanlan Conglomerate member, Dripping Spring Quartzite with the basal Barnes Conglomerate member, and Mescal Limestone. Locally, a thin amygdaloidal basalt layer occurs above the Mescal Limestone which, where present, serves as a marker horizon between the uppermost Apache Group sequence and the overlying Troy Quartzite. The latter is the youngest unit of the younger Precambrian sedimentary sequence.

Near Hackberry Spring the entire Apache Group and the diabase have been intricately intruded by the Laramide quartz diorite stock. Small apophyses of diorite extend into the sedimentary rocks and locally completely engulf individual blocks and fragments. No change in strike and dip is measurable in the adjacent Apache strata even though the units strike nearly at right angles into the diorite stock.

Because every formation of the younger Precambrian sedimentary sequence is present in this area a short description of each unit is in order. No attempt is made to give a complete stratigraphic analysis of the sequence nor to subdivide each formation into several members as was done by Creasey (1967) in the Mammoth quadrangle and by Shride (1967).

Apache Group

Pioneer Formation

The Pioneer Formation was named by Ransome in 1903 from exposures found near the abandoned mining settlement of Pioneer in the Mescal Range, located about 15 miles northeast of the study area. At the type locality, the formation is about 200 feet thick and consists of dark reddish-brown, somewhat arenaceous shales composed mainly of fine arkosic detritus. A coarse pebbly layer always present at the base of this Scanlan Conglomerate varies in thickness from a few inches to 5 feet. In agreement with Shride (1967), the Scanlan Conglomerate is considered by the author to be a basal member of the Pioneer Formation. The contact is therefore shown as a dotted line at the base of the Pioneer on the geologic map (Fig. 5, in pocket).

The Scanlan Conglomerate rests with an angular unconformity upon the older Precambrian granitic basement complex and represents the first reworked debris of the younger Precambrian transgressive sea. Judging from the unusually straight contact line, the erosion surface upon which the conglomerate was deposited must have been relatively smooth and without any major topographic relief. Later faulting complicated this relationship considerably as is shown in section 5 west of Hackberry Wash and section 12 north of the old Ripsey mine.

The Scanlan Conglomerate is composed of well-rounded 2-inch quartz and red chert pebbles in an arkosic matrix. The unit ranges from 5 inches to 5 feet in thickness. The arkosic matrix closely resembles the underlying Precambrian granite and obviously represents reworked granite. At some places, occasional quartz or chert pebbles are the only signs of the Scanlan Conglomerate (Fig. 25). Locally, the contact is offset by numerous cross faults with displacements up to several hundred feet.

In sec. 12, T. 5 S., R 13 E., good contact relationships between the Scanlan Conglomerate and the underlying granite are exposed.

Figure 25. Vertical Disconformable Contact Between Older Precambrian Oracle Granite (p€gr) and Younger Precambrian Pioneer Formation (p€pf)

A few quartzite pebbles at the base of the Pioneer Formation are the only sign of Scanlan Conglomerate in this outcrop. Looking north. SW1/4 sec. 32, T. 4 S., R. 14 E.

The conglomerate here is 2 feet thick and contains well-rounded quartz pebbles in an arkosic to shaly matrix. The north-trending contact is overturned with a dip of 63° SW.; therefore, Oracle Granite overlies Scanlan Conglomerate in outcrop. Five feet stratigraphically above this contact is a dark-purple sandy shale unit that contains a 3-inch layer rich in quartz and feldspar fragments. The individual pink K-feldspar crystals are subhedral to euhedral in outline and are aligned with their long prism faces parallel to the bedding. These fragments probably represent the reworked regolith of the old granite surface.

The basal conglomerate gives way upward to a firmly indurated dark-maroon siltstone or mudstone containing abundant arkosic detrital material. Fragments of pink K-feldspar are common. Delicate cross laminations in the red siltstone can be recognized. This same unit also contains numerous oxidation spots a few millimeters in diameter with limonite pseudomorphs after pyrite(?) in their centers. The upper part of the Pioneer becomes more quartzitic and light gray.

The thickness of the Pioneer Formation cannot be accurately determined because the unit is extensively intruded by diabase and covered by talus debris. Assuming that no assimilation by the diabase took place, a maximum thickness of 200 feet is evident from the outcrop pattern. Locally, the formation may thin to 75 to 100 feet.

The Pioneer Formation is overlain by the Barnes Conglomerate member of the Dripping Spring Quartzite with an apparent conformable contact.

Dripping Spring Quartzite

The Dripping Spring Quartzite and its basal Barnes Conglomerate were described by Ransome in 1903 from exposures at Barnes Peak, Gila County, the type locality for the Apache Group. There the quartzite conformably overlies the Pioneer Formation and is conformably overlain by the Mescal Limestone. At the type locality the Dripping Spring Quartzite measures 420 feet in thickness.

In the study area, as well as in other parts of central Arizona, the Barnes Conglomerate serves as an excellent marker horizon to separate the Pioneer Formation from the Dripping Spring Quartzite. In the Tortilla Mountains, the Barnes Conglomerate ranges in thickness from 35 to 50 feet and is therefore shown as a distinct unit on the geologic map. Even though the conglomerate attains a mappable thickness, it is here considered to be the basal member of the Dripping Spring Quartzite in compliance with Shride (1967) and not a separate formation.

The Barnes Conglomerate consists of very resistant, ellipsoidal quartz and red chert pebbles embedded in a coarse-grained arkosic matrix (Fig. 26). The pebbles are generally 4-6 inches in diameter and lie with their longest axes parallel to the bedding plane. The unit is very well indurated and usually breaks across the pebble fragments (Figs. 27, 28). Its resistance to weathering causes the conglomerate to be exposed along ridge tops. Excellent exposures occur near Hackberry Spring and in several canyons farther west where they cross the ridges at nearly right angles.

The sudden change from a shaly sequence to a conglomerate suggests a new period of erosion and sedimentation. However, no

Figure 26. Barnes Conglomerate Showing Well-rounded, White Quartz, Grayish-red Quartzite, and Red Chert Pebbles Embedded in Arkosic Matrix

Figure 27. Barnes Conglomerate Showing Well-rounded Red Chert and Quartzite Pebbles Embedded in a Firm Arkosic Matrix

Note closely spaced fracture system which cuts and slightly offsets individual pebbles and cobbles.

Figure 28. Detail of Fracture Surface Cutting Indiscriminately Through Well-rounded Pebbles and Firm Matrix of Barnes Conglomerate

Plastic scale is 6 inches long.

unconformity was observed between the Pioneer Formation and overlying Barnes Conglomerate. At one locality in section 12, about half a mile east of Ripsey Wash, the arkosic matrix of the conglomerate extends into the underlying shale for several inches along open fractures. This indicates that the Pioneer Formation was sufficiently consolidated at the time the Barnes Conglomerate was deposited to maintain fractures. How much of the Pioneer has actually been eroded prior to the deposition of the Barnes Conglomerate is impossible to estimate. The matrix of the Barnes certainly shows more affinity to the granitic basement complex than to the shale horizons lying immediately below it.

According to Granger and Raup (1964) the Barnes Conglomerate and portions of the overlying Dripping Spring Quartzite were sorted and redistributed from talus outwash by an encroaching sea and deposited in a shallow basin.

The conglomerate gives way to a massive, light reddish-brown, medium- to coarse-grained quartzite unit which forms prominent cliffs and ridge tops. Locally, the quartzite becomes arkosic and pebbly, containing abundant pink K-feldspar and quartz fragments. Crossbedding is common in the more massive units, and well-preserved ripple marks locally occur along steep bedding planes (Fig. 29).

The upper portion of the Dripping Spring is thin bedded giving the rock a laminated appearance. The individual beds range from 2 to 12 inches in thickness and are of a deep reddish-brown to pale yellowish-gray color. The sequence alternates between arenaceous shales and quartzite. Minute specks of iron oxide are finely disseminated in the coarser portions of the shale. These limonite specks appear to be pseudomorphs after diagenetic pyrite.

Figure 29. Ripple Marks in Dripping Spring Quartzite

Vertical bedding planes display excellent ripple marks. Fractures and bedding surfaces are coated with limonite. Outcrop is in a steep wash west of the Florence mine.

The thickness of the Dripping Spring Quartzite is difficult to determine because of the presence of extensive diabase sills and structural complications. Nowhere is the unit exposed in its entirety in one outcrop. As indicated on the geologic map (Fig. 4, in pocket), the thickness of exposures ranges from 500 to 650 feet.

Discussion. According to Granger and Raup (1964) and Shride (1967), who paid particular attention to the Dripping Spring Quartzite in Gila County, the source area for most of the clastic material was to the south. Granger and Raup (1964) based their conclusion on a careful examination of various sedimentary features, such as grain size, roundness, cross-stratification, imbrication, paleochannels, and ripple marks. The isopach map for the Dripping Spring Quartzite in Gila County (Fig. 30) indicates that the basin of deposition for the Apache Group apparently was a northeast-elongated embayment which was part of a much larger and deeper sea to the northwest (Pinal and Pima Counties). The isopach map also shows a persistent thinning of the Dripping Spring to the north toward the Mazatzal Mountains and to the southeast. Concomitant thickening of the formation occurs to the west and southwest. Unfortunately, very few exposures of Apache Group remain in areas that were once the deepest portions of the younger Precambrian sea (Slate and Vekol Mountains). The area of the present-day Tortilla Mountains lies south of the embayment along the edge of the basin.

Mescal Limestone

The Mescal Limestone overlies the Dripping Spring Quartzite with an apparently conformable contact. Ransome (1919) named the Mescal Limestone after exposures found in the Mescal Mountains about

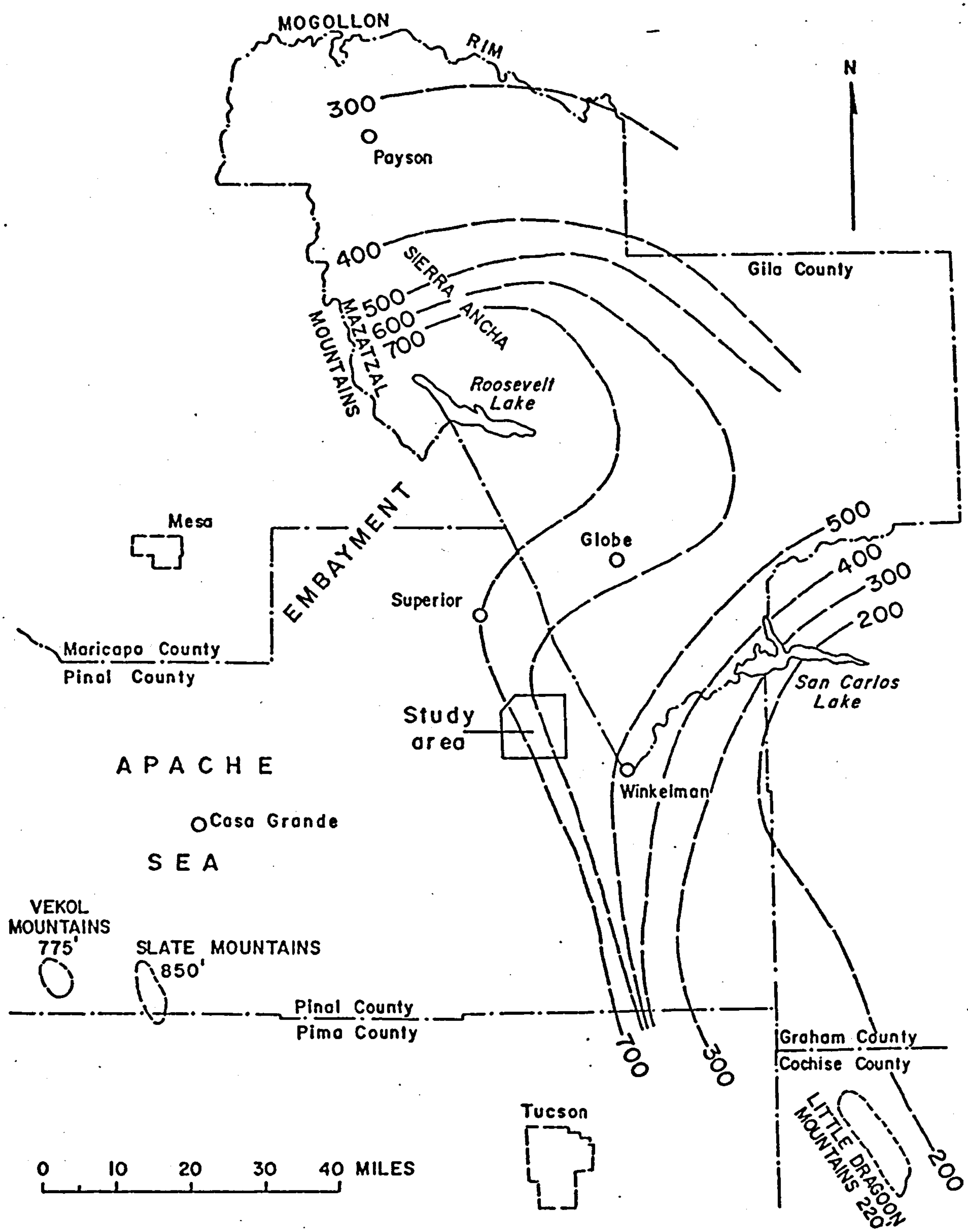


Figure 30. Isopach Map of Dripping Spring Quartzite in Central Arizona.--Modified from Granger and Raup (1964)

15 miles northeast of the investigated area. At El Capitan Canyon, the type locality, the formation is 225 feet thick. In the Tortilla Mountains the limestone varies in thickness from 200 to 250 feet. Excellent exposures of the unit occur at Hackberry Wash and west of the Florence mine where its attitude is either vertical or steeply inclined to the east.

The lower portion of the Mescal is a thinly bedded, impure, shaly limestone containing abundant riblike chert layers and chert concretions (Fig. 31). The rock is typically reddish brown to pale yellowish green. Near the southern boundary of sec. 1, T. 5 S., R. 13 E., a crudely bedded dolomitic limestone is present with distinct black chert nodules and laminae. This unit is brecciated and contorted. Only 25 feet of this black chert dolomite are exposed below Tertiary gravel cover.

Near the center of the formation there are numerous stromatolitic structures that are well exposed in a small wash west of the Florence mine within steeply dipping beds. This portion probably corresponds to the algal member of Shride (1967). Elsewhere in the area, the central portion of the Mescal is a massive, light-gray, recrystallized limestone in which the original bedding planes appear to be outlined by gray chert layers. Locally, epidote-rich zones occur in the limestone, especially where Laramide monzonite porphyry dikes and small diorite bodies cut the sedimentary sequence.

The upper portion of the Mescal Limestone is a 10-foot wide silicified layer which originally may have been a tuffaceous unit. This unit is very finely laminated, dark reddish brown, and resembles a banded rhyolite. This rock is well exposed in the wash west of the Florence mine.

Figure 31. Mescal Limestone

Siliceous laminae and cherty nodules stand out in high relief on the weathered surface of this dolomitic member. Length of exposure is about 2 feet. Photograph taken along power line road in S1/2 sec. 1, T. 5 S., R. 13 E.

A peculiar non-fossiliferous limestone, believed to be Mescal, occurs near the northern boundary of sec. 12, T. 5 S., R. 13 E., adjacent to the Tertiary gravel cover. The strata are strongly distorted and form a southwest-plunging fold. An irregular east-west-trending monzonite porphyry dike cuts the units and separates the Mescal(?) limestone from the Troy Quartzite exposed 50 feet to the south.

The Mescal Limestone is usually overlain by an amygdaloidal basalt flow 10-50 feet thick. The rock is dark purplish gray, strongly weathered, and oxidized, and contains abundant spherical to ellipsoidal amygdales that are filled with chalcedony and/or zeolites. The basalt flow is generally considered to be the uppermost unit of the Apache Group and aids greatly in separating the latter from the overlying Troy Quartzite.

Troy Quartzite

The Troy Quartzite is the uppermost formation of the younger Precambrian sedimentary sequence. The unit was first described by Ransome (1919) in the Ray quadrangles where he assigned a Cambrian age to the formation. The quartzite is named after Troy Mountain in the Dripping Spring Mountains where the unit attains a thickness of 362 feet.

The Troy rests with a paraconformable contact upon the vesicular basalt flow. On a regional scale, however, an unconformity between the Apache Group and the Troy Quartzite can be recognized (Shride, 1967).

Within the report area the formation is not as widely exposed as the Apache Group because of extensive overlap by the Tertiary gravel deposits. Good exposures of Troy Quartzite occur at Hackberry Wash (Figs. 32, 33) and west of the Florence mine in the east half of sec. 12, T. 5 S., R. 13 E.

Near the base of the unit there is a conglomerate layer 5-10 feet thick which contains well-rounded quartzite and red chert pebbles embedded in a coarse quartzitic matrix. The lower portion of the unit is commonly excessively iron stained.

The main part of the formation consists of massive, light-gray, pebbly quartzite beds that measure several feet in thickness. Abundant limonite coatings on weathered surfaces give the formation a dark reddish-brown appearance from a distance. The uppermost exposed Troy Quartzite at Hackberry Wash is thinly bedded, almost laminated, and quite different in character from the massive quartzite units below. In Hackberry Wash, the formation is about 350 feet thick; north of Florence mine, the quartzite is 400 feet thick. This figure is far less than the 1,200 feet measured by Shride in the Sierra Ancha Mountains and indicates that the Tortilla Mountains are located near the southern limit of the Troy Quartzite depositional basin as postulated by Krieger (1961, 1968a, b, and d).

Diabase

Mode of Occurrence

Diabase is one of the more extensive intrusive rocks in the Tortilla Mountains and appears in two modes of occurrence: as sill-like sheets 20-250 feet wide in the Apache Group and as irregular intrusive bodies and dikes up to 1,500 feet thick in the older Precambrian basement

Figure 32. Troy Quartzite near Hackberry Spring Looking West
The steeply inclined strata form conspicuous cliffs.

Figure 33. Troy Quartzite near Hackberry Spring Looking South

Individual beds of steeply inclined strata range from a few inches to 3 feet in thickness.

complex. The term "basement sill" will be used throughout this report for diabase intrusive bodies that occur in the granite basement complex to imply their original sheet-like nature (Hamilton, 1965). The larger diabase masses occur north of the Ripsey mine, sec. 12, T. 5 S., R. 13 E., and at various places throughout the Tortilla Mountains.

The diabase sills are generally concordant in the dipping Precambrian strata and trend in a northerly direction. Locally, they show crosscutting relationships. The sill contacts with the Apache sedimentary rocks are always straight and sharp, and there is no evidence of assimilation by the intruding diabase. Only the Pioneer Formation and the Dripping Spring Quartzite were penetrated by the diabase magma in the study area. Elsewhere in southeast Arizona, notably the Mescal Mountains (Ransome, 1919), the Mineral Mountain quadrangle (Schmidt, 1967), and at Superior (Sell, 1960), the Mescal Limestone serves as the favored host for the diabase intrusion. Because the diabase offers little resistance to erosion, exposures are generally poor except where steeply dipping sills are cut by washes and canyons (Fig. 34).

Chilling of the diabase is always present for several feet from the contacts indicating a significant temperature gradient across the contact zone at the time of intrusion. However, no megascopic metamorphic effect is evident in the adjacent sedimentary rocks. The sedimentary strata above and below the diabase sills show no change in their overall attitude nor do they bend where the diabase cuts across the units.

In the western part of the area, the largest and most varied diabase exposures occur within the granitic basement complex. The sill

Figure 34. Joint Pattern in a Diabase Basement Sill

At least three well-defined fracture directions can be recognized. Exposure is along a wash in NW1/4 sec. 30, T. 4 S., R. 14 E.

contacts are sharp, generally steep, and chilled for several feet. However, in detail, their trend is very irregular. Small diabase apophyses commonly extend into the granite for some distance before dying out. Some of the larger basement sills in the main Tortilla range can be followed for several miles before they diverge and continue as smaller sill-like bodies. Locally, large blocks of granite are completely surrounded by diabase at the present level of erosion giving the appearance of huge xenoliths. Some of the isolated blocks are 1,000 feet in diameter. However, the writer believes that the blocks are not true xenoliths as one would picture them "floating" in diabase magma but are merely slabs isolated in plan. Their third dimension could be much larger than the exposed two-dimensional diameter.

The diabase-granite contacts are very steep, dipping 90 degrees with a 15-degree variation either way. In the Kelvin area, however, many contacts appear nearly horizontal. The situation there is complicated by abundant low-angle faulting which is discussed in more detail in a subsequent chapter.

It is interesting to note that the more extensive diabase bodies in the Oracle Granite occur near or just below the Apache Group contact. This phenomenon is well exposed in the Ripsey mine area where the diabase intricately dissects the granite-Apache Group contact zone. If this spatial relationship holds true, i.e., that the more massive diabase sheets were preferentially emplaced in the granitic basement near the base of the Apache Group, then it is fair to assume that the Apache Group originally extended much farther north along the east side of the Tortilla Mountains, as is presently shown on the geologic map. The northernmost occurrence of Pioneer Formation and Dripping Spring Quartzite is in the southwest corner of sec. 32, T. 5 S., R. 14 E., where the units are discordantly overlain by mid-Tertiary conglomerates and sandstone. Father north, the conglomerate lies directly on the granitic basement, but its basal portion is invariably composed of angular to subangular cobbles and boulders of Apache sedimentary rocks and Troy Quartzite. This relationship suggests that the younger Precambrian sedimentary rocks were exposed to erosion during mid-Tertiary time perhaps as far north as Kelvin even though no Precambrian sedimentary rocks crop out there now.

Fartherwest in the granitic basement, the diabase sheets steadily decrease in thickness to an average of 50 to 75 feet. Just west of Ripsey Wash in the southern half of the map area, a north-trending diabase triplet occurs whose characteristic pattern aided greatly in deciphering deformation by serving as a marker horizon in the otherwise structureless granite.

The width of individual diabase sills apparently is not related to the grain size of the rock. Several 10 to 50 foot wide basement sills in the western portion of the area along the Florence-Kelvin road are extremely coarse grained, whereas large intrusive bodies in the Tortilla Mountains farther east are fine to medium grained. Sufficiently detailed work has not been carried out by the writer on each of the large diabase sills to determine whether one is dealing with single or multiple intrusive events. Multiple intrusive events have been recognized by Shride (1967), Nehru and Prinz (1970), and Smith (1970) in the Sierra Ancha Mountains and elsewhere in southeast Arizona.

Petrography

The diabase varies greatly in composition and texture from unit to unit as well as within a single dike or sill. The diabase is a greenish-gray to black, holocrystalline, phaneritic, fine- to coarse-grained, hypidiomorphic granular rock with a typical diabasic to ophitic texture. Locally, it becomes distinctly porphyritic. The margins of the diabase intrusive bodies are always chilled, and there is a complete gradation from a coarser grained core portion to an aphanitic border zone. No flow-banding, flow-differentiation, or crystal-settling phenomena were observed.

The diabase varies in composition from a tholeiitic quartz diabase to a quartz-free variety. The quartz diabase frequently contains granophyric intergrowths along the margins of plagioclase grains. Modal analyses from several thin sections are listed in Table 3.

Table 3.--Modal Compositions of Diabase

	K-245B	K-225	K-187	K-675	K-520A	G-86A	G-95
Plagioclase	44.4	41.6	52.0	53.0	55.9	56.0	44.5
Pigionite	49.1	5.9	40.5	24.0	35.9	--	--
Hornblende chlorite	0.3	40.0	4.0	13.0	--	41.0	51.5
Biotite	2.0	--	0.5	tr	1.1	--	--
Quartz	3.2	0.2	2.0	--	--	--	--
Magnetite (ilmenite?)	1.0	10.7	1.0	10.0	7.1	3.0	4.0
Apatite	--	2.5	tr	tr	tr	tr	tr

Plagioclase is the major constituent in nearly all specimens examined and ranges in composition from andesine to labradorite. It crystallized early in the magma and occurs in slender subhedral laths that measure between 0.3 and 2 mm in length. Plagioclase commonly shows incipient to nearly complete sericitization in a single specimen. This selective replacement of plagioclase may reflect compositional variation. In many specimens plagioclase encloses and cuts anhedral to subhedral augite and pigionite grains giving rise to a typical diabasic texture (Fig. 35). In other examples, large subhedral pyroxene masses with a greater diameter than plagioclase grew simplicially between the feldspar laths forming an ophitic texture. The pyroxenes show various stages of alteration to hornblende and chlorite. In two specimens (G-86A and G-95) original pyroxene is completely recrystallized to a felty mass of very fine grained hornblende (Fig. 36), and in specimen G-5A, pyroxene is complctely replaced by serpentine (Fig. 37). Hornblende and serpentine also extend into the adjacent plagioclase along minute cracks. The two specimens mentioned are actually gabbroic because of their very large grain size.

The percentage of magnetite (ilmenite?) varies greatly from sample to sample as shown in Table 3. The opaque minerals occur either finely disseminated throughout the rock or in larger irregular blebs penetrating plagioclase and pyroxene along grain boundaries. Skeletal magnetite blebs are common (Figs. 38, 39). Usually, a rim of red-brown biotite developed around the larger magnetite grains at the expense of pyroxene (Fig. 40).

Figure 35. Photomicrograph of Diabase (K-675)

Subhedral plagioclase laths extend into a large pigionite grain and form a subophitic texture. Crossed nicols. Bar is 1 mm.

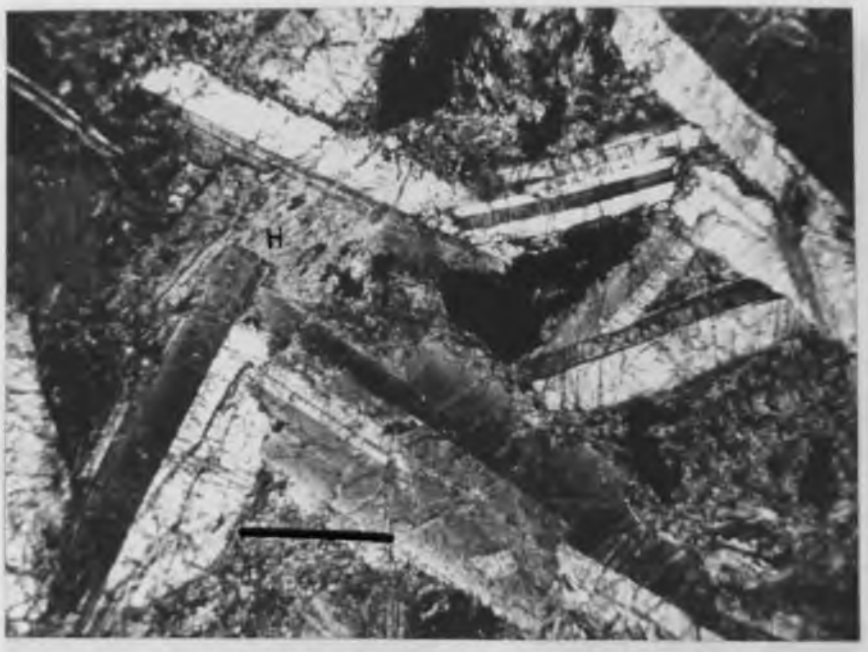


Figure 36. Photomicrograph of Altered Diabase (G-86A)

Finely crystalline hornblende (H) extends into plagioclase along minute cracks. The felty hornblende is an alteration product of augite and pigionite. Note the very coarse plagioclase crystals. Crossed nicols. Bar is 1 mm.

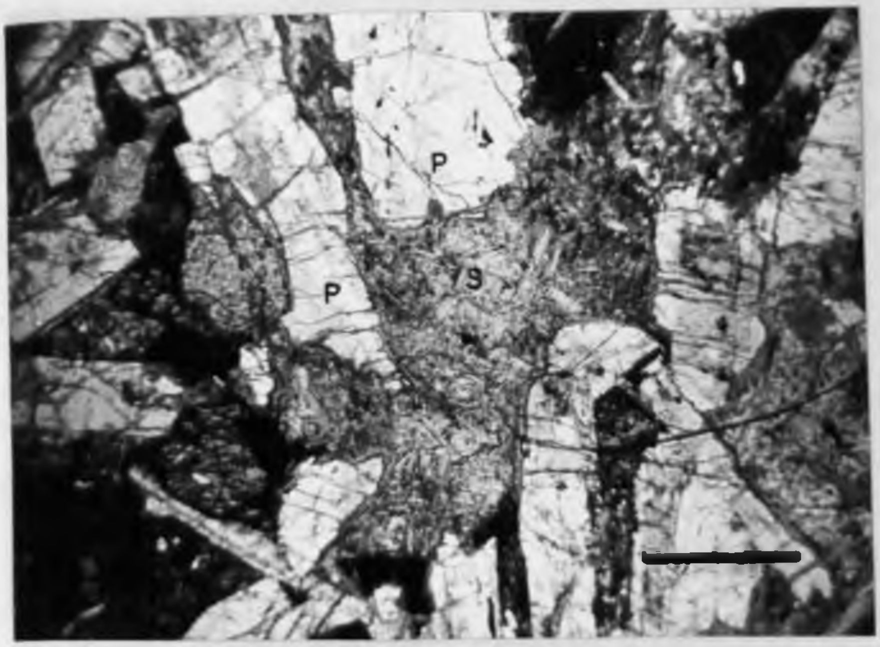


Figure 37. Photomicrograph of Altered Diabase (G-5A)

Complete serpentinization (S) of augite and pigionite has also attacked adjacent plagioclase (P). Serpentine commonly cuts plagioclase along fine hairline fractures. Parallel nicols. Bar is 1 mm.

Figure 38. Photomicrograph of Skeletal Magnetite in Diabase (G-5A)

Magnetite replaces augite and pigionite along crystallographic directions. Parallel nicols. Bar is 0.5 mm.

Figure 39. Photomicrograph of Skeletal Magnetite in Diabase (K-341)

Magnetite forms at the expense of augite and pigionite along crystallographic boundaries (A). Magnetite extends also partly into plagioclase (P). Parallel nicols. Bar is 0.5 mm.

Figure 40. Photomicrograph of Magnetite in Diabase (K-520A)

Irregular magnetite grain fills interstices between unaltered plagioclase (P) laths. Finely crystalline red biotite (B) forms adjacent to magnetite at the expense of pyroxene(?). Parallel nicols. Bar is 0.5 mm.

In the tholeiitic diabase sills, very fine grained, anhedral quartz occurs between plagioclase and pyroxene. Locally, a granophyric intergrowth of quartz and K-feldspar formed around individual plagioclase laths. Turner and Verhoogen (1960) explain the granophyres as late differentiates of a basaltic magma upon cooling during intrusion. Limited assimilation of the host rock (granite or sedimentary) at the time of intrusion may also enrich the magma in silica and alkalies near the margins. This possibility, however, has to be ruled out because no such features have been observed. As pointed out by Anthony (1960), no extensive assimilation of the host rock by the intruding diabase should be expected because of the extreme differences in composition between the rock types involved.

Anomalously large apatite crystals measuring 1-2 mm in length are locally present and cut plagioclase and pyroxene alike. Apatite may constitute 2.5 percent of the modal composition (K-225).

Petrography of a Diabase Sill

A 470-foot-wide diabase basement sill was systematically sampled to demonstrate the change in texture and mineral variation from the lower to the upper contact. The diabase intrudes Oracle Granite and is exposed in sec. 30, T. 4 S., R. 14 E. The feature is well exposed over its entire width because of the steep dip and can be easily traversed along a shallow wash. The samples were collected at predetermined intervals ranging from 1-5 feet near the contacts to 50 feet in the center of the diabase body. The upper and lower contacts with the Oracle Granite are very well exposed. Modal analyses that were used to construct Figure 41 are tabulated in Table 4.

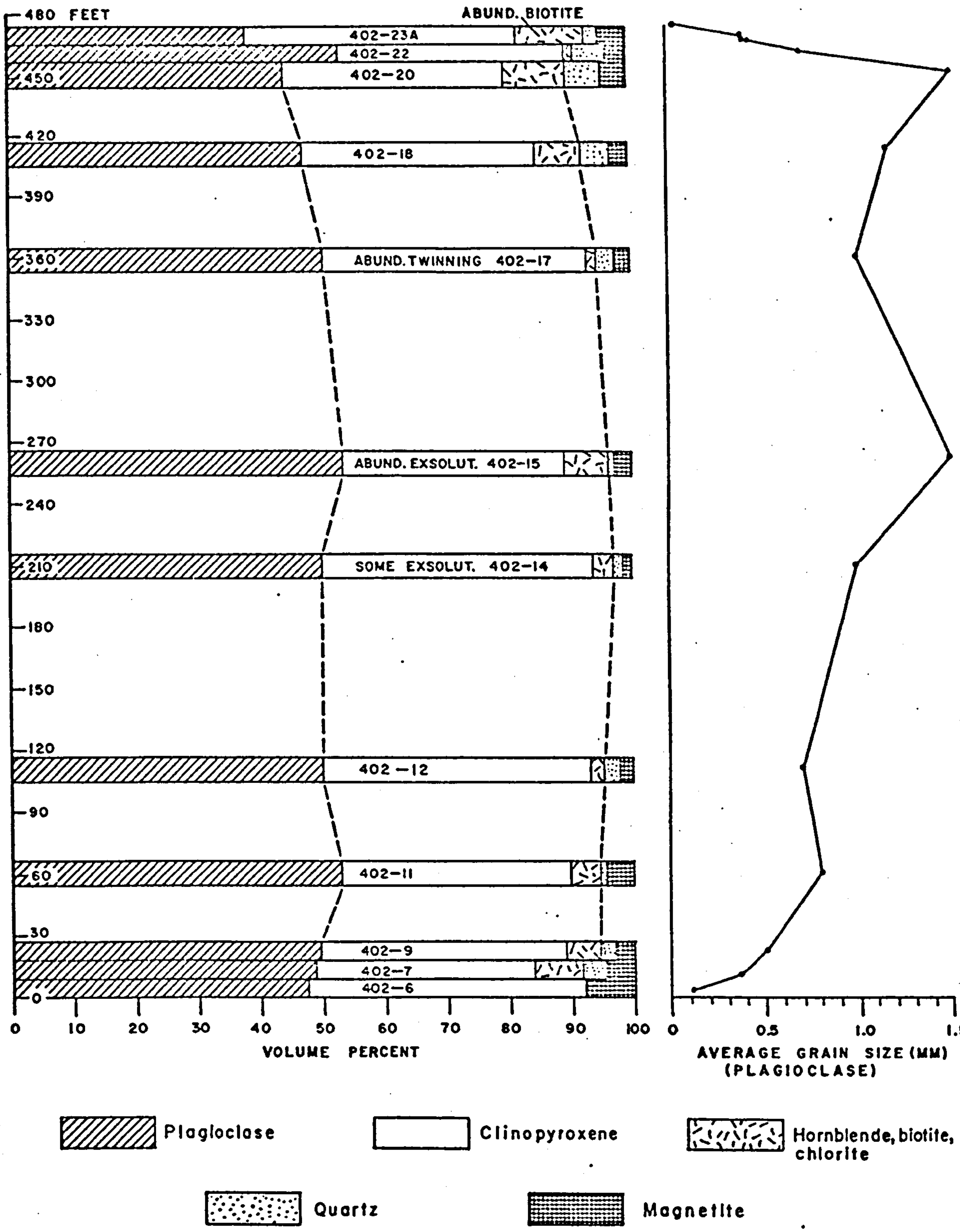


Figure 41. Mineral Variations in a Diabase Sill, Tortilla Mountains, Arizona

NW cor. sec. 30, T. 4 S., R. 14 E.

Table 4.--Modal Compositions of a Diabase Basement Sill

Sample No.	Plagioclase	Pyroxene	Hornblende Chlorite	Biotite	Magnetite Ilmenite(?)	Quartz
K-402-6	47.4	44.6	--	--	8.0	--
7	48.8	35.0	5.4	2.2	4.8	3.8
9	49.5	38.8	5.5	0.7	3.1	2.4
11	53.0	37.0	3.1	1.8	4.6	0.5
12	50.3	42.0	1.5	0.8	2.1	2.4
14	50.2	43.5	3.0	0.4	1.6	1.3
15	53.4	35.8	6.2	0.6	3.0	1.0
17	50.8	42.2	0.8	0.7	2.7	2.8
18	47.4	37.6	6.6	0.6	3.0	4.8
20	44.6	35.4	9.2	0.8	4.6	5.4
22	53.2	36.8	1.1	0.1	3.6	5.2
23A	38.6	43.5	1.3	9.6	5.0	2.0

The variations, slight as they are, show up well in Fig. 41. The grain size of plagioclase increases sharply within the first 5 feet above the contact from 0.01 to 0.4 mm and gradually attains its maximum of 1.5 mm (average) near the center and upper portion of the diabase. The grain size decreases much more rapidly at the upper contact than at the lower. Within 20 feet of the upper contact the average size of plagioclase decreases from 1.5 mm to cryptocrystallinity. The relative amount of plagioclase changes only slightly throughout the width of the sill, but a definite decrease is evident toward the contacts. No change in plagioclase composition was discernible. Magnetite shows a marked concentration near the contacts and a decrease near the center of the intrusive body. Quartz and granophyre show a similar relationship. Red-brown biotite is especially concentrated within 1 foot of the upper contact where clear augite is the main phase of the clinopyroxenes. Very little hornblende occurs here.

Generally speaking, the relative amounts of clinopyroxene vary much more erratically than plagioclase. This variation, no doubt, is due to the varying degree of alteration to hornblende and chlorite. The total of clinopyroxene, hornblende, and chlorite remains about constant throughout the sill. Augite and pigionite are the common pyroxenes present and are shown as one mineral in the analyses. Toward the center of the sill many clinopyroxene grains show exsolution in the characteristic herringbone arrangement. This may indicate that the interior of the diabase sheet cooled at a much slower rate relative to the border zones. The granular, interlocking texture of the diabase suggests that the sheet crystallized in place after its emplacement, with the chilled contacts serving as thermal insulators.

The interior of the sill is distinctly porphyritic, containing numerous 2-5 mm pyroxene(?) phenocrysts now completely altered to leuchtenbergite (chlorite). As determined by X-ray analyses, the phenocrysts weather out rapidly in outcrop and form conspicuous reddish-brown pits in the otherwise massive black diabase surface. The following sequence of photographs (Figs. 42-50) shows the compositional and textural changes across the diabase sill from the lower to the upper contact.

Age and Correlation

The diabase in this area is considered to be of younger Precambrian age. The following criteria substantiate this conclusion. Large diabase sills intrude the younger Precambrian sedimentary rocks in the Sierra Ancha Mountains in north-central Arizona, where they were dated by Silver (1960) and Damon et al. (1962) to be 1,200 and 1,140 $\pm$ 40 m.y. old, respectively. The diabase in the Tortilla Mountains is very similar to the dated Sierra Ancha sills and clearly postdates the deposition of the Apache Group. Furthermore, the diabase in the study area is cut everywhere by the Laramide hypabyssal dike swarms and the dioritic intrusive bodies, thus placing an upper limit on the diabasic intrusive event at pre-Laramide.

Shride (1967) concluded, after extensive studies of the diabase contact relationships, especially with the Paleozoic limestone sequence, that the diabase does not intrude the Paleozoic sedimentary section but that the latter overlie the diabase with a depositional contact wherever

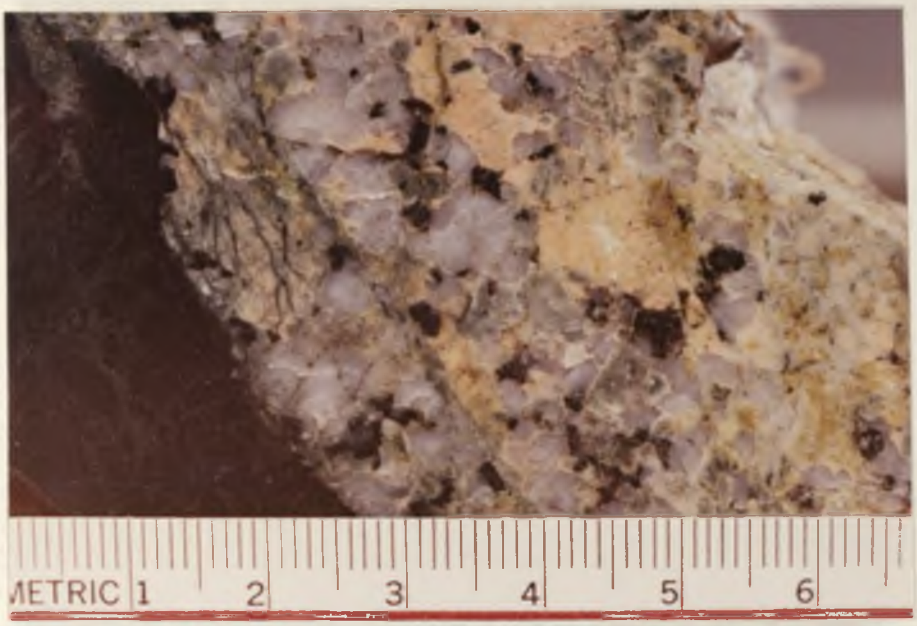


Figure 42. Diabase-Oracle Granite Contact (K-402-5A)

The chilled diabase forms a sharp but highly irregular contact with the granite. Plagioclase in the granite is altered to green sericite; pink K-feldspar forms irregular blebs; biotite is unaltered.

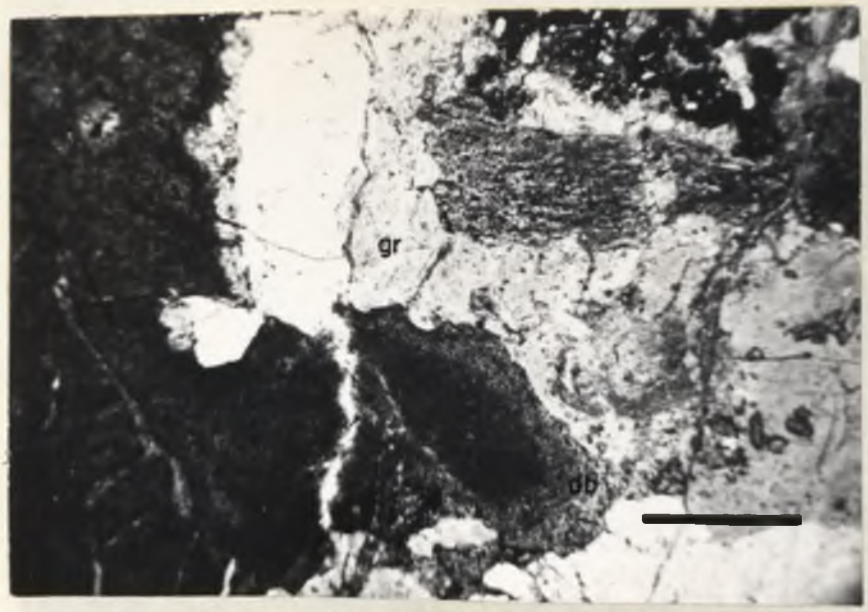


Figure 43. Photomicrograph of the Diabase-Oracle Granite Contact (K-402-5A)

Lobes of microcrystalline diabase (db) extend into coarse-grained granite (gr) forming a sharp but irregular contact. No extraordinary alteration occurs in the granite. A biotite-magnetite cluster is in the upper right corner. Parallel nicols. Bar is 1 mm.

Figure 44. Photomicrograph of Diabase Basement Sill (K-402-9)

Granophyric matrix with partly altered plagioclase and pyroxene. Twenty feet above contact. Crossed nicols. Bar is 0.5 mm.

Figure 45. Photomicrograph of Diabase Basement Sill (K-402-13)

Intergrowth of plagioclase, augite-pigionite, and magnetite forms medium-grained diabasic texture. One hundred sixty feet above lower contact. Crossed nicols. Bar is 1 mm.

Figure 46. Photomicrograph of Diabase Basement Sill (K-402-19)

Granophyric intergrowth in diabase matrix. Note wide range in plagioclase grain size. Rock is relatively unaltered. Forty feet below upper contact. Crossed nicols. Bar is 1 mm.

Figure 47. Photomicrograph of Diabase Basement Sill (K-402-19) Showing Detail of Figure 46

Excellent twinning in plagioclase (P) and pigionite (Po) is partly destroyed by incipient alteration. Crossed nicols. Bar is 0.5 mm.

Figure 48. Photomicrograph of Diabase Basement Sill (K-402-22)

Typical diabasic texture in fine-grained diabase. Plagioclase (white), pyroxene (gray), and magnetite (black). Five feet below upper contact. Parallel nicols. Bar is 1 mm.

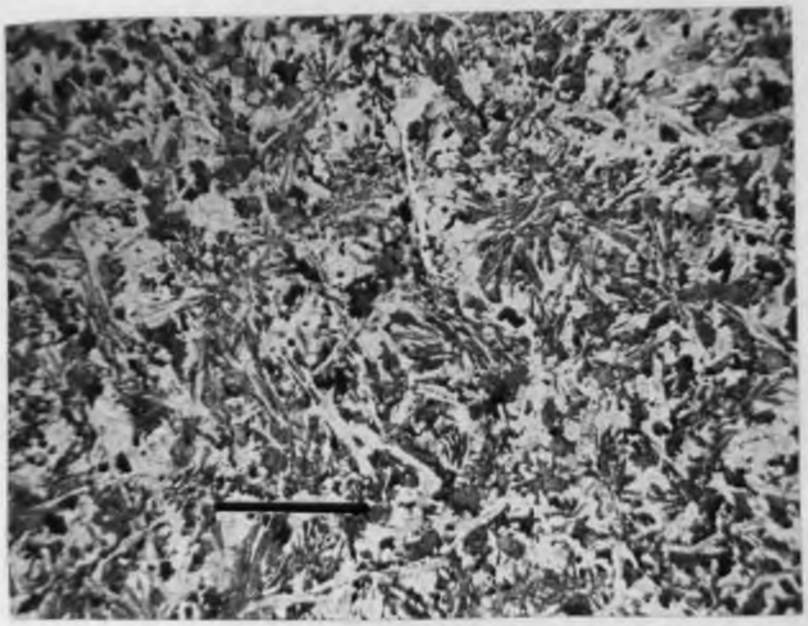


Figure 49. Photomicrograph of Diabase Basement Sill (K-402-23A)

Cluster of radiating augite and plagioclase crystals with disseminated magnetite in very fine grained diabase. No granophyre is present. One foot below upper contact. Parallel nicols. Bar is 1 mm.

Figure 50. Photomicrograph of Diabase Basement Sill (K-402-23A) Showing Detail of Figure 49

Cluster of radiating plagioclase crystals. Crossed nicols. Bar is 0.5 mm.

good exposures permit examination. The same conclusion was reached by Sell (1960) after detailed investigations in the Superior area, especially the underground workings of the Magma mine.

N. P. Peterson (1962), on the other hand, postulated a Tertiary age for the diabase in the Globe-Miami and Superior area on the basis of stratigraphic evidence. Because no Paleozoic rocks are in contact with diabase in the study area, Peterson's conclusion cannot be directly evaluated here, but the writer considers the diabase in the study area to be of younger Precambrian age.

PALEOZOIC ROCKS

Non-brecciated Limestone Blocks of Mississippian and Pennsylvanian(?) Age

Generally, there are no autochthonous Paleozoic sedimentary rocks exposed in the Tortilla Mountains, although a few isolated outcrops of Escabrosa Limestone occur in the SE cor. sec. 12, T. 5 S., R. 13 E., west and southwest of the Florence mine where they overlie the Apache Group with a fault contact. This limestone is a coarsely crystalline marble containing numerous crinoid stems. Bedding is well preserved and strikes approximately N. 5° W. and dips 87° NE. The rock does not show the intense internal brecciation which is so characteristic of the allochthonous limestone units exposed in the Hackberry Wash area. The western boundary of the limestone blocks is a fault dipping 45° E. To the east, the limestone is overlain with a depositional contact by steeply dipping, crudely bedded conglomerates (Fig. 51).

Several other limestone blocks occur over a distance of 1,500 feet west of the Florence mine toward Ripsey Hill. One of the larger blocks (150 x 400 feet) includes two 5-foot-wide clean quartzitic sandstone units that are interbedded with the massive limestone. This relationship has only been observed in the Epitaph and Scherrer Formations in southeast Arizona, but whether the limestone blocks in the Tortilla Mountains are of Permian age is questionable. Nevertheless, they do indicate that this area had once been covered by Paleozoic sedimentary rocks which are now nearly completely eroded away. In the Dripping

Figure 51. Steeply Dipping Depositional Contact Between Paleozoic Limestone and Crudely Stratified Mid-Tertiary Conglomerate Strata

SE1/4 sec. 12, T. 5 S., R. 13 E., looking north. The conglomerate consists of Precambrian granite, aplite, quartzite, and diabase. Note the abundance of diabase matrix material immediately above the contact.

Spring Mountains 10 miles to the east the Martin and Escabrosa Limestones as well as portions of the Naco Group are well exposed in a gently dipping regular sequence.

A small exposure of thinly bedded, light bluish-gray, finely crystalline limestone containing abundant brachiopod, crinoid stem, and bryozoa fossil fragments occur in the NE cor. sec. 12, T. 5 S., R 13 E. It is intruded by an olive-green monzonite porphyry which is similar in composition and texture to the Laramide monzonite dikes in this area. The monzonite porphyry is confined to the limestone block and does not extend into the adjacent strata of the Apache Group. Thus, the limestone block and the monzonite porphyry were tectonically emplaced in their present position.

Allochthonous Brecciated Limestone Blocks of Devonian, Carboniferous, and Permian(?) Age

In the N1/2 sec. 1, T. 5 S., R. 13 E., two spoon-shaped, completely brecciated Paleozoic limestone blocks rest upon Precambrian diabase. A similar occurrence of brecciated limestone is in the NW cor. sec. 8, T. 5 S., R. 14 E., where the unit rests on Laramide diorite with an apparent fault contact. A small quartzite breccia occurs at its southern terminus.

The largest, most spectacular brecciated limestone units occur in the Hackberry Wash area where they are exposed within steeply dipping sands, shales, and red-bed units of probable Miocene age. The limestone is fossiliferous and completely brecciated internally with very fine angular limestone material filling the interstices of the larger angular breccia fragments. The brecciated limestone forms prominent elongate ridges within the easily weathered sandstones and shales. Individual limestone units a few hundred feet wide can be followed for 2 miles along strike length.

A more detailed account of their character and emplacement will be given in a subsequent chapter. It suffices to say here that these limestone units represent Devonian, Mississippian, and probably Pennsylvanian strata that once covered the Tortilla Mountains area but have since been tectonically moved into their present location.

LARAMIDE INTRUSIVE ROCKS

Intrusive rocks of Laramide age are widespread in the Tortilla Mountains and occur as:

1. Irregular-shaped quartz diorite and diorite intrusive bodies with a biotite K-Ar date of 69 m.y. (Damon, 1970).
2. A large granodiorite pluton exposed predominantly west of the study area in the vicinity of Grayback Mountain, with a biotite K-Ar date of 63 m.y. (Damon, 1970).
3. Nearly east-trending individual dikes and elongate intrusive bodies ranging in composition from granodiorite to rhyolite with a biotite K-Ar date of 63 ± 1 m.y. (Damon, 1970). The dikes cut the quartz diorite masses and the granodiorite pluton, but no definite age relationship has yet been established between the quartz diorite and the granodiorite pluton.

The Laramide dikes and elongate intrusive masses are noncomformably overlain by the steeply dipping mid-Tertiary sedimentary sequences (Figs. 5 and 18). This relationship indicates that the eastward tilting of the Tortilla Mountains predominantly occurred after the Laramide intrusive rocks were emplaced. Therefore, all the dikes and elongate stocks were rotated eastward together with the Tortilla Mountains along a north-trending hinge line. Intrusive relationships discussed below have to be viewed in the aforementioned concept to be fully understood.

Quartz Diorite and Related Intrusive Bodies

These intrusive rocks crop out in two widely separated locations within the map area. One large exposure occurs northwest of Kelvin near the northern boundary of the area, and the others occur as irregular-shaped masses in the southeast portion of the map near Hackberry Wash.

The dioritic rocks northwest of Kelvin are considered by Metz and Rose (1966) to be the oldest of the Laramide intrusive rocks found in the Ray area. A new K-Ar date from biotite separates of the diorite (68.7 ± 1.7 m.y.) is in good agreement with the interpretation of Metz and Rose. The rock is referred to as Sonora diorite by geologists at Ray because of extensive exposures found near the former settlement of Sonora at the open pit periphery. The same name has been adopted in this report for all dioritic rocks occurring north of Kelvin.

The Sonora diorite is a holocrystalline, phaneritic, fine- to medium-grained, hypidiomorphic granular rock ranging in composition from a biotite-augite diorite to hornblende quartz diorite. It is dark gray to black and weathers readily into bouldery outcrops. Modal analyses of the Sonora diorite are listed in Table 5.

Under the microscope, a distinct parallel alignment of plagioclase laths can be seen which is not evident in hand specimen. Plagioclase is generally unaltered, strongly zoned, and is andesine (An_{40}) in composition. Its average length varies from 0.3 to 1 mm (Fig. 52). The presence of red-brown biotite and clear diopsidic(?) augite is a distinctive feature for most of the Sonora diorite (Fig. 53). Anhedral quartz occurs interstitially to the other silicates, but several isolated grains

Figure 52. Photomicrograph of Sonora Diorite (K-646)

Rock is fine-grained augite-biotite diorite and very similar in composition to K-129. It contains, however, less quartz. Note faint alignment of unaltered plagioclase crystals. This rock yielded a K-Ar age of 69 m.y. Crossed nicols. Bar is 1 mm.

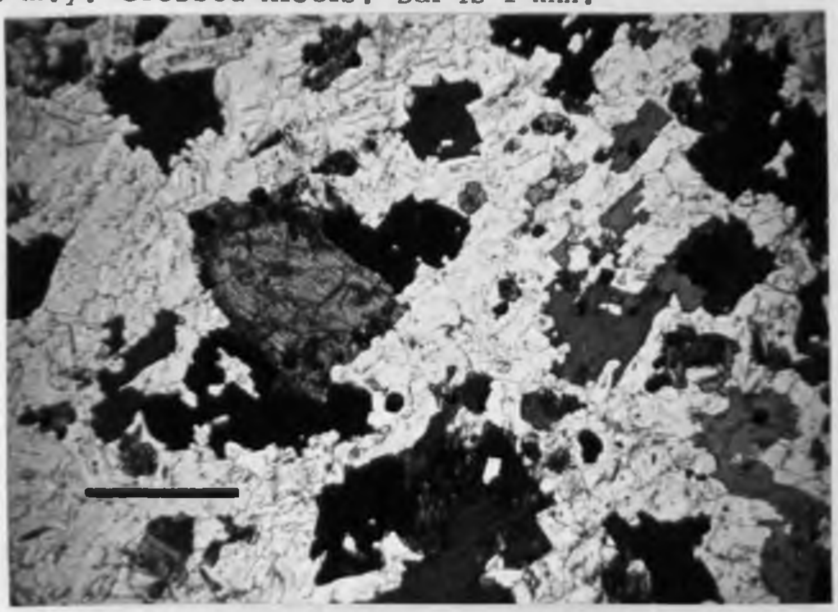


Figure 53. Photomicrograph of Sonora Diorite (K-129)

Rock is a holocrystalline, hypidiomorphic granular, non-porphyritic augite-biotite quartz diorite. Red-brown biotite contains a few magnetite inclusions and it is locally chloritized along the margins. Anhedral, interstitial quartz shows simultaneous extinction over a large area. Parallel nicols. Bar is 1 mm.

show simultaneous extinction. The quartz diorite is locally cut by east-west-trending epidote veinlets containing some sulfide mineralization with chlorite and calcite. Adjacent to these veinlets plagioclase is always strongly sericitized.

Table 5.--Modal Compositions of Sonora Diorite

	K-129	K-646	K-654	K-149	G-192
Plagioclase	48.7	51.6	59.9	61.3	51.1
Orthoclase	5.8	2.0	4.8	7.3	12.7
Quartz	12.5	8.2	7.0	7.7	11.2
Biotite	14.5	17.2	10.9	--	--
Augite	13.7	10.8	13.4	--	--
Hornblende	1.8	4.2	0.2	17.2	17.4
Chlorite	tr	1.2	0.6	2.5	4.5
Opaques	3.0	4.8	3.2	4.0	3.1

Along the high ridge crest northwest of Kelvin occurs a peculiar porphyritic variety of quartz diorite, in which andesine phenocrysts (3-5 mm) and extremely poikilitic biotite flakes are surrounded by a very fine grained aphanitic quartz-feldspar matrix (Figs. 54 and 55). Augite (1-2 mm) is usually rimmed by epidote.

The Sonora diorite is cut by a major east-northeast-trending Laramide dike swarm which, in general, follows the northern boundary of the map area for several miles before being faulted and covered by recent talus material. The southern contact of the diorite with the

Figure 54. Photomicrograph of Porphyritic Phase of Sonora Diorite (K-134)

Very fine grained groundmass of quartz, sericitized plagioclase and some K-feldspar encloses subhedral, zoned, unaltered andesine phenocrysts and resorbed biotite flakes. A few augite grains are rimmed by epidote. Crossed nicols. Bar is 1 mm.

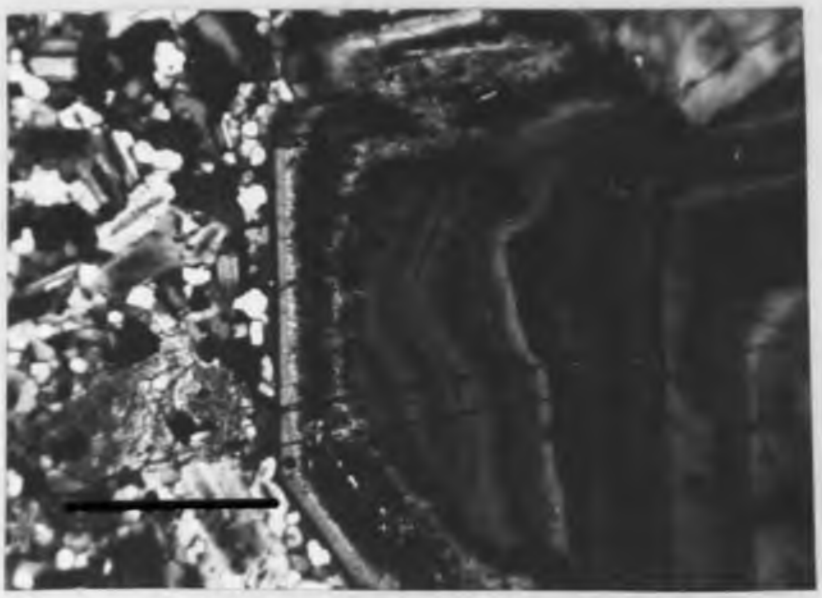


Figure 55. Photomicrograph of Porphyritic Phase of Sonora Diorite (K-134) Showing Detail of Figure 54

Oscillatory zoning in unaltered andesine phenocrysts. Very fine grained groundmass consists of quartz, plagioclase, and K-feldspar. Crossed nicols. Bar is 0.5 mm.

Oracle Granite is remarkably straight and also trends east-northeast parallel with the Laramide dike swarm.

In the southeastern portion of the map area west of Hackberry Wash, several dioritic intrusive bodies occur that superficially resemble the Sonora diorite just described. It is very likely that the rocks exposed belong to the same Laramide magmatic event. Similar to the Sonora diorite, the Hackberry intrusive bodies are cut extensively by an east-northeast-trending monzonite porphyry dike swarm. Unlike the Sonora diorite, however, the Hackberry exposures are generally narrow and irregularly elongated in an east-northeast direction. The contacts with the Precambrian granitic basement complex are either steep or nearly horizontal. Without doubt, much of sections 31 and 36 are underlain by diorite, and the granite represents a cover that has not yet been completely removed by erosion. In many instances, the diorite-granite contact can be traced around a hillside in nearly horizontal fashion so that the granite forms a resistant cap over the diorite. This relationship is well exposed in the center and southeast corner of section 36. Generally, narrow diorite apophyses extend over ridge tops and connect with larger diorite masses located on either side of the granite ridges.

A small tonguelike diorite mass occurs in the western half of section 31 near the section line. The diorite is exposed in a saddle and is surrounded on all sides except to the west by Oracle Granite. Its outcrop configuration suggests a flat bottom.

Generally speaking, all diorite exposures are confined to the east side of Ripsey Wash in spite of their east-west elongated configuration. This may reflect different levels of erosion on either side of Ripsey Wash.

The elongate diorite masses west of Hackberry Wash, with one exception, differ in composition from the Sonora diorite in that their principal mafic constituent is primary hornblende rather than augite and biotite. Plagioclase generally shows more extensive sericitization in the Hackberry diorites, but its composition is still andesine (An_{35-40}). A clear albite rim is always present. Hornblende is locally strongly altered to chlorite and zoisite. Modal analyses of hornblende quartz diorite are given in Table 6.

Table 6.--Modal Compositions of Hornblende Quartz Diorite

	K-198	K-693	K-672	K-98B	K-696
Plagioclase	52.8	52.5	56.6	61.2	67.3
Orthoclase	14.1	4.3	4.1	6.0	3.2
Quartz	8.3	13.1	11.6	8.8	3.8
Hornblende	14.8	24.6	15.7	19.4	--
Augite	--	--	--	--	10.9
Biotite	--	--	tr	--	9.5
Chlorite	7.4	2.1	9.2	0.8	2.0
Magnetite	2.6	3.2	2.7	3.8	3.3

As shown in Table 6, the rocks range from quartz diorite-diorite to syenodiorite (K-198). Sample K-696 is the only one in this suite containing augite and biotite and, in this respect, resembles the Sonora diorite. The compositional variations of the dioritic rocks are shown on Figure 56.

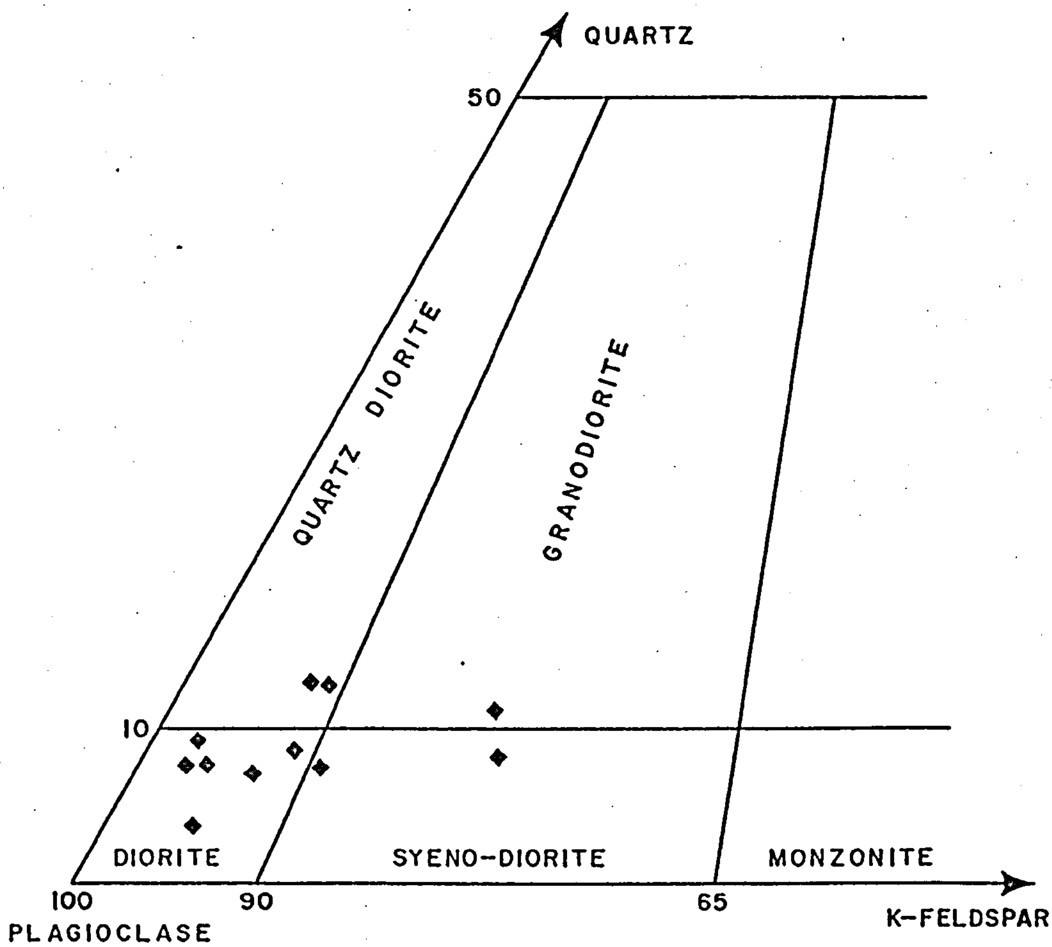


Figure 56. Compositional Variations of the Sonora and Hackberry Diorite Bodies.

Modal analyses are given in Tables 5 and 6.

Contact Relationships Between the Quartz Diorite Bodies and the Precambrian Rocks

Good contact relationships are locally exposed between quartz diorite and Oracle Granite. Invariably, the diorite becomes porphyritic near the borders with hornblende forming phenocrysts up to 1 cm long. This is well exposed in the northwest corner of sec. 31, T. 4 S., R. 14 E., where the elongate diorite mass terminates and plunges under the Oracle Granite.

About one mile west of this locality in section 36, a 15-foot-wide hornblende-rich zone developed near the granite contact forming schlieren-like configurations and very coarse nodules that are surrounded by diorite. It is difficult to determine whether these features are xenoliths incorporated by the intruding diorite magma or late-stage pegmatitic segregations. The adjacent granite is enriched in K-feldspar at the contact.

In the N1/2 sec. 31, T. 4 S., R. 14 E., complete brecciation and mixing of Oracle Granite and diabase occur near the diorite contact. On casual observation it appears that undisturbed Oracle Granite contains diabase inclusions which are aligned in a north-northwest direction. Detailed examination showed that the granite has a preferred fabric imparted by the elongate pink K-feldspar crystals parallel to the diabase inclusions. In places diorite served as matrix material.

Near the dividing line between sections 31 and 32, large blocks of granite and diabase do occur within the adjacent diorite; for example, a 3-foot-wide reddish quartzite boulder is present. Locally, pebble dikes, 1-2 feet wide, occur in strongly kaolinized and sericitized(?)

granite containing well-rounded, fine-grained, and altered diorite(?). Thus, it appears that during the waning stage of crystallization the diorite developed a highly mobile gas or fluid phase which was able to penetrate the host rock and cause extensive brecciation and alteration, particularly in the Oracle Granite. The pebble dikes probably represent channelways for the escaping gas phase. That no chilling effects are present in the diorite may suggest that the border zones of the diorite became enriched in volatiles with subsequent crystallization of coarse hornblende and K-feldspar and mobilization of the granite and diabase host rock. This probably occurred in an essentially closed system, that is, the diorite did not break through a fractured roof at this point.

Near Hackberry Spring in the extreme southeast portion of the map area, the quartz diorite very intricately intrudes the Apache Group (Fig. 57). Here blocks of Dripping Spring Quartzite and especially Mescal Limestone are completely submerged in the diorite and displaced nearly 1,000 feet below their original stratigraphic position. The Mescal apparently was the more favored of the sedimentary units to be incorporated as xenoliths judging from their wide distribution within the diorite. The limestone is also the least likely to be modified by a granitic melt. The individual blocks range from a few feet to 30 feet in diameter. Locally, the blocks are rotated 10-30 degrees; however, at other places they appear to have subsided into the diorite magma without any change in attitude. The blocks apparently did not sink deeper than about 1,000 feet into the magma. The viscosity in the intruding magma may have been great enough at this level to prevent any further downsinking.

Figure 57. Apache Group Intruded by Diorite

Portions of the Pioneer Formation and Dripping Spring Quartzite are intricately intruded by the Laramide quartz diorite stock. The steeply dipping Apache Group forms high ridge crests whereas the diorite is only exposed on deeply incised slopes and in washes. SW1/4 sec. 5, T. 5 S., R. 14 E.

At several places along the diorite contact there are many examples of complete mixing of quartzite and Mescal Limestone fragments cemented by diorite matrix. These features are indicated on the geologic map (Fig. 5, in pocket) with a breccia symbol. The breccia masses cap higher ridges and can be traced directly into the underlying diorite. The contacts between diorite and breccia are generally horizontal. As mentioned before, the diorite intruded the Precambrian terrane prior to the eastward tilting of the Tortilla block and one is therefore effectively looking at a cross section of the presently flat-lying to gently westward-plunging diorite intrusive masses. The breccia bodies, then, represent intrusive breccias that formed along the steeply dipping walls. Because of the eastward rotation they are now above the diorite rather than on either side of it.

The diorite intruded the entire Apache Group and the Troy Quartzite. How far it penetrated the Paleozoic sedimentary section is unknown because of the lack of exposures.

The diorite is overlain, in depositional contact, by the Miocene(?) conglomerates north of Hackberry Spring. Farther south the diorite is overlain by the quartzite and limestone crackle breccias of the Hackberry formation, and to the west the diorite is bordered by a fault zone that places the westward-dipping Miocene(?) red-bed sequences over the diorite.

Age and Correlation

The diorite intrusive masses near Kelvin and Hackberry Wash are older than the Laramide dike swarms because the diorite is cut by the dikes. The diorite is also intruded by a small granodiorite stock north of the Gila River in sec. 3, T. 4 S., R. 13 E., which very closely resembles the Grayback granodiorite pluton in composition and texture.

In the Christmas area located 15 miles to the east, Willden (1964) describes augite- and hornblende-bearing microdiorite intrusive bodies which are similar to the dioritic rocks in the Tortilla Mountains. The microdiorite at Christmas intrudes the Cretaceous andesite complex and is considered by Willden to represent the oldest of several Tertiary intrusive units in that area.

In the Winkelman quadrangle about 6 miles southeast of the Hackberry area, Medora Krieger (oral communication, 1969) obtained a K-Ar date of 66 m.y. from a diorite intrusive mass closely resembling the Hackberry Wash quartz diorite. The diorite intrudes Oracle Granite and displays a general east-west elongation. This date agrees well with the Laramide intrusive sequence in the study outlined above.

Grayback Granodiorite Pluton and Smaller Granodiorite Intrusive Bodies

The writer assigns the name "Grayback granodiorite" to a large igneous mass which has not been previously recognized on either the state or county geologic maps of Arizona. The name refers to Grayback Mountain, a prominent landmark in this area, which occupies the central portion of the pluton (Fig. 4, in pocket).

The Grayback granodiorite is exposed over at least 40 square miles west of the study area and covers large parts of Tps. 4 and 5, R. 12 E. Good exposures occur along the Florence-Kelvin road where the rock weathers into boulderlike forms. Only a small portion of the pluton extends into the western part of the map area, but it was clearly recognized as a separate intrusive mass because the granodiorite is distinctly different in texture and composition from the adjacent Oracle Granite.

The Grayback pluton intrudes the older Precambrian Oracle Granite and the Pinal Schist. This intrusive relationship is exposed near Cochran along the Gila River. The eastern contact of the pluton with the Oracle Granite trends generally north-south, but large portions of the western and southern contact zone are covered by recent sand and gravel deposits so that the true outline of the pluton is presently not well known. A general north-south elongation of the pluton is suggested by the outcrop pattern.

The granodiorite is a light-gray, holocrystalline, medium-grained, non-porphyritic rock easily distinguishable from the coarse-grained Oracle Granite (Fig. 58). Locally, numerous rounded diorite(?) inclusions measuring up to 2 feet in diameter are present. In the vicinity of Grayback Mountain, abundant aplite and pegmatite dikes occur which range from 1 inch to 1 foot in width; they cut the weak biotite foliation (average N. 37° E., 72° NW.) in the rock at nearly right angles. A few narrow hornblende andesite dikes are present which dip with a shallow angle to the north.

Under the microscope, the rock displays a medium- to coarse-grained, nearly equigranular fabric (Fig. 59). The grain size ranges from 1-5 mm with a few larger perthite patches measuring up to 7 mm in diameter. Modal analyses are given in Table 7 and are also plotted in Figure 60.

Figure 58. Grayback Granodiorite (G-262)

The rock is medium grained, non-porphyritic and easily distinguishable from the Oracle Granite. The granodiorite yielded a K-Ar date of 63 m.y.

Figure 59. Photomicrograph of Grayback Granodiorite (G-262)

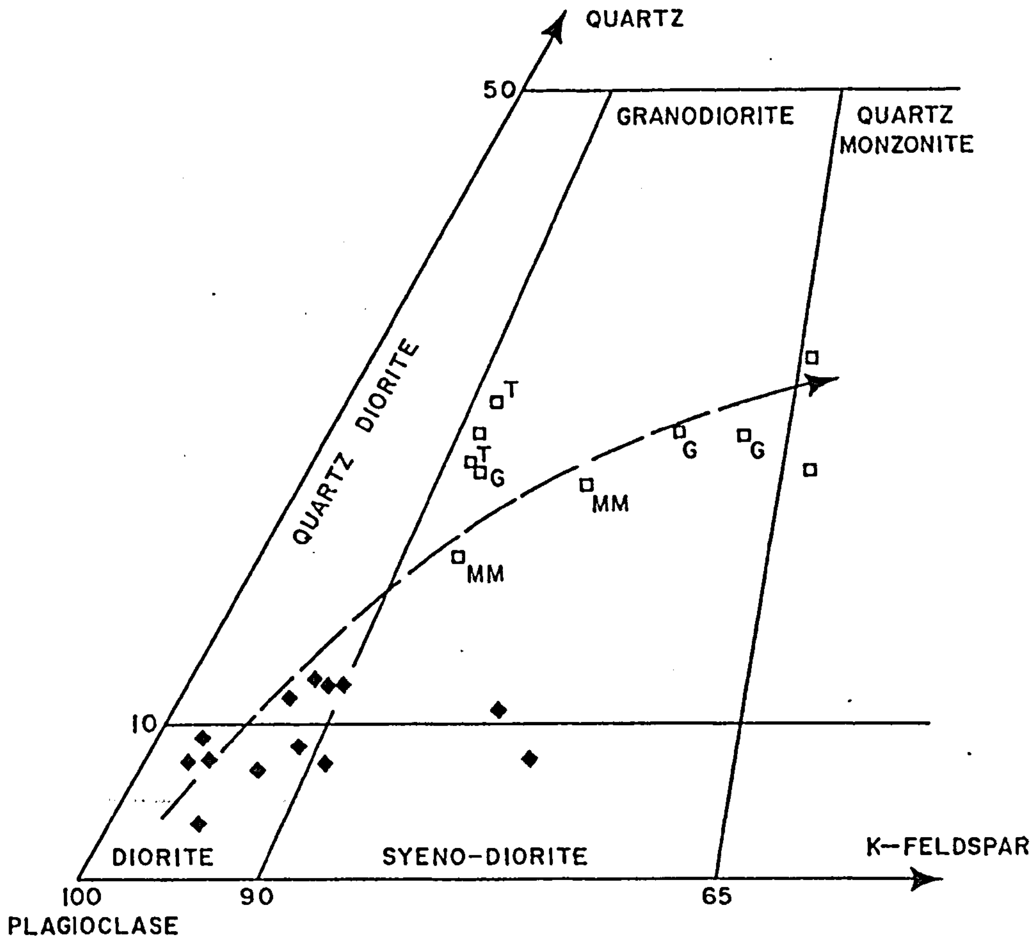
Rock is holocrystalline, medium grained with a hypidiomorphic granular texture. Note zoning and intergrowth of plagioclase. Anhedral quartz fills interstices between subhedral plagioclase and irregular perthite grains. Crossed nicols. Bar is 1 mm.

Table 7.--Modal Compositions of Grayback Granodiorite and Associated Intrusive Rocks

	G-103	K-267	K-262	G-174	K-200	K-203
Plagioclase	41.7	43.5	52.6	52.1	38.8	40.6
Orthoclase	18.3	16.2	7.1	9.2	21.4	25.0
Quartz	27.9	28.5	28.6	30.4	33.2	26.0
Biotite	10.7	11.2	9.6	6.7	1.6	4.8
Chlorite	0.3	0.2	0.5	0.6	0.4	2.8
Magnetite	1.1	0.5	1.6	1.0	4.6	0.8

Subhedral plagioclase laths (An_{25-28}) are usually surrounded by a clear albite-rich margin. In some grains the core portion is completely sericitized, but only incipient alteration occurs in others. Large anhedral K-feldspar patches enclose individual grains of fresh biotite, altered and fresh plagioclase, and anhedral quartz. Myrmekitic intergrowths commonly form between plagioclase and K-feldspar but were never observed between quartz and plagioclase. Locally, plagioclase shows corroded margins which indicates partial resorption after crystallization.

The range in composition of the Grayback granodiorite pluton, as well as of other selected Laramide intrusive bodies exposed in the near vicinity, is graphically shown on Figure 60. The rocks from Grayback Mountain, Mineral Mountain, Troy basin, and the one satellitic stock north of the Gila River (G-174) are all confined to the granodiorite field. The exceptions are two analyses from a satellitic stock in the southern part of the map which fall in the quartz monzonite field but



□ Grayback granodiorite,(G); Mineral Mountain quartz monzonite,(MM); Satellitic stocks in Tortilla Mountains, Troy granodiorite, (T)

◆ Sonora diorite, Hackberry Wash quartz diorite

Figure 60. Compositional Variations of Several Laramide Intrusive Rocks, Tortilla Mountains and Vicinity

Arrow indicates possible differentiation trend.

close to the granodiorite border. For the purpose of comparison, the analyses of the quartz diorite-diorite suite are also plotted in Figure 60. In a general way, the analyses define an arc which resembles the trend of Bowen's crystal differentiation in a magmatic cycle. Because the rocks are all of Laramide age, it is conceivable that the quartz diorite-diorite suite represents the earliest rock to solidify in the crystallization history and that the granodiorite-quartz monzonites are the later differentiation products which crystallized in the vicinity of the isobaric minimum of Tuttle and Bowen (1958).

Age and Correlation

The isotopic age of the Grayback granodiorite is 62.9 ± 1.3 m.y., as determined by the K-Ar method using biotite (Damon, 1970; Schmidt, 1970). Therefore, the rock belongs to the Laramide intrusive event as defined by Damon and Mauger (1966). The prominent east-west trending dike swarms extend part way into the eastern portion of the granodiorite stock and thus clearly postdate the granodiorite intrusive event. Their isotopic age dates, however, are within the limits of experimental error, suggesting a closely related intrusive event.

The Grayback granodiorite is similar in age to the Granite Mountain porphyry (60 and 63 m.y.), which is located about 6 miles northeast of Grayback Mountain near the Ray ore body (Table 8). Metz and Rose (1966) recognized a northeast-trending zone of porphyry intrusions ("porphyry break") in the Ray area which may very well reflect a fundamental zone of weakness during Laramide time. This zone, if followed to the southwest, extends into the Grayback granodiorite pluton.

Table 8.--K-Ar and Rb-Sr Ages of Laramide Intrusive Rocks in the Tortilla Mountains and Vicinity

Location	Apparent Age (m.y.)	Reference
Ray District		
Granite Mt. porphyry	60	Rose and Cook (1965)
Granite Mt. porphyry	63	Creasey and Kistler (1962)
Tortilla Mountains		
Sonora diorite	68.7±1.7	Damon (1970)
Grayback granodiorite	62.9±1.3	Damon (1970)
Quartz monzonite porphyry dike	63.1±1.3	Damon (1970)
Copper Hill quartz monzonite	68	Damon, Mauger, and Bikerman (1964)
Crozier Peak quartz diorite intrusives	66	Krieger (oral commun.)
San Manuel monzonite	69	Rose and Cook (1965)
San Manuel monzonite (altered)	65, 69	Creasey (1965a)
Dripping Spring Mtns.		
Christmas quartz diorite	62	Creasey and Kistler (1962)
Troy quartz monzonite	71.1±3.2	Damon and Mauger (1966)
Globe-Miami District		
Schultze granite	58	Creasey and Kistler (1962)
Schultze granite	58	Damon et al. (1964)
Schultze granite	60	Creasey (1965a)
Lost Gulch quartz monzonite	62	Creasey and Kistler (1962)
Barren granite (drill core)	54.5±1.2	Damon (1970)

The Granite Mountain porphyry as well as the Schultze granite (58-60 m.y., Table 8) in the Globe-Miami area are considered to be responsible for the copper mineralization in the adjacent Pinal Schist and diabase host rocks. The Oracle Granite near the Grayback granodiorite contact contains, locally, a series of north-east trending oxidized fissure veins with quartz, limonite, and some malachite stain. The granodiorite body itself shows little evidence of hypogene alteration over its entire exposed portion. In one outcrop near the eastern contact, however, fresh-appearing granodiorite contained minute specks of malachite associated with tiny limonite grains spatially associated with fresh biotite clusters. No unusual alteration was noted in thin section from the same hand specimen.

A smaller quartz monzonite-granodiorite intrusive body located about 8 miles northwest of Grayback Mountain has been described in the Mineral Mountain quadrangle (Schmidt, 1967). In texture and composition, this rock cannot be distinguished from the Grayback granodiorite, and the Mineral Mountain stock is therefore tentatively considered to be of Laramide age, pending an isotopic age determination.

The small mineralized granodiorite stock in the Troy basin within the Dripping Spring range was dated by Livingston (in Damon and Mauger, 1966) to be 71 m.y. old and, thus, is so far the only Laramide intrusive rock in this area showing an anomalously older age. The compositions of the Mineral Mountain granodiorite and the Troy stock are plotted in Figure 60. Both intrusive units are cut by east-west trending dike rocks which resemble in minute detail the hypabyssal rocks in the investigated area.

Isolated Granodiorite and Quartz Monzonite Stocks

Two small igneous masses that range in composition from granodiorite to quartz monzonite intrude the quartz diorite bodies described above. One is located in sec. 3, T. 4 S., R. 13 E., north of the Gila River where it clearly intrudes the Sonora diorite. The intruding stock is a biotite granodiorite with a holocrystalline, non-porphyritic, medium- to coarse-grained texture (Fig. 61). In composition, the rock closely resembles the Grayback granodiorite, as shown in Table 7 (G-174). For this reason, the biotite granodiorite is considered to be a satellitic intrusive body of the Grayback granodiorite, and therefore of similar age. The biotite granodiorite forms an elongate mass measuring 1,000 feet by 2,500 feet. However, the trend of the eastern contact with the quartz diorite is partly controlled by a major westward-dipping fault zone, and the western contact is overlain by talus. The true configuration of the intrusive body is thus not known. Contact relationships with the adjacent quartz diorite mass are not well exposed, but at a few places granodiorite apophyses clearly extend into the quartz diorite. Both the biotite granodiorite and the quartz diorite are cut by a granodiorite porphyry dike.

The other intrusive mass is located in the southern half of sec. 36, T. 4 S., R. 13 E., east of Ripsey Wash; it is in contact with Oracle Granite and quartz diorite. No good contact relationships are observable, but the writer believes that this rock is also a satellitic intrusive mass associated with the Laramide magmatic event. The rock is a medium-grained, non-porphyritic, holocrystalline quartz monzonite characterized by abundant perthitic orthoclase, strongly sercitized plagioclase, and

Figure 61. Photomicrograph of Satellitic Granodiorite Stock (G-203)

Rock is holocrystalline, hypidiomorphic granular and medium grained. Oscillatory zoning in plagioclase is common. Note incipient to nearly complete sericitization of different plagioclase grains suggesting compositional variations. Crossed nicols. Bar is 1 mm.

finely disseminated biotite. The rock can easily be distinguished from the coarse-grained Oracle Granite and the much darker quartz diorite. Two modal analyses of quartz monzonite (K-200 and K-203) are shown in Table 7.

Discussion

Viewed on a regional scale, the various Laramide intrusive bodies discussed above lie within a 15-20 mile wide belt trending east-northeast across the Tortilla Mountains and the Dripping Spring range. The Ray copper deposit is located near the northern boundary of this belt and the Christmas mine lies near the southern margin. This Laramide trend is particularly well outlined by the numerous dike swarms and elongate intrusive masses in both ranges and certainly reflects a fundamental tensional zone generated during Laramide time. The intrusive belt does not extend farther east into the Mescal Mountains, judging from the absence of any throughgoing systematic dike swarms. The intrusive belt, however, extends for at least 12 miles to the west-southwest from the Tortilla Mountains where it is covered by Holocene gravel in the Florence area.

East-west-trending Dike Swarms

Mode of Occurrence

The youngest Laramide intrusive rocks in this area are individual dikes and dike swarms that cut all rocks of pre-Laramide and Laramide age. The dikes generally occur in groups trending east-northeast and west-northwest across the map area. Several such dike swarms are present. One dike swarm follows the northern boundary of the study area and cuts Precambrian Oracle Granite, diabase, and Laramide quartz diorite indiscriminately. Another dike swarm occurs in the vicinity of the Gila River cutting mainly Oracle Granite, and a third zone of closely spaced dikes is in the southern part of the map area.

Individual dikes can be followed for several miles along strike, but invariably they are terminated by major mid-Tertiary fault structures. The dikes range in thickness from 10 to 150 feet with an average width of 50 to 75 feet. Commonly several parallel dikes merge into larger porphyry masses from which they diverge on the other side into numerous individual dikes.

On a large scale, the dikes describe a somewhat sinuous path. A good example of this pattern is shown in the western half of the map in secs. 7, 8, and 9, T. 4 S., R. 13 E. Here, a 100-foot-wide, N. 70° E.-trending quartz-feldspar porphyry dike changes suddenly to an east-west and then to a N. 75° W. direction, describing an arclike pattern. Several smaller but discontinuous dikes follow the same configuration. A similar pattern is outlined by two parallel, 100-foot-wide quartz feldspar porphyry dikes in secs. 19, 20, and 21, T. 4 S., R. 13 E. However, abundant transverse faulting complicates the picture in this region. An interesting intrusive relationships exists between a quartz monzonite porphyry dike and a diabase sill in the central part of the map area (Figs. 62 and 63). A small porphyry apophysis with excellent flow banding extends into the diabase for a short distance. The porphyry apparently followed an earlier fracture direction and wedged the diabase apart.

In the southern portion of the map area there is a 2-mile-wide zone of closely spaced east-west-trending hornblende granodiorite

Figure 62. Quartz Monzonite Porphyry (qmp) Dike Intruding Diabase (db)

A portion of the dike with a well-developed flow structure intrudes in a wedgelike manner the adjacent diabase. Hammer is on contact. Oracle Granite is in upper right corner. SW1/4 sec. 19, T. 4 S., R. 14 E.

Figure 63. Wedge of Quartz Monzonite Porphyry in Diabase

Detail of Figure 62. Flow banding in the chilled quartz monzonite presently forms a synformal arrangement with a nearly horizontal axis. Pencil is 6 inches long.

porphyry dikes that intrude Precambrian Oracle Granite, Apache Group, diabase, and Laramide quartz diorite. The dikes can be followed for nearly 5 miles across the map area. The belt is interrupted by the north-trending Ripsey Wash near the center of the map, and an apparent left lateral offset of about one mile is indicated. Small but significant bending of the dikes adjacent to the Ripsey Wash fault zone supports the above hypothesis. Farther west, the dikes become complexly involved in small-scale transverse faulting indicating a prevailing left lateral displacement.

The systematic arrangement of the dikes serves as an excellent "marker horizon" in the otherwise featureless Precambrian granitic terrane and aids greatly in deciphering the mid-Tertiary tectonism in this area. For this reason the individual dikes are recorded in detail on the geologic map (Fig. 5).

Petrography

Although each dike varies compositionally in some detail from the others, three main varieties of hypabyssal rocks are recognized in the study area:

1. Hornblende-biotite granodiorite porphyry, exposed predominantly in the southern part of the map area,
2. Biotite quartz monzonite(?) and quartz-plagioclase porphyry exposed in the central and northern portions, and
3. Rhyolite porphyry, observed only in the northern part.

This nomenclature is primarily based on phenocryst composition because the content of the microcrystalline matrix could not be determined under the microscope.

The hornblende-biotite granodiorite porphyry is a greenish-gray rock forming dikes 50 to 150 feet wide that locally broaden into small intrusive masses. The rock contains conspicuous hornblende and/or biotite phenocrysts in various stages of chloritization and epidotization (Figs. 64, 65, 66). Quartz eyes are either absent or occur in only minor amounts. Subhedral andesine plagioclase phenocrysts measuring 2 to 4 mm in diameter commonly exhibit clouded margins a fraction of a millimeter in width (Fig. 67). Strong oscillatory zoning can locally be seen in plagioclase. The matrix is a very fine grained to microcrystalline aggregate of quartz and clouded feldspar locally containing hornblende microlites. Matrix plagioclase and hornblende form, in places, a pilotaxitic texture because of their parallel arrangement. Plagioclase phenocrysts, however, show no preferred orientation. Orthoclase phenocrysts are absent, but K-feldspar may be present in the matrix.

The biotite quartz monzonite(?) porphyry dikes are characterized by distinct 3 to 10 mm dipyramidal quartz phenocrysts, zoned plagioclase, and black biotite (Fig. 68, 69). Clear to cream-colored subhedral plagioclase phenocrysts are ubiquitously present (Figs. 70, 71, 72). The quartz phenocrysts show varying degrees of resorption with tubelike embayments that are filled with matrix material and common plagioclase crystals. The color of the matrix ranges from dark greenish gray to orange gray depending on the relative amount of mafic microlites and K-feldspar. Some dikes are nearly devoid of any mafic constituents and essentially consist of quartz and plagioclase phenocrysts set in a light-gray quartz-K-feldspar matrix (Fig. 73). These rocks are herein called quartz-plagioclase porphyry.

Figure 64. Hornblende-biotite Granodiorite Porphyry Dike

Up to 0.5-inch black hornblende and chalky white plagioclase phenocrysts stand out clearly from the greenish-gray matrix. The bouldery disintegration is typical for all Laramide dike rocks in this area. Scale is 6 inches long.

Figure 65. Photomicrograph of Biotite-hornblende Porphyry (K-302)

Nearly completely resorbed and chloritized hornblende phenocrysts are surrounded by a microcrystalline groundmass. Quartz and magnetite occur within the altered phenocryst. Parallel nicols. Bar is 1 mm.

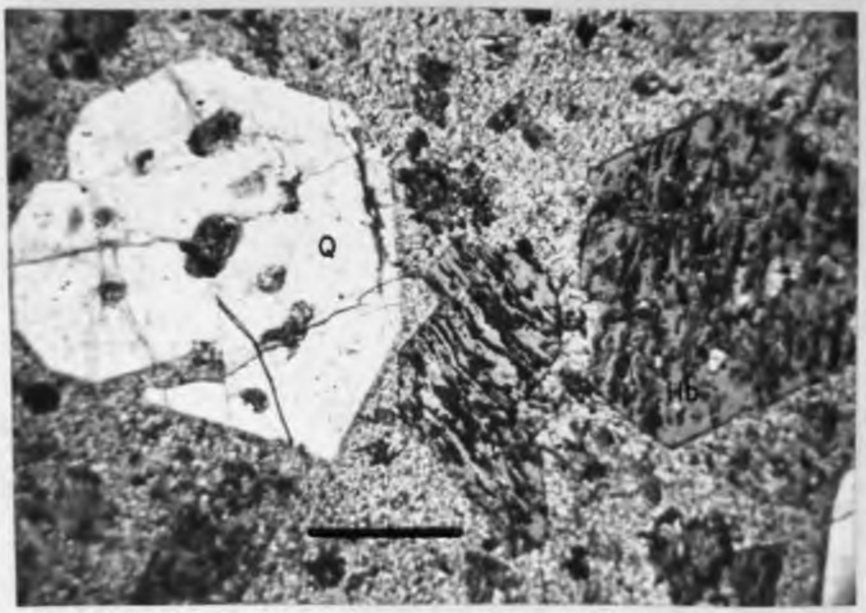


Figure 66. Photomicrograph of Biotite-hornblende Granodiorite Porphyry (K-253)

The chloritized hornblende phenocrysts (Hb) and the subhedral quartz grain (Q) are slightly resorbed by the matrix. The quartz grain contains inclusions of epidote and chlorite. Parallel nicols. Bar is 1 mm.

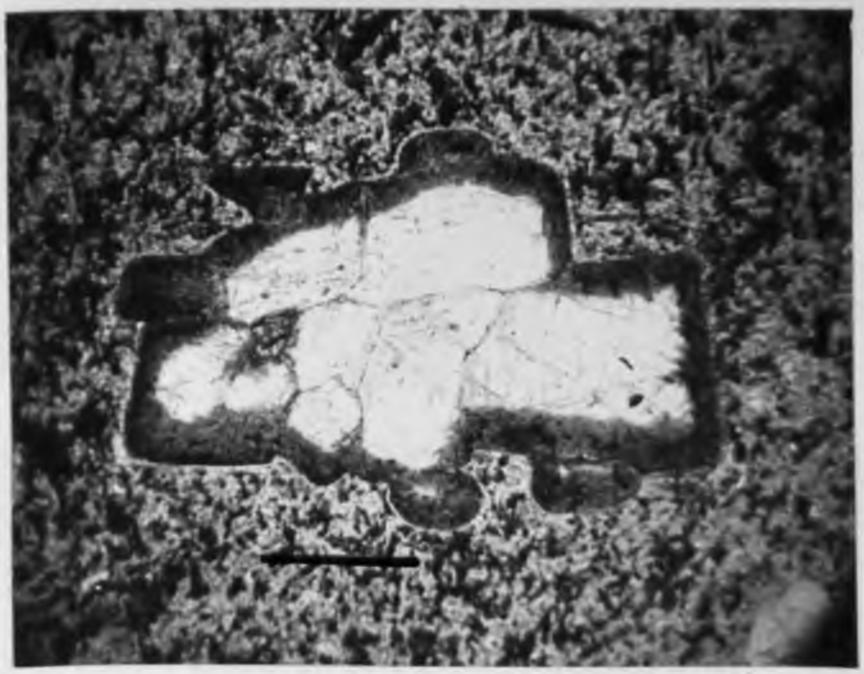


Figure 67. Photomicrograph of Granodiorite Porphyry (K-17)

A cluster of individual plagioclase crystals has been extensively kaolinized along the outer margin. The surrounding groundmass contains a large amount of fine-grained non-aligned hornblende Parallel nicols. Bar is 1 mm.

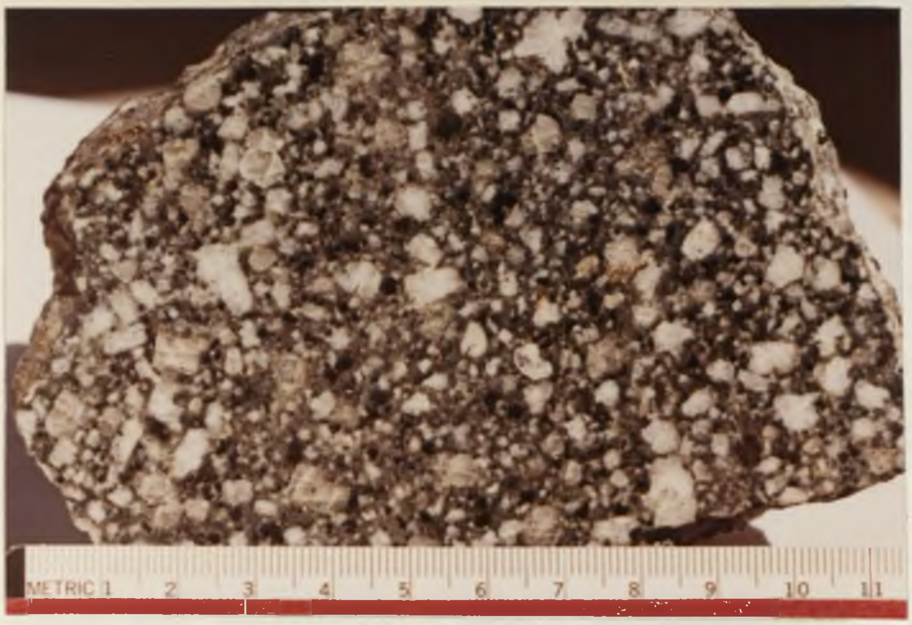


Figure 68. Biotite Quartz Monzonite Porphyry (G-268)

The rock contains glassy plagioclase, dipyramidal quartz eyes and black biotite set in a dark greenish gray matrix. This rock yielded a K-Ar date of 63 m.y.

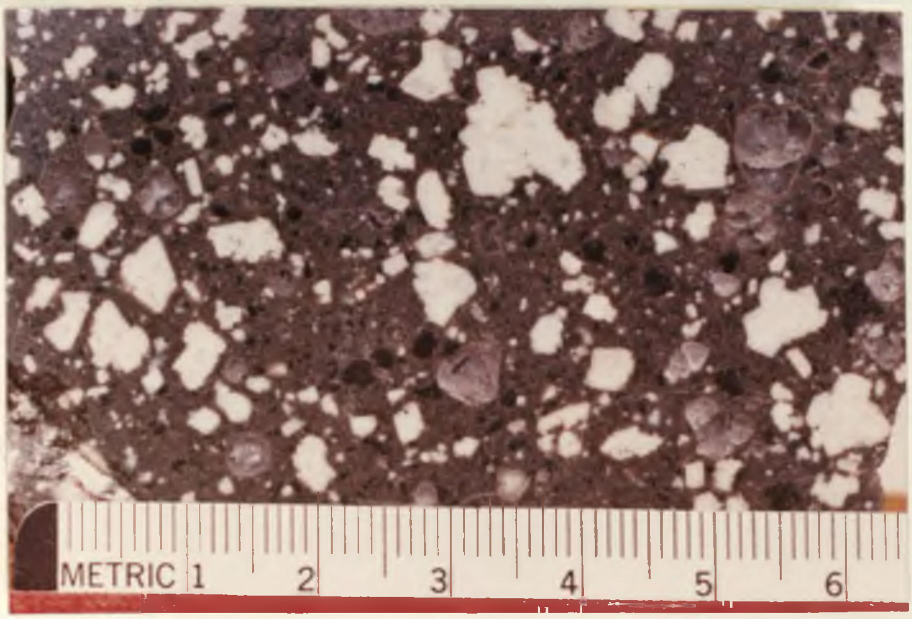


Figure 69. Quartz Monzonite Porphyry (K-130)

Dipyramidal quartz and chalky plagioclase grains are surrounded by finer quartz, plagioclase, K-feldspar, biotite matrix.

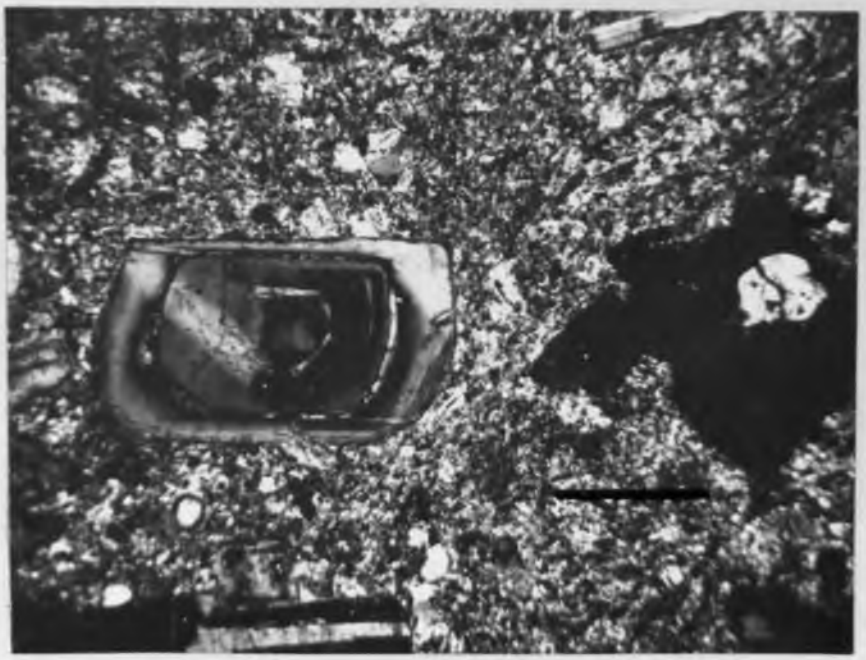


Figure 70. Photomicrograph of Quartz Monzonite Porphyry (K-77)

The zoned plagioclase phenocryst is set in a fine-grained quartz-feldspar-hornblende matrix. The irregular biotite grain (black) contains a plagioclase inclusion. Crossed nicols, Bar is 1 mm.

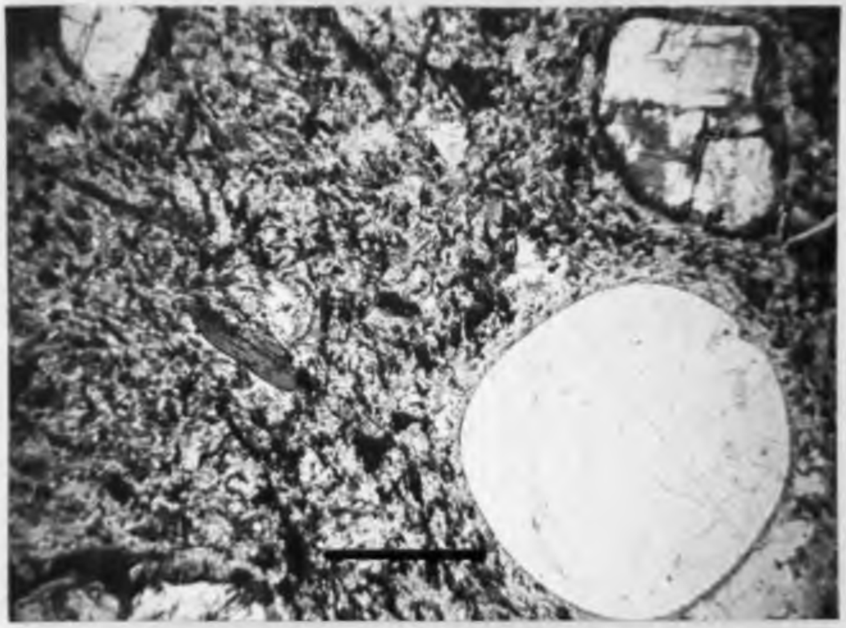


Figure 71. Photomicrograph of Quartz Monzonite Porphyry (K-77) Showing Resorbed Quartz and Plagioclase Grains

The foliation is caused by the alignment of hornblende needles. Parallel nicols. Bar is 1 mm.

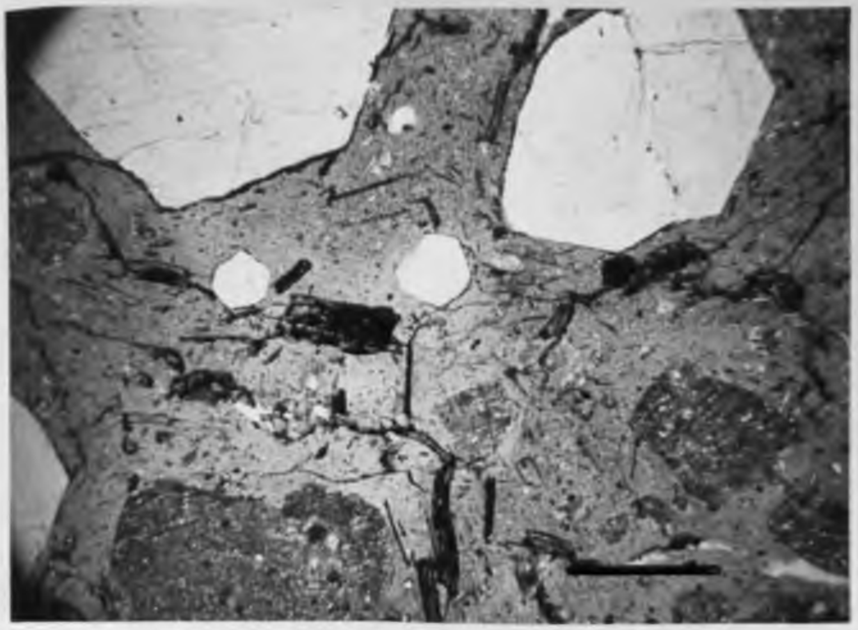


Figure 72. Photomicrograph of Quartz Monzonite Porphyry (K-55)

Subhedral phenocrysts of clear quartz, clouded plagioclase, and chloritized biotite are set in a microcrystalline matrix. A faint fluidal fabric is shown by the alignment of biotite. Parallel nicols. Bar is 1 mm.

Figure 73. Photomicrograph of Quartz Plagioclase Porphyry (G-44)

Subhedral phenocrysts of quartz and plagioclase are set in a fine-grained, non-foliated quartz-feldspar matrix. Crossed nicols. Bar is 1 mm.

Several 10 to 20 foot wide rhyolite porphyry dikes occur near the northern map boundary where they cut the earlier mentioned dike rocks. The rhyolite porphyries are pinkish gray with 1 to 3 mm pink orthoclase and plagioclase phenocrysts, 0.50 to 1 mm finely disseminated quartz eyes, and minor biotite. Phenocrysts constitute only 5 to 10 percent of the rock, the remaining being dense, pinkish-gray matrix composed primarily of microcrystalline quartz and orthoclase in a pilotaxitic arrangement.

Generally speaking, then, the dike rocks change from a biotite-hornblende-rich but quartz-poor assemblage in the south to a distinctly "quartz porphyritic" variety in the central and northern portion. However, this general trend does not exclude hornblende-rich rocks that are also present in the northern part of the map, but these varieties always contain distinct quartz phenocrysts, whereas the biotite-hornblende granodiorite in the south is devoid of quartz phenocrysts.

Age and Correlation

A K-Ar age determination on biotite from one of the biotite quartz monzonite porphyry dikes in the vicinity of the Rare Metals mine indicated a date of 63.1 $\pm$ 1.3 m.y. (Table 8). The dikes are therefore indistinguishable in age from the Grayback granodiorite pluton by K-Ar methods. However, field evidence shows that the dikes must be slightly younger than the Grayback granodiorite because they extend partly into the eastern half of the pluton. The close agreement of the two ages nevertheless suggests that the dikes are genetically related to the intrusion of the Grayback granodiorite pluton.

Dikes of similar composition and occurrence are found throughout the Dripping Spring range, the Crozier Peak quadrangle, south of Christmas, and in the South Butte area 10 miles west of the Tortilla Mountains. They are, without doubt, part of the east-northeast-trending Laramide intrusive belt discussed above.

TERTIARY SEDIMENTARY ROCKS

The youngest rocks in the study area are various conglomerates, sandstones, shales, and tuffaceous units that nonconformably overlie the Precambrian basement complex and the Laramide intrusive rocks. Three major sedimentary sequences have been recognized which differ in composition, texture, mode of occurrence, and geographic distribution within the map area:

1. Hackberry formation and allochthonous breccia masses exposed along the east front of the Tortilla Mountains,
2. Ripsey Wash sequence exposed on both sides of Ripsey Wash in the central portion of the map area, and
3. Gila(?) Conglomerate exposed east of the Gila River in the northeast portion of the map area.

Except for the Gila(?) Conglomerate which overlies the Hackberry formation with a distinct angular unconformity, no definite age correlation exists between the Hackberry formation and Ripsey Wash sequence. Thus, the Hackberry formation is here definitely older than the Gila(?) Conglomerate but may or may not be time equivalent with the Ripsey Wash sequence.

Hackberry Formation

The name Hackberry formation is assigned to a series of sedimentary rocks exposed along the entire eastern front of the Tortilla Mountains. The formation is named after Hackberry Wash, a major drainage feature in the southern part of the Kearny quadrangle, along which excellent exposures of the formation occur.

In the study area, the Hackberry formation consists of a poorly sorted and poorly bedded cobble-boulder conglomerate basal sequence, a light-gray to grayish-red-purple, poorly indurated, friable but well-bedded sandstone and shale sequence and a very well indurated and well-stratified grayish-red cobble conglomerate upper sequence. The distinct reddish color of this unit stems from the oxidized volcanic matrix material. The reddish cobble conglomerate sequence changes up section and along strike gradually into a granite and aplite-rich cobble conglomerate sequence. The exposed thickness of the Hackberry formation within the report area is calculated to be 4,500 feet from the outcrop pattern. The formation nonconformably overlies the Precambrian basement complex and is in turn disconformably overlain by Gila(?) Conglomerate.

The Hackberry formation crops out continuously for 7 miles along the eastern front of the Tortilla Mountains. The formation strikes north-northwest, dips 35°-80° northeast toward the Gila River and can be followed northward to the vicinity of Riverside. The northwest-flowing Gila River serves generally as dividing line between the Hackberry formation on the west and Gila(?) Conglomerate to the east. However, a few exposures of steeply dipping light-gray shales and sandstones believed to be part of the Hackberry formation crop out on the east side of the Gila River along the railroad tracks in secs. 7, 17, and 20, T. 4 S., R. 14 E., where they are overlain by Gila(?) Conglomerate with a marked unconformity (Fig. 74).

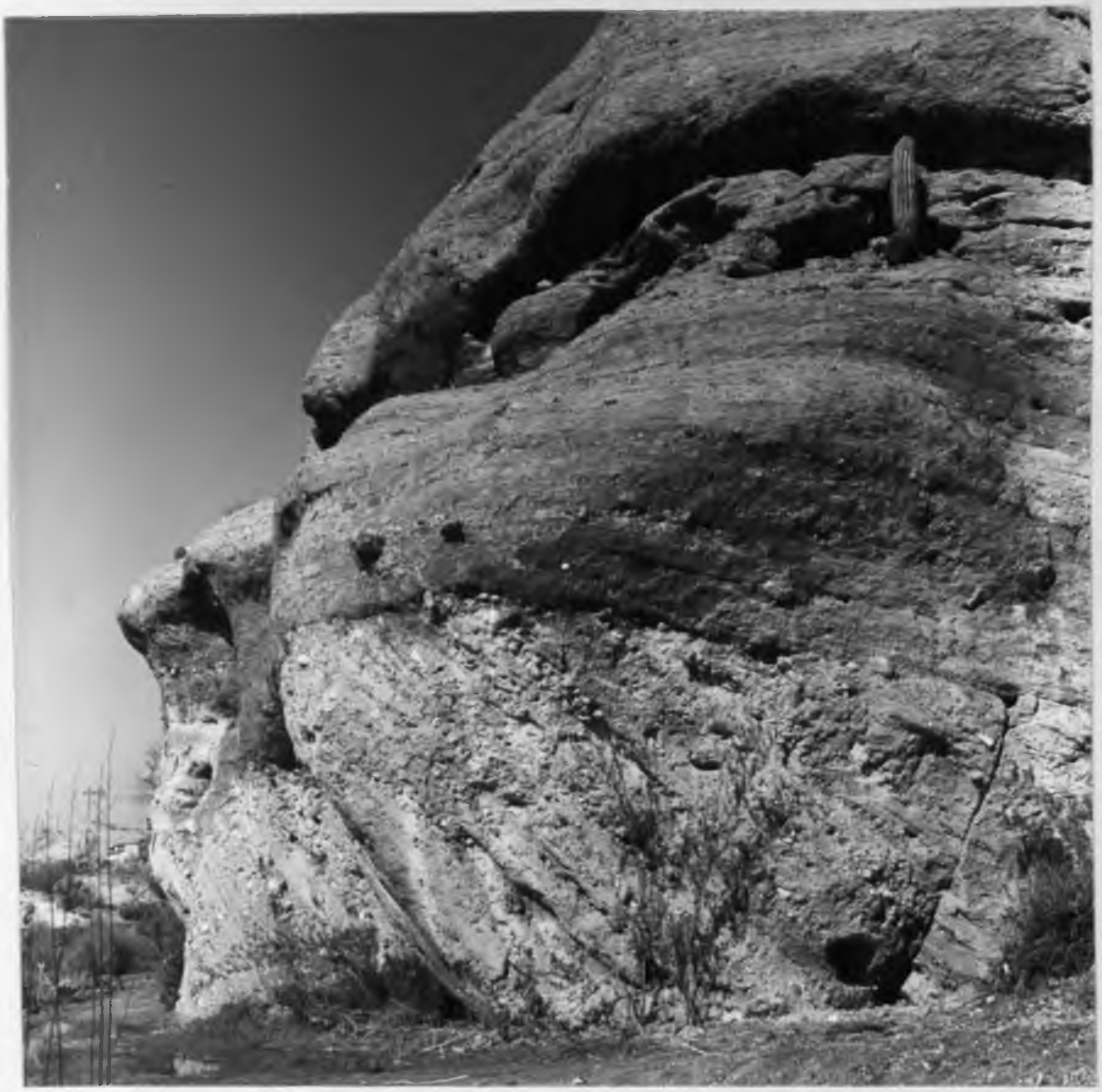


Figure 74. Unconformable Contact between Gently Dipping Gila Conglomerate (above) and Steeply Inclined Hackberry Formation (below)

Small fault in Hackberry formation is terminated by the overlying Gila Conglomerate. Outcrop is along section line between secs. 6 and 7, T. 4 S., R. 14 E. near the railroad tracks of the Southern Pacific Co., looking north.

Heindl (1958, p. 88-89) describes red sandy beds about 1.5 miles north of the present boundary on the east side of Mineral Creek. The red beds generally strike N. 60° E., dip 10°-15° SE., and are faulted against the Dripping Spring Mountains. The dip of the red beds steepens considerably and the strike is more varied near the fault contact. The red beds are unconformably overlain by Gila Conglomerate which strikes N. 25° W. and dips about 5° SW. According to Heindl, the Gila Conglomerate is in depositional contact with the bedrock of the Dripping Spring Mountains. Heindl tentatively correlates these red beds with similar units in the Hackberry Wash area of the present report. The Elder Gulch red beds are the northernmost-known occurrence of the Hackberry formation in this area.

The lower portion of the Hackberry formation is a moderately well indurated cobble and boulder conglomerate composed of angular to subangular blocks of Oracle Granite, aplite porphyry, diabase, sediments of the Apache Group, Paleozoic limestone, and Laramide hypabyssal rocks in various proportions (Fig. 75). The composition of the conglomerate reflects closely the nature of the underlying basement complex. The angularity and ill sorting of the material suggests deposition close to its original source. The contact between conglomerate and basement complex is depositional, and it is either vertical or dips steeply to the east (Fig. 51). Only locally is there some faulting present along the contact.

Bedding is generally difficult to recognize in this basal conglomerate member, but occasional 1 to 2 inch thick arkose and shale layers and the alignment of pebbles and cobbles indicate the structural attitude.

Figure 75. Typical Exposure of the Poorly Bedded but Well-indurated Basal Cobble and Boulder Conglomerate Sequence of the Hackberry Formation

The conglomerate consists here mainly of older Precambrian granite and aplite. Note the discontinuous arkosic sandstone lenses and fine pebble horizons suggesting crude layering. N1/2 sec. 19, T. 4 S., R. 14 E.

North of Hackberry Spring in secs. 5 and 8, T. 5 S., R. 14 E., the cobble conglomerate directly overlies Troy Quartzite. Here the conglomerate consists mainly of Apache quartzite and Paleozoic limestone fragments embedded in a reddish arkose matrix. No boulders of Oracle Granite and aplite porphyry are present. The occurrence of Paleozoic limestone cobbles in the conglomerate suggests that limestone strata once covered the site of the present Tortilla Mountains but have since been completely removed by erosion. At Hackberry Spring, the conglomerate wedges out completely, and in its place occur the allochthonous breccia sheets resting directly upon Laramide quartz diorite.

Farther north in sec. 19, T. 4 S., R. 14 E. and sec. 30, T. 5 S., R. 14 E., the conglomerate contains abundant quartzite material of the Apache Group even though no Apache Group rocks crop out in this area. The conglomerate rests directly on Oracle Granite. The writer believes that the Apache Group extended at one time much farther to the north along the eastern front of the Tortilla Mountains than is presently evident from the outcrop pattern. Isopachs indicate it. The conglomerate is the erosional representation of the missing Apache Group strata.

Monolithologic breccia lenses of aplite porphyry, Oracle Granite, and diabase are conformably interbedded with the conglomerate sequence in secs. 18 and 19, T. 4 S., R. 14 E. and sec. 30, T. 5 S., R.14 E. The breccia lenses are 2,000 to 3,000 feet long, up to 200 feet thick, and are confined more or less to a certain stratigraphic horizon within the conglomerate sequence. The breccias occur either directly on the granite basement complex or within a few hundred feet from the granite-conglomerate contact. The breccia lenses consist of tightly packed angular fragments a few inches to several feet in diameter. Matrix material is virtually absent. Diabase and granite breccias are often superposed in shinglelike fashion without any obvious mixing. The enclosing conglomerate is usually rich in fragments of the Apache Group. A 10 by 100 foot brecciated quartzite sliver of Pioneer Formation rests directly on a granite breccia lens in the N1/2 sec. 30, T. 5 S., R. 14 E. Apparently, both were emplaced simultaneously. The breccia lenses are probably of landslide origin as a result of uplift and tilting in the neighboring Tortilla Mountains. The composition of the breccia lenses is certainly identical to the rock types exposed in the Tortilla Mountains. The Tortilla Mountains are therefore considered to be the source area for the breccia lenses.

In the W1/2, sec. 32, T. 4 S., R. 14 E., the boulder conglomerate wedges out below the thinly bedded shale and sandstone sequence so that the sandstone sequence rests directly on the Precambrian basement complex. In the general stratigraphic sequence of the Hackberry formation, the shale and sandstone units are above the basal boulder conglomerate. Because of their friable nature, the shales and sandstones are easily eroded and heavily covered with talus debris. Generally, 1 to 2 inch thick tuffaceous(?) sandstone beds alternate with extremely friable shale layers. Locally, a few cobble horizons measuring up to half a foot thick are present.

The sandstone-shale sequence varies from light gray to deep maroon red and ranges from less than 100 to 3,000 feet in thickness (Figs. 76 and 77). It is in this sequence that the large allochthonous breccia sheets are found. Numerous mud cracks and ripple marks in the

Figure 76. Steeply Eastward Dipping, Thinly Bedded, Friable Sandstone and Shale Sequence of the Hackberry Formation

SE1/4 sec 30, T. 4 S., R. 14 E., looking south.

Figure 77. Outcrop Pattern of Hackberry Formation and Paleozoic Crackle Breccia

The ridge-forming limestone crackle breccia occurs within the red-brown, steeply dipping, thinly bedded, sandy shale and mudstone sequence. NW1/4 sec. 32, T. 4 S., R. 14 E., looking northeast.

shales and sands indicate a shallow-water environment, but no trace of any fossil material has been noted. Locally, 0.25 to 0.5 inch thick gypsum layers occur within the maroon-red shale horizons indicating evaporation in a closed basin.

Stratigraphically above the shale-sandstone sequence is the very well indurated and well-bedded cobble conglomerate unit exposed along the course of Hackberry Wash (Fig. 78). The unit consists of alternating thinly bedded arkose and mudstone layers with numerous cobble horizons (Fig. 79). The cobbles are generally well rounded and well sorted. Individual beds range from 0.25 inch to several feet in thickness. Graded bedding and cross laminations are common. Numerous interbedded mudstone units show mud cracks; others exhibit interference and oscillation ripple marks indicative of a shallow lacustrine environment.

The cobbles range in composition from andesite agglomerate through vesicular basalt, diabase, and Oracle Granite to younger Precambrian quartzite, Paleozoic limestone, granodiorite porphyry, and a distinctive variety of hornblende andesite (Fig. 80). The andesite contains slender black hornblende phenocrysts up to 0.75 inch long in a light-gray aphanitic matrix. Nowhere is there a rock exposed in the investigated area that could have served as source material for this particular hornblende andesite. A similar problem exists for the vesicular basalt and andesite agglomerate of the Hackberry formation. The nearest exposures of andesite and basalt are in the Christmas area (Willden, 1964). There extensive exposures of Cretaceous andesite flows overlie the gently dipping Paleozoic limestone sequence. In hand specimen, the

Figure 78. Hackberry Formation

Thinly bedded, well-indurated sandstone and cobble conglomerate sequence dipping 35°-55° E. Hackberry Wash, looking north.

Figure 79. Detail of the Hackberry Outcrop Seen in Figure 78

Note the alternating cobble conglomerate, sandstone, and shale sequence. Red-brown coloration results from andesitic matrix material. The light-gray cobbles are hornblende andesite(?) probably derived from the Christmas-Winkelman area. Hackberry Wash. Pencil is 6 inches long.

Figure 80. Close-up of Alternating Cobble Conglomerate and Sandstone Sequence in Hackberry Formation

Note vesicular basalt (b) and hornblende andesite (h) cobbles in the well-bedded and well-indurated andesite-rich matrix material. Hackberry Wash. Pencil is 6 inches long.

andesite agglomerates from the Christmas area are indistinguishable from the andesite cobbles in the Hackberry formation. This suggests that at least the andesite-rich cobble conglomerate was transported into this region from the Winkelman-Christmas area during mid-Tertiary time. Alternatively, one can assume that the Tortilla Mountains were once covered by Cretaceous andesite agglomerate flows which since then have been completely removed by erosion. These could have served as ready source for the cobbles and matrix material in the Hackberry formation as well as for the andesite agglomerate units within the allochthonous breccia sheets.

West of Hackberry Spring in secs. 7, 8, and 17, T. 5 S., R. 14 E., an isolated area of grayish-red Hackberry formation is separated by the Hackberry fault from Precambrian Oracle Granite, diabase, and Laramide quartz diorite. The beds strike generally west-northwest and dip 18°-80° SW., opposite to the dip of the main Hackberry formation exposed farther east. The Hackberry fault is well exposed and dips 30°-55° SW. This structure is a branch of the major Ripsey fault system, which, farther north, separates the entire mid-Tertiary conglomerate sequence in the Ripsey Wash area from the underlying granitic basement complex. The reddish cobble conglomerate units west of Hackberry Spring are indistinguishable from the well-stratified grayish-red Hackberry formation exposed a short distance to the east. A poorly sorted, poorly stratified, light-gray cobble and boulder conglomerate overlies the Hackberry formation west of Hackberry Spring with apparent angular unconformity.

Discussion

The reversed dip direction within the Hackberry strata suggest a northwest-trending anticlinal structure whose southwest limb is comprised of the strata west of Hackberry Spring and whose eastern limb is the sequence exposed along Hackberry Wash. The core of this hypothetical anticline is presently occupied by the Laramide quartz diorite stock and portions of the Precambrian basement complex. The structural setting, however, demands a different explanation. First of all, the sedimentary sequence in Hackberry Wash overlies the basement complex with a depositional contact, and its present steeply dipping attitude is the result of homoclinal eastward tilting of the entire Precambrian block. The western segment of the Hackberry formation, on the other hand, is in fault contact with the underlying Laramide quartz diorite and Oracle Granite indicating that the unit was displaced into its present position. The two adjustments probably were simultaneous.

Age and Correlation

The Hackberry formation nonconformably overlies the Precambrian basement complex and the Laramide hypabyssal rocks. The formation therefore postdates the youngest intrusive event in this area, which occurred at 63 m.y. In the vicinity of Riverside, the Hackberry formation is overlain by Gila Conglomerate with a distinct angular unconformity (Fig. 73). Thus, from stratigraphic evidence, the Hackberry formation is younger than the Laramide intrusive event but older than the Gila Conglomerate. Furthermore, the presence of volcanic detrital material in the formation indicates that the sediments postdate the Cretaceous andesite-basalt extrusive event so widely exposed in the Christmas quadrangle.

Dr. E. Lindsay of the Department of Geosciences and the writer made a special but unsuccessful attempt to discover fossils in the sandy and shaly portions of the formation. No isotopic age dates of the Hackberry formation are available from the immediate study area. However, 2 miles south of the map boundary in the adjacent Crozier Peak quadrangle, Medora Krieger (personal commun., 1969) obtained two K-Ar dates from an intraformational rhyolite bed which is part of a sequence considered by the writer to be the southern extension of the Hackberry formation. The dates were obtained from biotite and sanidine separates which yielded ages of 20 and 24 m.y., respectively. The Hackberry formation, therefore, is of early to middle Miocene age.

Sedimentary units similar to the Hackberry formation in physical appearance and stratigraphic position are the Cloudburst Formation of Creasey (1967), the San Manuel Formation of Heindl (1963) in the San Manuel area, the Mineta beds of Chew (1962) near Redington, portions of the lower Rillito Formation south of the Santa Catalina Mountains (Voelger, 1953; Pashley, 1966), and an unnamed red-brown cobble conglomerate sequence in the Owl Head mining district exposed 8 miles northwest of Oracle Junction along State Highway 80-89.

The Cloudburst Formation is considered by Creasey to be of Late Cretaceous or early Tertiary age as determined from stratigraphic evidence and correlation with similar-appearing strata in Reed Basin southeast of Christmas. The Cloudburst is a sequence of steeply dipping alternating mafic volcanic, fanglomeratic, and sedimentary breccia units. The major portion of the fanglomerate is very similar to the well-bedded, well-indurated Hackberry formation. The latter, however, does not contain andesite-basalt flows. Similar to the Hackberry formation, the Cloudburst contains granodiorite porphyry cobbles probably derived from a nearby Laramide-age stock. It may be that the Hackberry formation is the northern equivalent of the Cloudburst Formation.

Watson (1967) strongly believes that the Cloudburst Formation at least in part predates the Laramide granodiorite porphyry at San Manuel because he established an intrusive relationship between the porphyry and the Cloudburst Formation at a locality where Creasey had mapped a fault contact. Creasey (1967) however maintains that the presence of Laramide granodiorite porphyry fragments in the Cloudburst Formation establishes a post-Laramide age for the formation. Because of these discrepancies in the interpretation, a direct correlation between the Hackberry and Cloudburst Formations is not attempted at the present time.

The San Manuel Formation of Heindl is synonymous with Creasey's lower Gila Conglomerate member. According to Heindl, the San Manuel Formation overlies the Cloudburst Formation with both a nearly conformable and a distinctly unconformable contact, and it is clearly younger than the Cloudburst. Heindl considers the San Manuel Formation to be of mid-Tertiary age, whereas Creasey assigns a Plio-Pleistocene age to his lower Gila Conglomerate member. The units of the San Manuel Formation are moderately well stratified and dip 20^{o}-45^{o} E. toward the San Pedro River. This dip, in fact, is very similar to the attitude of the Hackberry formation. In composition, the San Manuel formation resembles the granite-rich portions of the Hackberry formation. Thus, the Hackberry formation shows affinities to both the Cloudburst and San Manuel Formation making a direct correlation with either one of the latter two units very difficult.

To recapitulate, the following arguments have to be considered in any correlation scheme:

1. The Hackberry formation is of Miocene age as determined by two K-Ar dates. Stratigraphic evidence also indicates a post-Laramide age for the formation.
2. Creasey (1967) considers the Cloudburst Formation to be of post-Laramide age because of the presence of granodiorite porphyry pebbles, whereas Watson (1967) argues for a pre-Laramide age because of intrusive relationships between granodiorite porphyry and the Cloudburst Formation.
3. The San Manuel Formation of Heindl (1963) (lower Gila Conglomerate member of Creasey, 1967) is definitely younger than the Cloudburst Formation and is considered to be of mid-Tertiary age of Heindl but of Pleio-Pleistocene age by Creasey.
4. The Hackberry formation is structurally and compositionally very similar to both the Cloudburst and San Manuel Formations. All these sedimentary strata under consideration strike generally north-northwest and dip steeply to the northeast toward the Gila-San Pedro valley trough.

The Miocene Mineta beds of Chew (1962) exposed near Redington along the San Pedro Valley on the east side of the Rincon Mountains have certain similarities to the red-bed sequence of the Hackberry formation. The units strike north-northwest and dip steeply to the east. The upper mudstone-sandstone units of the Mineta may correlate with the maroon shale units of the Hackberry formation. Fossil teeth and jaw bones of a rhinocerous species indicate an early Miocene age for the upper Mineta beds. The Mineta Formation is overlain by a "Turkey Track"-like andesite flow which has been dated by Damon (1970) at 26.3 $\pm$ 2.4 m.y. The "Turkey Track" andesite is not exposed in the Hackberry area. Further study in the Redington area may reveal a continuation of the red-bed sequence to the north and eventually establish the presence of a continuous mid-Miocene sedimentary sequence along the San Pedro-Gila River valley which has hitherto only been suspected from widely scattered exposures.

A reddish-maroon, well-stratified cobble and boulder conglomerate described by Barter (1962) and Iles (1967) in the Owl Head mining district resembles to some extent the red-bed sequence of the Hackberry formation. The unit strikes northwest and dips 20°-75° NE. It certainly conforms with the present attitude of the other mid-Tertiary strata mentioned above. Barter correlates this formation with the Miocene Pantano Formation of southeast Arizona (Brennan, 1962).

Studies by Voelger (1953) and Pashley (1966) in the southern foothills of the Santa Catalina Mountains north of Tucson indicated the presence of maroon-red mudstone units measuring up to 300 feet in thickness and dipping 10°-40° S. away from the Santa Catalina Mountain front toward the Tucson basin. The mudstone layers contain locally abundant gypsum and resemble the silty-sandy portions of the Hackberry formation. From stratigraphic relationships, Voelger considers this lower part of his Rillito formation to be of mid-Tertiary age.

It is difficult to evaluate whether or not these isolated mid-Tertiary units were deposited in one continuous basin or playa lake during Miocene time. Post-Miocene tectonism has modified too many features to allow a simple correlation between outcrops, and recent talus material has covered critical exposures that are essential for a regional investigation. Heindl (1958, Fig. 7) suggests a definite sequence between Pantano-, Whitetail-, and Hackberry-type conglomerates with Pantano being the oldest and Hackberry the youngest deposit. He envisions an initially more or less continuous basin of deposition (1963, plate 3) which became involved in the Basin and Range tectonic episode and deformed into numerous block-faulted basins. These individual basins now expose the tilted Miocene conglomerate sequences. The writer believes that the localities mentioned above represent time-equivalent but separate basins of deposition of early Miocene or late Oligocene age. Table 9 is an attempt to correlate various mid-Tertiary sedimentary units which occur in widely spaced localities throughout southern Arizona.

Allochthonous Breccia Sheets of the Hackberry Formation

One of the most interesting features of the Hackberry formation is the presence of allochthonous breccia sheets and lenses that are conformable with the shale and sandstone units of the formation. The breccias are generally confined to a certain horizon within the formation. For reasons given below, the writer believes these allochthonous breccia sheets to be landslide masses or avalache-type deposits emplaced under

Table 9. Correlation between Mid-Tertiary Sedimentary Rocks in Southern Arizona

AGE M.Y.	AGE Epoch	Ray: Ransome (1919)	Tortilla Mtns.: This Report	San Manuel: Creasey (1967)	San Manuel: Heindl (1963)	Owl Head: Barter (1962), Iles (1967)	Redington: Chew (1962), Clay (1970)	Tucson Basin: Voelger (1953), Pashley (1966)	Tucson Basin: Brennan (1962)
1	PLEISTOCENE	Pediment Gravels	Pediment Gravels	Pediment Gravels	Pediment Gravels; Sacaton Fm.		Pediment Gravels	Alluvium Valley Fill	Alluvium Pediment Gravels
13	PLIOCENE	Gila Cgl.	Gila Cgl.	Gila Cgl.	Gila Group: Quiburis Fm.	Alluvium Pediment Gravels	Banco Beds		
20, 25	MIOCENE	Dacite	Ripsey Wash Sequence		Gila Group: San Manuel Fm.	? ?	Soza Beds	? ?	? ?
36	OLIGOCENE	Whitetail Fm.	Hackberry Fm. (20-24 m.y.)	Cloudburst Fm.	Fanglom.; Cloudburst Fm.: Volcanic Unit	Unnamed Tilted Red Cobble Cgl. Sequence and Andesite Agglomerate	Turkey Track Porphyry (26 m.y.) Mineta Fm.	Rillito Fm.	Pantano Fm. (33-37 m.y.)
	PRE-OLIGOCENE	Paleozoic Sediments and Precambrian Basement	Precambrian Basement	Precambrian Basement	Precambrian Basement	Precambrian Basement	Catalina Gneiss Pinal Schist	Catalina Gneiss	Cretaceous Sediments Pinal Schist

the force of gravity from a rising mountain front, rather than the remnants of a major overthrust.

These bluish-gray breccia sheets are clearly visible across the Gila River from Kearny where they appear to rest directly upon the Precambrian basement.

Individual breccia lenses measure from 50 to 100 feet in thickness and many can be followed for nearly 2 miles along strike. Because of their high resistance to erosion, the breccia sheets stand out in bold relief above the shale and sandstone units of the Hackberry formation (Figs. 77 and 81). The breccia sheets trend north-northwest parallel to the enclosing sediments and dip 40°-70° E.

The breccias crop out along the eastern margin of the map area in three separate exposures over a cumulative strike length of 6 miles (Fig. 5). The southernmost breccia mass is exposed along Hackberry Wash near Hackberry Spring and measures a little over 2 miles in length. The central breccia mass is confined to secs. 19, 29, 30, and 32, T. 4 S., R. 14 E. and crops out about half a mile west of the Gila River. It is separated along strike from the southern breccia mass by 3,500 feet of sandstone and shale. The northernmost breccia mass occurs in sec. 18, T. 4 S., R. 14 E., along a tributary wash of the Gila River. This breccia is separated along strike from the central mass by 6,000 feet of Hackberry formation.

Composition of the breccia sheets. Each one of the breccia masses is composed of a series of individual monolithologic breccia lenses that range in composition from Precambrian diabase and quartzite, to various units of Paleozoic limestone, Cretaceous andesite agglomerate,

Figure 81. Allochthonous Crackle Breccia in Miocene Hackberry Formation

The breccia is composed of Paleozoic limestone and younger Precambrian quartzite units which dip with the Hackberry formation steeply to the east. SE1/4 sec. 19, T. 4 S., R. 14 E., looking south.

and Laramide-age granodiorite porphyry. Within each breccia mass the individual lenses are stacked up on top of each other like shingles on a roof. Each breccia lens represents a separate glide unit. In spite of the wide compositional range represented among them, the individual monolithologic breccia lenses are not mixed with other rock types except for some intermingling along mutual contacts.

Each individual rock unit is extensively shattered and recemented. Each lens is, nevertheless, continuous enough to be a mappable unit. In every breccia lens, the smaller angular fragments fill the spaces between the larger angular fragments. Bedding is on rare occasions still discernible within individual breccia lenses, but no part of any surface measuring over 5 inches in diameter is left intact by the shattering process (Fig. 82). Generally speaking, the quartzite lenses show a higher degree of brecciation than the overlying limestone units.

All limestone breccias are fossiliferous, containing abundant crinoid stems, brachiopod shells, and bryozoan remnants. Because of the intense brecciation, no fossils have remained intact for precise identification (Fig. 83). North of Hackberry Spring, a breccia lens contains a few thinly bedded limestone slabs with abundant brachiopod shells which Dr. D. L. Bryant of the Department of Geosciences identified as Atrypa. These forms are diagnostic of the Devonian Martin Formation.

The southern breccia mass shows the most complicated structural arrangement. It consists of up to 10 superimposed lenses each measuring 20 to 50 feet in thickness. In order to indicate the internal structure of the breccia masses, the individual lenses were separated

Figure 82. Dolomitic Crackle Breccia with Remnant Bedding

Same location as Figure 81. Pencil in center of picture is 6 inches long.

Figure 83. Limestone Crackle Breccia

Intensely brecciated Paleozoic limestone recemented by a fine-grained carbonate-limonite matrix. The breccia is monolithologic. N1/2 sec. 8, T. 5 S., R. 14 E. Pencil is 6 inches long.

on the geologic map (Fig. 5). Good contact relationships between the underlying shales of the Hackberry formation and the overlying breccia sheets are exposed in sec. 5 near the northern termination of the breccia mass. Here the steeply eastward-dipping, thinly bedded, friable sandstones and shales are more or less conformably overlain by a 1 to 2 foot thick dolomite breccia sheet. No evidence of faulting occurs along the contact. The underlying shale units are undisturbed, except at the very contact. The shale tends to penetrate the overlying dolomite breccia as apophyses along minute cracks suggesting reaction to loading in a lacustrine(?) environment.

The dolomite breccia thins out rapidly to the south and its place is taken by a 15 to 20 foot thick diabase breccia. Immediately above the diabase is a white to reddish-gray coarse quartzite breccia which, as one traverses eastward across the entire unit, gives way succesively to Escabrosa Limestone, diabase, more quartzite, and, finally, to the composite Paleozoic limestone breccia sheets that form the prominent dip slope along Hackberry Wash. The limestone breccias are locally overlain by a thin veneer of andesite agglomerate and granodiorite porphyry breccia before they are covered by the steeply dipping, light-gray to red-maroon shales of the Hackberry formation.

The lower contact of the main breccia unit with the Hackberry formation is remarkably straight even though the individual lenses within the breccia mass pinch out and alternate continuously.

North of Hackberry Spring in the N1/2 of sec. 8, the entire breccia mass can be viewed in cross section where a small wash cuts across the exposure (Fig. 84). Here, the main limestone breccia is

Figure 84. Allochthonous Paleozoic Limestone Breccia near Hackberry Spring

The breccia is underlain and overlain by the steeply dipping Miocene Hackberry Formation. Ridges in the background are underlain by the steeply dipping younger Precambrian Apache Group and Laramide quartz diorite intrusive masses. Looking southwest.

overlain by a thin band of andesite agglomerate and underlain by a white quartzite breccia lens. The quartzite breccia lens overlies a block of Pioneer Formation which still retains its original bedding. The Pioneer overlies brecciated dolomite, white quartzite, and limestone. The entire breccia mass is then terminated at its lower contact by steeply eastward dipping, friable sandy shale units of the Hackberry formation. The shales separate a second series of quartzite and limestone breccia lenses situated about 400 feet stratigraphically below the main breccia mass just described. This second breccia series is also underlain by the friable shales which in turn grade rapidly into the cobble and boulder conglomerate of the basal Hackberry formation (Fig. 85).

South of Hackberry Spring, the andesite agglomerate increases rapidly in volume and becomes a major constituent of the breccia mass. The agglomerate generally separates individual breccia lenses and, thus, may have served as a glide horizon for the emplacement of the breccia sheets.

From the center of sec. 8, T. 5 S., R. 14 E. southward the breccia lenses directly overlie the Laramide quartz diorite stock rather than the sandy shale units. The basal conglomerate and the shale members of the Hackberry formation apparently lap out southward against the quartz diorite stock so that the breccia sheets were emplaced directly upon the Laramide intrusive rock. A thin veneer of andesite agglomerate is usually present along the lower contact of the breccia mass. The andesite appears to have been emplaced together with the breccia over the Laramide stock.

Figure 85. Limestone and Quartzite Breccia Sheets in Hackberry Formation

Each individual breccia sheet shows considerable slickensides at the base, which resembles superficially a major fault surface. The slickensides trend generally downdip and attest the movement of these sheets into their present position.

The central breccia mass shows a very similar structural arrangement as the southern one. A few hundred feet stratigraphically below the main breccia mass, well within the sandy shales of the Hackberry formation, are several parallel breccia lenses measuring 10 to 80 feet in thickness and up to half a mile in length. The breccias are composed of Pioneer Formation, Troy Quartzite, Paleozoic limestone, andesite agglomerate, and granodiorite porphyry. The younger Precambrian quartzite breccias generally overlie the Paleozoic limestone breccia lenses. This reversed stratigraphic relationship is to be expected in an area of rapid erosion near a rising mountain front.

The main central breccia mass thins rapidly to the north and in the E1/2 sec. 19, T. 4 S., R. 14 E., the breccia loses its identity. The breccia trails along strike into a true limestone conglomerate which is indistinguishable from the other conglomerate horizons of the Hackberry formation.

Emplacement of the Allochthonous Breccia Masses

The rock types represented in the breccia masses range from Laramide to younger Precambrian in age. As is evident from the foregoing description and the geologic map (Fig. 5), no order exists in the stratigraphic arrangement of individual breccia sheets within the main breccia masses. The proposition of a landslide origin for the breccia masses would require under certain conditions that the youngest rock units occur near the bottom of the pile and the older diabase and quartzites near the top. Such a sequence is certainly not represented here. In fact, the more competent younger Precambrian quartzite breccia lenses are invariably at the bottom of the stack, and the Paleozoic limestone breccia lenses usually form the uppermost layer. This heterogeneous stacking order, however, does not negate a landslide origin.

As pointed out above, the breccia masses are conformably underlain and overlain by the sandy shales of the Hackberry formation. The shales indicate a very wet if not lacustrine environment of deposition. As the Tortilla Mountains rose they were actively eroded. The material was transported rapidly into the adjacent basin to the east, and it forms now the ill-sorted basal conglomerate member of the Hackberry formation. Large masses of diabase, quartzite, and limestone became unstable during this time of uplift and detached themselves from their original position. The Tortilla Mountains must have been tilted about 30°E., judging from the angular discordance between basal conglomerate and sedimentary rocks of the Apache Group. This inclination of the Tortilla block probably aided the detachment of the various rock slabs which then moved down the steep mountain front en masse over the alluvial fans and into the shallow lake that had formed at the present site of the Gila Valley. Because all breccia masses presently lie in the same stratigraphic horizon of the Hackberry formation, the emplacement of these breccias must have occurred during a relatively short time interval, probably in response to increased uplift. The underlying shales upon which the breccia sheets were deposited show no sign of disturbance. This relationship suggests that the sheets moved into their depositional sites in a very orderly fashion. Rock creep and sliding down a gentle, well-lubricated slope of 5° to 10° appears to be a plausible mechanism for the breccia emplacement.

The cause of brecciation of the individual rock masses is difficult to explain. Because the underlying and overlying Hackberry sediments are undisturbed, the brecciation could not have taken place after the rock slabs were emplaced. Furthermore, brecciation did not take place prior to the detachment of the rock slabs from their source area in the Tortilla Mountains because the few remaining Paleozoic limestone exposures south of the Florence mine are not brecciated. The same is true for the younger Precambrian quartzite units and the diabase. Therefore, brecciation must have occurred during transport as the individual brittle rock slabs moved over some irregularities or obstacles on the ground surface. A similar emplacement mechanism was proposed by Van Alstine (1970) for allochthonous Paleozoic blocks in the Tertiary San Luis-upper Arkansas graben of Colorado. Bell (1971) studied an allochthonous glide sheet in the Shadow Mountains of California where the plate slid into Tertiary lake beds causing little or no deformation of the underlying sediments. It is unlikely that a talus or rock avalanche can produce a series of monolithologic breccia sheets that show so little sign of intermingling. The writer favors the explanation that each individual breccia sheet represents a rock slab which became detached from its source while the Tortilla Mountains were in the process of vertical uplift with slight rotation to the east. The rock slabs can be viewed as glide sheets moving down a gentle slope under the force of gravity.

The Tortilla Mountains are considered to be the source of the breccia masses because every allochtonous breccia sheet can ultimately be traced to a corresponding outcrop area in the adjacent mountain range, except the andesite agglomerate which is so prevalent in the southern breccia mass. As mentioned above, the nearest exposures of similar andesite agglomerate are in the Christmas-Winkelman area about 10 miles southeast of here where they are part of a vast Cretaceous volcanic-sedimentary sequence. The presence of andesite in the breccia masses gives strong support to the idea that portions of the Tortilla Mountains were once covered by a Cretaceous extrusive sequence. Certainly, no trace of this volcanic record has been found in the Tortilla Mountains proper, probably as a result of extensive erosion in mid-Tertiary time. The presence of Cretaceous volcanic rocks would also explain the high percentage of andesite and basalt cobbles in the Hackberry formation.

The steeply inclined attitude of the breccia masses and enclosing sediments is the result of continuing eastward tilting of the Tortilla block during late Miocene or early Pliocene time.

Ripsey Wash Sequence

The name "Ripsey Wash sequence" is here given to a series of boulder conglomerate and tuffaceous sandstone units conspicuouly exposed along the entire length of Ripsey Wash in the central part of the map area. Three members are recognized:

1. A lower, poorly sorted and poorly stratified, moderately indurated cobble and boulder conglomerate;

2. A middle, well-stratified, zeolitic tuff and tuffaceous sandstone unit; and

3. An upper, massive, poorly sorted boulder conglomerate, very similar in appearance to the lower conglomerate unit.

The entire sequence strikes north-northwest and dips 10^{o}-50^{o} N.E. (Fig. 86). The inclination is usually highest at its contact with the basement complex flattening gradually to the east. The zeolitic tuff member forms generally massive dip-slope exposures along Ripsey Wash. The exposed thickness of the Ripsey Wash sequence is about 5,500 feet. This figure should, however, be considered a minimum because the eastern contact is faulted against the Precambrian basement complex.

The lower conglomerate member rests with a nonconformable contact upon the older Precambrian basement complex to the west. In the northern part of Ripsey Wash, the lower conglomerate pinches out, and here the zeolitic tuff member rests directly on the Precambrian granite.

The lower and upper boulder conglomerate members are very similar in lithology and general appearance. Both are moderately well indurated, crudely stratified, and weather into rounded bluff-like exposures. The conglomerate consists of angular to subrounded fragments and boulders of diabase, Oracle Granite, Apache quartzite, Paleozoic limestone, and Laramide dike rocks. No dacite fragments were noted in either of the conglomerate members. Individual boulders may range up to 5 feet in diameter.

The composition of the conglomerate units closely reflects the character of the nearby basement complex which, for this reason, is

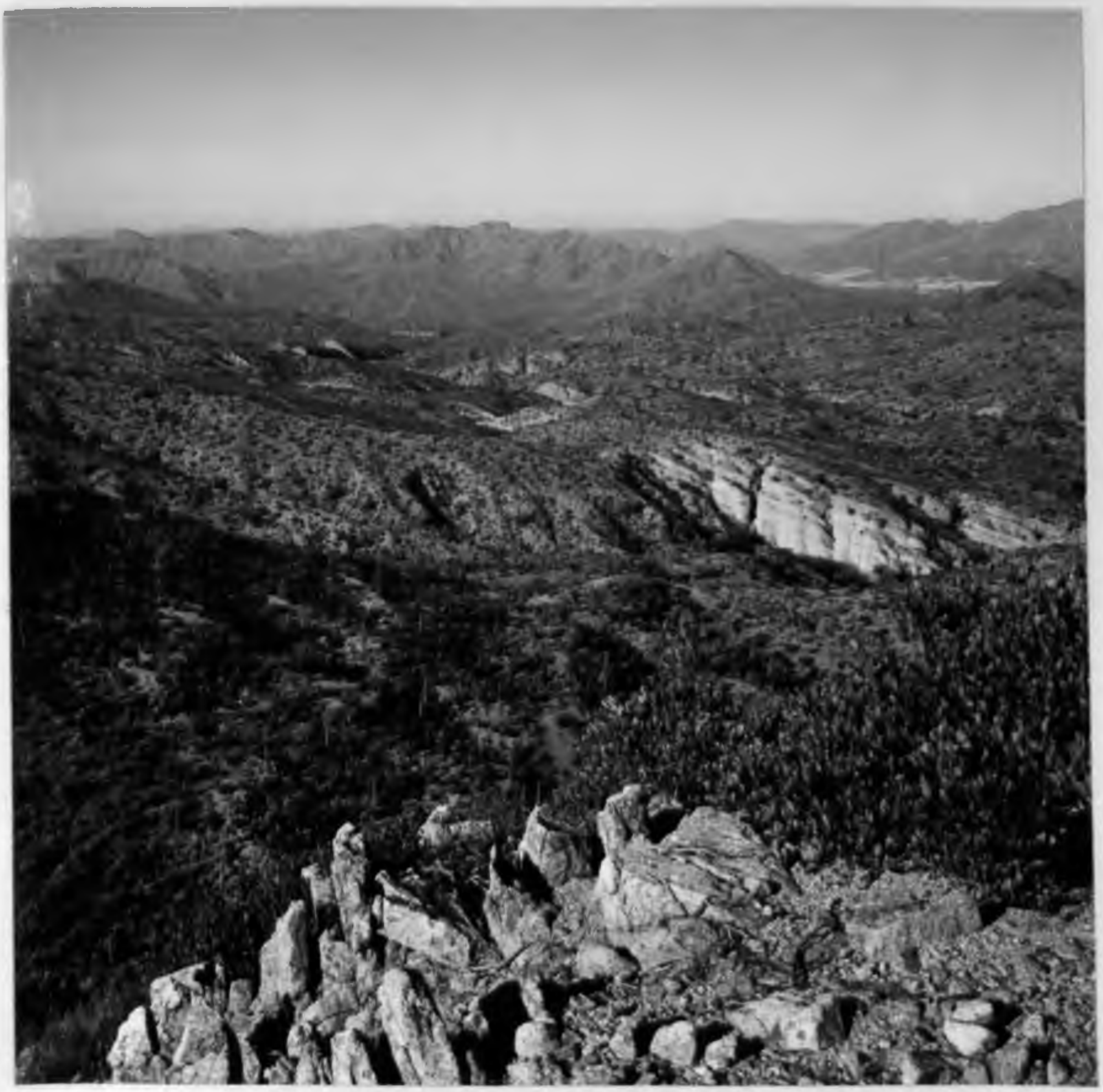


Figure 86. Outcrop Pattern of Ripsey Wash Sequence

Moderately eastward dipping conglomerate and tuffaceous sandstone units rest unconformably on older Precambrian Oracle Granite. The Ray mine is located between the Tortilla and Dripping Spring Mountains in the upper right corner. Looking north.

considered to be the source for the conglomerate sequence. Bedding is ill defined in the conglomerate members and is indicated by occasional arkosic sand and mudstone layers. Locally, one or several parallel chalky-white tuffaceous units in the conglomerate measure 1-2 feet in thickness and contain granite and Pinal Schist fragments. The fragments must have been derived from schist exposures found a few miles north of the Gila River.

Locally, monolithologic breccia lenses composed of Precambrian aplite and/or diabase occur within the lower conglomerate member. They range from 50 to 200 feet in thickness and can be followed along strike for over 1,000 feet. The breccias are very similar in character to the ones described from the lower Hackberry formation. Very little mixing is evident in the breccia lenses.

Brecciated limestone boulders, measuring up to 4 feet in diameter, are locally abundant in the upper conglomerate member (sec. 35, T. 4 S., R. 13 E.). In composition, they closely resemble the Paleozoic limestone breccia masses of the Hackberry formation, and it is very likely that the limestone boulders were derived from these breccia masses. Certainly, there are no other limestone breccia masses presently in this area that could have served as source material.

The middle tuff and tuffaceous sandstone member is a very well-stratified unit containing large pumice whose feldspars fragments are now completely altered to clinoptilolite. Individual beds range from a few inches to several feet in thickness (Figs. 85, 86, 87). The contacts with the lower and upper conglomerate members are always transitional. The upper portion of the lower conglomerate unit becomes increasingly

Figure 87. Tuffaceous Sandstone Unit of the Ripsey Wash Sequence

Characteristic outcrop pattern of the steeply inclined tuffaceous sandstone units along Ripsey Wash. Looking south.

Figure 88. Tuffaceous Sandstone along Ripsey Wash

The sandstone is underlain and overlain by the cobble and boulder conglomerate and serves as an excellent marker horizon within the Ripsey Wash sequence. Looking southeast.

Figure 89. Small, High-angle Normal Fault in Tuffaceous Sandstone, Ripsey Wash Sequence

sandy until tuffaceous arkose predominates. The contact was drawn where the rock consists of at least 75 percent tuffaceous arkose. Conversely, the upper part of the tuffaceous unit becomes increasingly conglomeratic until coarse clasts predominate.

The sandy portions of the tuffaceous member consist entirely of granitic fragments derived from the Precambrian Oracle Granite and accompanying aplite phases. Locally, however, diabase fragments become an important constituent.

In the northern portion of Ripsey Wash, secs. 15 and 22, T. 4 S., R. 13 E., the lower conglomerate member is absent and the tuffaceous unit rests with a depositional contact on Oracle Granite. A high-angle normal fault brings the tuffaceous unit in juxtaposition with granite in sec. 15.

The tuffaceous member is about 1,000 feet thick in the central portion of Ripsey Wash, but it thins to only a few hundred feet in the northern part. In the southern portion of the map area, the tuffaceous member flattens considerably and a synclinal structure is suggested with the axis trending about 45° NW.

The writer believes that the tuffaceous sandstone member represents a fluviolacustrine deposit. This is substantiated by the presence of occasional ripple marks and mudstone layers. The zeolitic tuff portion with the large pumice fragments probably represents an airfall deposit that settled in the shallow lake. On the whole, however, the tuffaceous sandstone member is sufficiently contaminated by lithic fragments of Oracle Granite, diabase, quartzite, and Pinal Schist to indicate that a considerable portion of this unit was transported into the study area from the north or northwest where extensive exposures of Pinal Schist occur.

The cyclic nature of the Ripsey Wash sequence suggests a tectonically unstable time during which the lower and upper conglomerates record uplifts, and the tuffaceous sandstone member suggests relative stability with volcanism.

Age and Correlation .

No isotopic age determinations are known from the Ripsey Wash sequence at this time. The thin tuffaceous layers within the conglomerate units usually contain a moderate amount of biotite. In addition to the biotite, there are, however, numerous Pinal Schist and Oracle Granite fragments in these tuffaceous layers suggesting considerable reworking of the volcanic units. Some of the biotite in the tuff lenses, therefore, could have been derived from Precambrian detrital material causing serious errors in any dating effort.

Judging from the lack of dacite fragments in the lower and upper conglomerate members, it can be postulated that the sequence is older than the mid-Tertiary extrusive event so prominently represented in the Ray-Superior area 10 miles to the north. The Ripsey Wash sequence would then be time equivalent to the Whitetail Conglomerate. The present attitude of the Ripsey Wash sequence also suggests that the conglomerate is older than the structural event which caused the eastward tilting of the Tortilla block.

A poorly bedded conglomerate very similar in appearance to the Ripsey Wash sequence overlies with an angular unconformity the Hackberry formation and Apache Group in the southeast portion of the map.

The conglomerate dips up to 80 degrees at the Apache contact but flattens gradually eastward. This relationship suggests that the Ripsey Wash sequence is at least in part younger than the Hackberry formation.

Gila Conglomerate

The youngest sedimentary unit in the report area occurs in the extreme northeast corner of the map. It is a moderately indurated cobble and boulder conglomerate which is here tentatively correlated with the Gila Conglomerate (Fig. 90). The sequence is very massive, poorly bedded, and forms conspicuous rounded bluffs. This conglomerate is part of a vast fluviatile deposit that extends from Ray southward to Hayden and beyond into the San Pedro Valley. Good exposures of this unit occur along State Highway 177 between Kelvin and Kearny and along small creeks and washes that are deeply entrenched in the sequence.

The conglomerate consists of all the rock types recognized in the neighboring mountain ranges. The fragments included Pinal Schist, Oracle Granite, diabase, younger Precambrian quartzite, non-brecciated Paleozoic limestone, various Laramide-age intrusive rocks, and dacite boulders (Fig. 91). The individual fragments range from less than 1 inch to 10 feet in diameter, are angular to well rounded, and are generally crudely stratified. The coarsest material occurs near the base of the Dripping Spring Mountains to the east. In the vicinity of State Highway 177, the Gila Conglomerate contains abundant arkosic material and silty laminae which enhance the stratification considerably.

Bedding in the coarser and poorly sorted conglomerate is very discontinuous. Virtually no single horizon can be traced along strike for any great distance. High-angle north-northwest-trending normal faulting

Figure 90. Typical Exposure of Gila Conglomerate

Poorly stratified, moderately well indurated cobble conglomerate consists of Precambrian granite, diabase, and quartzite, Paleozoic limestone, Laramide-age porphyry, and mid-Tertiary dacite boulders. Bedding is nearly horizontal. Sec. 5, T. 4 S., R. 14 E., looking northwest.

Figure 91. Close-up of Gila Conglomerate

Poorly sorted, well-rounded boulders and cobbles of Precambrian, Paleozoic, and Tertiary rocks are set in a sandy matrix. Note large dacite boulder in foreground. The unit dips slightly west. Sec. 5, T. 4 S., R. 14 E.

is common in the conglomerate, but the displacement along these faults is indeterminate because of the absence of any distinct marker horizon.

The presence of abundant dacite boulders clearly distinguishes this conglomerate unit from the similar-appearing lower and upper conglomerate members of the Ripsey Wash sequence. The abundance of Pinal Schist and dacite fragments in the Gila Conglomerate strongly suggests that the source area for this unit lies in the vicinity of Ray where these two rock types are widely exposed.

The Gila Conglomerate forms a north-northwest-trending asymmetrical synclinal structure with the steeper eastern flank occurring adjacent to the Dripping Spring Mountains. The strata flatten out in the vicinity of the highway and then reverse their attitude near the Gila River. In places along the river, the conglomerate overlies with a marked unconformity the shale and sandstone sequence of the Hackberry formation. These are the only relative age indications between the Hackberry formation and the Gila Conglomerate.

The thickness of the Gila Conglomerate in the study area is difficult to estimate because no continuous sections are exposed. From the outcrop pattern, however, several thousands of feet are indicated.

In contrast to the Hackberry formation and the Ripsey Wash sequence, the Gila Conglomerate has not been involved in the strong eastward rotation which affected the mid-Tertiary strata. The Gila Conglomerate therefore represents the erosional product of a late Tertiary tectonic cycle.

QUATERNARY DEPOSITS

Holocene Gravel Cover

On either side of the Gila River occur gently sloping terraces that formed on Gila Conglomerate and the Hackberry formation. Even though the terraces are extensively dissected by the present drainage system, they collectively form a conspicuous erosion surface that resembles a tableland, if viewed across a distance of several miles. The terrace surfaces are covered by recent debris derived from the adjacent mountain slopes.

The settlements of Kelvin and Riverside are situated on river gravel benches which formed at the confluence of Mineral Creek and the Gila River.

A pediment-like gravel surface extends west of the map boundary for tens of miles into the Florence basin. The pediment cover represents primarily the decomposition product of the underlying Oracle Granite. This plateaulike pediment surface is topographically 1,400 feet above the Gila River floor, and its eastern edge marks the boundary between the westward-sloping erosion surface and the extremely dissected Tortilla Mountain system. The decomposed material on the pediment is extensive enough to mask any structural detail in the underlying Oracle Granite. This cover considerably hampered the geologic investigation in the western part of the study area.

STRUCTURE

The Tortilla Mountain area lies within the mountain region of the Basin and Range province as defined by Ransome (1903). It is transitional between the Colorado Plateau province to the northeast and the Desert region to the southwest. The area has a complex tectonic history ranging from older Precambrian to Plio-Pleistocene time. Many of the older structural features have been modified by the younger tectonic events, especially during Laramide and mid-Tertiary time, so that the complete structural history is difficult to decipher.

The Tortilla Mountains proper are part of a vast older Precambrian terrane that extends from the vicinity of Oracle in the south, past the Black and Tortilla Mountains, to the vicinity of Ray and Superior to the north (Figs. 3 and 4). This Precambrian outcrop area is a major tectonic block which, as presently exposed, measures 55 miles in length and at least 25 miles in width. The predominant rock is older Precambrian Oracle Granite and associated intrusive phases dating around 1,460 m.y. North of the Gila River, however, the Precambrian terrane consists of Pinal Schist which forms a broad east-northeast-trending belt.

Upon this Precambrian basement several magmatic and tectonic events were superimposed during Laramide and Miocene-Pliocene time. The Precambrian block is bounded on the west by extensive gravel deposits of the Florence-Casa Grande basin. The present eastern boundary marks the north-northwest-trending Gila-San Pedro valley lineament which is an integral part of the central Arizona structural belt as defined by Mayo (1958). The northern boundary is ill defined because of abundant mid-Tertiary extrusive volcanism which now covers large portions of the Ray-Miami-Superior area.

In order to evaluate the regional tectonic setting adequately and to unravel the complex tectonic picture, the various structural elements discovered in the study area have to be discussed in detail. The structural features will be discussed in chronologic order, beginning with the older Precambrian and closing with the late Tertiary tectonic events.

Older Precambrian Structures

Foliation in Oracle Granite and Aplite Porphyry

In the northeast portion of the map area a distinct biotite and quartz foliation occurs in both the coarse Oracle Granite and the finer grained aplite porphyry phase. This structure is well developed in secs. 6, 7, and 18, T. 4 S., R. 14 E. and secs. 1, 2, 3, 11, 12, and 13, T. 4 S., R. 13 E. The biotite foliation is generally weaker than the quartz foliation. The latter is locally so pervasive that the rock attains a nearly gneissose texture.

Both foliation types trend conformably N. 50° E. to east-west and dip steeply to north and south. Figure 92 is an equal area projection of 173 foliation poles. The diagram clearly shows the preferred east-northeast orientation with a strong maximum at N. 80° E.

In general, the biotite and quartz foliation pattern indicates a gentle northward-bending arc whose apex lies in the Kelvin-Riverside area. In the vicinity of Kelvin Wash, the foliation trends predominantly

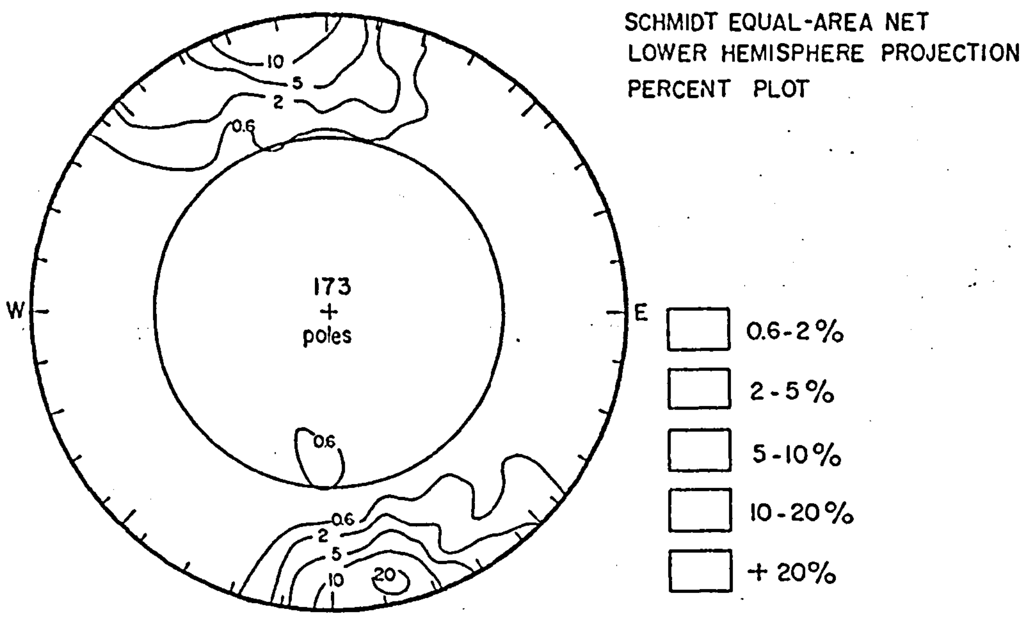


Figure 92. Stereographic Projection of 173 Biotite and Quartz Foliations in Oracle Granite and Aplite Porphyry, Kelvin Area

N. 60^{o}-70^{o} E. Following the trend eastward to the vicinity of Riverside Wash, the structure rotates into N. 80^{o} E. and thence into an east-west direction north and south of Riverside. This gentle arcing of the foliation pattern does not appear to be affected by the mid-Tertiary tectonism because no erratic distribution in the foliation pattern is noticeable. The intensity of biotite foliation diminishes gradually to the southeast until it becomes unrecognizable in hand specimen. Conversely, the intensity of the quartz foliation increases toward the northeast. It is strongly developed south of Riverside between Riverside Wash and the Gila River. Here, the rock has lost its typical Oracle Granite texture and more closely resembles a hybrid phase. Strongly elongate quartz eyes, crudely aligned pink K-feldspar phenocrysts, and irregularly distributed green plagioclase grains are all embedded in a strongly foliated aplitic matrix. Sufficient igneous characteristics, however, still remain so that the material is not considered to be metamorphosed Precambrian sedimentary rock.

The biotite and quartz foliation appears to be of primary magmatic origin. It is probably the result of differential movement within the crystallizing igneous body during the final phase of emplacement. Very little cataclastic deformation is evident under the microscope. It is not likely that the large diabase basement sills supplied the heat for the remobilization of the host rock because the foliation trends nearly at right angles to the diabase contacts. Furthermore, no Laramide intrusive rocks to furnish the necessary thermal energy are exposed in the immediate vicinity of the foliated granite. In fact, the Laramide intrusive bodies in general had very slight thermal effects on the surrounding country rock, be it Oracle Granite, diabase, or Apache Group sedimentary rocks.

It seems that the foliation is of older Precambrian age. It is genetically associated with the emplacement of the Oracle Granite-aplite porphyry complex, and it was not superimposed on the Oracle Granite at a later time because the crosscutting diabase sheets show no evidence whatever of any foliation. Therefore, the foliation originated prior to the younger Precambrian diabase intrusive event.

A very faint biotite foliation occurs in the aplite porphyry mass west of Ripsey Wash in sec. 28, T. 4 S., R. 13 E. The foliation trends generally N. 45° W. at a distinct angle to the main foliation pattern in the Kelvin area. Its areal distribution, however, is very limited. The faint foliation in the aplite porphyry is probably the result of local friction that occurred during the last stage of emplacement.

Banerjee (1957), in a structural study of the Oracle Granite between the town of Oracle and the Mogul fault, has clearly outlined a northeast-trending biotite foliation pattern. However, this pattern was later modified by left lateral movement along the Mogul fault. As pointed out above, no deflection of the biotite and quartz foliation occurs in the study area where the foliation arc has been transected by the mid-Tertiary faulting. Therefore, whatever the displacements along the faults, they were of insufficient magnitude to disrupt the regular foliation pattern.

Aplite-pegmatite Dikes

As discussed in an earlier chapter, numerous aplite and pegmatite dikes, ranging in width from one inch to tens of feet, occur throughout the older Precambrian granitic terrane. The preferred direction tends to be north-northwest and north-northeast. The dip, however, is moderately shallow, and the dikes follow therefore a very irregular path. Because the Tortilla Mountains experienced a minimum of 90° E. tilting since Precambrian time, the present dike attitudes do not reflect the original emplacement positions. Dikes presently showing a shallow inclination were originally nearly vertical, and dikes presently showing a steep dip represent original flat structures.

Younger Precambrian Structures

Position of the Apache Group

The sedimentary rocks of the Apache Group occur in two separate but parallel north-trending belts. One is near Hackberry Wash and the other near Ripsey Hill. Additional smaller exposures occur along Ripsey Wash as isolated blocks in the immediate vicinity of the major fault zone.

In the main outcrop areas, the Apache Group strata trend generally north to northwest and dip either steeply to the east, are vertical, or are overturned up to 70° W. The two sedimentary belts are presently over one mile apart and are separated by a thick sequence of Tertiary conglomerate. This conglomerate unconformably overlies the Apache Group of Ripsey Hill on its eastern side, but the conglomerate of the Ripsey Wash sequence is faulted against the Apache Group along its western side so that the Precambrian sedimentary rocks appear to pinch out to the north (Fig. 5, in pocket). Near the southern map boundary, the Apache Group is intricately intruded by the younger Precambrian diabase and the irregularly east-west-trending Laramide intrusive bodies.

Wherever it is exposed, the Apache Group-older Precambrian contact is a depositional nonconformity. In spite of their steeply upturned attitude, the sedimentary units of the Apache Group have not been observed to be faulted along the contact with the underlying granite. In other words, the homoclinal tilting did not involve only the Apache Group but also a two-mile-wide section of the underlying granitic basement complex. The narrow belts of Apache Group are not detached fault blocks as they are indicated to be, for instance, on the geologic map of Arizona (1969) in the Mineral Mountain area. In this case, the Apache Group rests with an angular unconformity on older Precambrian Pinal Schist.

The general north-south trend of the Apache Group is modified in detail by numerous east-west-trending cross faults. In the Ripsey Hill area, the overall displacement is left lateral with individual strike-slip separation of up to 500 feet. Smaller steplike offsets showing several tens of feet of displacement are much more common, however. Collectively, they achieve the same result as the larger single fault displacements. Some right-lateral displacements are also present.

The southern portion of the Apache Group of Ripsey Hill is intricately intruded by the Laramide hornblende granodiorite porphyry mass which completely engulfs individual blocks of all the Precambrian rocks present. Numerous intrusion breccias adjacent to the porphyry mass are probably genetically related to the intrusive event.

The main portion of the Apache Group of Hackberry Wash is intricately intruded by the Laramide Hackberry quartz diorite stock. The general north-south trend of the sedimentary units still prevails, however, and signifies a very passive intrusive mechanism for the quartz diorite stock. Extensive right-lateral cross faulting occurs just north of the intrusive mass. Displacements are on the order of a few to 500 feet. In the vicinity of Hackberry Spring, the Apache Group is terminated by the quartz diorite stock and no Apache Group sedimentary rocks occur beyond this point to the south in the mapped area. The northernmost exposure of the Apache Group is in sec. 32, T. 4 S., R. 14 E., where it is overlain with an angular unconformity by the steeply dipping Miocene Hackberry formation. As pointed out before, the Apache Group was apparently removed by erosion in the northern part of the mapped area prior to the deposition of the Miocene strata.

Numerous intrusion breccias spatially associated with the Hackberry quartz diorite are especially concentrated in the Hackberry Spring area. They contain fragments of Oracle Granite, diabase, and various members of the Apache Group. The matrix consists of intrusive matter and comminuted material of all the rock types involved.

A small exposure of Pioneer Formation resting unconformably on Oracle Granite occurs west of Ripsey Wash near the northern boundary of sec. 11, T. 5 S., R. 13 E. Here the overturned strata dip 60°-75° SW. and indicate an eastward rotation of up to 120° at this particular locality.

Several smaller exposures of completely brecciated Apache Group rocks occur in Ripsey Wash in sec. 11. They are related to the major north-trending fault zone which follows the course of the wash. Easy recognition of the Barnes Conglomerate member aided greatly in the structural investigation of this area.

The parallel position and present separation of the two main Apache Group exposures can be explained in the following manner. The slightly eastward inclined Apache strata and overlying Ripsey Wash sequence were cut in post-Miocene time by a north-northwest-trending high-angle normal fault. The western side subsided relative to the eastern side. Simultaneously with the faulting occurred an eastward rotation of each block which continued until the sedimentary rocks attained a nearly vertical attitude and the separation of the two Apache exposures was completed. Evidence for northwest faulting occurs in the Hackberry formation in sec. 7, T. 5 S., R 14 E. and northward from the large diabase mass in sec. 1, T. 5 S., R. 13 E. The termination of the Ripsey Hill Apache Group to the north can be attributed to extensive erosion in pre-Miocene time and the deposition of the thick Ripsey Wash conglomerate sequence prior to tilting.

A right-lateral displacement of the Apache Group of Hackberry Wash from the Apache Group of Ripsey Hill could be an alternative explanation to bring about the separation of the units. In the light of this hypothesis, the southern end of the Hackberry group would match the northern end of the Ripsey Hill group, and the present Hackberry fault would mark the trace of separation. Very little evidence for large-scale right-lateral faulting exists elsewhere in the map area; therefore, the writer favors the first explanation.

Mode of Diabase Emplacement

The steeply dipping attitude of the diabase sills and dikes does not represent the original configuration at the time of emplacement. A minimum westward rotation of 90 degrees is required in the Tortilla Mountain block in order to restore the younger Precambrian sedimentary strata into a nearly horizontal position. With this rotation the diabase sills in the sedimentary rocks as well as in the granitic basement complex will also acquire a more or less horizontal attitude. At the time of diabase intrusion, then, the area that is now the Tortilla Mountains consisted of the granitic basement covered by approximately 1,500 feet of flat-lying sedimentary strata deposited in a littoral environment. As the diabase magma invaded the host rock it took advantage first of the already established flat-lying joints and fractures in the upper part of the Oracle Granite near the old erosion surface and then cut upward into the sedimentary strata before following preexisting bedding surfaces in the more shaly horizons of the Pioneer Formation and Dripping Spring Quartzite. No assimilation took place, and the sedimentary strata and portions of the granitic basement were uplifted and dilated. Judging from the sedimentary thickness, the combined load pressure even in the granite could not have exceeded 300 bars. In the report area there is no evidence that the diabase broke through its roof and attained an extrusive character, unless the basalt in the top of the Mescal Limestone is the extrusive equivalent of the diabase.

De Sitter (1956, p. 139-140) reports a vertical dolerite dike which clearly changes into a dolerite sill at a certain level of intrusion. As the ascending magma is subjected to less and less vertical stress, a point will be reached in the near-surface region where the principal stress axes are interchanged and the dike becomes one or a series of sills.

Mudge (1968) in a study of depth control of some concordant intrusions gives three factors that govern the depth at which a sill-like body is emplaced:

1. Well-defined parting surfaces have to be present (bedding planes, unconformities, flat fractures),
2. Sills generally intrude at depths of 3,000-7,500 feet, probably reflecting the balance between lithostatic pressure and fluid pressure of the magma, and
3. An impermeable mudstone layer serves as fluid barrier retarding the upward movement and causing the magma to inject laterally.

Factors (1) and (2) seem to apply pretty well to the study area. Factor (3), however, cannot be applied rigorously here. The intruding diabase favored the shale horizons rather than being barred by them. Furthermore, the diabase extensively intruded the granitic basement in a sill-like fashion and no claim for a mudstone fluid barrier can be made here. It seems more likely that the diabase followed the path of least resistance, which happened to be the flat joints in the granite.

Hills (1963) argues that the magmatic pressure must exceed the load pressure so that the overlying strata can be lifted and that lateral compression as well as preexisting subhorizontal planes of weakness will aid sill intrusions.

In the light of the fluid wedge concept, very little vertical force is required at the toe of the advancing diabase sheet to lift the overlying rock cover. Thus, the fluid pressure of the mobile magma is sufficient to drive the diabase for tens of miles in either direction of a postulated conduit. It is interesting to note that, with the exception of one sill, there are no observed crosscutting features exposed in the report area or the Crozier Peak quadrangle to the south which resemble possible feeders for the ascending diabase magma. This imples that the diabase might have had to travel at least 15 miles laterally or that pipelike conduits exist at a depth not yet exposed by erosion or that the present erosion surface follows more or less the hypothetical trend of dikelike feeders which are either at depth or already eroded away.

The one crosscutting dike noted is in the N1/2 secs. 23 and 24, T. 4 S., R. 14 E., where it transects the granitic basement complex in a sinuous pattern and dips gently to the south. This feature is about 100 feet thick and at the time of intrusion prior to the tilting of the Tortilla Mountains it constituted a nearly vertical structure.

Geologically speaking, the diabase could be emplaced in a relatively short time span (B. E. Nordlie, oral commun.) Even so, the intrusive event did not cause any major structural disturbances in the host rock because the stratigraphic attitudes in the sedimentary strata are well maintained except for complications caused by later cross faulting. Some of the sedimentary blocks have been displaced vertically for 50 to 100 feet by the intruding diabase.

In summary, the following picture is visualized. The relatively fluid diabase magma migrated through the Precambrian basement complex along vertical conduits somewhere outside the present study area utilizing the fluid wedge mechanism. As long as the confining pressure of the host rock was somewhat greater than the fluid pressure of the magma, the latter could only intrude in a dikelike fashion. When the diabase reached the near-surface environment, the delicate stress balance inverted and the load pressure was no longer the maximum principal stress axis. Subhorizontal parting planes in the granite as well as in the overlying sedimentary rocks provided ready channelways for the diabase to spread rapidly for tens of miles away from the central conduit. Crystallization of the diabase occurred essentially in place because there is no evidence for flow differentiation and flow banding in the sills. In other words, the diabase magma remained a fluid until it reached the site of its emplacement. The chilled margins of the sills acted as thermal insulators to permit continuous crystallization in each unit. The low viscosity of the diabase magma probably prevented the formation of single laccolithic or lopolithic intrusive bodies and rather favored the formation of a series of superposed sills.

Paleozoic-pre-Laramide Faulting

A low-angle fault zone occurs near the present ridge crest in Oracle Granite in secs. 30 and 31, T. 4 S., R. 14 E. The structure dips 5°-45° W, trends in a northerly direction, and tends to separate Oracle Granite in the footwall from a more hybrid rock in the hanging wall. The fault cannot be traced continuously along the hillsides because it is obliterated by numerous Laramide quartz diorite intrusive bodies and dike rocks.

The structure is best exposed in the west half of sec. 30 along steep slopes and crosscutting washes. The fault forms a distinct dark-brown outcrop and consists of a 10-15-foot thick quartz breccia recemented by sideritic calcium carbonate. The unit is very resistant to erosion and forms small cliffs along the hillsides. Isolated patches of diabase occur in places just above or below the fault. Within 250 feet of the lower contact, the Oracle Granite becomes sheared and contains numerous chlorite seams that are oriented more or less parallel to the fault. The overlying hybrid rock is sheared beyond recognition adjacent to the upper fault contact.

Because the structure is cut by the various dike rocks, the fault is definitely older than the Laramide intrusive event. Furthermore, diabase is involved in the faulting which places the age of this structure between younger Precambrian and Laramide.

In view of the eastward tilting of the Tortilla block during mid-Tertiary time, the now moderately westward dipping fault must have been a nearly vertical northward-trending structure in pre-Laramide time. The only other exposure of a similar feature is in the E1/2 sec. 13, T. 4 S., R. 13 E., where remnants of a quartz-calcium carbonate-cemented breccia either cap small ridge tops or dip 10^{o}-40^{o} E. into Oracle Granite. In this area, the breccia is cut by several north-northwest-trending high-angle post-Laramide faults.

Laramide Structures

The numerous Laramide hypabyssal rocks and the fissure veins show a predominant east-northeast to west-northwest orientation. This direction reflects a fundamental zone of structural weakness which functioned during Laramide time and appears to be the result of north-south extension. The various dike rocks outline this direction exceptionally well, whereas the quartz diorite intrusive bodies indicate a more irregular but still recognizable east-west elongation (Fig. 93). The only exception to this regular pattern is the Grayback granodiorite pluton which does not show a preferred orientation and which in this respect resembles somewhat the Granite Mountain porphyry stock west of Ray.

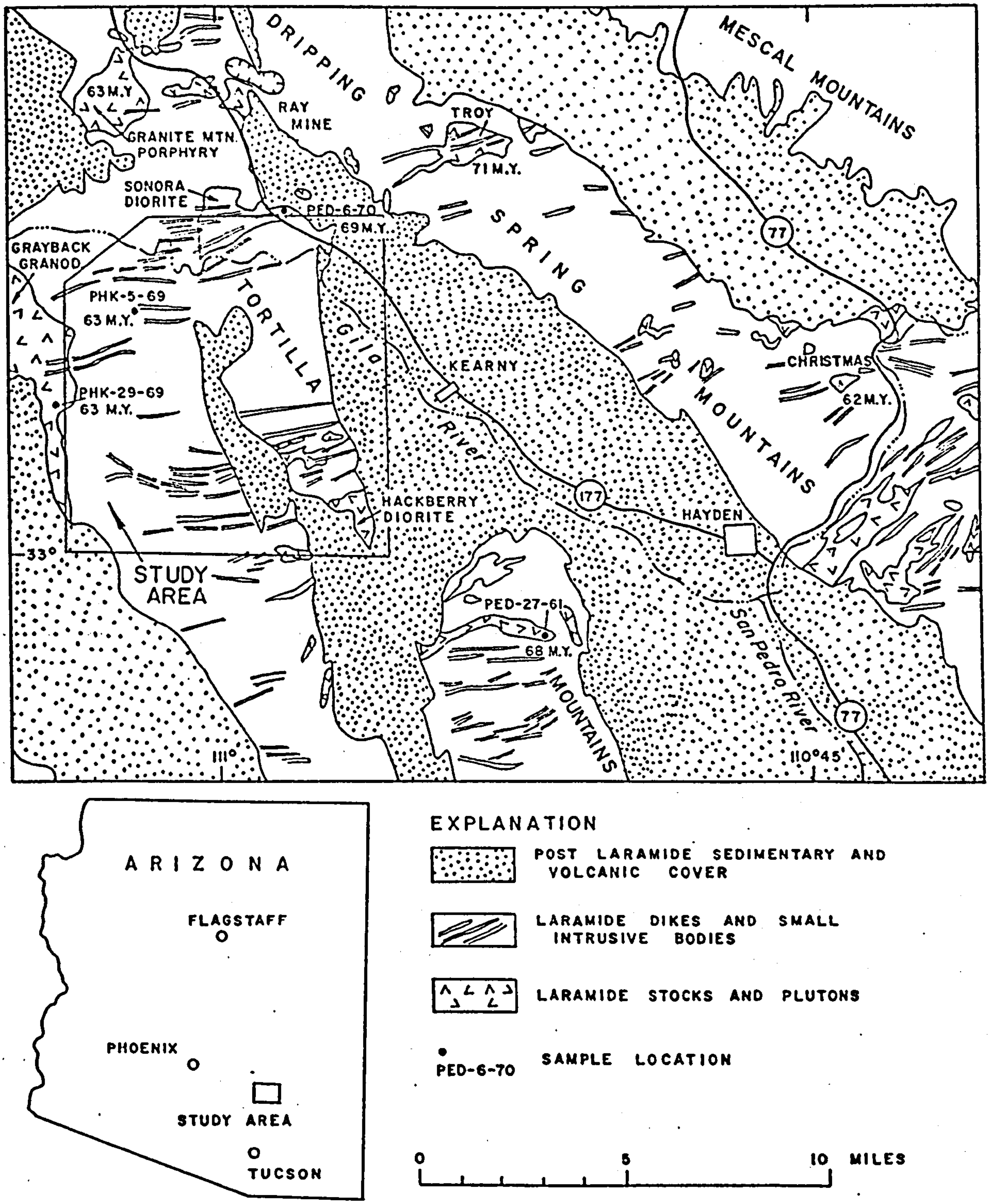


Figure 93. Distribution of Laramide-age Intrusive Rocks in the Tortilla Mountains and Vicinity

The writer believes that the Laramide trend of this area is of regional importance. It is recognized not only in the study area but is repeated several times to the north and south, notably at Ray, in the Globe-Miami-Superior area, at Troy, in the Christmas-Winkelman area, at Copper Creek, in the Red Hills area, in the Mineral Hills area, and at Sacaton (H. Courtright, personal commun., 1970). In fact, this belt of subparallel Laramide intrusive rocks and fissure veins may measure in its entirety over 30 miles wide and about 70 miles long.

Laramide Dike Swarms

As already pointed out in an earlier chapter, the study area is transected by several east-west-trending dike swarms ranging in composition from hornblende-biotite granodiorite porphyry to rhyodacite. Regardless of their composition, the dikes trend consistently east-northeast to west-northwest and cut every rock type in this area except the Ripsey Wash sequence and the Hackberry formation.

The dike swarms can be followed along strike for several miles, but small offsets by later cross faults are common. Ripsey Wash appears to follow a major north-south-trending structural zone which is now covered for the most part by the conglomerate and tuffaceous sandstone sequences. It is evident from the geologic map that the north-trending Ripsey fault zone terminates the prominent east-west-trending dike swarm. Individual dikes cannot be projected directly across Ripsey Wash to the west and matched with a counterpart. Taken as a unit, however, the dike swarm north of Hackberry Wash can be fairly well correlated with the dike swarm west of Ripsey Wash along the southern map boundary. Both dike swarms are similar in composition. An apparent left lateral displacement of about one mile is indicated where the dikes meet Ripsey Wash. The bending of the dike terminations near Ripsey Wash strongly supports this left-lateral movement. Two large granodiorite porphyry dikes in secs. 25 and 26, T. 4 S., R. 13 E. indicate a similar left-lateral displacement by curving southward as they approach Ripsey Wash from the east. The dikes do not continue directly across Ripsey Wash to the west. A 1-mile left-lateral displacement along Ripsey Wash is again indicated.

An east-west-trending dike swarm transects Sonora diorite along the northern map boundary and is terminated to the west by the moderately westward-dipping Dry Wash fault zone. The dike swarm appears to have been displaced southward for 0.25 to 0.5 miles on the west side.

Three parallel 100-150-foot wide quartz monzonite porphyry dikes in the western half of the study area display a prominent arcing convex to the north (Figs. 5). The dikes enter the western map boundary trending N. 60° E., then bend abruptly into an east-west direction and continue with a S. 60° E. trend. The zone of maximum curvature centers around Johnson Wash. This convex bending is also reflected in the arrangement of numerous fissure veins in the vicinity of the Rare Metals mine. The dikes become intricately faulted farther east near Zelleweger Wash. A left-lateral displacement of 0.25 miles is suggested but poor exposures make definite correlations difficult between several disjointed dike portions.

Wooley Wash appears to mark another north-northeast-trending fault zone along which the east-west-trending dike swarms are disrupted and displaced southward (secs. 3 and 4, T. 5 S., R. 13 E.). The southernmost dike of this zone, however, is merely bent southward and not offset. This relationship suggests a more plastic yielding to the lateral stresses rather than a failure by rupture. In general, no single fault is responsible for the indicated displacements. These displacements are always accomplished by a series of small-scale step faults. On the whole, however, the east-west Laramide trend has never been obliterated by the more recent cross faulting, only modified in detail.

Fissure Veins and Mineralized Fractures

A 1.5-mile-wide zone of closely spaced east-northeast- to west-northwest-trending fissure veins cuts the Oracle Granite, aplite porphyry, and diabase in the northern part of the map area. The mineralized belt occurs just south of the Gila River and can be followed westward beyond the present map boundary. To the east, the fissure veins are terminated by the mid-Tertiary conglomerate sequence.

Even though the fissures follow more irregular paths than the Laramide dikes, their overall trend conforms closely to the dike trend. The fissure veins postdate the Laramide dikes as indicated by several crosscutting relationships.

Individual veins range from a few inches to 5 feet in width and are either vertical or steeply inclined to north and south. They generally contain quartz, specular hematite, magnetite, some malachite, azurite, and chrysocolla. The vein structures are extensively iron stained and protrude above the granite weathering surface in distinct ridgelike exposures. The Sultana-Arizona mine is located along several of these fissures where they cross a diabase basement sill.

Individual veins are spaced 10 to 200 feet apart. Alteration in the adjacent granite host rock is limited and strictly confined to the vein margins. Plagioclase is generally converted to green sericite, and K-feldspar shows a certain degree of clouding. In places where several fissure veins merge, the intervening host rock becomes completely altered, and the outcrop is stained brick red over widths of several hundred feet. Finely disseminated limonite is commonly present. Pervasive alteration of this type is well exposed along the ridge between Zelleweger Wash and Johnson Wash in the vicinity of the Rare Metals mine. This zone of closely spaced fissure veins coincides with the area of maximum northward arcing mentioned above and may indicate that the ascending mineralizing fluids took advantage of the developed tension zones and consequently permeated the entire granite host.

The attitudes of several hundred fissure veins within this mineralized zone are shown on equal-area projections in Figs. 94, 95, and 96. Their trends clearly change within the belt from N. 73° E. in the west (Fig. 94), over N. 77°-90° W. in the vicinity of Zelleweger and Ripsey Washes (Fig. 95) to N. 72° E. in the eastern part of the zone (Fig. 96). The maximum is well defined in Figures 94 and 96, with a variation of only 10-15 degrees. It is interesting to note that the vein trends coincide exactly in the western and eastern part of the zone whereas the attitudes are much more diffuse in the central portion, where a large number of crossing fissure veins form a small dihedral angle which accounts for the broad maximum in the corresponding equal-net plot (Fig. 95). Generally speaking, the fissure veins describe a sinuous pattern across the northern portion of the map area. This pattern

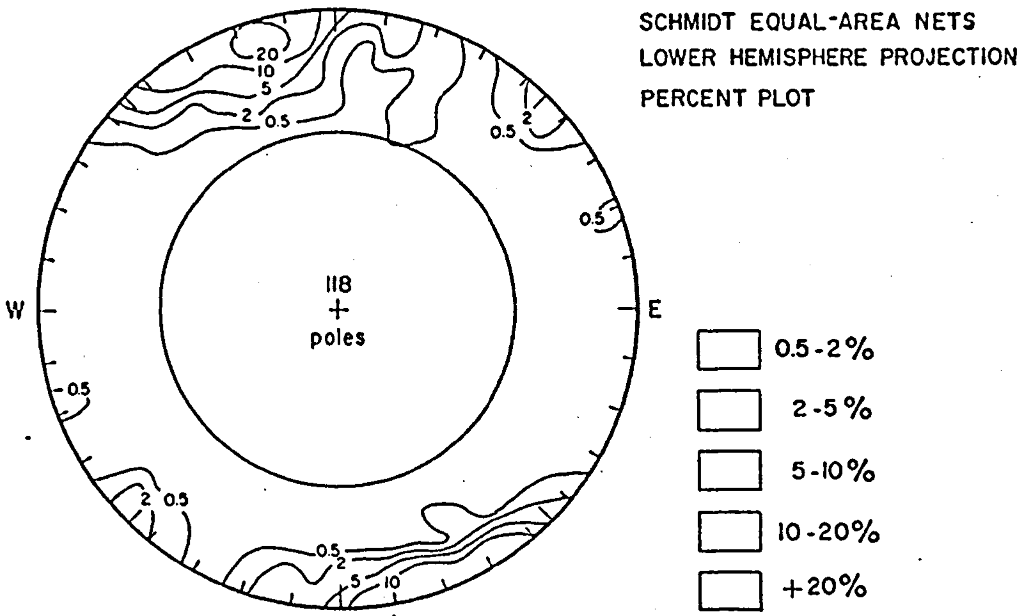


Figure 94. Stereographic Projection of 118 Fissure Veins in Oracle Granite, Vicinity of Rare Metals Mine

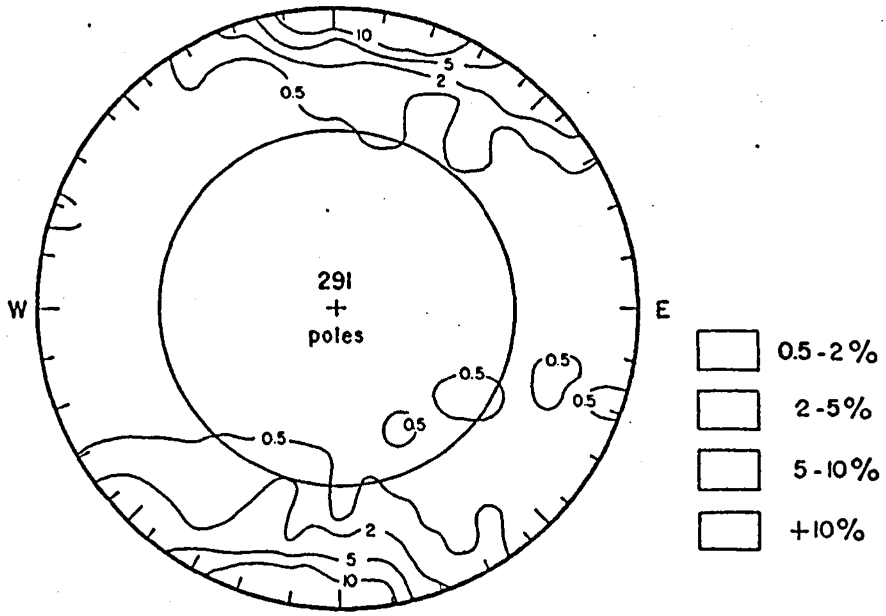


Figure 95. Stereographic Projection of 291 Fissure Veins in Oracle Granite, Area between Johnson Wash and Zelleweger Wash

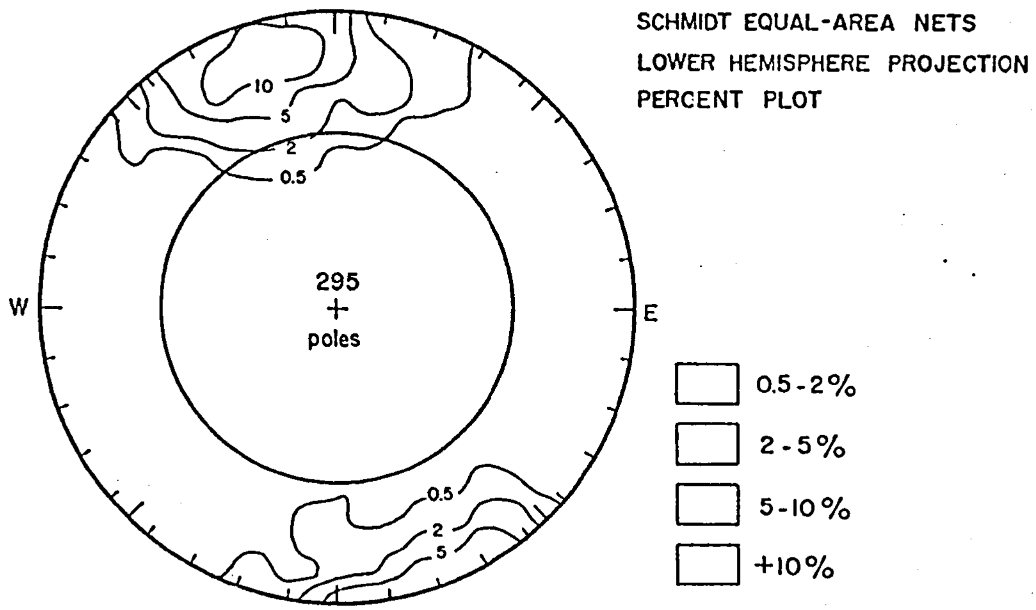


Figure 96. Stereographic Projection of 295 Fissure Veins in Oracle Granite and Aplite Porphyry, Kelvin Area

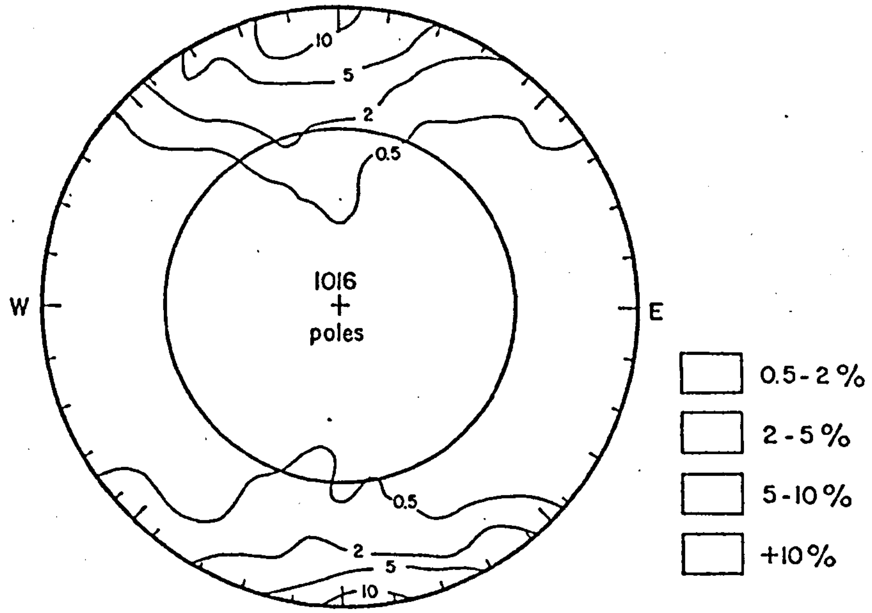


Figure 97. Summary Plot of 1016 Fissure Veins from the Mineralized Belt between Rare Metals Mine and Kelvin.

The overall trend is east-west.

could be the result of differential lateral movement along several structural blocks concurrently with or after the formation of the vein structures. The overall trend, however, is clearly east-west as shown in Figure 97. This plot represents the sum of all fissure veins recorded in the field from the mineral belt between the Rare Metals mine and the Kelvin area. In spite of their local sinuous pattern, the vein structures conform to the regional east-west Laramide trend.

Several attempts have been made in the past to explore the more promising fissure veins for possible ore-grade mineralization. Inspiration Copper Company drilled several veins in sec. 11, T. 4 S., R. 13 E., but results are not known. During the summer of 1969, a churn drill program was carried out in Johnson Wash near the Rare Metals mine apparently to test the extent and amount of mineralization present in the prominent alteration zones exposed nearby. After the completion of nine holes, the program was terminated.

A zone of closely spaced mineralized fractures and intense alteration occurs between Kelvin and Riverside Wash near the dividing line of secs. 12 and 13, T. 4 S., R. 13 E. The alteration is especially prominent in the two aplite porphyry blocks that overlie Oracle Granite. Generally, the aplite porphyry and the adjacent Oracle Granite are cut by closely spaced limonite veinlets which exhibit a 0.25-0.5-inch quartz-sericite alteration envelope (Figs. 98 and 99). Where the spacing of the limonite veinlets is close enough, the entire rock is altered to quartz and sericite. Abundant copper carbonate in one of the main washes attests to the presence of copper mineralization in this area (Fig. 100). The preferred orientation of the mineralized fractures is conformable with

Figure 98. Closely Spaced Mineralized Fractures in Older Precambrian Aplite

Every fracture is surrounded by a 0.25-inch quartz-sericite alteration envelope which encloses a central limonite hairline veinlet. The alteration seams contrast well with the overall iron staining of the host rock. These mineralized fractures are part of the regional east-west-trending mineral belt. Large wash, SW1/4 sec. 12, T. 4 S., R. 13 E. Pencil is 6 inches long.

Figure 99. Limonite Veinlets in Oracle Granite

Every goethite veinlet and hairline fracture shows a narrow alteration halo in which plagioclase is changed to green sericite. The veinlets are parallel and conform to the main east-northeast-trending mineral zone. Pencil is 6 inches long.

Figure 100. Cupriferous Stream Gravels

Copper carbonate cemented stream gravels in an area of intense alteration and iron staining. Large wash in SW1/4 sec. 12, T. 4 S., R. 13 E. Pencil is 6 inches long.

the fissure veins and is shown in the equal-area plot (Fig. 101). The fracture trend forms a well-defined maximum around N. 87° E., but the dips are in places shallower than 45 degrees. This pervasive alteration zone was the target for Occidental Petroleum's drilling program in the fall of 1967 where they explored for a possible enriched copper sulfide blanket below the oxide capping. Five holes were drilled before the project was terminated.

The Sonora diorite near the northern map boundary and the various diabase sills south of Riverside are cut by numerous chlorite-serpentine-epidote-K-feldspar veinlets which also conform to the regional east-northeast-trending mineralized vein system (Fig. 102). The veinlets are parallel, spaced 0.5 to tens of feet apart, and dip steeply to the north and south (Fig. 103). Some of these structures are multiple veins measuring several inches in thickness.

Concentrations of mineralized fractures in Oracle Granite occur at several places throughout the central and southern part of the map area where they are closely associated with the Laramide quartz diorite intrusive masses. The fractures are closely spaced, trend east-northeast, and are heavily coated with goethite and jarosite. Abundant limonite cubes indicate the former presence of pyrite. The intervening Oracle Granite is strongly sericitized, and the outcrops are excessively stained by limonite. No copper mineralization has been observed in these particular localities.

A half-mile-wide zone of intense fracturing occurs west of Ripsey Wash in secs. 11 and 14, T. 5 S., R. 13 E. The fractures trend east-northeast to east-west and are vertical or dip steeply to north and

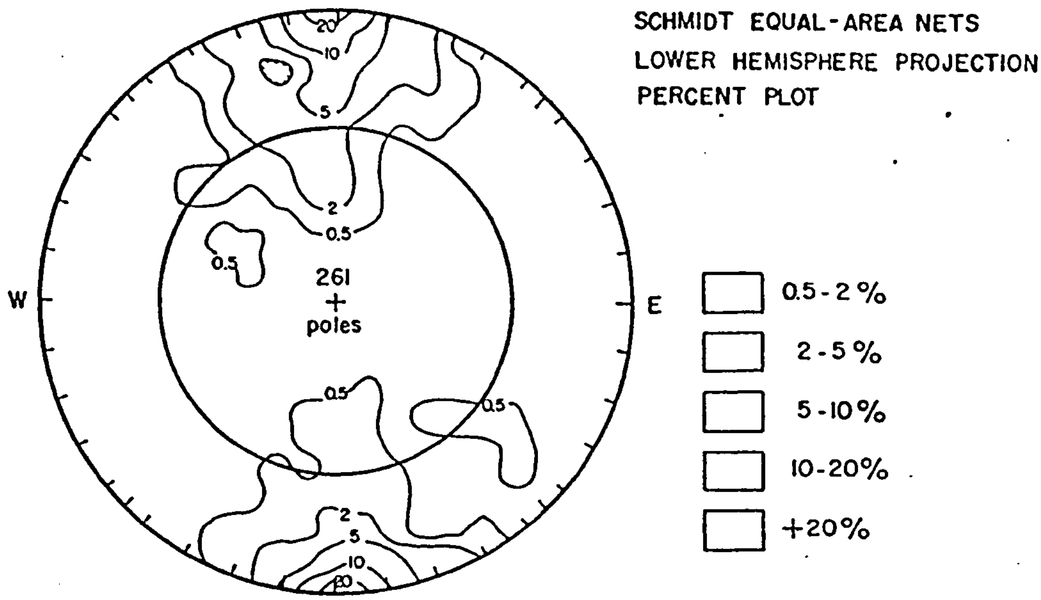


Figure 101. Stereographic Projection of 261 Mineralized Fractures in Oracle Granite and Aplite Porphyry, Kelvin Area

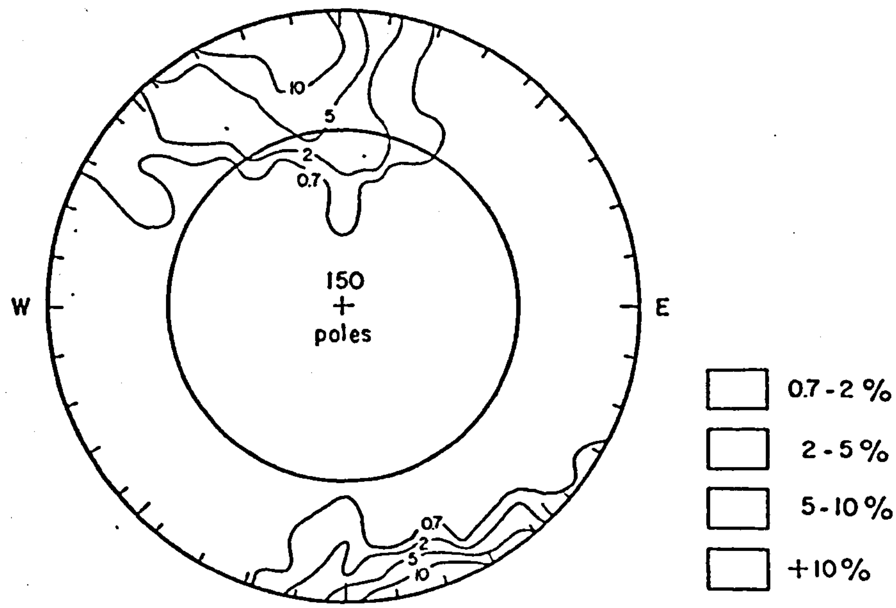


Figure 102. Stereographic Projection of 150 Epidote and K-feldspar Veinlets in Sonora Diorite

Figure 103. Chlorite-serpentine-epidote-K-feldspar Veinlets in Diabase

The parallel veinlets cut across the diabase sills systematically and conform to the regional east-northeast-trending mineralized fracture system. Note the pervasive K-feldspar flooding (K) around the epidote hairline veinlets. Pencil is 6 inches long.

south. In the vicinity of Ripsey Wash, they swing markedly northward parallel to the Laramide dike swarm and suggest drag along the Ripsey fault as the western block moved southward.

Visible sulfide mineralization is exposed at the Ripsey mine, which is located along a prominent N. 70° E.-trending fissure vein in sec. 12, T. 5 S., R. 13 E. The vein dips 45°-50° S. and cuts Oracle Granite and diabase. Little alteration is evident in the immediate vicinity of the structure. The mine has long been inactive. According to Ransome (1923), the vein contains chalcopyrite, pyrite, sphalerite, and galena in a gangue of finely crystalline quartz and calcite, but the mine had been worked primarily for gold and silver. The vein is terminated by the Ripsey fault to the west, and to the east its trace is lost in the diabase basement sill.

A prominent fissure vein is exposed in the Florence mine in the SE1/4 sec. 12, T. 5 S., R. 13 E. The vein trends nearly east-west and dips 60°S. Mineralization occurs along the contact and within the Paleozoic limestone block. Nodules of galena are abundant with minor amounts of wulfenite, siderite, and the new mineral hemihedrite, which has recently been described by Williams and Anthony (1970).

Regional Considerations

The preferred east-northeast to east-west orientation of the Laramide dikes and intrusive masses as well as the numerous fissure veins and mineralized fractures reflect a fundamental zone of weakness that was activated extensively during Laramide time. These structural elements follow to some degree the older Precambrian foliation pattern in the Oracle Granite and the associated aplite porphyry masses. As the foliation arches convexly northward in the Kelvin area, the dikes and mineralized structures do the same. This coincidence may be fortuitous. However, the writer believes that at least in the Kelvin area the older Precambrian fabric controlled to some degree the emplacement of the Laramide dike swarms and the formation of the tension fractures which subsequently became paths for mineralizing solutions. In order to accomplish this, the entire region must have been subjected to north-south extension during Laramide time.

The formation of an east-west-trending tensional zone can be accomplished in several ways: first, by direct east-west lateral compression; second, through the formation of an east-west elongated dome with the subsequent formation of longitudinal tension fractures resulting from vertical stress; third, through regional homoclinal bending around an east-west axis; and, fourth, through a regional northeast-southwest directed shear couple.

Evidence for east-west compression is not very well displayed in the investigated area, although Gilluly (1956) favors such an interpretation in southeast Arizona where he recognized thrusting and folding in the Cretaceous sediments. No folding of this kind is present in the study area.

It is unlikely that a regional shear couple caused the east-west tension zone because the resulting pattern would be an en echelon arrangement rather than a continuous belt that can be followed for tens of miles along strike.

Homoclinal bending and elongate doming along an east-west axis are very attractive concepts to explain north-south extension.

Scale model experiments by Cloos (1939) and Beloussov (1960, 1961) demonstrate that subparallel extension fractures will develop along the crest of an uplifted domal feature. According to Cloos, the amount of uplift is minimal for the first appearance of longitudinal tension fractures. For this condition to be realized, the ratio of dome height to dome width is about 1:300. In other words, if the elongate dome had an original width of 30 miles, the uplift required to form visible fractures is 500 feet. This corresponds to a 21-minute inclination of the dome flanks, which for all practical purposes is unrecognizable and certainly cannot be measured with a Brunton compass.

Arching or domal uplift in this region has to involve the older Precambrian granitic rocks, the Apache Group, and the entire Paleozoic limestone section. Even though no bending is recognized in any of these strata, the slight amount of curvature necessary to produce zones of weakness would not be reflected in the present structural position of these units. Post-Laramide block faulting in the Dripping Spring Mountains and eastward tilting in the Tortilla Mountains has obliterated any slight amount of arching that may have previously existed in this area.

The amount of extension indicated by the accumulated width of the dikes is nearly 2,000 feet over a 6-mile distance, or about 6 percent. If the widths of the irregular quartz diorite intrusive masses are added to this figure, the amount of extension increases to 1 mile in 7 miles or about 14 percent. In the latter case, the assumption is made that no assimilation took place by the quartz diorite intrusive bodies.

Because of the 90^0 E. tilting of the Tortilla Mountain range, the present attitudes of the dike swarms are in fact cross sections exposing a penetration to a depth of about 1.5 miles into the Precambrian basement. Ideally, the dikes should show a fan-shaped arrangement and converge to the west if the curvature of the arc was pronounced. However, as pointed out above, the required doming is so slight that the dikes are practically vertical for the distance exposed to observation, a fact well born out by the dike pattern in the map area.

Many attempts have been made in the past to bring forward tectonic explanations for the distribution of Laramide intrusive bodies and associated mineral deposits in the western United States. Butler (1933a) was one of the first to call attention to this problem, and many investigators have since contributed significantly to its solution, notably Billingsley and Locke (1935, 1941), Mayo (1958), Wisser (1960), Gilluly (1965), Schmitt (1959, 1966), Sumner (1967), and Guilbert and Sumner (1968), to mention a few.

The results of the present study concur to some extent with the ideas outlined by these investigators, but in many other ways they differ considerably. The most important local and regional Laramide direction in the investigated area is N. 70° E. to east-west. This direction is revealed by various intrusive rocks, fissure veins, and the pattern of mineralized fractures (Fig. 93). However, it neither conforms strictly with the N. 70° W.-trending Texas zone as defined by Hill (1902) and Ransome (1915), discussed by Albritton and Smith (1956), and outlined by Sumner (1967) and Guilbert and Sumner (1968) nor with the N. 20°-40° E.-trending mineral belts outlined by Landwehr (1967). Mayo (1958, p. 1172) in his paper on lineament tectonics states that concerning the Texas lineament "strands within this belt, as in southern Arizona, are marked by nearly east-west faults and elongated or aligned intrusions." This certainly agrees with the exposed Laramide pattern in the study area.

According to Landwehr's (1967) terminology, the northern Tortilla Mountains are part of his northeast-trending Globe belt, which stretches from Ajo in southwest Arizona past Silverbell, Ray, Superior, Miami, and Globe to northwest New Mexico. Aside from the apparent alignment of these various mineral deposits, there is no indication from local geologic data that all of these mentioned localities are connected by one particular structure zone. Northwest-trending faults and fractures are the main ore control at Ajo, and east-northeast to east-west-trending chains of Laramide hypabyssal rocks and fissure veins are evident at Silver Bell, Ray, Superior, Globe, and Inspiration (Fig. 104). In fact, there is no Laramide structure that connects Ray and Superior, and certainly there is no direct connection between Ray and Silver Bell. Data from the present investigation clearly show that the Ray deposit is part of an east-northeast-trending Laramide intrusive belt, herein called the Ray-Sacaton belt, which is recognized in the Sacaton Mountains north of Casa Grande, at Mineral Butte northwest of Florence, in the Red Hills and Mineral Mountain area, in the present study area, and at Troy in the Dripping Spring Mountains. A second parallel Laramide intrusive belt, the Christmas-Copper Hills belt, is exposed in the Christmas-Winkelman Copper Hills area and characterized by dike swarms and elongate intrusive bodies. The deposits of Globe, Miami, Copper Cities, Inspiration, Castle Dome, Pinto Creek, and Superior are part of a third Laramide intrusive belt that includes the Schultze granite, the Silver King granodiorite stocks, and the intrusive bodies in the Haunted Canyon area. This zone is here named the Globe-Superior belt and is parallel to but north of the Ray-Sacaton belt.

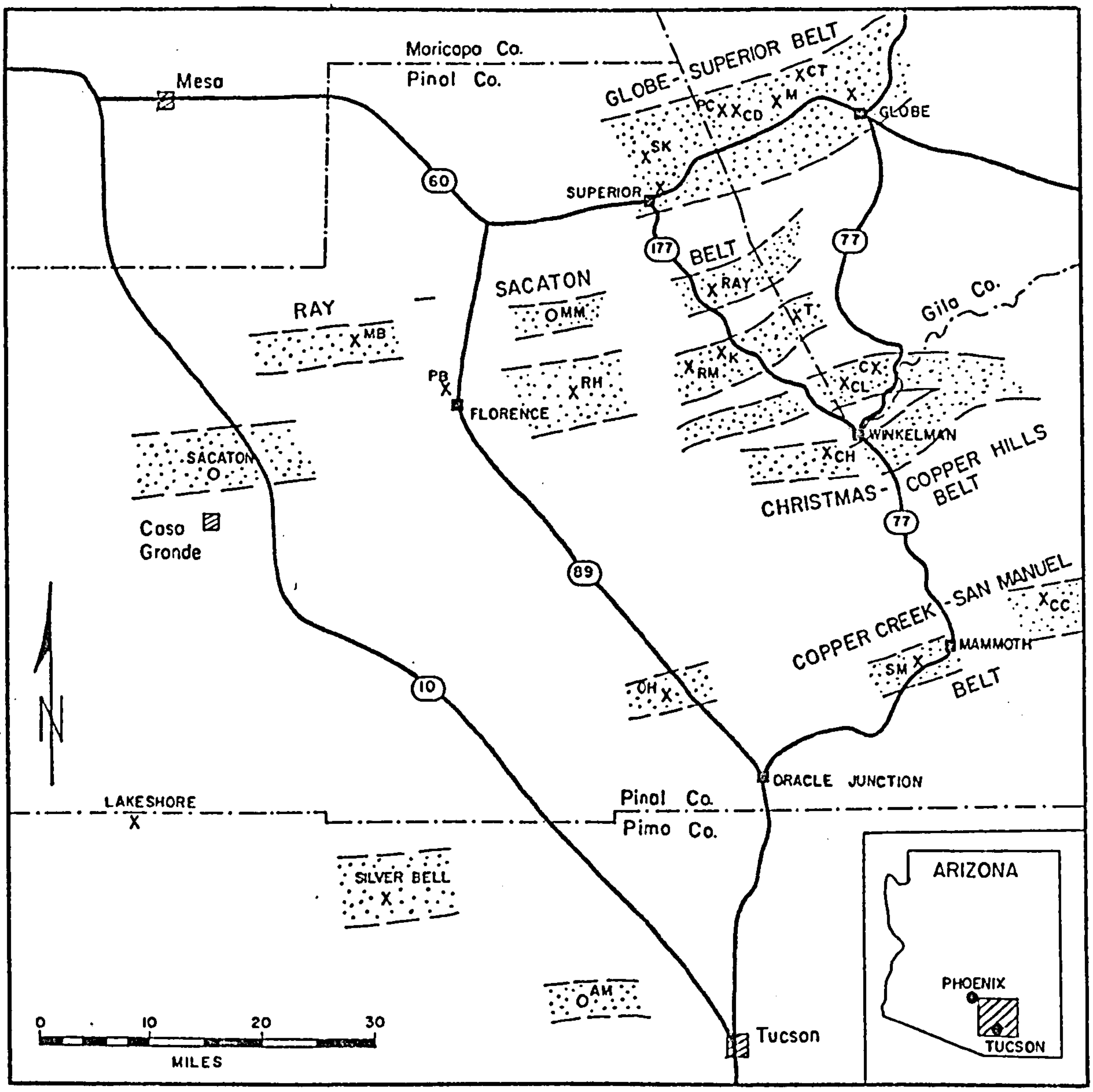
A fourth major zone of mineralization includes the deposits of San Manuel and Copper Creek and is herein called the Copper Creek-San Manuel belt. This zone projects eastward past Safford to Morenci and constitutes one of the most important mineralized zones in central Arizona.

At Silver Bell, the mineralized fissure veins and monzonite porphyry dikes trend predominantly northeast to east-northeast, cutting a dacite porphyry-quartz monzonite stock and strongly altered sedimentary rocks. The eastern continuation of the Silver Bell zone is lost in the intervening adjacent valley fill. The deposit could, however, represent a portion of the Copper Creek-San Manuel belt which became displaced to the south during mid-Tertiary Basin and Range tectonics.

As shown in Figure 102, the individual belts change from a nearly east-west to northeast direction. This bending may be the result of regional post-Laramide wrenching as suggested in an earlier chapter or it may reflect the influence of the older Precambrian fabric direction.

Breccias Associated with Laramide Intrusive Masses

Breccia masses genetically associated with quartz diorite and granodiorite porphyry intrusive bodies occur in sec. 31, T. 4 S., R. 14 E., the SW1/4 sec. 5 and NW1/4 sec. 8, T. 5 S., R. 14 E., and the NE1/4 sec. 13, T. 5 S., R. 13 E. The breccias are a mixture of Apache Group fragments with some Oracle Granite. The fragments are a few



AM - Amole	K - Kelvin	RH - Red Hills
C - Christmas	M - Miami-Inspiration	RM - Rare Metals
CC - Copper Creek	MB - Mineral Buttes	SK - Silver King
CD - Castle Dome	MM - Mineral Mountain	SM - San Manuel
CH - Copper Hills	OH - Owl Head	T - Troy
CL - Chilito	PB - Posten Butte	
CT - Copper Cities	PC - Pinto Creek	

Figure 104. Belts of Laramide-age Intrusive Rocks and Fissure Veins in South-central Arizona

inches to several feet in diameter, angular to well rounded, and are embedded in a dioritic matrix. Some larger blocks still preserve bedding, but their mutual orientation is quite erratic. Individual breccia masses may be completely surrounded by the intrusive rock, and outcrop relationships indicate that in many instances breccia masses cap the elongate intrusive bodies. This flat position of the breccias is the result of mid-Tertiary eastward rotation of the mountain range. Because the intrusive event occurred prior to the eastward rotation, the breccias constitute the original walls of the stocks and not the brecciated roof.

In the E1/2 sec. 31, a normal-appearing portion of Oracle Granite contains numerous pebbles and cobbles of Dripping Spring Quartzite. The quartzite fragments are well rounded and range in diameter from 2 inches to 5 feet. Locally, the smaller quartzite pebbles are aligned N. 35° W. and dip 65° NE. For some reason, this preferred orientation is conformable with the internal structure of the Kelvin breccia column located 4 miles to the northwest. Some dark-gray schistose xenoliths are present measuring 0.25 to 2 inches in diameter. They show no preferred orientation. No schist exposures occur within 8 miles of this locality. Numerous highly altered dioritic apophyses extend into the breccia mass and adjacent Oracle Granite near the southern breccia contact. A larger quartz diorite body is exposed a few hundred feet to the west. The writer believes that the Oracle Granite, diabase, and the Apache Group became mobilized, at the time the quartz diorite was emplaced. Presently, no Apache Group is exposed in the immediate vicinity, but the occurrence of quartzite pebbles certainly suggests their former presence. The entire breccia mass measures several hundred feet in diameter and is altered to argillite and sericite. Finely disseminated limonite occurs throughout the rock and a N. 75° E.-trending fracture zone contains abundant goethite and jarosite.

Small breccia remnants and a larger breccia mass composed of younger Precambrian quartzite occur in the N1/2 sec. 13, T. 5 S, R. 13 E. They are spatially and genetically associated with a broad hornblende granodiorite porphyry body which intricately intrudes the Precambrian basement complex and the entire Apache Group. The breccias consist of subangular greenish-gray quartzite fragments ranging from less than one millimeter to several inches in diameter. In the north half of section 13, large blocks of Apache sedimentary rocks are intimately mixed with diabase and Laramide porphyry. Every breccia block is completely engulfed by the granodiorite porphyry mass.

The larger breccia occurrence in the NE1/4 sec. 13 contains abundant pinkish-gray quartz monzonite porphyry, greenish-gray quartzite, siltstone, and diabase fragments. The matrix appears to be finely comminuted material derived from the rock fragments.

It appears that all these breccia occurrences are genetically associated with the Laramide quartz diorite and granodiorite porphyry intrusive events along the contact.

A small breccia exposure involving diabase and Oracle Granite crops out in the N1/2 sec. 30, T. 4 S., R. 14 E., but no dioritic intrusive mass is recognized nearby. In texture and general appearance, this breccia closely resembles the ones just described, and it is conceivable that a small diorite plug, which is not yet breached by erosion, is situated below the breccia.

Breccias of Questionable Age

Wooley Breccia Mass

The Wooley mine is located in a peculiar breccia deposit about half a mile east of the Kelvin-Florence road in the N1/2 sec. 33, T. 4 S., R. 13 E. The breccia forms an elongate exposure 400 by 800 feet and is entirely in Precambrian aplite porphyry. No Laramide intrusive bodies are exposed in the general region. Unlike the breccia masses described above, the Wooley breccia is monolithologic and contains no foreign fragments.

The breccia consists of subangular aplite porphyry fragments 2 to 4 inches in diameter recemented by drusy quartz veinlets which superficially resemble a quartz vein stockwork. Locally, the drusy quartz forms 2-inch pockets filled with 0.25 to 1 inch limonite pseudomorphs after chalcopyrite. The limonite pseudomorphs are generally accompanied by chrysocolla and malachite. Disseminated limonite pseudomorphs up to 0.25 inches in diameter and rimmed by chrysocolla occur locally in the non-brecciated aplite porphyry near the breccia periphery. The aplite shows generally extensive green sericite alteration. The contacts between the drusy quartz veins and the aplite porphyry fragments are sharp and generally no alteration is present in the fragments.

The breccia mass is bounded on the north by a steep east-west fault, but on all other sides it grades into non-brecciated aplite porphyry. The Wooley breccia has been explored by several shafts and adits, but no production figures are known. Several exploration companies have recently conducted induced polarization surveys over the breccia body, but results were discouraging. Several years ago, The Anaconda Copper Company drilled a few exploratory holes to test the extent of mineralization and brecciation at depth. Apparently the breccia mass plunges 30°-40° SW as an elongate body (R. W. Thomssen, personal commun., 1969). The moderate inclination of the breccia mass results from the 50°-60° E. tilting of the western Tortilla block during mid-Tertiary time. The original configuration of the breccia mass probably resembles a steeply plunging pipelike body.

The age of the Wooley breccia is difficult to determine. Because no foreign fragments are involved and no Laramide intrusions are exposed nearby, the breccia could very well be a Precambrian structure.

Kelvin Breccia Column

Mode of occurrence. The Kelvin breccia column is located south of the Gila River in the NE1/4 sec. 12, T. 4 S., R. 13 E., about one mile southeast of Kelvin and 2,500 feet southwest of Riverside. The breccia mass measures 900 by 1,000 feet and shows a very irregular contact with the enclosing host rock. The breccia is situated for the most part in a 600-foot wide diabase basement sill which extends into the breccia area from the south. A small portion of the breccia is in foliated Oracle Granite.

The breccia column is bounded to the north by a steep west-northwest-trending fault zone, to the west by Riverside Wash which conceals a major north-trending fault zone, to the south by a gradational contact with the diabase basement sill and Oracle Granite, and to the east by a complicated eastward-dipping low-angle fault system involving diabase and Oracle Granite. A small north-trending wash cuts the entire breccia mass and provides excellent exposures of the internal structure (Fig. 105, in pocket).

Composition. The breccia column can be separated into two portions on the basis of composition. The western half consists predominantly of diabase breccia with a moderate amount of isolated or aligned cobbles and boulders of Oracle Granite, younger Precambrian quartzite, and porphyritic dike rocks. The eastern half is predominantly a mixture of Oracle Granite, younger Precambrian quartzite, Paleozoic limestone, and a minor amount of diabase. The fragments range in size from a fraction of an inch to 5 feet in diameter. The cobbles and boulders are generally very well rounded, whereas the smaller fragments are quite angular. Individual Oracle Granite cobbles commonly show a distinct outer epidote-rich zone 0.25 inches wide that grades inward to a narrow K-feldspar-rich zone. Limestone cobbles found next to these altered granite cobbles show no sign of alteration.

The matrix of the western diabase breccia is mainly comminuted and reconstituted diabase and a microcrystalline aggregate of quartz and epidote as determined from thin sections and X-ray diffraction patterns. The microcrystalline aggregate forms minute apophyses which penetrate the entire breccia mass in an irregular network.

The matrix of the eastern breccia consists of comminuted material of all rock fragments present (Figs. 106, 107, and 108). Where there is a concentration of Oracle Granite fragments, the matrix is predominantly arkosic. A higher percentage of diabase in the rock fragments will also be reflected in the corresponding matrix material. Generally, however, the Oracle Granite appears to have contributed primarily to the

Figure 106. Eastern Half of Kelvin Breccia Column

Brecciated Oracle Granite is cemented by a diabase-rich matrix material consisting of comminuted diabase and granite fragments.

Figure 107. Central Part of Kelvin Breccia Column

Angular blocks of Oracle Granite (gr), Apache quartzite (qtz), and diabase are cemented by greenish-gray matrix material. The matrix is a comminuted mixture of all the megascopic rock types present. Pencil is 6 inches long.

Figure 108. Eastern Portion of Kelvin Breccia Column

Brecciated Oracle Granite is cemented by a fine-grained mixture of diabase and granite. Pencil is 6 inches long.

matrix in this part of the breccia column. Individual grains of plagioclase, cloudy K-feldspar, and quartz are easily recognized in the outcrop. In thin section, a minor amount of quartzite fragments is also present in the matrix (Fig. 109).

In the southern and central portions of the breccia mass numerous slabs of Barnes Conglomerate and Dripping Spring (?) Quartzite occur with their long axes aligned in a north-south direction. Paleozoic limestone cobbles are concentrated mainly in the northeastern part of the breccia (Fig. 110). The presence of younger Precambrian quartzite and Paleozoic limestone fragments is of great interest because none of these rock types are exposed in the immediate vicinity of the breccia column. The nearest outcrop of Apache Group is about 4 miles south, and no autochthonous Paleozoic limestones are present in this part of the Torrilla Mountains. The source area for these fragments was most likely above the breccia mass and is now completely removed by erosion.

Internal structure. One of the most interesting features of the breccia column is the distinctly preferred orientation of the constituent rock fragments. In order to show the internal structure in sufficient detail, the breccia column was mapped on a scale of 1 inch = 200 feet, using the enlarged topographic map as base. Strike and dip readings were taken on individual elongate granite and quartzite blocks as well as on elongate concentrations of rock fragments. The data were plotted on an equal-area net as shown in Figure 111. The diagram clearly indicates a preferred orientation ranging from N. 15° E. to N. 40° W., with a strong maximum at N. 15° W. The elements dip either vertically or steeply to east and west. However, there is a general indication of a

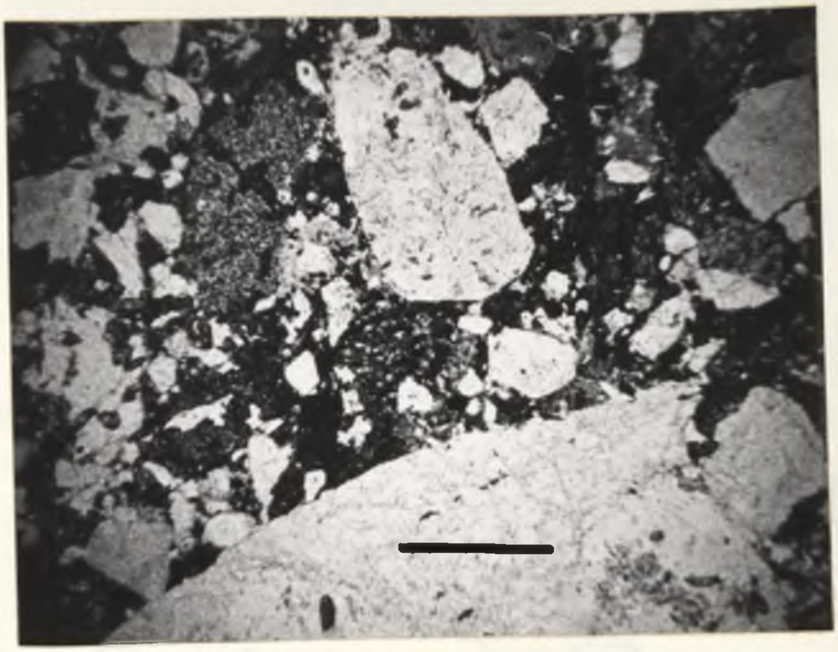


Figure 109. Photomicrograph of Kelvin Breccia Matrix

The matrix consists of quartzite and disintegrated granite fragments surrounded by comminuted diabase (dark gray). Bar is 1 mm.

Figure 110. Northeastern Portion of Kelvin Breccia Column

A heterogeneous assemblage of well-rounded Oracle Granite, diabase, and Paleozoic limestone cobbles immersed in a greenish-gray matrix. The granite cobbles have a distinct epidote-rich rind whereas the limestone cobbles are unaltered.

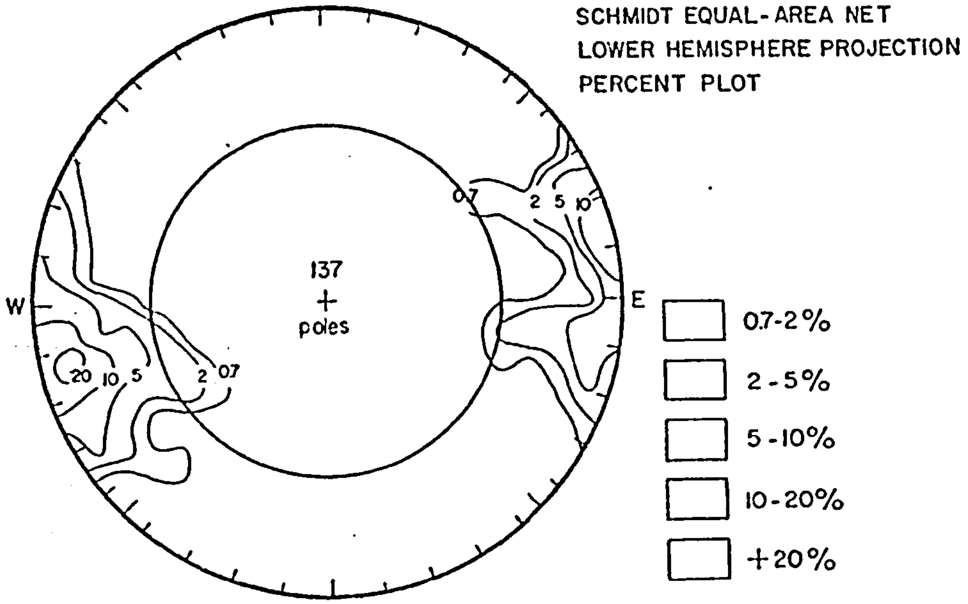


Figure 111. Stereographic Projection of the Preferred Orientation of Fragments in the Kelvin Breccia Column

funnel-shaped arrangement. The fragments in the western breccia half dip steeply to the east whereas the bands of rock fragments in the eastern half of the breccia mass dip generally westward. The fragments near the center of the breccia are vertical. Thus, the internal structure of the breccia column suggests a northward-elongated, upward-flaring funnel centered in Precambrian diabase and Oracle Granite which involves rock types not exposed in the immediate vicinity of the structure.

Two parallel east-northeast-trending Laramide quartz monzonite porphyry dikes transect the breccia mass. The dikes are 20 to 30 feet wide and are terminated with the breccia column by Riverside Wash to the west. One of the dikes extends a little way into foliated Oracle Granite to the east before being cut off by the eastward-dipping low-angle fault zone. The dikes are severely disjointed, especially in the central and eastern half of the breccia mass where the rock fragments show the strongest alignment. The displacement of individual dike sections amounts to about 80 feet. Some cross faulting is evident. However, the fragmentation in most places appears to be of different origin. Good contact relationships between individual dike segments and breccia material are exposed in the small north-trending wash. There it is obvious that numerous rotated dike blocks are not segmented by faulting. In many places, the breccia material penetrates the dikes along minute cracks and fractures and locally forms small embayments (Fig. 112). This relationship suggests that the dikes were disjointed and rotated by the same process that caused the pronounced alignment of the granite, quartzite, and limestone fragments in the breccia column. Flow banding in the chilled margin of the porphyry dike is present in the disjointed

Figure 112. Kelvin Breccia Column

Breccia matrix material intricately intrudes the Laramide quartz monzonite porphyry dike. Moderate amounts of epidote coat the dike fractures. Exposure is in small north-trending wash, northeast part of the breccia column.

blocks within the breccia column as well as in the undisturbed dike portion that extends into non-brecciated Oracle Granite to the east. It seems that the quartz monzonite porphyry dikes predate the formation of the breccia column.

A 30-foot wide rhyolite porphyry dike trends toward the breccia mass from the south but loses its identity at the contact between diabase breccia and Oracle Granite. Fragments of the dike occur in the diabase breccia several hundred feet away from the last dike exposure. An isolated 200-foot long rhyolite porphyry dike section forms part of the southern contact between diabase breccia and non-brecciated diabase basement sill. This relationship is additional evidence that the Laramide dikes have been involved in the brecciation process.

Good contact relationships between the breccia column and the enclosing host rock are exposed in the southwestern part of the structure where the diabase breccia is in contact with Oracle Granite. Here the breccia material penetrates the granite as minute apophyses and forms a zone 10 feet wide of intimate mixing. Large blocks of granite become completely isolated. Away from the contact zone smaller fragments and granite cobbles are in the diabase breccia and show the typical north-northwest preferred orientation.

Generally speaking, the contacts between brecciated diabase and non-brecciated diabase are much less obvious than the diabase-granite contacts and appear to be very gradational. In the field, the contact was drawn on the first appearance of foreign fragments and distinctly recognizable brecciation in the diabase.

The non-brecciated diabase at the contact to the north and south contain numerous K-feldspar and epidote veinlets which do not occur in the diabase breccia. The occurrence of these veinlets was an additional factor that aided in the delineation of the breccia periphery.

The breccia column is cut by numerous nearly east-trending, steeply dipping fissure veins ranging in width from 1 to 3 feet. They contain various amounts of limonite, chrysocolla, malachite, and some chalcopyrite. Smaller mineralized veinlets occur in places throughout the breccia mass trending persistently east-northeast to east-west. The only exception to this pattern is a major north-trending mineralized fissure vein exposed in the eastern half of the breccia column. The zone is nearly 10 feet wide and exhibits intense silicification together with abundant magnetite. Some specular hematite as well as minor amounts of malachite and chrysocolla staining. Limestone cobbles and boulders within this mineralized zone have been replaced by garnet and epidote in a 1-2 inch thick band around the outer margin. The vein crops out near the northern contact of the breccia and can be followed intermittently southward for about 800 feet. Coarsely crystalline actinolite occurs in places along the trace of this mineralized zone.

No crosscutting relationships are exposed between the two mineralized trends in the breccia column, but both are clearly post breccia emplacement.

Aside from the local epidotization of the granite fragments and the microcrystalline epidote-quartz matrix, no pervasive hydrothermal alteration is evident in the breccia mass. Even the intensely mineralized fissure veins show only a minor amount of sericitization in the adjacent host rock.

Age. The disruption of the Laramide quartz monzonite porphyry dikes and the presence of quartz monzonite porphyry fragments in the diabase breccia clearly indicates that the Kelvin breccia column is of Laramide age, but older than the mineralizing event. The steeply inclined attitude of the pebble trains and rock slabs in the breccia mass also suggests that the formation of the breccia must have taken place after the Tortilla Mountains were tilted to the east, otherwise the originally vertical fabric would now have attained a horizontal position. This then puts the crosscutting mineralized fissure veins into the mid-Tertiary or younger age group. At the present time, it is impossible to assign a more definite age to the Kelvin breccia column.

Origin. In order to arrive at a meaningful explanation for the formation of the breccia mass, the features mentioned above have to be considered. The north-northwest-trending internal fabric suggests that the breccia formed under certain conditions that did not favor a random distribution and orientation of the component rock fragments. A fluidized mechanism, as proposed by Reynolds (1954) and Cloos (1941), may have been an important agent here. The presence of younger Precambrian quartzite and Paleozoic limestone fragments in the predominantly Precambrian diabase breccia column requires a downward-moving mechanism that was able to stratify the component rock fragments. As pointed out above, the sedimentary rocks found in the breccia mass are not exposed within a 4-mile radius around this structure.

The pervasive epidotization of the granite fragments and the presence of the microcrystalline epidote-quartz matrix strongly suggest that the breccia formed in the 300°-400°C temperature range which generally corresponds to the greenschist facies of regional metamorphism. Because a major portion of the matrix is crystalline, hydrothermal or magmatic conditions must have prevailed during breccia formation. The source for the fluids is problematic because no post-Laramide igneous rocks are exposed in the nearby surroundings. Nevertheless, it may be that the breccia column represents some sort of vertical channelway for pulsating hydrothermal fluids which ultimately caused the differential downward movement and stratification of the overlying rock column within the Kelvin breccia mass. A collapse mechanism resulting from magmatic pulsations and subsequent withdrawal has been called upon by Metz and Phillips (1968) to explain the origin of the Calumet breccia pipe located 6 miles north near the Ray ore body.

Post-Laramide Faulting

The recognition and evaluation of faulting in a predominantly granitic terrane, such as the northern Tortilla Mountains, presents a greater problem than in a mountain range displaying various sedimentary strata. The tracing of individual structures is difficult, tedious, and sometimes impossible. Once a fault structure has been located, there generally is no marker horizon to indicate the direction of movement and amount of displacement. However, several features greatly aided the structural interpretation in the study area: first, the persistent, parallel northward trend of nearly vertical diabase sills; second, the east-west-trending Laramide intrusive rocks and fissure veins; third, the steeply dipping remnants of Apache Group strata; and, fourth, the presence of the tilted Cenozoic Ripsey Wash and Hackberry conglomerate sequences.

Faulting is very widespread in the Tortilla Mountains and dominates the structural picture. Fig. 113 (in pocket) shows the general fault pattern as it occurs in the Precambrian basement complex and the Cenozoic conglomerate sequences. The present study attempts to outline the general directions and age relationships of the more prominent structures and to demonstrate their dependence on the regional tectonic framework. In this respect, it is of paramount importance to evaluate the various structural patterns in their respective time periods lest a chaotic interpretation results as has recently been so ably demonstrated (Wertz, 1970).

Two ages of post-Laramide faulting are recognized in the Tortilla Mountains. One predates the mid-Tertiary conglomerate sequences and trends predominantly east-northeast to west-northwest. The other postdates the mid-Tertiary conglomerate sequence and trends generally north to northwest.

Pre-Miocene Faulting

Numerous west-northwest- to east-northeast-trending cross faults are exposed throughout the study area. They are easily recognized in the steeply inclined Apache Group and the north-trending diabase sills. Lateral offsets occur invariably along these fault structures. In the Ripsey Hill area, the predominant offset direction is left lateral with individual displacements ranging from 10 to 500 feet. Closely spaced sequences of parallel faults may show only several feet of displacement along individual structures, but the net result may amount to several hundred feet.

The overall displacement pattern of the Apache Group in the Hackberry area is right lateral and thus opposite to the movement in the Ripsey Hill block. The net right-lateral displacement is about 2,000 feet, as indicated by the disjointed position of several Apache Group segments. The presence of the Barnes and Scanlan Conglomerate members proved invaluable in developing the structural picture.

Many of the east-trending cross faults are nearly parallel with the Laramide dike rocks and thus cut the latter at a very small angle. This is well displayed in the S1/2 sec. 11 and N1/2 secs. 13 and 14, T. 5 S., R. 13 E. The numerous small-scale northwest- and northeast-trending offsets in the dike swarms are probably related to the major east-west-trending cross faults.

A 2,000-foot left-lateral offset is indicated in the displacement pattern of several north-trending diabase basement sills exposed west of Ripsey Wash in sec. 34, T. 4 S., R. 13 E. Here, a series of steeply dipping west-northwest-trending cross faults disrupted the intrusive pattern in steplike fashion so that each sill was progressively offset three times and each northern segment moved farther west. Simultaneous with the displacement occurred convex bending of the sill segments in the direction of relative movement. The nearby Precambrian aplite porphyry mass has also been affected by the left-lateral displacement.

It is important to realize that neither the Ripsey Wash nor the Hackberry conglomerate sequence has been appreciably involved in the cross faulting. The lower conglomerate members disconformably overlie the basement complex and terminate every cross fault in this area. Generally, no offsets occur in the conglomerate units where the faults meet the lower contact. One exception to this, however, occurs in the center of sec. 30., T. 4 S., R 14 E., where a major N. 45° E.-trending fault involves the lower Hackberry formation. The indicated right-lateral displacement of 200 feet at the hackberry contact is opposite to the 1,000-foot left-lateral displacement of a 500-foot-wide diabase sill along the same structure.

The major fault zones usually develop 20 to 30 feet of gouge and cause extensive shearing in the granitic host rock. Because the mid-Tertiary conglomerate sequences have not been affected to any degree by the cross faulting, the structural deformation in the Precambrian basement complex must have taken place before the conglomerates were deposited and before they were tilted to the east. In pre-Miocene time, the diabase sills and the Apache Group were either horizontal or inclined not more than 30° E., as indicated by the unconformable relationships with the conglomerate sequences. High-angle, east-west, normal faulting then occurred dropping the north or south sides successively downward. The Miocene conglomerates were then deposited on the already eroded fault blocks, and after this, 60°-90° E. rotation took place parallel to the major fault surfaces. Thus, the left-lateral or right-lateral offsets presently indicated are actually high-angle normal faults with either the north or south side dropped down. The sequence of events leading to the development of apparent lateral offsets on vertical diabase sills is graphically illustrated in Figure 114.

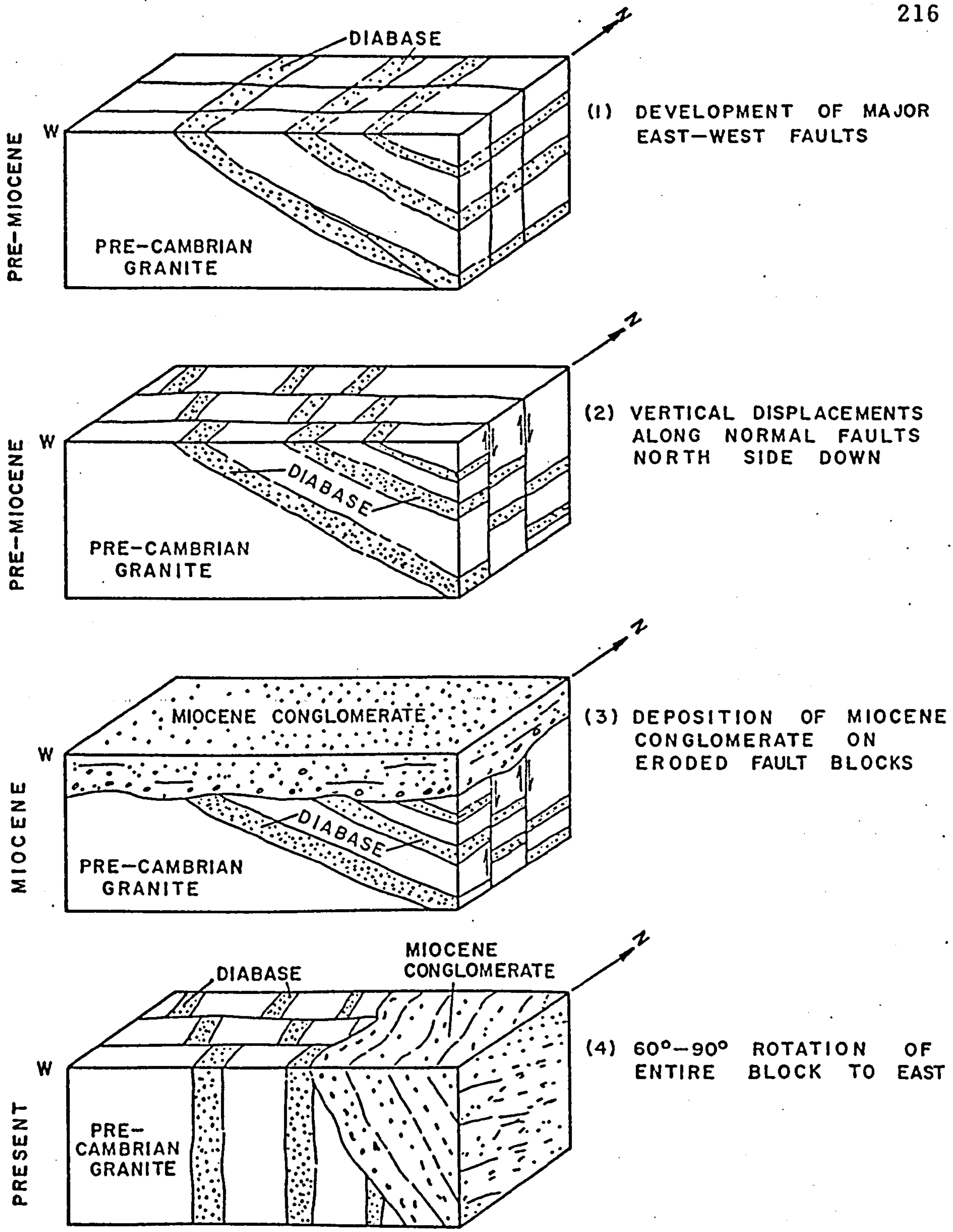


Figure 114. Sequence of Events Leading to the Development of Apparent Left-lateral Offsets on Vertical Diabase Sills in the Tortilla Mountains

The 50 to 100-foot wide east-trending A-Diamond fault zone crosses the Kelvin road near the boundary line of secs. 11 and 14, T. 4 S., R 13 E. Its trace can be followed westward from Kelvin Wash for nearly one mile, but there the fault zone is lost in the extensive talus cover of Ripsey Wash. On the east side, the structure is probably terminated by later north-trending normal faults.

Several low-angle normal faults are present in the Kelvin-Riverside area. One eastward-dipping fault is well developed in the E1/2 sec. 11, T. 4 S., R. 13 E. The upper plate of Oracle Granite overlaps and partly conceals a 600-foot wide vertical diabase basement sill and causes an apparent pinching out of the sill to the north. The fault dips 30°-45° E. and may continue across the Gila River northward. Whether or not it merges with the steeply dipping north-trending Sonora fault is not known. The low-angle fault cuts several east-west Laramide dikes and numerous fissure veins.

Extensive low-angle faulting occurs in secs. 12 and 12, T. 4 S., R. 13 E., where strongly mineralized and altered aplite porphyry has been emplaced over relatively unmineralized Oracle Granite. The contact is a 15° to 45° S.-dipping fault zone. The aplite porphyry is cut by closely spaced, systematically east-trending mineralized joints and fissure veins. Finely disseminated limonite specks in the rock indicate the former presence of sulfides. Moderate amounts of copper carbonate are present in the larger fissure veins and also as a cementing agent in the ferruginous conglomerate along the northwest-trending Kelvin fault zone. The source for these allochthonous mineralized plates is problematic. The southward dip tends to suggest a northern source area, but no aplite porphyry is presently exposed north of the Gila River unless it is covered by Gila Conglomerate. Numerous aplite porphyry masses crop out farther to the south, and it is very likely that the allochthonous plates did originate there. The northward movement occurred probably in response to continued uplift and eastward rotation of the Tortilla range. Faulting is postmineral in age. In this respect it is interesting to note that the trend of the mineralized fractures and fissure veins in the upper plate conforms reasonably well with the regional mineralization pattern in the Oracle Granite. Thus, very little rotation, if any, took place during the emplacement of the upper plates.

A north-trending low-angle fault system is exposed west of the Sultana-Arizona mine in the E1/2 sec. 12, T. 4 S., R. 13 E. The faults dip 20° to 40° E. and separate strongly foliated Oracle Granite in the upper plate from regular granite and diabase in the lower plate. The southward continuation of the low-angle fault is complicated by northeast cross faulting. A small segment of the fault is exposed, however, in the extreme SE1/4 sec. 12 where Oracle Granite overlies a vertical diabase basement sill with a shallow eastward-dipping fault contact. The age of this faulting is definitely post-Laramide because an east-trending Laramide quartz monzonite porphyry dike is terminated by this structure. No crosscutting relationships with the tilted Hackberry formation are exposed; consequently an upper age limit for the low-angle faulting cannot be estimated.

Post-Miocene Faulting

The latest tectonic even in the study area is manifested by a series of north- to northwest-trending normal faults involving the mid-Tertiary Ripsey Wash and Hackberry sequences as well as the Gila Conglomerate.

The Ripsey and Hackberry faults bring the mid-Tertiary conglomerate sequences in fault contact with the Precambrian basement complex. The Ripsey fault is a north- to northwest-trending structure dipping 30° to 65° WSW. Its trace is well exposed and can be followed for nearly 6 miles through the central portion of the map area (Figs. 5 and 18).

The Ripsey fault divides the map area into two large structural blocks. The western block consists mainly of older Precambrian granitic rocks, vertical diabase basement sills, and east-trending Laramide dike swarms. The eastern block constitutes the northern Tortilla Mountains proper and contains remnants of the steeply inclined Apache Group resting on the Precambrian basement complex, diabase sills, and various Laramide intrusive bodies. The Ripsey Wash sequence dips at 15° to 30° into the Ripsey fault. This relationship suggests that the western block tilted independently of, but simultaneously with, the eastern block when the entire range became structurally unstable.

The Hackberry fault merges with the Ripsey fault in sec. 1, T. 5 S., R. 13 E., and is considered to be a branch of the latter fault. The Hackberry fault brings the southwest-dipping portion of the Hackberry formation in contact with the Precambrian Oracle Granite and Laramide quartz diorite. The fault dips 30° to 55° W. and SW., which is very similar to the attitude of the Ripsey fault.

Near the southern border of the mapped area, a moderately west-dipping normal fault brings portions of the Ripsey Wash sequence in juxtaposition with Oracle Granite. This structure is probably part of the main Ripsey fault system. The writer suspects that this fault continues into the Crozier Peak quadrangle to the south, but Krieger (1969) does not show any north-trending faulting in this particular area on her preliminary geologic map.

To the north, the Ripsey fault is concealed by talus in the vicinity of the east-trending A-Diamond fault. Several isolated rock exposures in this general area show high- and low-angle faulting, but their erratic distribution prohibits an accurate tracing of the fault zone.

The westward-dipping Dry Wash fault enters the mapped area in the north and may very well represent the northern extension of the Ripsey fault. According to Creasey (personal commun., 1969), the Dry Wash fault forms a major low-angle structure in the Teapot Mountain quadrangle bringing Miocene Whitetail Conglomerate in fault contact with Granite Mountain porphyry and Pinal Schist. The cumulative strike length of the Dry Wash fault is over 6 miles. If the Ripsey and Hackberry faults are added to this figure, the total length of the low-angle westward-dipping fault zone in this area is at least 15 miles.

In the study area, the Dry Wash fault separates Oracle Granite from Sonora diorite and cuts the east-trending Laramide dike swarm. The most striking effect is the apparent left-lateral offset of the dike swarm by the fault. The writer made a special attempt to correlate individual dikes on either side of the fault to determine the amount of possible strike-slip separation. The results are inconclusive because the compositional variations between dikes are not great enough to permit a direct correlation between groups of dikes across the fault. The arrangement of the entire dike pattern suggests that the western block has moved half a mile southward which is in accord with left-lateral offsets suggested along the Ripsey fault in the southern map portion. On the other hand, the uniform east-northeast-trending Sonora diorite-Oracle Granite contact in the eastern block should have also been displaced southward if the movement were truly left lateral. A contact displacement to the south is not indicated on the west side of the fault. If anything, the contact seems to have been displaced several hundred feet to the north.

A broad north-trending fault zone is exposed just east of Kelvin Wash along the base of the aplite porphyry ridge. The zone strikes north to north-northeast and generally dips 55° to 75° W., although many eastward-dipping fault surfaces are present within the same system. The structure cuts Oracle Granite, aplite porphyry, diabase, and Laramide dike rocks, and it can be traced intermittently along strike for about 1.5 miles. In places, the fault zone is over 200 feet wide. The Oracle Granite is sheared to such extent that the original texture is completely destroyed. This fault zone may represent a portion of the hinge line along which the eastward rotational movement took place. Heavy talus cover in the vicinity of the A-Diamond fault masks the continuation of this major shear zone. However, there is an indication that the fault follows Kelvin Wash northward until it merges with the Sonora fault.

The Sonora fault is a 50-100-foot wide shear zone dipping generally 50°-75° W. Several eastward dips have been observed. The fault zone trends northward into the adjacent Sonora quadrangle and toward the Ray ore body. It separates for the most part Sonora diorite to the east from Oracle Granite, diabase, and diorite to the west. The amount of shearing and gouge is very similar to that of the fault zone just described, and the two structures may actually be the same.

A series of northwest-trending faults is exposed east of Kelvin between the Gila River and State Highway 177. The structures cut Oracle Granite and slightly offset several east-trending Laramide dikes. One steeply westward dipping normal fault brings a section of mid-Tertiary conglomerates in contact with Oracle Granite and diabase. This conglomerate exposure represents the northernmost occurrence of the tilted mid-Tertiary sequence in the study area and signifies that eastward rotation of the Tortilla block has proceeded at least to this point. The Kelvin fault is part of the same system. The fault dips steeply to the east and cuts the mineralized allochthonous aplite porphyry plates.

Several north-trending shear zones are exposed west of Ripsey Wash where they cut and terminate all of the east-trending Laramide dikes. The structures, however, are poorly exposed and difficult to follow. The western set of these faults may comprise another hinge line that borders the western tilted block. Unfortunately, no sedimentary rocks are exposed in this part of the map area to indicate the exact amount of rotation. The numerous north-trending diabase basement sills, however, still maintain a nearly vertical attitude and suggest that this block has also been rotated at least 90^{o}E.

A zone of north-trending, mainly eastward-dipping faults occurs in Gila Conglomerate in the northeast corner of the map area. The amount of displacement along individual faults is difficult to estimate because of lack of marker horizons. Locally 5 to 10 feet of dip-slip separation was observed. These northwest-trending faults are related to the latest tectonic adjustments in this area and must be of Plio-Pleistocene age.

GEOLOGIC SYNTHESIS

The complex arrangement of the structural elements in the study area is evident from the detailed descriptions in the foregoing chapters. All observed structural features are the result of regional tectonic stresses that operated in different directions at different times throughout geologic history.

The older Precambrian foliation in the Oracle Granite trends northeast to east-west in the map area. In the vicinity of Ray, the Pinal Schist foliation trends nearly east-west. This foliation is the fundamental structural grain in the area and appears to have been reactivated during the Laramide orogenic period. This older Precambrian foliation, however, exerted no observed influence on the emplacement pattern of the extensive younger Precambrian diabase sills. The sills clearly crosscut the biotite-quartz foliation of the Oracle Granite in the Kelvin area. The emplacement of the diabase magma was controlled first by the flat sheeting directions in the upper portions of the Oracle Granite below the Apache unconformity, and second by the bedding plane orientations in the Apache Group itself. These two sets of structural surfaces apparently provided directions of least pressure to the advancing wedge of diabase magma. The present steeply dipping, northward-trending diabase sills are the result of eastward tilting of the entire Tortilla Mountain range during early and mid-Tertiary time.

The Laramide magmatic event occurred in three distinct pulses as shown by isotopic age determinations and crosscutting relationships

(Fig. 93). First the intrusion of individual diorite stocks dated at 69 m.y. occurred. This event is well represented by the Sonora diorite and the Hackberry quartz diorite in the immediate study area. The Troy granodiorite (71 m.y.) in the Dripping Spring Mountains and the Copper Hill granodiorite (68 m.y.) southwest of Winkelman fall within the same age range. The second magmatic pulse occurred at 63 m.y. and is manifested by the Grayback granodiorite pluton, the Granite Mountain porphyry at Ray, and the granodiorite stock (62 m.y.) at Christmas. The third event is closely related in time with the intrusion of the Grayback granodiorite and is manifested by the emplacement of the prominent east-west-trending dike swarms which are also dated at 63 m.y. The dikes clearly cut the Grayback granodiorite pluton and the Granite Mountain porphyry. However, the identical isotopic ages of the stocks and the dikes suggest that the dikes are genetically related to the larger intrusive masses. Deep-reaching regional fractures probably tapped the reservoir that earlier supplied the material for the stocks and plutons.

The well-developed east-west-trending fissure vein and mineralized fracture system is younger than the dike rocks. The conformable nature of dikes, fissures, and mineralized fractures indicates that the formation of the latter two was influenced by the same regional stress pattern that controlled the dike emplacement.

This characteristic east-northeast to east-west trending zone of Laramide intrusive masses and mineralized structures is not only present in the study area but has also been recognized in several other mountain ranges of southeast Arizona (Fig. 4, in pocket), especially in the Dripping Spring Mountains, Sacaton Mountains, Silver Bell Mountains, and near Red Hills and Mineral Butte. The Laramide structures invariably cut across the northwest-trending mountain ranges. A similar relationship has been described by Stokes (1968) in the eastern Great Basin of Utah. The recognition of this relationship is, in the writer's opinion, of great economic significance. The margins of the covered basins between the northwest-trending mountain ranges constitute excellent exploration targets for potential base metal deposits wherever they cross the projected trends of the Laramide intrusive belts.

Post-Laramide deformation is characterized by extensive block faulting, rotation, and delineation of the present mountain ranges. The sedimentary strata in the nearby mountains show very little folding. In the report area, the fault pattern resembles a chaotic assemblage of breakage directions on casual observation (Fig. 113). A careful study, however, reveals at least two periods of post-Laramide faulting, each one represented by a characteristic trend. One is mainly easterly, and the other trends predominantly northwesterly. Even though the east-west faults cut the Laramide dikes, their conformable attitude with the Laramide direction in this area suggests that the east-west faults represent the waning stage of the Laramide orogeny. These faults are definitely older than the mid-Tertiary Ripsey Wash and Hackberry conglomerate sequences. Some of these east-west faults could have served as hinge lines along which the initial eastward tilting of individual blocks has taken place.

The north- to northwest-trending fault pattern formed in response to the post-Miocene deformation and is genetically associated with the extensive eastward tilting of the Tortilla block as well as with the differential subsidence of the Dripping Spring Mountains. The present study has shown that the tilting of the northern Tortilla Mountains was accomplished by two major blocks now separated by Ripsey Wash that rotated individually but simultaneously eastward during the breakup of this region.

Evidence for eastward tilting occurs at many localities along the west side of the San Pedro-Gila River lineament (Fig. 4). Krieger (1969) has mapped several steeply dipping Apache Group exposures in the Crozier Peak and Putnam Wash quadrangles. In the Ray area to the north, eastward rotation becomes less evident because of extensive late Tertiary volcanic cover and the general absence of tilted sedimentary units on the west side of Mineral Creek. Recent developments in the Ray open pit mine, however, have disclosed a section of the Apache Group unconformably resting on Pinal Schist and dipping 45°E. toward the Ray fault (Phillips, personal commun., 1970). This exposure is overlain by the Emperor thrust sheet which consists entirely of Pinal Schist. The emplacement of this thrust plate probably occurred in response to the eastward rotation of the northernmost Tortilla Mountains.

The Miocene Whitetail Conglomerate beneath Teapot Mountain northwest of Ray dips 30° to 65° E. and is unconformably overlain by the Superior dacite extrusive complex. The eastward tilting of the Whitetail Conglomerate, therefore, had to be mostly completed by the time the 20 m.y. old dacite was extruded. Thus, there is now sufficient evidence to indicate that the Ray area west of Mineral Creek experienced up to 60° E. rotation. Because the tilting is of post-Laramide age, the present outcrop pattern of the Granite Mountain porphyry stock and associated intrusives (porphyry break) should reveal this deformation. The writer suspects that a critical examination of the contact relationships between the intervening Pinal Schist and the porphyry bodies will reveal gently dipping contact zones very similar to the relationships observed northwest of Hackberry Wash between the elongate quartz diorite masses and Oracle Granite.

The northernmost exposure indicating eastward tilting is in the Mineral Mountain area where a narrow belt of steeply eastward dipping Apache Group and Martin(?) Limestone rests unconformably on Pinal Schist. The tilted sedimentary strata are in turn unconformably overlain by the rhyolite extrusive complex which is younger than the Superior dacite eruption. The tilted sedimentary strata are terminated to the south by a gently eastward dipping plate of Pinal Schist (Schmidt, 1967) which resembles closely the Emperor thrust plate at Ray.

Peterson (1968) postulates a northwest-trending structural hinge line measuring about 3 miles in width to explain the various tilted sedimentary exposures mentioned above. This disturbed zone passes west of Superior and continues southwest into the present study area. The writer concurs with Peterson's idea, and he suggests that the San Pedro lineament constitutes the major element of this structural hinge line. All rock units of pre-dacite age located west and southwest of the San Pedro Valley and its northern extension have been tilted significantly to the east. This western block must have been a positive area for a long time span and subjected to considerable erosion because very few or no Paleozoic and younger Precambrian sedimentary strata are found. In many localities. dacite lies directly on older Precambrian basement complex.

The Dripping Spring Mountains east of the Gila-San Pedro Valley expose thick sections of gently dipping but profusely block-faulted Paleozoic and younger Precambrian strata. Farther to the northeast, the gently westward-dipping strata in the Mescal Mountains rests unconformably on the older Precambrian Pinal Mountain block and form a structurally undisturbed dip-slope sequence (Fig. 115).

These four mountain ranges then appear to be part of or involved in a large-scale uplift-collapse structure that centers around the Dripping Spring-Galiuro mountain chain. The Tortilla Mountain block forms the western portion and the Mescal-Pinal Mountain block the eastern portion of this structure. It is inconceivable, however, that one is dealing here with a simple dome which stretches from the Tortilla Mountains in the west to the Pinal Mountains in the east. It is much more likely that the Tortilla Mountain block tilted independently of but simultaneously with and opposite to the Pinal Mountain block and that the centrally located Dripping Spring Mountains experienced intimate block faulting with several thousand feet vertical displacement but virtually no rotation. The observed features clearly developed in a tensional stress field characterized by east-northeast to west-southwest directed distention.

Most investigators on the problem of Basin and Range tectonics agree that the western United States was subjected to large-scale extension during mid-Tertiary time. However, the various explanations given to bring about distention and collapse differ considerably.

Cook (1965, 1969) postulates a rising convection cell beneath the Basin and Range province along the landward projection of the East Pacific Rise into the Gulf of California. The model involves one large

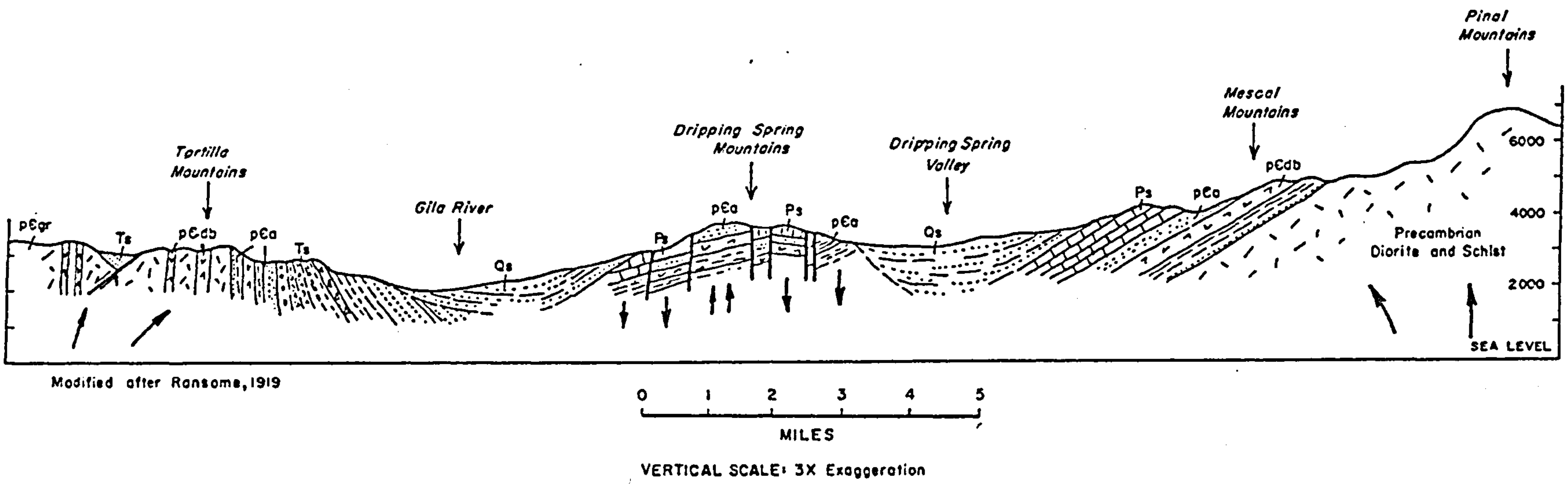


Figure 115. Generalized Cross Section through Tortilla, Dripping Spring, and Pinal Mountains, Arizona, Looking Northwest

The Tortilla and Pinal Mountains represent deeply eroded Precambrian blocks that were uplifted and tilted in mid-Tertiary time. The centrally located Dripping Spring Mountains experienced intimate differential block faulting but virtually no tilting. Arrows indicate directions of relative movement. This style of deformation is outlined by the attitudes of the younger Precambrian Apache Group (pCa) and diabase sills (pCdb), the Paleozoic limestone sequence (Ps), and the various Tertiary conglomerate sequences (Ts).

westward-flowing mantle convention current which is the driving mechanism for rifting and block faulting in the relatively thin lithosphere (25-30 km). Sufficient heat energy is supplied to cause partial melting in the lower crust (mantle-crust mix) and to enable extensive silicic volcanism in the overlying dissected crust (Fig. 116). The high heat flow could also be a ready source for the thermal energy necessary to reset completely the Ar clock in the Catalina-Tortolita gneiss cores.

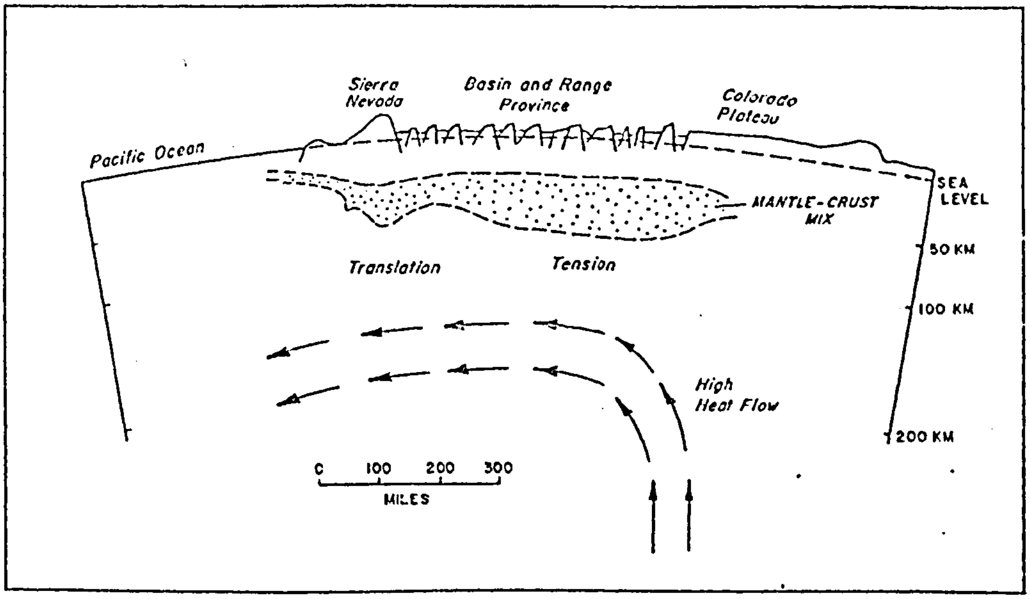


Figure 116. Structural Model for the Western United States.--Modified from Cook (Figure 10 B,C; 1969)

From a detailed structual study in the Yerington area of Nevada, Proffett (1971) concluded that Cenozoic normal faulting resulted from about 35 percent east-west extension in the Great Basin. This extension, according to Proffett, can only be explained through the presence of the East Pacific Rise and the phenomenon of crustal thinning under the Great Basin.

Thompson (1965) suggests local convection as a result of expansion in the lower crust in connection with phase changes and igneous intrusions (Fig. 117). The subcrustal expansion would cause regional extension in the upper crust and concomittant graben and horst formation. However, Thompson's model envisions very little tilting, if any, of the involved crustal blocks.

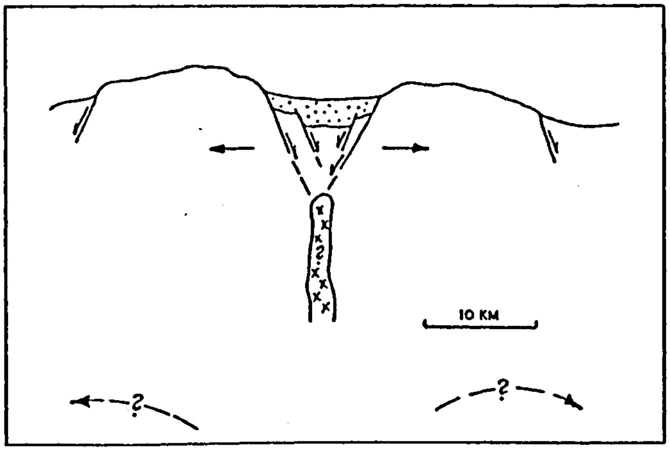


Figure 117. Model of Basin and Range Structure after Thompson (1965)

Hamilton and Meyers (1966) relate the Basin and Range tectonic activity to oblique tensional rifting as a result of right-lateral strike-slip separation in the continental plate of western United States. Slemmons (1971) also considers strike-slip and some oblique-slip faulting a major factor operating in the Basin and Range province. He ultimately relates strike-slip faulting to rifting in the basement similar to the tectonic patterns along the San Andreas fault zone. Very little evidence for this kind of deformation, however, exists in the Tortilla Mountains and vicinity. Noble (1971) rejects east-west tension as the controlling factor for basin-and-range type structures and relates the arcuate form of the entire Basin and Range province to laminar flow in the upper mantle.

A close causal relationship between Cenozoic volcanism and Basin and Range tectonism has been proposed by Mackin (1960) and Damon and Mauger (1966). Gilluly (1965), on the other hand, argues that a causal relationship between volcanism, tectonism, and plutonism does not exist in the western United States. Damon and Mauger (1966) attribute Basin and Range tectonism to uplift of the East Pacific Rise and subcrustal volume increase as a result of solid-liquid phase transitions. Partial melting of the lower crust is aided by high convective heat flow and radioactive decay. The resulting volume increase will ultimately rupture the upper crust causing excessive volcanism on the surface.

Mackin (1960) relates crustal collapse directly to the extrusion of large volumes of volcanic rocks in the Great Basin area whereby individual fault blocks tilt upward and rotate away from the centers of volcanism to form an intricate antithetic fault pattern (Fig. 118). According to this model the crustal breakup occurs mainly after the eruption of volcanic rocks so that these volcanic rocks are also involved in the tilting process.

Large volumes of silicic volcanic material cover the Ray-Superior area, but the extrusive event took place largely after the main phase of structural disturbance. The dacite ash flow sheets overlie the tilted sedimentary strata with a marked unconformity. However, evidence for some earlier silicic volcanic activity is indicated by several thin rhyolite bands in the tilted Hackberry and Ripsey Wash conglomerate sequences and by the massive tuffaceous sandstone units in the

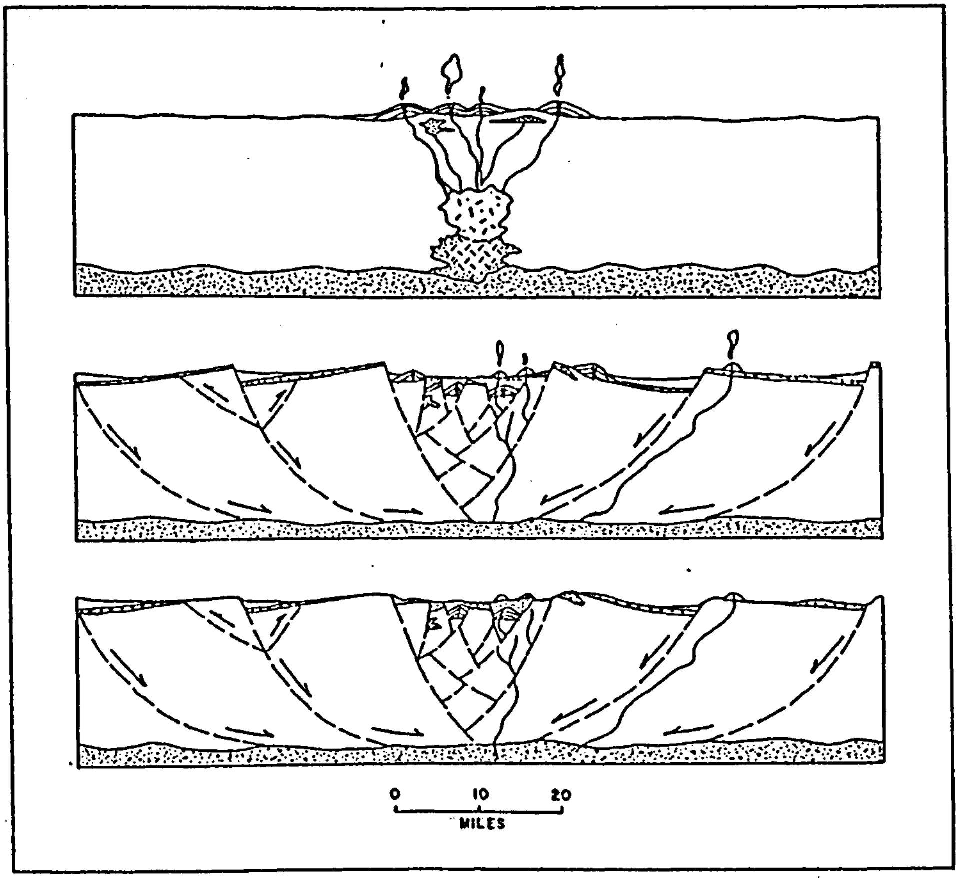


Figure 118. Model of Basin and Range Structure after J. H. Mackin--From Roberts (1968)

central part of the Ripsey Wash sequence. As far as the study area is concerned, it seems unlikely that crustal breakup resulted directly from volcanic extrusive activity. It is more likely that silicic volcanism in this area formed in response to the crustal breakup.

Wilson and Moore (1959) proposed the concept of broad, open folding in the Arizona portion of the Basin and Range province. They suggest three major northwest-trending anticlinal structures between Tucson and Yuma to account for periodic dip reversals in the mountain ranges. Wilson and Moore indicate that the easterly dips of the mountain blocks are generally steeper than the westerly dips; a fact well borne out in the present study (Fig. 113). Wilson and Moore relate this asymmetrical pattern to faulted folds similar to the large fold structures on the Colorado Plateau.

The writer believes that antithetic rotation as a result of doming is an attractive concept to explain the structural configuration observed in the investigated region. According to Cloos (1939), a rising and expanding dome will collapse in the center whereby the individual blocks tilt upward and rotate away from the dome center along curving fault planes (Fig. 119).

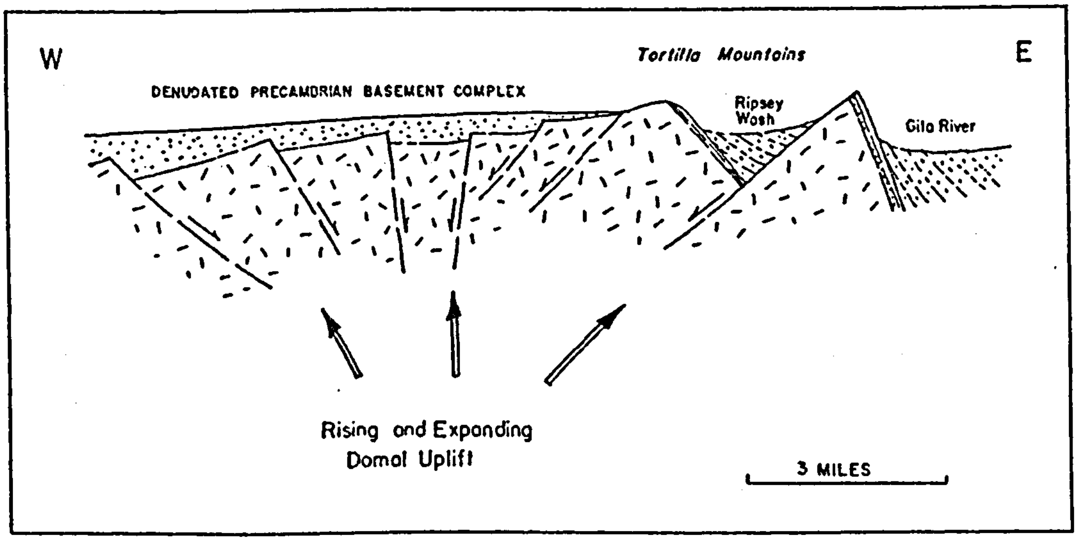


Figure 119. Sketch of Antithetic Rotation as Applied to the Tortilla Mountains

Figure not drawn to scale.

Applying this concept to the study area, the center of the rising dome or elongate welt is not located between the Tortilla and Pinal Mountains but west of the Tortilla Mountains in an area now largely covered by Holocene gravel deposits. The center of this structure would lie on the northwestward projection of the Santa Catalina-Tortolita gneiss block which yields uplift-cooling ages of 25-30 m.y. (Mauger, Damon, and Livingston, 1968). This thermal welt could possibly extend farther to the northwest past the Picacho Mountains to South Mountain near Phoenix and could constitute a major northwest-trending belt of mid-Tertiary crustal heating, doming, and subsequent tilting.

Gravity data (Peterson, 1968) in this part of Arizona outline numerous north- to northwest-trending anomalies bordered by steep gradients that probably reflect first-order discontinuities in the basement.

The close time correlation between crustal heating and extensive block faulting is, in the writer's opinion, not fortuitous. Stratigraphic evidence in the study area indicates that eastward rotation continued up to 21 m.y. ago. Cooling of the reheated crustal portions in the Catalina-Tortolita gneiss belt was sufficiently advanced between 25 and 30 m.y. ago to reset completely the argon clock. Thus, there is a 5 to 10 million year interval during which continued uplift and concomittant rotation took place.

A second belt of mid-Tertiary crustal heating and uplift could include the Pinaleno Mountains and several gravel-covered areas to the northwest. The westward tilting of the Pinal-Mescal Mountain block would then be genetically related to the rise of the Pinaleno welt.

A consequence of the foregoing concept is that the Dripping Spring-Galiuro Mountains constitute a downdropped block bordered on both sides by Precambrian uplifted cores. Further detailed structural investigations in conjunction with isotopic age dating have to be carried out in this critical part of Arizona to test this hypothesis.

The writer is well aware that the study area represents only a small portion of a complex structural region in Arizona where the indicated deformations may ultimately relate to tectonic forces operating over tens if not hundreds of miles. Nevertheless, the writer is confident that the present study has called attention to a structurally and economically important area of Arizona and that the study has contributed greatly to the understanding of the tectonic framework in this part of the Basin and Range province.

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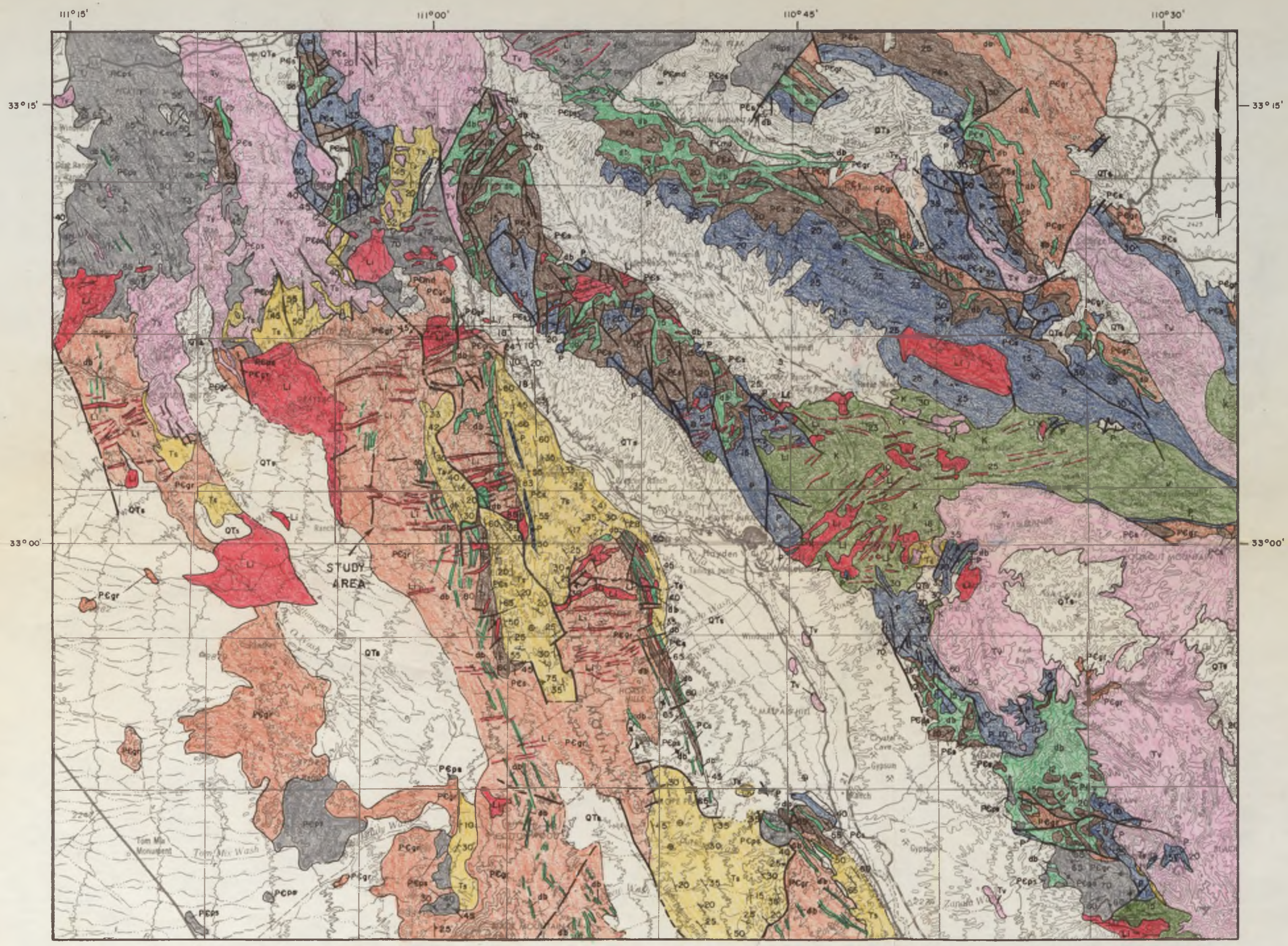
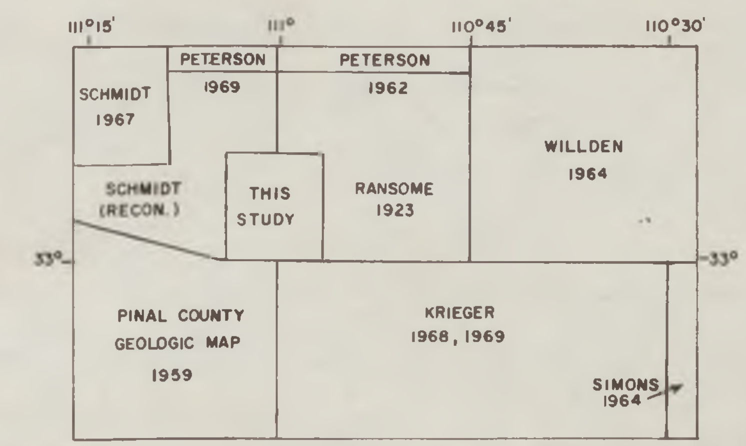


E.A. SCHMIDT, Ph.D. DISSERTATION, GEOLOGY, 1971

FIGURE 4, GENERALIZED GEOLOGIC MAP OF THE TORTILLA MOUNTAINS AND SURROUNDING AREA, SOUTHEAST ARIZONA



SOURCE OF DATA

COMPILED BY E.A. SCHMIDT

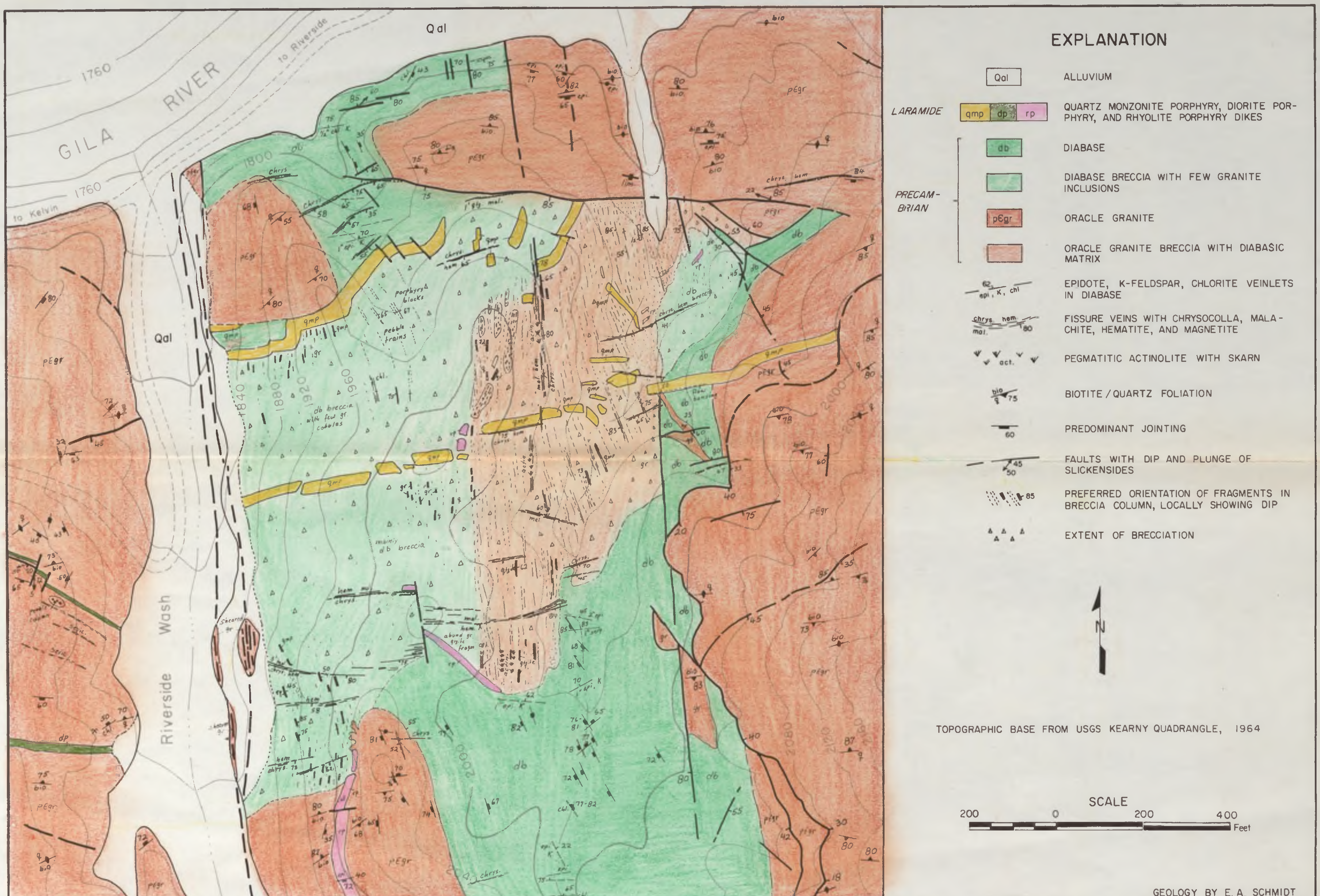


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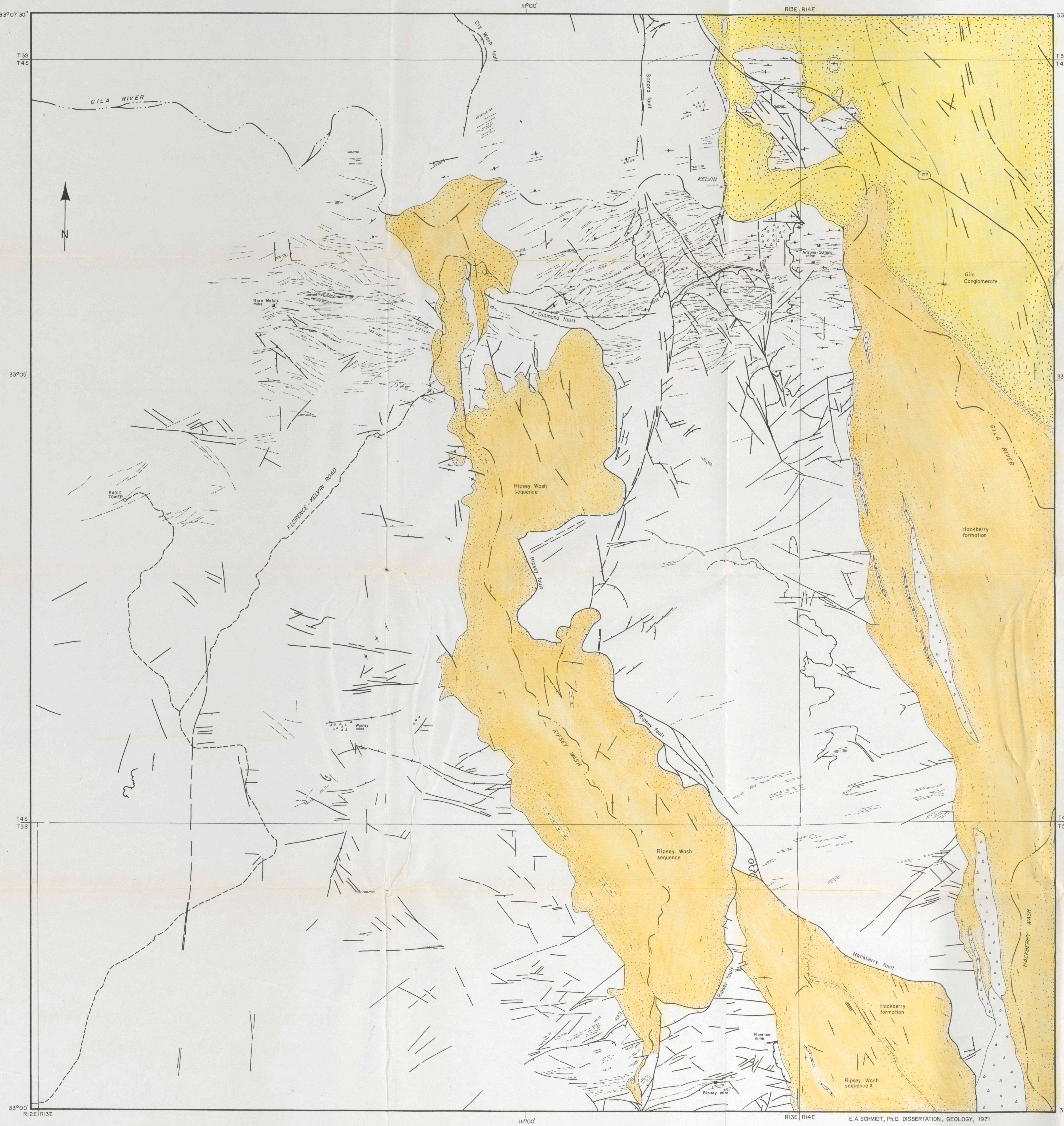
FIG. 105 KELVIN BRECCIA COLUMN, PINAL COUNTY, ARIZONA



EXPLANATION

- GILA CONGLOMERATE
- RIPSEY WASH SEQUENCE AND HACKBERRY FORMATION
- ALLOCHTHONOUS BRECCIA SHEETS CONSISTING OF PRECAMBRIAN APLITE, DIABASE, QUARTZITE, AND PALEOZOIC LIMESTONE
- BRECCIAS IN PRECAMBRIAN ORACLE GRANITE AND DIABASE
- FISSURE VEINS
- MINERALIZED FRACTURES
- HIGH ANGLE FAULTS; TICK MARKS SHOW DIP DIRECTION
- LOW ANGLE FAULTS; TICK MARKS SHOW DIP DIRECTION
- BEDDING
- FOLIATION
- MINE SHAFT

SCALE 1:24000

2000 0 2000 4000 6000 Feet

FIGURE 113

STRUCTURE MAP
NORTHERN TORTILLA MOUNTAINS
PINAL COUNTY, ARIZONA

FIGURE 5 GEOLOGIC MAP OF THE NORTHERN TORTILLA MOUNTAINS, PINAL COUNTY, ARIZONA

GEOLOGY BY E.A.SCHMIDT

SCALE 1:12000

1000 0 1000 2000 3000 4000 FEET

CONTOUR INTERVAL 20 AND 40 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

QUATERNARY

Qal ALLUVIAL DEPOSITS IN WASHES

Qt TALUS COVER ON PEDIMENT SURFACES; ELLUVIAL DEPOSITS (Qel) AND SAND (Qs)

TERTIARY

RIPSEY WASH AREA

RIPSEY WASH SEQUENCE

Truc POORLY-BEDDED UPPER COBBLE AND BOULDER CONGLOMERATE

Trt MASSIVE TUFFACEOUS SANDSTONE; EXTENSIVELY ALTERED TO CLINOPTILOLITE

ap db INTRAFORMATIONAL MONOLITHOLOGIC BRECCIAS COMPOSED OF APLITE (ap) AND DIABASE (db)

Trlc POORLY-BEDDED, MASSIVE LOWER BOULDER CONGLOMERATE

GILA RIVER AREA

QTg GILA CONGLOMERATE; POORLY BEDDED, MODERATELY INDURATED COBBLE AND BOULDER CONGLOMERATE CONTAINING PRECAMBRIAN, PALEOZOIC AND TERTIARY ROCK FRAGMENTS CONTAINING:

HACKBERRY FORMATION

Thrc WELL-BEDDED, WELL-INDURATED RED COBBLE CONGLOMERATE WITH ANDESITE MATRIX

INTRA-FORMATIONAL MONOLITHOLOGIC BRECCIAS COMPOSED OF APLITE (ap), DIABASE (db), YOUNGER PRECAMBRIAN QUARTZITE (q), PALEOZOIC LIMESTONE (Pls), LARAMIDE PORPHYRY (Lp), AND CRETACEOUS (?) ANDESITE AGGLOMERATE (Ka)

Ths THINLY-BEDDED, GRAY TO MAROON SHALE AND SANDSTONE UNITS

Thbc POORLY-BEDDED, WELL INDURATED COBBLE AND BOULDER CONGLOMERATE CONTAINING ORACLE GRANITE, APLITE, DIABASE, QUARTZITE, LIMESTONE AND LARAMIDE PORPHYRY ROCK FRAGMENTS

LARAMIDE

Lmp GRANODIORITE PORPHYRY (gdp), MONZONITE PORPHYRY (mp), QUARTZ MONZONITE PORPHYRY (qmp), RHYOLITE PORPHYRY (rp) DIKES AND SMALL INTRUSIVE BODIES (K-Ar AGE 63 M.Y.)

Lgd / Lqm SATELLITIC GRANODIORITE (Lgd) AND QUARTZ MONZONITE (Lqm) STOCKS

Lggd GRAYBACK GRANODIORITE PLUTON (K-Ar AGE 63 M.Y.), WELL-EXPOSED ON GRAYBACK MTN.; RANGES FROM BIOTITE-RICH GRANODIORITE TO MUSCOVITE QUARTZ MONZONITE

Lsd / Lhd DIORITE-QUARTZ DIORITE INTRUSIVE BODIES INCLUDING SONORA DIORITE (K-Ar AGE 69 M.Y.) AND HACKBERRY DIORITE (Lhd)

CRETACEOUS

Ka ANDESITE AGGLOMERATE ASSOCIATED WITH ALLOCHTHONOUS CRACKLE BRECCIAS IN HACKBERRY FORMATION; PROBABLY OF CRETACEOUS AGE

PALEOZOIC

Pls UNDIFFERENTIATED FOSSILIFEROUS LIMESTONES; INCLUDE DEVONIAN, MISSISSIPPIAN AND PENNSYLVANIAN( ) STRATA; NON-BRECCIATED IN THE FLORENCE MINE AREA; COMPLETELY SHATTERED AS MONOLITHOLOGIC BRECCIAS WITHIN THE HACKBERRY FORMATION

YOUNGER PRECAMBRIAN

db DIABASE, DARK GREENISH GRAY SILLS AND DIKES IN APACHE GROUP AND GRANITIC BASEMENT COMPLEX

tq TROY QUARTZITE, RED TO LIGHT GRAY, THIN- TO THICK-BEDDED FELDSPATHIC QUARTZITE

APACHE GROUP

ml MESCAL LIMESTONE, DOLOMITIC LIMESTONE WITH SILICEOUS SEGREGATIONS AND STROMATOLITE UNITS

ds DRIPPING SPRING QUARTZITE, THIN- TO THICK-BEDDED FELDSPATHIC QUARTZITE AND SILTSTONE

bc BARNES CONGLOMERATE; WELL-ROUNDED QUARTZ, QUARTZITE AND RED CHERT PEBBLES IN FIRM ARKOSIC MATRIX

pf PIONEER FORMATION WITH BASAL SCANLAN CONGLOMERATE, MAINLY THINLY-BEDDED, SLOPE FORMING MAROON MUDSTONES AND SILTSTONES OVERLYING 0.5-1 FOOT THICK PEBBLE CONGLOMERATE

OLDER PRECAMBRIAN

app / ap APLITE PORPHYRY MASSES (app) AND IRREGULAR APLITE DIKES (ap); APLITE MASSES CONTAIN K-FELDSPAR AND PLAGIOCLASE PHENOCRYSTS AND SOME BIOTITE CLOTS; UNIT INCLUDES MUSCOVITE GRANITE ALONG SOUTHERN MAP BOUNDARY

gr ORACLE GRANITE, COARSE GRAINED WITH 0.5-1 INCH PINK K-FELDSPAR PHENOCRYSTS AND LARGE BIOTITE AGGREGATES; LOCALLY STRONGLY FOLIATED

45 STRIKE AND DIP OF BEDDING

80 STRIKE AND DIP OF OVERTURNED BEDS

HORIZONTAL BEDS

75 STRIKE AND DIP OF FOLIATION

75 STRIKE AND DIP OF JOINTS, LOCALLY CONTAINING EPIDOTE (epi), CHLORITE (chl), LIMONITE (lim) AND K-FELDSPAR (K)

65 TREND OF FISSURE VEINS SHOWING DIP

TREND OF MINERALIZED FRACTURES

q TREND OF BRECCIATED MAJOR QUARTZ VEIN

75 STRIKE AND DIP OF HIGH ANGLE FAULT SHOWING DIP, DASHED WHERE INFERRED, FAULT TRACE LOCALLY INDICATED BY CALICHE (cali)

30 TRACE OF LOW ANGLE FAULT SHOWING DIP, DASHED WHERE INFERRED

BRECCIATION IN ALLOCHTHONOUS SEDIMENTARY ROCKS

INTRUSION BRECCIAS RELATED TO DIORITE AND GRANODIORITE INTRUSIVE MASSES

A A' LINE OF CROSS-SECTION

DRILL HOLE

MINE SHAFT

X PROSPECT PIT

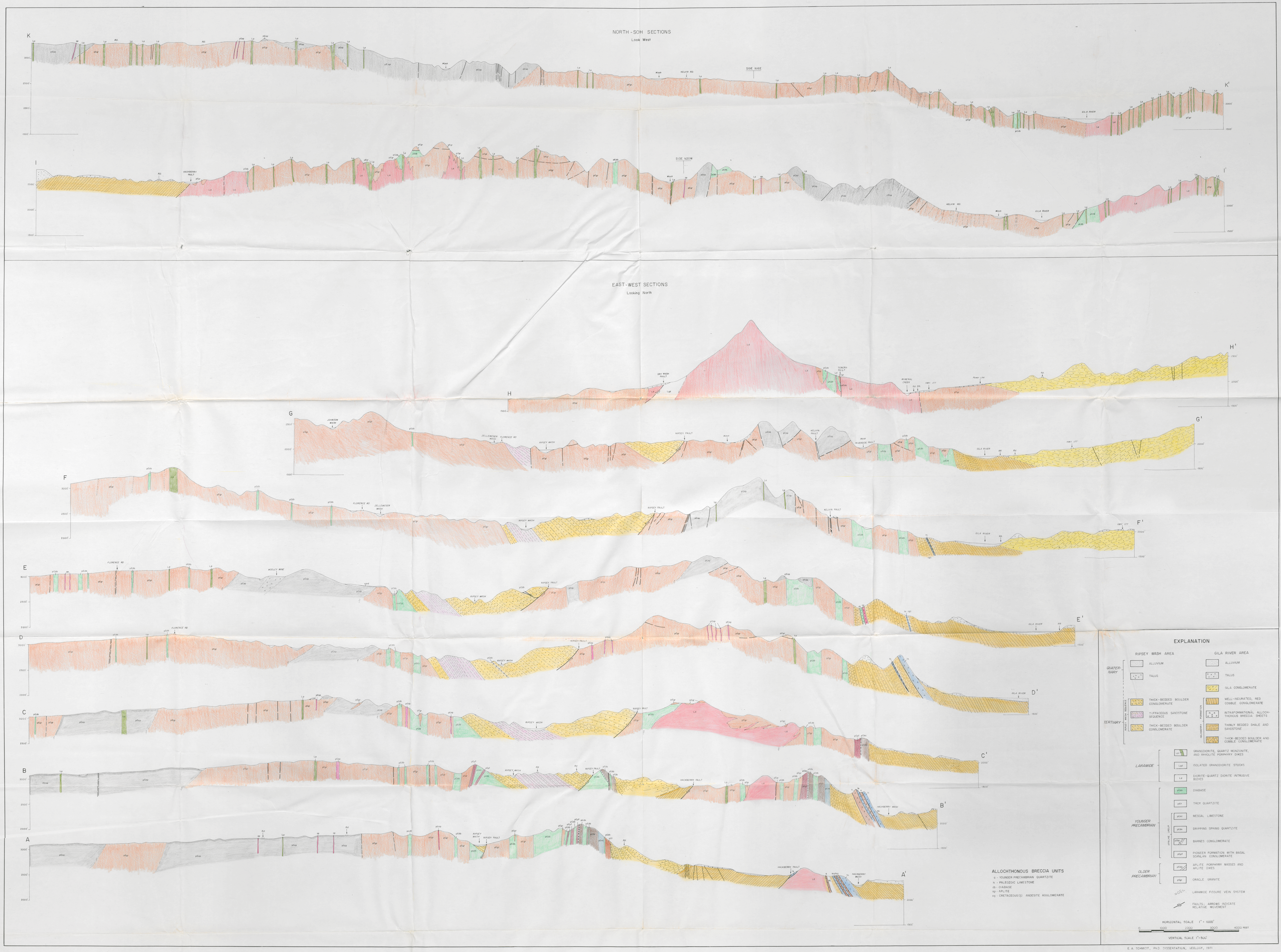


FIGURE 18 GEOLOGIC CROSS SECTIONS, NORTHERN TORTILLA MOUNTAINS, PINAL COUNTY, ARIZONA