RESULTS OF MAPPING PROJECT
NEAR RAY PINAL COUNTY,
ARIZONA

RESULTS OF MAPPING PROJECT NEAR RAY

PINAL COUNTY, ARIZONA

BUREAU OF GEOLOGY
OGY

by

Stanley B. Keith

STATE OF ARIZONA
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OPEN-FILE REPORT

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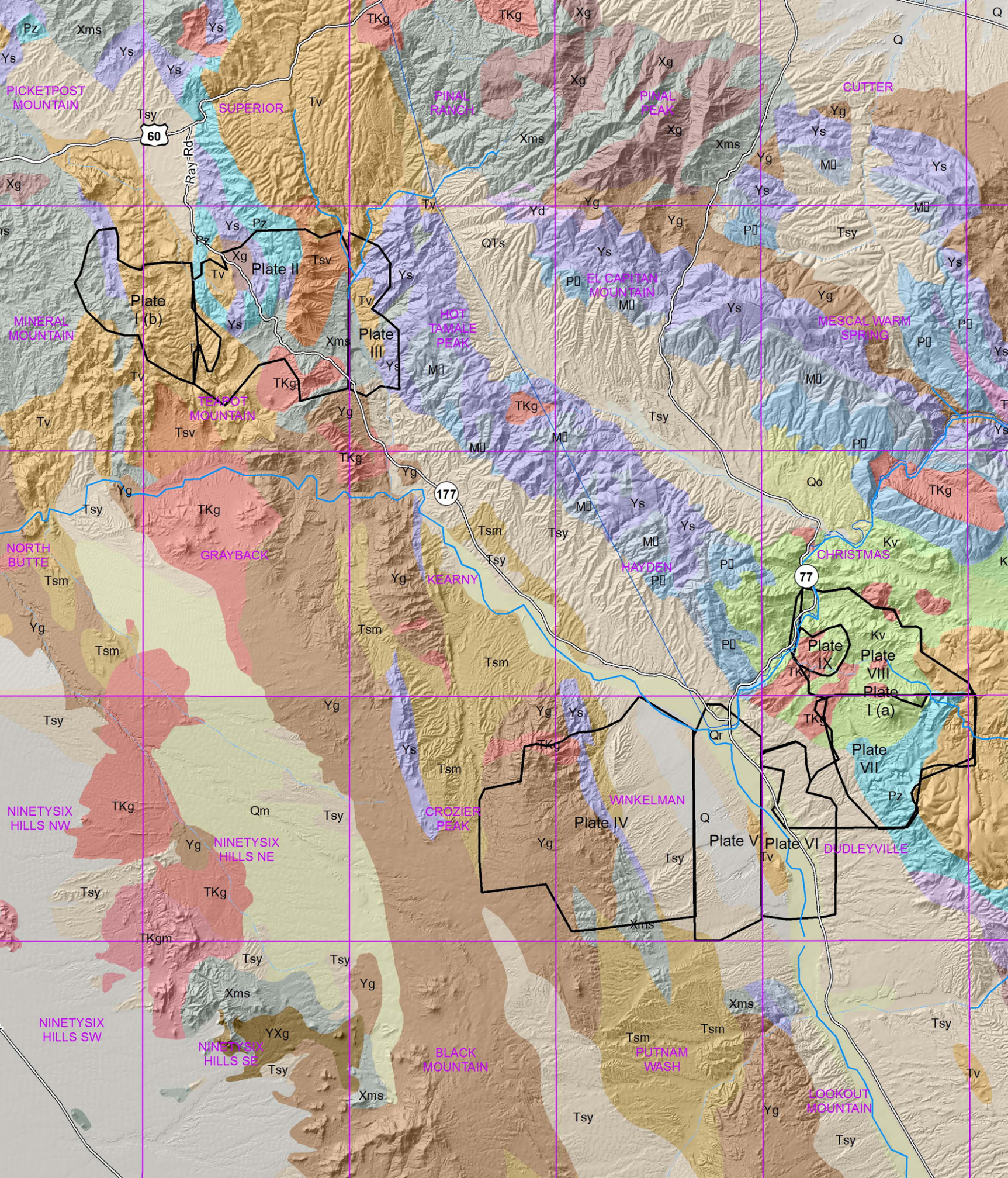
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RESULTS OF THE RAY MAPPING PROJECT

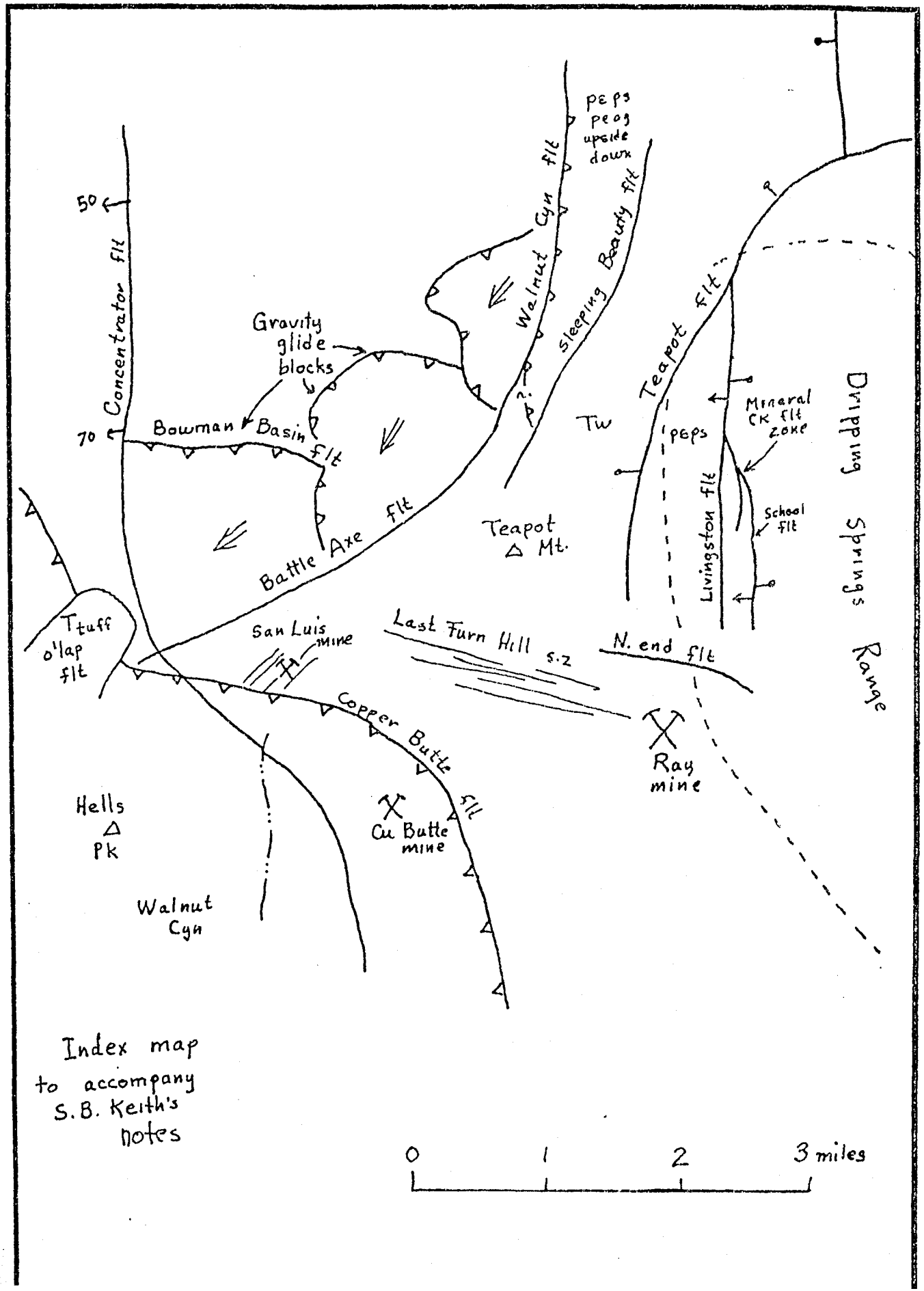
(The following notes were transcribed from an informal tape-recorded talk presented by Stan Keith at the Ray mine, April 15, 1976)

The area mapped by Stan lies north and west of Ray and comprises an area of about 14 by 5 miles. Mapping scale is 1" = 1000' and the base is enlarged USGS topographic maps.

Low-Angle Faults

Low-angle reverse faults. -- A series of major low-angle reverse faults exists northwest of Ray. The nearest of these thrust faults to Ray is the Walnut Canyon fault which has a north-south trace north of Teapot Mountain (see index map). Deformed Paleozoic rocks lie in the footwall of this fault, and a section of Paleozoic and Apache group rocks completely inverted lies in the hanging wall. The block of inverted rocks is truncated on the east by a steep-angle normal fault, the Sleeping Beauty fault, with Whitetail conglomerate in the hanging wall and Paleozoic and Apache group rocks in the footwall. The Walnut Canyon fault has a complex history. An early period of reverse movement probably accompanied overturning of the footwall rocks. A second period of normal movement produced a synclinal drag and further overturned the overturned rocks such that the rocks are now overturned overturned! Thrusting along the Walnut Canyon fault is thought to be associated with a compressional event, probably of Laramide age, which produced shortening in this area of at least 12 miles (assuming a continuous overthrust from Telegraph to Walnut Canyon). It is important to mention here that there is no positive evidence for a decollement along the base of the sedimentary section in contact with the crystalline basement. The base of the Apache group section where well exposed is generally and almost always in normal sedimentary contact with the crystalline basement. Very little evidence for shearing is apparent. Indeed, the crystalline basement, which includes some diabase sills, appears to have been folded along with the overlying Phanerozoic section.

Low-angle normal faults. -- The Copper Butte fault west of Ray is a low-angle normal fault of major extent. It extends southward into the Grayback Mountain quadrangle, through the Kearny quadrangle, (the Ripsey fault of Schmidt, 1971) to the vicinity of Crozier Peak, Winkleman 15' quadrangle, (the Camp Grant fault of Krieger, 1974) and probably extends on to San Manuel. This fault is a member of a group of faults which extend along the west margin of the Tortilla hinge line and as a group is characterized by a period of low-angle normal displacement. One member of this group offsets the San Manuel-Kalamazoo orebody.



Index map
to accompany
S.B. Keith's
notes

The low-angle normal displacement on the Copper Butte fault can be dated in the Ray map area. In the SW$\frac{1}{4}$ sec. 12, T. 3 S., R. 12 E., Apache Leap tuff, dated at 20 m.y., lies in low-angle normal fault contact with Pinal schist and Whitetail conglomerate. The low-angle fault is interpreted to be an imbricate slice of the Copper Butte fault. One mile farther northwest, the Copper Butte fault is overlapped unconformably by volcanics which postdate the Apache Leap tuff and which yield age dates of 18 to 16 m.y. Thus the period of low-angle normal faulting occurred between 20 and 18 m.y. It should be noted that this fault may have had an earlier period of reverse displacement, but the present juxtaposition of stratigraphic units indicate the latest normal movement occurred during the 20 to 18 m.y. period. Also, movement on the Copper Butte fault appears to be younger than movement on the Battle Axe fault because of truncation relationships in SW$\frac{1}{4}$ sec. 12, T. 3 S., R. 12 E. Geologic relationships to the south do not substantiate but are consistent with normal displacement along the entire system at about the same time as in the Copper Butte area. For example, in the vicinity of San Manuel, the San Manuel formation is commonly offset by normal displacement, and age dates of the San Manuel yield 24 m.y. Thus much of the movement in the south is post-24 m.y. Also, the Big Dome formation (14-17 m.y.) is not generally known (with one exception of the White Canyon fault) to be involved in the low-angle normal faulting, although it occurs in close proximity to normally faulted San Manuel formation. Hence normal faulting may be pre-17 m.y. in age.

One interesting feature of the Copper Butte fault is the contrast in structural coherency of the Pinal schist in the hanging wall and footwall blocks. Pinal schist in the hanging wall of the fault is strongly deformed, broken, and shattered. Pinal schist in the footwall block appears to exhibit only the metamorphic structures dating from Precambrian time. This shattering is thought to be related to near-surface movement on the Copper Butte fault under low confining pressure. Examination of small fold structures in the Pinal schist indicates possible early reverse movement on the Copper Butte fault, but the latest movement appears to be low-angle normal. Likewise, exposures of a similar low-angle fault in Walnut Canyon (near CB-9) provide some indication of an early reverse movement period. Here, Big Dome-equivalent rocks lie in the hanging wall of the fault and Whitetain conglomerate in the footwall, but the drag in the Whitetail suggests reverse movement on the fault. Evidence for two-phase movement, i.e., an early reverse movement, is persistent on the low-angle faults throughout the San Pedro hinge zone. A series of gravity glide blocks is present in the footwall of the Walnut Canyon fault. These appear to be thin slabs of Paleozoic rocks which have detached and moved generally to the southwest under the response of gravity prior to the last movement of the Walnut Canyon fault because of truncation relationships.

High-Angle Normal Faults

The Concentrator fault is a major high-angle normal fault with west side down extending southward into the vicinity of Copper Butte. The Concentrator fault dips steeply to the west with normal displacement that involves all stratigraphic units (except the Quaternary alluvium). This is in contrast to Creasey's interpretation which shows most recent movement on the Concentrator fault as pre-Apache Leap tuff. Stan's mapping shows that the Concentrator fault cuts all units up and including the youngest gravels (Big Dome age). The Concentrator fault thus implicity cuts the Copper Butte fault, although the intersection of these two faults is covered. However, the Concentrator fault appears to continue south into the hanging wall of the Copper Butte fault. The trace of the Concentrator fault appears to have a left lateral separation south of the intersection with the Copper Butte fault.

The Concentrator fault appears to be a simple, single strand fault break where it intersects Tertiary volcanic rocks. To the north part of the map area and farther north near Superior where the Concentrator fault cuts Paleozoic rocks, relationships are more complex with many parallel fault slivers. The Concentrator fault thus may be an old structure reactivated in late Tertiary time. Older mapping by E. D. Wilson shows the Concentrator fault merging into and becoming the Copper Butte fault. Stan does not believe this is the case.

The Teapot Mountain fault is an important structural feature in the Ray area. This high-angle normal fault extends northward from the Ray pit up Mineral Creek and essentially marks the northwestern boundary of the Dripping Springs range. Whitetail conglomerate in the hanging wall on the west is relatively downfaulted against Pinal schist on the east. Farther north along a northward projection of this fault beneath the Apache Leap dacite, deep drilling by ASARCO and Inspiration in the Devils Canyon area indicates that this fault may continue northward under Apache Leap tuff cover as a major structural break. The deep drilling indicates a block of Pinal schist to the east, faulted against a block of Whitetail and Paleozoic rocks on the west. Drill holes collared in the east block penetrate ± 1,000 feet of Apache Leap dacite, a few hundred feet of Whitetail, and then goes directly into Pinal schist or in some cases Schultze granite. Drill holes collared in the west block penetrate ± 1,000 feet of Apache Leap dacite, up to 3,000 to 4,000 feet of Whitetail conglomerate, and finally penetrate Paleozoic rocks at 5,000 or 6,000 feet. These relationships hold in the Ray area where the block west of the Teapot Mountain fault contains a very thick section of Whitetail conglomerate, possibly up to 3,000 feet. Hence most of the normal movement on the Teapot Mountain fault is pre-Apache Leap tuff in age based on the drilling in the Devils Canyon area, although in the Ray area there is probably some post-Apache Leap movement

West- to Northwest-Trending Structures of the Texas Zone

An element of the Texas zone in the Ray area may be the Last Turn Hill shear zone which extends in a west-northwest direction from the Ray pit. It is well defined from Ray to the vicinity of the San Luis mine where northeast fractures appear to intersect it. The Concentrator fault appears to bend from a north-south trace to a northwest trace where it intersects the projection of the Last Turn Hill shear zone. The Last Turn Hill shear zone appears to be a major crustal break. Generally the rocks north of the projection of Last Turn Hill shear zone comprise a terrane of Paleozoic sedimentary rocks strongly deformed by thrusting. The rocks south of this zone are crystalline basement rocks. Thus a vertical offset is inferred along this fault zone.

The Last Turn Hill shear zone appears to have had both vertical and left-lateral displacement along its trace. The evidence for left-lateral displacement is the apparent offset of north-south fault structures and drag folds adjacent to the major shears. A problem exists in extending the Last Turn Hill shear zone southeastward into the Dripping Springs range. A possible solution to this problem is that the Last Turn Hill shear zone merges with the Diabase fault via the North End faults, bends to the southeast, and forms the southeast boundary fault to the Dripping Springs range. A lesser element may cross over the Dripping Springs range in the vicinity of the Ray silver mines and extend on to the southeast to the vicinity of the Christmas mine where it may become part of the Joker fault and the Christmas fault. It may further extend down to the Williamson Canyon area of Larry Barrett's mapping and become the Red Rooster fault in that vicinity. Together these faults are the expression of this west-northwest structure. Definite left-lateral offsets along the Last Turn Hill shear zone have not been documented in the Ray pit area; however, several features of the area geology are consistent with left-lateral displacement on this fault zone. Bedding attitudes in the Whitetail conglomerate on Teapot Mountain bend around in the vicinity of the shear zone and are consistent with left-lateral drag along the fault zone. Also, the Dripping Springs Mountains trend northwest, and at the projection of the Last Turn Hill shear zone east of Ray bends around to a north-south orientation. Faults within the Dripping Springs Mountains also change their strike at this location, indicating a possible warping or bending in the crust but not a throughgoing break.

The Mineral Creek Fault Zone

Another major fault zone found in the east part of the area mapped is the Mineral Creek fault zone which trends down Mineral Creek and goes into North Crossing. A relatively thin section of Whitetail conglomerate-Apache Leap tuff-Big Dome sediments is faulted down on the east against

Pinal schist on the west. This complex fault zone is composed of several fault strands. The east-dipping westernmost fault strand is named the Livingston fault, following the suggestion of Neil Gambell. The term School fault is reserved for that part of the Mineral Creek fault zone which is composed of reverse faults that dip 30°-60° west and crop out east of the presumed trace of the Livingston fault. Note that the School fault is a low-angle reverse fault near the surface and is interpreted to steepen at depth. The Pinal schist block has moved up. The geometry of this fault as shown is inferred from analogy to other basement-cored uplifts of Laramide age. In the case of the Ray area, however, much of the Laramide-style deformation is of Miocene age. It is an open question as to whether the School is younger than the Livingston or vice-versa.

The overall structural interpretation of the area north of the Ray pit essentially is that the crystalline block of Pinal schist bounded on the west by the Teapot Mountain fault and on the east by the Mineral Creek fault zone represents the remnants of a basement-cored uplift that was active several separate times furing Tertiary time. An early, possibly Laramide, compression initially elevated this block. Post-Laramide normal faulting on the Teapot fault formed a depression to the west into which Whitetail conglomerate accumulated. The Whitetail itself was faulted. Pre-Apache Leap rotation of the Whitetail is inferred to be induced by folding in the region between 24 and 20 m.y., the age of the San Manuel and Apache Leap tuff, respectively. A third event of compression, post-rhyolite tuff in age, further elevated the block. Post-14 m.y. basin and range faulting completes the story.

DISCUSSION

Normal movement probably occurred along bounding faults between the compressive episodes, but the overall effect is elevation of the central Pinal schist block relative to the adjacent blocks. The faults bounding this crystalline block are thought to be steeply dipping at depth. Near surface under low confining pressure they attain low dip angles as the material expands laterally. The most recent compression of upper Tertiary age predates the movement on the Concentrator fault and the basin and range extensional event. This upper Tertiary compression appears to fold Galiuro volcanic rocks, dated at 20 m.y., and the Big Dome formation, dated at 14-17 m.y. Formation of the Spine syncline in the Copper Butte area is post-20 or 18 m.y. True basin and range structure is dated as post-14 m.y. Thus the late compressional event appears to have been active approximately 16 to 17 m.y. ago. Thus the folding in that area appears to record affects of a regional compressional late Tertiary event older than displacement on the Concentrator fault, the Diabase fault, and Livingston fault of the Mineral Creek fault zone, and some of the movement appears to be very recent with displacements in some of the most recent Pleistocene terrace [illegible]vels north of Ray.

Megabreccias

A large block of shattered Paleozoic rocks enclosed in Whitetail conglomerate occurs in the hanging wall of the Teapot Mountain fault. Origin of this block is controversial. F. Zoerner contends that this is a fragment of basement, probably faulted into place. The block contacts do not parallel attitudes of the enclosing Whitetail sediments, and the block appears to be oblique to bedding. S. Keith contends as S. Creasey that the overall trend of the Paleozoic block is subparallel to the strike of the Whitetail sediments. Secondly, the block is internally shattered and brecciated similar to the Kearny megabreccia. Thirdly, the stratigraphic section within the shattered blocks is telescoped north, presumably by internal bedding plane faults which have faulted out less competent units and retained more resistant units. This is thought to have been the results of "landsliding" under low confining pressure. Fourthly, nearby diabase and Apache group sediments do exist as a megabreccia deposited upon Whitetail conglomerate in Devils Canyon, one-quarter mile upstream from the confluence with Mineral Creek(?). Keith interprets the Paleozoic block as a megabreccia or a slide block, the source of which is the relatively high crystalline block between the Teapot Mountain and Mineral Creek faults. Clastics and megabreccia blocks slid off into the developing Whitetail basin to the west. This event is thought to be pre-32 m.y., which is the youngest age obtained in the Whitetail conglomerate. Actual age of the deposition may extend back into Eocene time. The Whitetail formation then is thought to be deposited in a fault trough, and the argument can be developed that this fault trough formed in response to rifting or basin and range-style structure which is post-Laramide and pre- to mid-Tertiary in age. The southward extension of the Teapot Mountain fault is not well defined. It can be traced to about 1,000 feet north of the North End fault in the vicinity of Red Hills. Somehow the Whitetail basin must truncate or be truncated by the Last Turn Hill zone. In any event, the Whitetail section markedly thins to the south toward the Last Turn Hill zone and to the east of the Teapot Mountain fault.

Tertiary Stratigraphy

Stratigraphy of the upper post-Whitetail Tertiary gravels used in this study is as follows: The oldest unit is the San Manuel formation, a sequence of tilted gravels dated at 24 to 18 m.y. This is overlain unconformably by generally gently inclined or horizontal gravels of the Big Dome formation dated at 14-17 m.y. These are overlain unconformably by the Quiburis formation dated at 5 m.y., and unconformably above this are small patches of terrace gravels which appear to be about .01 to .6 m.y. in age. The Big Dome formation is largely gravels in the vicinity of Kearny. In the vicinity of Ray, significant amounts of rhyolite tuff interfinger with the gravels. In the Copper Butte area age-equivalent rhyolite tuffs and flows exceed in volume the Big Dome-equivalent gravels.

Summary

In summary, the area north of Ray is a block of ground which has alternatively been under compression in Laramide time, then a release of compression and perhaps active rifting. Further compression in mid-Tertiary time, release, and then a late Tertiary compression with final release during development of basin and range structure. It is suggested that the Dripping Springs range acted as a butress during these various compressional events, and the response of the Dripping Springs range to this deformation has been to strongly shatter and fault the rocks exposed.

Dips in the Whitetail conglomerate were established during rotational tectonism associated with a compressional event between 24 and 20 m.y. The same time that the Whitetail formation is being rotated is the same time the San Manual formation is being rotated. In the Ray area this rotation predated the 20 m.y. Apache Leap tuff. Keith believes that the field evidence supports the idea that much of this rotation was in response to compressive stresses as it is closely associated in time and space with the reverse movement of thrusting on faults. Slickenside directions indicate that the compressive tectonic transport has been in a northeast-southwest direction, and the subsequent tensional tectonic transport has been in the very same direction, only the sense of movement has been reversed. Normal faults do not seem to have produced any associated significant rotation of the blocks. Most of the steep dips in the map area have been produced by folding. This is shown to be the case in the Telegraph Canyon area.

Exploration Significance

Possible exploration significance results are as follows:

1. The Red Hills sulfide system is probably autochthonous. Evidence for a low-angle fault underlying the sulfide system is not present.

2. Possible deep mineralization may be present west of the surface trace of the Teapot Mountain fault, but this mineralization would have to be tested by very deep drill holes. Keith suggests that DDH 1007 did not intersect the Teapot Mountain fault. It is possible that after passing through a thick section of Whitetail conglomerate, this drill hole intersected Apache group megabreccia and finally Precambrian Pinal schist in the hanging wall of the Teapot Mountain fault.

3. Further mapping has established that the granodiorite or quartz diorite in the Red Hills area probably is a phase of the Madera diorite. Similar granodiorite is exposed in the Dripping Springs range overlain unconformably by Apache group sediments. The Laramide age suggestion of Keith (1976) is thus invalid.

4. The most attractive areas for exploration in the Red Hills area are the south and southeast of the present drilling between the Red Hills area and the Ray pit.

5. Neil Gambell maintains that the sulfide system at Red Hills and that of the Ray deposit are separate systems. This argument is based mainly on independent patterns of alteration and mineralization. The Red Hills system is younger than Teapot Mountain porphyry, as mineralization in the Red Hills area cuts that igneous rock type.

6. Geologic mapping by Keith has provided some evidence explaining the source of the aeromagnetic anomaly in the White Canyon area. The anomaly is centered in the area of Paleozoic rocks which have been extensively intruded by basaltic sills. Similar basaltic rocks intrude Paleozoic sediments in the Galiuro Mountains, and these sills are thought to be related to the Williamson Canyon volcanic sequence.

7. Amount of movement on the Copper Butte fault has not been established definitely. However, Keith regards displacement up to about 1 mile as possible, with the hanging wall having moved westerly. Movement of the upper plate of this fault from Ray is very unlikely.

8. The Concentrator fault is well exposed in road cuts northwest of Ray. Slickensides exposed in these cuts show that latest movement on the Concentrator fault is not entirely dip slip. The slickensides rake off to the southeast. This implies that the Magma vein, which is offset by the Concentrator fault, is not displaced purely by dip-slip movement but may have been displaced also to the south.

9. Scattered mineralization along east-west fractures cutting Paleozoic sediments in the Teapot Mountain quadrangle is regarded as possible Magma-type vein mineralization but has no economic value. The mineralization is simply too sparse to be of any interest.

In summary, the best mineralization exposed in the Ray mapping area is that in the Red Hills area. Possible deep exploration potential exists in the footwall of the Teapot Mountain fault concealed by postmineral Whitetail conglomerate in the hanging wall. The fault block of Pinal schist containing the Red Hills mineralized area is a block of very large postmineral-positive structural relief. Mineralization exposed probably represents the deep expression of a porphyry system. Pre or postmineral rotation of the mineralized block is problematic.

Keith's mapping at Ray has failed to generate any new exploration targets in the Ray area. In the Copper Butte area, the exotic mineralization at Copper Butte appears to be offset by a strand of the Concentrator fault.

Additional reserves of low-grade oxide copper mineralization may be encountered by drilling across the Concentrator fault from the Copper Butte deposit. The source of the exotic copper mineralization at Copper Butte remains a mystery, probably the copper was derived from the same source as the red schist facies of the Whitetail formation. Keith's mapping north of Copper Butte failed to disclose any outcrops of red schist in place in the Pinal schist units mapped.

APPENDICES

ADDENDUM TO STAN KEITH'S RAY REPORT

(Transcribed and edited from tape-recorded talk by Stan Keith, Sept. 1976)

Note: These notes and remarks are preliminary interpretation of work in progress.

Bowman Basin Fault System (Plates II, VIII, and IX)

Preparation of structure cross sections (Plates VIII and IX) for the Ray map area provides new information on the Bowman Basin fault system.

The Bowman Basin fault system is a series of low-angle, spoon-shaped, imbricate gravity glide faults lying north of the Battle-axe fault zone. The Bowman Basin fault itself is considered to be the low-angle fault which runs up along Highway 177 to just west of Walnut Gap, then bends and continues to the west south of the feature known as Bowman Basin (see index map which accompanies Stan Keith's report).

The west end of the Bowman Basin fault appears to be truncated against the Concentrator fault. In the $S\frac{1}{2}$ of section 36 the fault dips about 20°-30° to the west; slickensides in the fault plane trend S. 70° W. and plunge about 15°-30° indicating that low-angle normal movement was from east-northeast to west-southwest. This low-angle normal movement appears to have been cut by high-angle normal movement related to the last movement on the Concentrator fault.

Another group of low-angle faults lies north of Bowman Basin. These structures are mapped by Creasey and can be viewed from Bowman Gap looking north. Large landslide-like blocks of Paleozoic rocks apparently have shifted westward from Apache Leap in this area. The low-angle normal faults in the Bowman Basin area may be part of the same system of low-angle gravity glide features found farther north toward Superior. All of these low-angle faults may be soled or floored into one large low-angle fault which Keith terms the Bowman Basin fault.

Age relationships of these low-angle faults to the Concentrator fault suggest that the basin formed to the west in the vicinity of Florence sometime before movement on the Concentrator fault. The low-angle faults represent caving off of large blocks from the plateau-like area of Apache Leap, and, under the influence of gravity, these blocks moved westward into the basin. This structure is thought to be analogous to large similar structures along the margin of the Colorado Plateau (e.g., near the Grandwash cliffs, northwest Arizona).

Bowman Basin is a low area in which erosion has removed hanging wall rocks and exposed relatively less-deformed rocks in the footwall of the Bowman Basin fault. Rocks of the upper plate are strongly deformed, cut by normal faults, and show rotation of blocks. Slickensides are abundant on small normal faults, and they consistently trend N. 60° E. This structural pattern is consistent from Walnut Gap up to the town of Superior. This entire region seems to be characterized by low-angle gravity glide faults which have moved from the Apache Leap plateau westward toward Florence Basin.

Structural relationships between the Bowman Basin fault and the Concentrator fault as outlined above creates some geometrical problems in interpretation. The Bowman Basin fault is not found west of the trace of the Concentrator fault, yet if the normal movement on the Concentrator fault is younger than the Bowman Basin fault, the latter should lie at depth west of the Concentrator fault.

Tortilla-Northern Galiuro Mountains Cross Section C-C' (Plate XII)

The Romero Wash fault is interpreted as a folded thrust. Structure beneath the San Pedro River Valley is thought to be broad, open folds in the "foreland" of the monoclinal belt. Thicknesses of mid-Tertiary volcanic rocks and sedimentary rocks shown on the cross section should be considered to be probable minimum thicknesses. A significant feature of the mid-Tertiary geology is the requirements that the west margin of the Galiuro Mountains be bounded by a major west-dipping normal fault with displacements at least 5,000 feet. This basin-range fault is interpreted as near vertical and could flatten at depth. The west side of the San Pedro River Valley is not bounded by a comparable basin-range fault.

Crozier Peak Structure Cross Section A-A' (Plate IV)

The Smith Wash fault near Crozier Peak is interpreted as a low-angle reverse fault which steepens at depth. The cumulative reverse motion on this fault is contrary to the displacement shown on Medora Kreiger's map. A late period of normal movement has dropped the San Manuel formation back to the west, but this displacement is relatively minor compared to the earlier reverse movement. Earlier interpretations of last year of the Smith Wash fault by Keith show that the fault dip flattens with depth. The dip is now thought to steepen with depth to conform with the concept of compressive origin of the monoclinal uplift.

Tortilla-Northern Galiuro Mountains Cross Section B-B' (Plate XI)

The structural interpretation along this section is similar to that along section C-C' (Plate XII), specifically with the folded Romero Wash fault's gently warped and folded sediments beneath the San Pedro River Valley and reverse movement on the Smith Wash fault. The Camp Grant fault, a low-angle normal fault, is located at the west edge of this section. Very reliable offsets along the Camp Grant fault indicate about 1.5 miles of normal dip-slip movement.

Ray Structural Study Cross Section B-B' (Plate IX)

This section contains several dog legs in order that the section passes essentially normal to the structural grain and also so that the section can maximize use of surface information from diamond drill holes in the Ray mine area. Beneath Teapot Mountain the Whitetail formation is thought to rest unconformably but nearly parallel to underlying beds of Precambrian Pioneer formation. The Pioneer formation has moved laterally and produced a megabreccia on the east which grades into relatively undeformed Pioneer formation directly beneath Teapot Mountain. Movement of the plane of dip along the contact between these formations is from west to east.

The Ray structural cross sections (Plates VIII and IX) and structural development of the Ray area may best be described in age sequence. The structural cross sections are an attempt to present an interpretation which is consistent with field observations with paleogeographic constraints.

The oldest major flat thrust structure in the Ray area is thought to be the Walnut Canyon thrust which is shown on the west edge of the cross sections. It is thought to be caused by a compressive event, and it is associated with extreme crustal shortening. The Telegraph Canyon fold, a large recumbent fold of nappe-like dimensions, has been chopped off by the Walnut Canyon fault, and part of this recumbent fold has been thrusted eastward to the vicinity of Walnut Canyon. The overturned beds east of the highway represent the middle limb of this recumbent fold; the roots of this fold are in the Telegraph Canyon area. The crustal shortening implied by the inferred movement on the Walnut Canyon fault is about 8 or 9 miles. If the folded beds are restored to a horizontal position, then the inferred shortening is about 10 to 12 miles. This large-scale thrusting is one of the earliest events recorded in the structure of the Ray area, and pieces of the Walnut Canyon fault are preserved across the structural cross section.

Monoclinal uplifts of the type found farther to the south, if present in the Ray area, postdates the Walnut Canyon thrust. The recumbent fold and associated thrust is thought to have formed under shallow cover, probably related to an

uplift to the east. The tectonic slip line is from west to east or from southwest to northeast. The age of the Walnut Canyon fault is not well bracketed. One piece of relevant data is found in upper Arnett and upper Walnut Canyon where a mineralized fault cuts and offsets the Walnut Canyon fault. That offset can be interpreted several ways. The most simple explanation is that the high-angle fault offsets the Walnut Canyon fault and was later mineralized. This mineralization is similar to mineralization in the Superior area which is associated with the Laramide Schultze granite. This would date the fault as older than Laramide mineralization. Another interpretation is that there has been postmineral reactivation on the mineralized fault and that second period of movement offset the Walnut Canyon fault. In this case the Walnut Canyon fault could be postmineral or post-Laramide.

Correlation of Low-Angle Faults

Upon completion of the structural cross sections, it became apparent that the Walnut Canyon fault, the Copper Butte fault, and the Emperor fault may all be part of the same coherent thrust sheet. If this hypothesis is correct, then a reliable date on the thrusting may be obtained in the Ray area where the patterns of mineralization at Ray are superimposed upon the Emperor thrust fault and the mineralization at Ray is thought to have been emplaced into a thrust faulted terrane. This means that the Granite Mountain porphyry, the porphyries at Ray, and mineralization has intruded the Emperor fault, and by implication the Copper Butte fault. Thus the major low-angle displacement would be pre-62 m.y. Warping and folding of Laramide to mid-Tertiary age has deformed the Emperor and Copper Butte faults. In addition, low-angle normal movement along the Copper Butte fault has occurred and is probably middle to late Tertiary in age. This late normal movement on the Copper Butte fault may be about 1 mile.

The low-angle thrust fault system of which the Walnut Canyon, Copper Butte, and Emperor faults are related cannot be traced much farther north than the Ray map area. There is no evidence, for example, that low-angle thrusting is present in the area of Superior. To the south of Ray, however, one may correlate the flat faults at Ray with the Romero Wash fault in the vicinity of Crozier Peak. Here the Romero Wash fault has been emplaced and then later folded by the monoclinal event and intruded by an 80.6 m.y. sill. If this correlation is correct, then the low-angle thrusting could be regional extent, extending at least from the Ray vicinity down into Crozier Peak, Winkleman, Saddle Mountain and probably farther south where the Romero Wash fault is concealed by alluvium, and could be early Laramide (i.e., late Cretaceous) in age. Thus a large area could be involved in this premineral thrusting event.

The second major tectonic event in the Ray area is Laramide monoclinal tectonics. This event is represented by deformation associated with the School fault zone which has been described in the main part of this text on the Ray mapping project. It is also represented by movement on the Sleeping Beauty fault, namely high-angle reverse faulting. In other words, in the Ray area there is an uplifted monoclinal block centered just west of Mineral Creek bounded on the west by the Sleeping Beauty fault and on the east by the School fault. This block has been caught up in a compression and has been elevated vertically, and shortening is accommodated by reverse movement on the Sleeping Beauty fault and on the Mineral Creek fault zone. The block became a high in Laramide time. The Teapot Mountain area contains the only evidence in the Ray vicinity of this monoclinal uplift event. Most of the Laramide intrusions appear to postdate or be about the same age as this monoclinal tectonic event.

The next tectonic development, and this is thought to be early Tertiary in age, is the development of a graben basin into which sediments of the Whitetail formation accumulated. The Teapot fault was the principal active fault during this time of basin development. Keith's interpretation of a steep angle on the Teapot fault is contrary to the interpretation of Zoerner who believes the Teapot fault has a very gentle dip west. Faulting apparently was active during the deposition of the Whitetail formation and continued after Whitetail time and dropped the Whitetail sediments down against the Red Hills block. The Red Hills block represents a slice of the Laramide basement-cored uplift; a stable slice which remains a positive area; the other part of the slice has been faulted down to the west by the Teapot fault. Principal movement on the Sleeping Beauty fault and the Teapot fault is normal and older than deposition of the Apache Leap tuff, thus confining the graben-forming event largely to Whitetail and pre-Miocene time, approximately during the interval of 40 to 32 m.y. This inferred tectonic history implies two periods of movement on the Sleeping Beauty fault: early reverse movement of probable Laramide age and a later normal displacement of mid-Tertiary age.

Relationships depicted in the cross sections concerning relative ages of the Concentrator and Bowman Basin faults are highly interpretational; specifically the Concentrator fault is thought to have been active before and after emplacement of the Bowman Basin glide fault. Thus the Concentrator fault had early movement which was overridden by the Bowman Basin fault, offsetting part of the Concentrator fault to the west. Subsequent to this, the Concentrator fault was reactivated and cut the Bowman Basin fault, offsetting that fault plane. This interpretation is shown on section A-A'.

The Concentrator fault is a complex fault zone with many fault slices. Last movement along the Concentrator fault definitely postdates the Bowman Basin fault. The argument for multiple movement on the Concentrator fault really is based upon different amounts of offset for the Walnut Canyon fault and for the sediments which overlie it compared to offsets in the Dripping Spring quartzite in the footwall of the Walnut Canyon fault. Both of these units show different amounts of offset along the Concentrator fault.

EXPLANATION TO MAPS AND STRUCTURE SECTION

This explanation covers all letter symbols used on SBK maps, cross sections, correlation charts, and diagrams

ROCKS

Map Symbol	Description of Map Unit
	QUATERNARY GEOMORPHIC UNITS*
Qs	Geomorphic surface, low relief, low gradient surfaces which may be erosionally beveled cut on pedimented bedrock (pediment and beveled water fill & non indicated alluviums) or alluvial valley fills, reflecting different heights of. Age determined by height (oldest = highest) above adjacent present-day stream channels. Surfaces of slope <5° were mapped as Qs.
Qc	Colluvium or hillwash overlying bedrock in hillslopes. Locally continuous with Qs. Surfaces of slope >5° but <12° were mapped as Qc.
Qtl	Talus or debris material resting on steeper slopes >12°. Locally continuous with Qc.
Qld	Landslide deposits containing boulders consistently larger than 5 x 5 x5' were mapped as Qld regardless of slope angle.
Qm	Landslide deposits which contain structurally coherent blocks of bedrock. That is, the blocks within the slide have not been internally rotated with respect to each other, and the original preslide lithology can be mapped within the slide at the map scale. The preslide lithologies are designated by the appropriate letter symbols enclosed by parentheses, e.g., (Me).
	QUATERNARY ROCK UNITS
Qd	Mine dumps and tailings; road fill.
Qs_5	Modern alluviums (Holocene) within present-day stream channels; younger than 10,000 years.
Qs_4	Floodplain surface ~~cut~~ on alluviums adjacent to modern stream channels 2 to 10 feet above present-day stream base levels. Does not contain red soils.

*All Quaternary geomorphic units are tentatively considered younger than the upper Saint Davids formation in the upper San Pedro Valley. The upper Saint David formation at Curtis Range has a magnetostratigraphy which probably contains Brunhes-Matuyama boundary dated at 0.69 m.y. (Johnson, et al., 1975). If so, alluviums deposited during and after Qs_1 time are younger than about 600,000 years.

Qs_3	Surface 15 to 18 feet above present-day stream base levels. Present along or at confluences of major streams. Red soils, if present, are poorly developed compared to those on Qs_1 and Qs_2 surfaces. On streams with greater than ~2° gradients, "boulder terraces and levys" were mapped as Qs_3.
Qw	Winkleman formation (10 to 100 feet). Gravels which underlie Qs_3 surface but are younger than gravels related to Qs_2. ~~Surface~~ Formation named for exposures in Highway 77 roadcuts along north side of Gila River at Winkleman, Arizona. Generally an unconsolidated coarse gravel containing well-rounded pebbles, cobbles, and boulders of older rocks; contains fine-grained light yellow lenses of silty material locally.
Qc_3	Colluvium graded to Qs_3 surface. Mapped in the Saddle Mountain area of Winkleman $7\frac{1}{2}$ minute quadrangle and Teapot Mountain area of Teapot $7\frac{1}{2}$ minute quadrangle.
Qtl_3	Talus graded to Qc_3 and Qs_3 surface. Deposits overlie Qtl_2 and are distinguished by lack of soil development. Fine-grained material between rock fragments has been washed away. May represent debris flows.
Qs_2	Widespread surface 15 to 80 feet above present-day stream base levels. Contains well-developed red soils. A mature soil exposure in a haulage roadcut 1 mile north of the Ray mine has 2 feet of dense red clay at the B2T horizon and 2 to 3 feet of calcareous C horizon.
Qsc	Sacaton formation (10-200 feet). Alluviums which underlie the Qs_2 surface and with less certainty ~~the~~ on Qs_1 surfaces along lower reaches of San Pedro River, which rests in erosional unconformity on lacustrine facies of Quiburis formation (Tql). Tentatively correlated with the Sacaton formation at Mammoth, Arizona (Heindl, 1963) on the basis of similar lithology and stratigraphic position.
Qc_2	Colluvium graded to Qs_2 surface.
Qlt_2	Talus graded to Qc_2 and Qs_2.
Qm_2	Megabreccia masses stratigraphically related to Qs_2 surfaces.
Qld_2	Landslides graded to Qs_2 surface.

Qtr — Travertine. Especially well developed along Highway 177 near Walnut Spring in the Teapot Mountain quadrangle.

Qs_1 — Surface 100 to 250 feet above present-day stream base levels; contains well-developed red soils. Generally ~~cut~~ on alluvial facite ~~os~~ facies of the Quiburis formation; questionably cut on alluviums of Sacaton age. In the Tortilla Mountains veneer, gravels of possible Sacaton age rest on an extensive pediment surface cut on Oracle quartz monzonite. This pediment surface is believed equivalent to the Rillito pediment surface in the Tucson area defined by Pashley (1966). Qs_1 and Qs_2 surfaces merge downward with the pediment surfaces in the upper reaches of streams in the Tortilla Mountains. The pediment surface is therefore inferred to be older than Qs_1 and Qs_2. Qs_1 is poorly preserved in the valley fill areas and more common in pedimented bedrock areas.

Pediment in Saddle Mt. area

Qm_1 — Megabreccia graded to Qs_1 surface. The megabreccias north of Ray in White Canyon north of Hells Peak and south of Walnut Gap are inferred to be related to Qs_1 base levels.

TERTIARY ROCKS*

Tqa — Alluvial facies of Quiburis formation (600 feet ±); composition and degree of induration variable.

Tql — Fine-grained lacustrinal or lake facies of Quiburis formation (600 feet ±). Ash fall tuffs within the lake facies have been dated by the K-Ar method on glass at 4.5 to 5.5 m.y. (Scarborough, 1975).

Tb — Basalt (40 feet ±). Dense, black, aphanitic olivine basalt which caps Apsey conglomerate in the Tablelands section of the northern Galiuro Mountains. Dated by the K-Ar method on whole rock at 8.4 m.y. (Keith and Scarborough, unpub. data).

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*See Figure 1 for northwest-southeast distribution and correlation of Tertiary rocks.

Tentative Correlation of Tertiary Rocks,
Superior to Aravaipa Canyon, Arizona

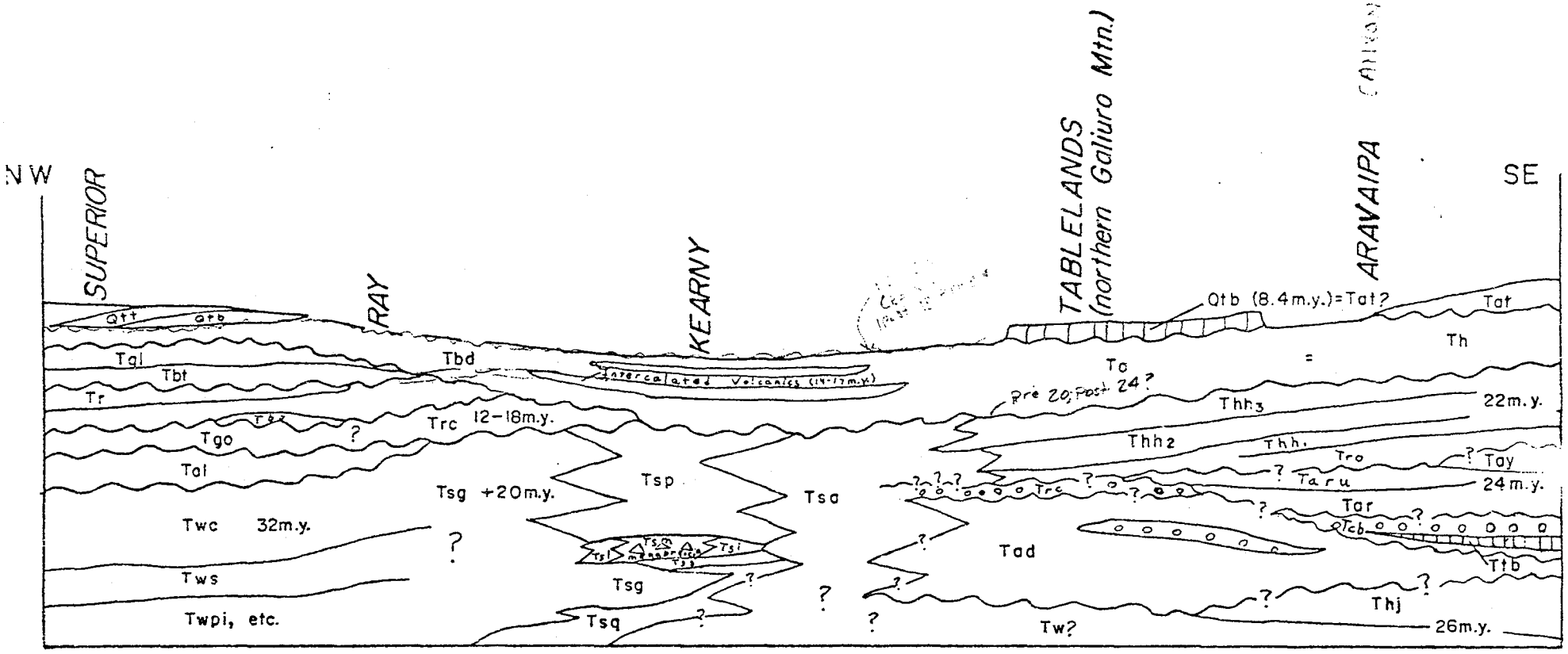

Fig. 1

Tat	Andesite of Table Mountain (400 feet ±) named by Krieger (1968a) for exposures which overlie Apsey conglomerate in Holy Joe Peak quadrangle. Krieger correlated these rocks with Tb and considered Tb and Tat to be within the Galiuro volcanics. Based on the 8.4 m.y. age date, basaltic composition of the Tb and unconformable relations of Apsey and Hellhole conglomerate on the 22.4 m.y. Hells Half Acre tuff, the Galiuro volcanics are considered to underlie the Apsey conglomerate. Tat and Tb are therefore part of an independent younger magmatic event.
Trt	Bedded rhyolitic tuff (50-100 feet) which overlies Qtb and contains fragments of Qtb in the northcentral Teapot Mountain quadrangle.
Tby	Aphanitic dense basalt (300 feet ±) possibly basaltic andesite which overlies Big Dome-equivalent gravels in the northcentral Teapot Mountain quadrangle.
Tbyi	Aphanitic dense basalt which intrudes a normal fault in the Wood Canyon area of Teapot Mountain quadrangle.
	Miocene Conglomerates
Tbd	Big Dome formation (2,000 feet ±). Alluvial deposits named by Krieger, et al. (1973) for exposures at Big Dome, Sonora quadrangle. Biotite and hornblende from a quartz latite ash flow tuff below the middle of the formation gave ages of 14 and 17 m.y., respectively (Banks, et al. 1972). Big Dome equivalents are considered to be conglomerate in the Superior area, Apsey conglomerate (Krieger, 1968a, 1968b) in the Galiuro Mountains, and Hellhole conglomerate in the Klondyke quadrangle (Simmons, 1964).
Tbdc	Big Dome formation; mixed conglomerate facies (500-1,000 feet).
Tbdql	Quartz latite ash flow tuff (0-40 feet) embedded in Big Dome formation near Kearny, Arizona. The 14 and 17 m.y. ages are from this flow (see Cornwall and Krieger, 1975a).
Tbdlt	Thinly laminated to massive rhyolite lapilli tuff (0-40 feet) contains abundant pumice shards (see Cornwall and Krieger, 1975a).

Tbdl	Big Dome formation; limestone conglomerate (1,000 feet ±); see Cornwall and Krieger (1975a).
Tbds	Big Dome formation; sandstone and conglomerate (1,000 feet ±); see Cornwall and Krieger (1975a).
Tbdwc	Big Dome formation. Conglomerate containing clasts of Williamson Canyon volcanics (1,000 feet ±) present along southwest margin of Dripping Spring Mountains in Hayden quadrangle.
Tbdpi	Big Dome formation; Pinal schist bearing conglomerate (400 feet ±).
Ta	Apsey conglomerate (0-700 feet); equivalent of Big Dome formation in northern Galiuro Mountains (see Krieger, 1968a, 1968b).
Th	Hellhole conglomerate (600-2,000 feet); equivalent of Big Dome formation in Klondyke quadrangle (see Simmons, 1964).

Picketpost Mountain Volcanics

An extensive sequence of dominantly rhyolitic volcanic rocks unconformably underlie the Miocene conglomerates and overlie older conglomerates and Apache Leap tuff northwest of Ray and southwest of Superior. These rocks are named the Picketpost Mountain volcanics for a thick section exposed at Picketpost Mountain 4 miles west-southwest of Superior, Arizona. Creasey (1975) has mapped many of these units in the Teapot Mountain $7\frac{1}{2}$ minute quadrangle.

Tql	Quartz latite flows showing basal vitrophyre as a cross-hatched band (250 feet ±).
Tqli	Intrusive quartz latite (intrusive equivalent of quartz latite flows).
Trd	Rhyodacite porphyry. Medium to medium coarse-grained biotite rhyodacite porphyry contains biotite, resorbed quartz, and plagioclase within a light pink groundmass. Forms a prominent north- to northwest-trending dike south of Telegraph Canyon in the Mineral Mountain

quadrangle. Intrudes Tri. Phenocrysts are 40% of rock. Equals coarse-grained rhyolite porphyry in reports of Lyon and Clayton.

Trp — Rhyolite porphyry. Rhyolite porphyry with biotite and quartz "eye" phenocrysts set in a white groundmass. Phenocrysts are approximately 20% of rock. Forms numerous pluglike masses south and west of Telegraph Canyon in the Mineral Mountain quadrangle.

Tbt_{1-4} — Bedded cream-colored rhyolite tuffs, probably in part waterlain. A sequence of four units intercalated with Tp and Tr. Contact between Ttb_1 and Ttb_3 in the White Canyon area is very approximately located on topographic criteria. Approximate thicknesses as follows: Tbt_1, 100-250 feet; Tbt_2, 100 feet ±; Tbt_3, 100-250 feet; Tbt_4, 100-200 feet. Tbt north of Ray mine is tentatively correlated with more extensive Tbt in Teapot Mountain quadrangle. Creasey (oral communication) has dated Tbt_1(?) at 17 m.y.

Tmt — Massive rhyolitic lithic tuff (100-250 feet) thick, well exposed in Wood Canyon area of Teapot Mountain quadrangle. Lithic fragments are of Tr + Tp 70% ± and pi 30% ±.

Tr_{1-4} — Massive fine-grained rhyolite flow breccia, a sequence of four yellowish-white flow units intercalated with Tp and Tbt. Brecciation is probably due to autobrecciation during extrusion of flow. Approximate thicknesses as follows: Tr, 50-75 feet; Tr_2, 50-100 feet; Tr_3, 50 feet ±, Tr_4, 50-100 feet. Creasey (oral communication) has dated one of these flows at 16 m.y.

Tri — Massive fine-grained flow-banded rhyolite (intrusive equivalent of Tr). Cross-hatched band is vitrophyre which commonly occurs at the contacts of Tr and its host rock.

Tp — Perlite flows: A sequence of two flows intercalated in Tbt and Tr; ptygmatic flow banding and associated b lineation are common. Rock has a glassy, ropey outcrop texture and is light gray in color. Flows are 100 to 200 feet thick.

Tpt	Bedded to massive pink lithic tuff (15-30 feet). Lithic fragments in tuff are mostly Pinal schist. Generally present below Tbt and above Tgo. However, in the Telegraph Canyon a pink lithic tuff occurs at the base of Tgo.
Tbo	Dark purplish aphanitic vesicular basalt flows (0-75 feet), may be basaltic andesite.

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Tgo	Older gravel (50 to +300 feet). Alluvium above Apache Leap tuff and below Tpt. Consists of coarse gravel alluviums dominated by rounded clasts of Oracle quartz monzonite. In the vicinity of Hells Peak, Tgo consists of finer grained sediments. As unit is traced northwest, clast's proportion becomes progressively more Pinal schist-rich. Unit may be an equivalent of the Ripsey Wash sequence (Schmidt, 1971) in the Kearny and Grayback quadrangles farther south. Gravel unit which rests between rhyolite tuff and Apache Leap tuff north of Ray mine is tentatively correlated with Tgo. Age is between 20 and 18 m.y. based on radiometric dates in the underlying Apache Leap tuff and overlying bedded rhyolite tuffs.
Txg	Sedimentary breccia (0-250 feet ±). Unbedded aggregate of silt, sand, pebbles, cobbles, and boulder-sized clasts. Clast composition is predominantly Oracle quartz monzonite with some Grayback granodiorite. Unit is a mud flow or megabreccia derived from a source area to the south in the Grayback quadrangle(?).
Tr	Ripsey Wash sequence (Schmidt, 1971), 0 to 1,500 feet ±; tentatively correlated with Tgo on the basis of a 17.1 m.y. age date (Cornwall and Krieger, 1975a) and angular discordance of Truc on Tsp (Schmidt, 1971).
Truc	Ripsey Wash sequence, upper boulder conglomerate member (500 feet ±); massive, poorly sorted boulder conglomerate. Boulders are mostly Oracle quartz monzonite. Limestone megabreccia boulders are abundant locally.
Trt	Ripsey Wash sequence. Tuffaceous sandstone and conglomerate (500 feet ±). Well stratified tuffaceous sandstones which contain zeolitic tuff interbeds. Biotite from one of these tuffs gave a K-Ar age of 17.1 m.y. (Cornwall and Krieger, 1975a).

Trlc	Ripsey Wash sequence. Lower conglomerate member (500 feet ±), poorly sorted and poorly stratified, moderately indurate cobble and boulder conglomerate. Clast composition is predominantly Oracle quartz monzonite with subordinate diabase. Apache group, Paleozoic, and Laramide intrusive rocks.
Tal	Apache Leap tuff (averages 200-500 feet in mapped area, 2,000 feet at type section in Superior quadrangle (Peterson, 1968, 1969)). A nonwelded white tuff 0 to 5 feet thick at base is commonly overlain by a 10- to 30-foot densely welded black vitrophyre (cross-hatched band). Black vitrophyre grades upward into a less densely welded brownish weathering tuff commonly with flattened pumice shards. Vapor phase crystallization increases near top. K-Ar ages are 20 m.y. (Creasey and Kistler, 1962) and 19.8 m.y. (Damon and Bikerman, 1964). Outcrops extensively in northwest Sonora quadrangle and entire Teapot Mountain quadrangle.
Ts	San Manuel formation (10,000 feet +). Alluvial deposits with interbedded megabreccias. Formation in mapped area was first mapped and named Hackberry formation by Schmidt (1971). Correlated with and renamed the San Manuel formation for the type locality at San Manuel, Arizona (Heindl, 1963), by Krieger, et al. (1973), by Krieger (1974b, 1974c, 1974d), and Cornwall and Krieger (1975a, 1975b). Biotite and sanidine from a rock considere by Krieger to be San Manuel but which may be equivalent to Truc or Trlc (Schmidt, 1971) gave K-Ar ages of 18 and 24 m.y., respectively. Outcrops extensively in Kearny and Crozier Peak quadrangles. Lower parts of San Manuel may be Whitetail in age(?).
Tsg	San Manuel formation; granitic conglomerate (0 to 4,500 feet +), see Cornwall and Krieger (1975a, 1975b).
Tsp	San Manuel formation; playa deposits (0-4,000 feet), see Cornwall and Krieger (1975a). Not on S. Keith maps.
Tsl	San Manuel formation; limestone conglomerate (0-100 feet), see Cornwall and Krieger (1975a). Not on S. Keith maps.

Tsm — San Manuel formation; megabreccia (0-750 feet). Large landslide blocks embedded in the San Manuel formation west of Kearny, Arizona (see Schmidt, 1971; Cornwall and Krieger, 1975). Not on S. Keith maps.

Tss — San Manuel formation; playa sandstone (0-500 feet), see Cornwall and Krieger (1975a). Not on S. Keith maps.

Tsq — San Manuel formation; quartzite conglomerate (0-1,300 feet), see Cornwall and Krieger (1975a). Not on S. Keith maps.

Tsa — San Manuel formation. Alluvium (0-4,000 feet) interbedded siltstone, sandstone, and conglomerate containing Williamson Canyon volcanics, Tortilla quartz diorite, andesite, rhyodacite, diabase, Apache group, and andesite of Depression Canyon. Outcrops in southern Kearny, Hayden, and Winkelman quadrangles (see Cornwall and Krieger, 1975; Krieger, 1974b).

Galiuro Volcanics (0 to 2,000 feet +)

Named by Cooper and Silver (1964) for an extensive outcropping of Tertiary volcanic and interbedded clastic sediments in the Galiuro Mountains. Age dates reported on the volcanics by Krieger (1968a, 1968b) and Johnson and Todd (1975) in the Holy Joe and Brandenburg Mountain quadrangles range from 26-22 m.y. Galiuro volcanics contain much more andesitic material and less ash flow tuffs than the volcanics in the Ray and Superior area. From this work, the Galiuro volcanics are considered to be those volcanics which underlie the Apsey and Hell-hole conglomerates of Krieger (1968a, 1968b) and Simmons (1964), respectively, and overlie a nonvolcanic clast-bearing conglomerate correlated with Whitetail conglomerate.

Thh — Hells Half Acre tuff member named by Krieger (1968b) for exposures at Hells Half Acre south of Aravaipa Canyon. K-Ar ages are 24.56 ± 1 and 22.4 ± 1 on biotite and sanidine, respectively. Divisible into three members; equals upper tuff unit of Simmons (1964); upper tuff member of Simmons does not include Apsey conglomerate as indicated by Krieger (1968b).

Thh_3	Upper bedded tuff (0-100 feet); well-bedded rhyolite tuff. North of Ash Creek. Contains a cliff-forming fragmental "mud flow" about one-half way up in unit which contains cobbles and boulders of Tro and Troy quartzite. Also contains a few lithic air fall tuffs.
Thh_2	Massive lithic rhyolite air fall tuff (0-100 feet).
Thh_1	Lower bedded lithic rhyolite tuff (0-40 feet); contains pumice shards locally.
Tro	Rhyolite obsidian member. Outcrops extensively in eastern Brandenburg $7\frac{1}{2}$ minute and northwest Klondyke 15 minute quadrangles (see Krieger, 1968b; Simmons 1964). Includes numerous flows, cinder cones, etc. which will be subdivided in future mapping. Ptygmatic flow folding is common. Lithophysa in some flows contain quartz bixbyite and topaz.
Tuav Tcv Tlav	Andesite (Tuav and Tlav) and conglomerate (Tcv) of Virgus Canyon (0-200 feet), see Krieger (1968a, 1968b). Tuav = Tgua of Simmons (1964) in Aravaipa Canyon. Tlav = intermediate andesite of Simmons (1964) in Aravaipa Canyon.
Tar	Aravaipa member of Galiuro volcanics. Rhyolitic ash flow tuff (see Krieger, 1968b). K-Ar ages are 25.9 ± 1 and 23.4 ± 1 on biotite and sanidine, respectively.
Taru	Upper nonwelded zone (0-100 feet), see Krieger (1968a, 1968b); equals white tuff of Simmons (1964).
Tar	Partly welded, welded, and lower nonwelded zones (see Krieger, 1968a, 1968b); equals upper welded tuff of Simmons (1964).
Tcb	Tuff of Bear Springs Canyon. Conglomerate (0-50 feet) above and below tuff unit (see Krieger, 1968a, 1968b). May be equivalent to upper Tcd of Krieger (1968d, 1968c) in northwest part of Brandenburg and northeast part of Saddle Mountain quadrangles or Trc of this mapping.
Ttb	Tuff of Bear Springs Canyon. Rhyolitic ash flow tuff (0-120 feet), see Krieger (1968b). A K-Ar date on biotite from the tuff is 24.4 ± 1 m.y.

Trc — Rattlesnake Canyon conglomerate (0-250 feet). Named for exposures of a conglomerate in Rattlesnake Canyon, northern Brandenburg Mountain $7\frac{1}{2}$ minute quadrangle and southern Jerusalem Mountain $7\frac{1}{2}$ minute quadrangle. Contains a 2- to 8-foot-thick tuff about 30 feet below top of unit. In Rattlesnake Canyon the conglomerate rests between Thh and Tad. Equals upper Tcd of Krieger (1968a, 1968c). Could be equivalent to conglomerate unit in Bear Springs Canyon (Krieger, 1968a, 1968b). Composed of clasts from Paleozoic, younger Precambrian rocks, and Tad.

Tad — Andesite of Depression Canyon (see Krieger, 1968a, 1968c). Outcrops extensively in eastern Saddle Mountain quadrangle and western Brandenburg Mountain quadrangle (0 to 700 + feet thick). Petrographically identical to volcanics in San Pedro Valley at and near Malpais Hill 5 miles south of Winkleman, Arizona. Questionably equals Tgia of Simmons (1964) at north edge of Klondyke quadrangle. Mostly flows of massive fine-grained andesite containing phenocrysts of plagioclase and olivine (mostly altered to iddingsite). Tops of many flows are brecciated with rocks becoming very vesicular. Cracks and vesicules are often filled with zeolites (stillbite and mesolite(?) are most common). At Malpais Hill lithophysae in the andesite are filled by heulandite and erionite.

Thj — Holy Joe member. Quartz latite ash flow tuff (0-100 feet thickening to 300 feet south of Aravaipa Canyon), see Krieger, 1968a). K-Ar age dates are 25.6 and 25.4 m.y. for biotite and sanidine, respectively.

Tw — Whitetail conglomerate (0-6,000 feet thick). Named by Ransome (1903) for exposures in the Globe quadrangle Conglomerate units which rest beneath mid-Tertiary volcanics above pre-Tertiary rocks and contain no mid-Tertiary volcanic clasts are generally assigned to the Whitetail conglomerate. One exception is in the Telegraph Canyon area where the basal conglomerate can be traced southeast where it is found to rest on Tal.

The Whitetail is divisible into three members which are lithologically and stratigraphically distinct. The lowest member consists of conglomerates with multiple mono-lithologic lithologies which grade and interfinger laterally

and appear to have local sources (for example, see Phillips, 1976). The middle member is comprised of sandstone and siltstone, some of which is of lacustrine origin. In Walnut Canyon 0.5 mile upstream from its confluence with White Canyon gypsum is interlayered with siltstones of the middle member. The upper member consists of coarse conglomerate with clasts of variable lithology. North of Ray this unit contains sizeable masses of megabreccia. A tuff from the upper Whitetail at Ray is dated at 32.4 ± 0.6 m.y. (Banks, et al., 1972).

Whitetail Conglomerate, Upper Member

Twc — Conglomerate (50 to 4,500+ feet thick). Coarse conglomerate with subrounded to angular clasts of variable composition. North of Ray this unit contains several large megabreccia masses.

Twm — Megabreccia (0-300 feet thick). Found in Twc north of Ray. Lithologies mapped within the megabreccia are designated by the appropriate symbol enclosed in parentheses.

Whitetail Conglomerate, Middle Member

Tws — Sandstone and siltstone (50-400 feet thick). Thin- to medium-bedded sands and silts, some conglomerate interbeds. Unit in Walnut Canyon contains intercalated gypsum beds; very soft; equals Twss of Phillips (1976).

Whitetail Conglomerate, Lower Member

Twpi — Conglomerate containing gray to grayish-brown angular clasts of unmineralized schist (0-300 feet thick) found west of Teapot Mountain and in Walnut Canyon area; equals Tws of Phillips (1976).

Twpim — Conglomerate containing angular clasts of metamorphosed Pinal schist. Clasts are gray to silverish and commonly contain numerous folds (0-300 feet thick) mapped northwest of Teapot Mountain.

Twq — Conglomerate containing angular clasts of quartzite derived from Dripping Spring and Troy quartzite. Diabase, Mescal limestone, and basalt clasts are less common (0-300 feet thick); mapped northwest of Teapot Mountain.

LATE CRETACEOUS-EARLY TERTIARY IGNEOUS ROCKS*

Numerous late Cretaceous-early Tertiary igneous rocks have been mapped (dikes, stocks, and sills). Based on relative ages established by crosscutting relationships, five principal stages of intrusions are defined on a regional basis (Table 1). Fifty-four age determinations are summarized in Table 1. In general, rocks of intrusive period I are more mafic than those of intrusive period II which in turn is more mafic than those in intrusive periods III and IV. Age data are commonly erratic with single rock bodies and numerous inconsistencies with respect to relative ages occur. Nevertheless rocks of intrusive period I are generally older (average of 75.9 for 18 dates) than periods II (average 68.6 for 11 dates), III (average of 61.9 for 5 dates), IV (62.8 for 8 dates), and V (61.3 for 3 dates). Using the current radiometric definition of Laramide magmatism (Damon and Mauger, 1966; Damon, 1968, 1970) in Arizona and New Mexico (75-50 m.y.), rocks of intrusive period I in general are pre-Laramide. Tectonic considerations too lengthy to develop here are also consistent with this definition.

The microdiorite (Km in Saddle Mountain area), diorite (Kdi in Crozier Peak area), and Tortilla quartz diorite (Kt in northern Tortilla and central Dripping Springs Mountains) are similar petrographically, chemically, and geochronologically and have the same relative ages. It is possible that these bodies are comagmatic and should be included under the same name (not done in this mapping). Relationships in the Saddle Mountain area suggest that the microdiorite and Williamson Canyon volcanics may be related. The volcanic pile is intruded by microdiorite, but within the pile lithic fragments of a rock petrographically identical to the microdiorite are found within lithic lapilli tuff flows.

Dike rock types which have regional extent are those of intrusive period III. In order of decreasing abundance the rocks are Tr_1-Tr_2, Kmr, Tkha, and Tql. Figure 2 is a correlation diagram for early T-late K intrusions based on crosscutting relationships observed in the field.

*See Figure 2 and Table 1.

Schematic Correlation of Late Cretaceous, Early Tertiary Intrusives
Ash Creek to Superior, Arizona

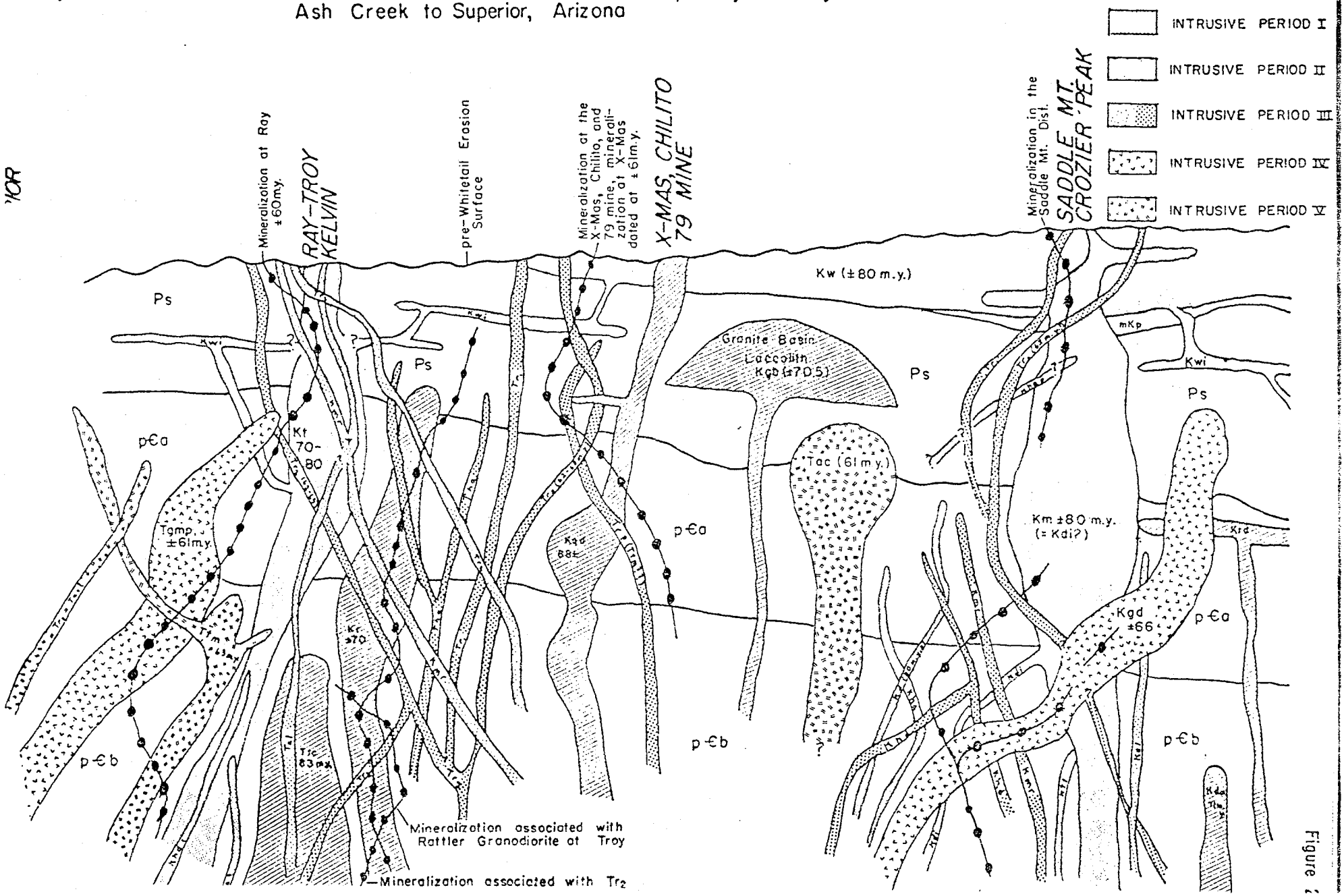


Figure 2

TABLE I

CHRONOLOGY OF LATE CRETACEOUS-EARLY TERTIARY IGNEOUS ROCKS
FROM SADDLE MOUNTAIN TO RAY, ARIZONA

		K-Ar				Fission Track	
Rock	W.R.	Biotite	Hornblende	K-Spar	Sphene	Zircon	Apatite
			Intrusive Period I 22 dates, average age 75.9 m.y.				
Kw		75.6 ± 1.4[1]					
			74.3 ± 2.6[2]				
Kwi							
Km			79.7 ± 1.8[2]				
			81.7 ± 1.9[1]				
Kdi			65.6 ± 2.0[4]				
Kt		71.5 ± 1.4[5]	83.1 ± 1.7[5]			69.8 ± 2.5[3]	69.5 ± 6.1[3]
		70.6 ± 1.4[5]				69.8 ± 4.0[3]	72.4 ± 8.4[3]
		71.3 ± 2.1[5]					
		68.7 ± 1.7[6]					
		80.0 ± 1.4[5]					
			285 ± 10[5]				
			110 ± 2[5]				
			93.7 ± 1.9[5]				
Kha$_1$			128 ± 3(?)[5]				
			74.3 ± 1.3[2]				
			79.3 ± 1.4[1]				
Kha$_2$							
d	80.6 ± 1.8[1]						
hd							
Ktt							
			Intrusive Period II 11 dates, average age 68.6 m.y.				
Kda Kda			71.3 ± 2.1[7]				
d			68.0 ± 0.9[2]				
Kgb Kgb			70.5 ± 1.6[2]				
Kr		68.5 ± 1.4[5]					
		71.1 ± 3.2[8]					
		69.7 ± 1.4[5]	74.4 ± 1.5[5]		68.3 ± 2.3[3]		68.5 ± 4.2[3]
neralization associated with Kr							
		62.9 ± 1.3[6]			61.4 ± 3.4	(garnet)[3]	

TABLE 1 (Continued)

Rock	W.R.	Biotite	Hornblende	K-Spar	Sphene	Zircon	Apatite
			Intrusive Period III 5 dates, average age 61.9 m.y.				
Kr							
Tkha							
Tr_1-Tr_2		63.1 ± 1.3[6]					
		62.1 ± 1.2[5]					
		62 ± 2[9]					
mineralization associated with Tr_2 at Christmas							
		61.0 ± 1.0	(sericite)[2]				
		61.4 ± 1.1	(hydrothermal biotite)[2]				
Kmr							
Tql							
			Intrusive Period IV 8 dates, average age 62.8 m.y.				
Kgd		68.0[12]					
		66.0 ± 2.0[4]					
		65.7 ± 2.0[4]					
Tgm		59.5 ± 1.2[5]				61.0 ± 2.1[3]	
		63.0 ± 2[9]					
		60[10]					
		59.5 ± 1.8[11]					
			Intrusive Period V 3 dates, average age 61.3 m.y.				
Ttm Teapot Mtn por.				63.0 ± 0.7[5]			
mineralization at Ray and Crozier Peak							
		65.6 ± 1.1 hydrothermal		biotite 63.[illegible] 6.0		61.4 ± 3.2 (garnet)	
		65.1 ± 1.1 at Ray					
							60.0 ± 6[*]
Tr_3 rhyodac. dikes		69.7 ± 1.4					
Tac		61.0 ± 2					

(1) Keith and Damon (unpub.)
(2) Koski (written communication, 1976)
(3) Banks and Stuckless (1973)
(4) Krieger (1974a)
(5) Banks, et al. (1972)
(6) Damon, et al. (1970)
(7) Krieger (1974b)
(8) Damon and Mauger (1966)
(9) Creasey and Kistler (1962)
(10) Rose and Cook (1966)
(11) McDowell (1971)
(12) Damon, et al. (1964)

Intrusive Period V

Tr_3 Rhyodacite dikes, fine-grained, orangish, weathering, east- to west-trending dikes that cut Teapot Mountain porphyry northeast of Ray, Rattler granodiorite at Troy, central Dripping Springs Mountains, and Williamson Canyon volcanics west of Saddle Mountain. Equals Tr3 (Cornwall, et al., 1972) and Tr3 (Cornwall and Krieger, 1975b). Banks, et al. (1972) reports a 69.7 ± 1.4 m.y. date on chloritized biotite from the dikes which cut the Troy intrusion. The date is anomalously old and was interpreted by Banks, Cornwall, Siberman, and Marvin (1972) to represent extraneous radiogenic argon introduced by late-stage magmatic or hydrothermal fluids.

Tac Ash Creek rhyolite. A 1-square-mile stock intruding Pinal schist and Paleozoic rocks and overlain by Whitetail conglomerate 1.5 miles east of Saddle Mountain. Yellowish-white, very fine-grained rhyolite with flow foliation. Contains sparse phenocrysts of euhedral thin biotite books to 3 mm and K-spar(?). The biotite has yielded a K-Ar age of 61 ± 2 m.y. (Krieger, 1968c). This rock may be related to Tr3 on the basis of its texture and proximity to Tr3 dikes 1 mile to the west.

Ttm Teapot Mountain porphyry. White to light yellow porphyry containing large euhedral phenocrysts of K-spar and euhedral to slightly resorbed quartz eyes 3 to 12 mm in diameter. Banks, et al. (1972) reports a 63.0 ± 0.7 m.y. date on orthoclase. The date is older than the granite porphyry which it intrudes on Granite Mountain. The porphyry crops out in the Ray area (see also Cornwall, et al., 1971).

Intrusive Period IV

Tgm Granite Mountain porphyry. Medium-grained biotite granodiorite. Comprises large stock west of Ray and small stocks at Ray mine. Average of five dates from four sources (Table 1) is 60.6 m.y. (see also Cornwall, et al., 1971). Truncates Tr2 dikes.

Kgd Medium-grained biotite hornblende granodiorite porphyry stocks and dikes in Crozier Peak area. Forms a small stock and subsidiary dikes on Ripsey Ridge at boundary of Kearny and Crozier Peak 7½ minute quadrangles. Average of therr K-Ar ages on biotite (Table 1) is 66.6 m.y.

Intrusive Period III

Tql — Quartz latite porphyry dikes in Crozier Peak, Kearny, and Winkleman $7\frac{1}{2}$ minute quadrangles. Equals Tql of Cornwall and Krieger (1975a, 1975b), Trp of Schmidt (1971), and Tkly of Krieger (1974b, 1974c. Tal near Crozier Peak is intruded by Kgd and is therefore older and not younger than Kgd as indicated by Krieger (1974a, 1974b).

Kmr — Melanocratic rhyodacite porphyry. Phenocrysts of plagioclase, resorbed quartz (to 10 mm), biotite, and accessory hornblende in a medium dark greenish-gray groundmass. Equals Kmr of Cornwall, et al. (1971), Krieger (1974b, 1974c), and Cornwall and Krieger (1975a, 1975b). In areas mapped by S. Keith intrudes Tr_2 which is consistent with existing literature above.

Tr_1-Tr_2 — Rhyodacite porphyry dikes. East-northeast- to east-west-striking dike swarms. Probably the most common dike type.

Tr_1 — Rhyodacite porphyry which contains phenocrysts of andesine, biotite, minor hornblende, and <u>no</u> quartz set in a tan to light greenish-gray groundmass.

Tr_2 — Rhyodacite porphyry. Same as above except contains resorbed quartz grains (5-13%) about 5 mm in diameter.

Both varieties were mapped separately. Individual dikes may or may not contain quartz. No crosscutting relationships between these dikes were observed. Rock type is identical except for presence or absence of quartz. Similar positions in relative age sequence suggest these two dike types are comagmatic. Analogous observations have been made by other workers (Tkd and Tkq of Barrett, 1972, and Tkr-Tkrq of Krieger, 1974~~a~~b, 1974~~b~~c). Tr_1-Tr_2 is also equivalent to Tkr_2 of Cornwall, et al. (1971), Tr_2 of Cornwall and Krieger (1975a, 1975b), Tqmp of Schmidt (1971), and Tkfm of Willden (1964). An average of three K-Ar ages on biotite from three dikes in this series is 62.4 m.y.

Intrusive Period II

Krp — Rhyodacite porphyry. Porphyritic (plagioclase) medium to light gray with a greenish, brownish, or olive cast rhyodacite. Contains smaller euhedral phenocrysts of hornblende and biotite; accessory magnetite; visible quartz is rare. Forms dikes and a large sill in Apache group east of Crozier Peak. Questionably assigned to intrusive period II on the basis of its sill-like nature.

Ttc — Teacup granodiorite (see Cornwall and Krieger, 1975b). Equals Grayback granodiorite of Schmidt (1971); not on S. Keith maps. Average of two dates (Table 1) is 62.2 m.y. Large pluton in Grayback and North Butte quadrangles. Cut by dikes of intrusive period III.

Kr — Rattler granodiorite (see Ransome, 1923; Cornwall, et al., 1971). Equals granodiorite of Troy (Ransome, 1923); referred to informally as Troy granodiorite by Schmidt (1971) and others. Main phase is a medium-grained biotite hornblende granodiorite. Average of six dates from three sources (Table 1) is 70.1 m.y. Forms a 2-square-kilometer stock at Troy in central Dripping Spring Mountains.

Kgb — Granodiorite of Granite Basin (see Willden, 1964). Forms large laccolithic intrusion into Naco group 5 miles east of Christmas mine. Biotite hornblende granodiorite included by Willden (1964) as Tkfm. K-Ar date on hornblende is 70.5 ± 1.6 m.y. (Koski, written communication, 1976). Not on S. Keith maps. Rock closely resembles Rattler granodiorite (Koski, personal communication).

Kqd — Quartz diorite. Medium-grained biotite hornblende quartz diorite. Comprises small stock southeast of 79 mine in southern Dripping Springs and MacDonald stock 1 mile east of Christmas. K-Ar age of hornblende is 68.0 ± 1.6 m.y. (Koski, written communication) from MacDonald stock. MacDonald stock not on S. Keith maps.

Kda — Dacite (see Krieger, 1974c). Consists of a sill in Apache group rocks in central Crozier Peak quadrangle. K-Ar age on hornblende is 71.3 ± 2.1 m.y. (Krieger, 1974c). Not on S. Keith maps.

Kv — Volcanics on east side of Ripsey Ridge in Crozier Peak quadrangle (see Krieger, 1974c). Not on S. Keith maps.

Intrusive Period I

Ktt — Turkey Track porphyry. Large (to 15 mm) plagioclase laths poikilitically enclosed in a dark gray groundmass exhibiting Turkey Track texture. Only one east-west striking dike mapped northwest of Crozier Peak. Dike appeared to be truncated by Kdi.

Khd — Hornblende diorite porphyry. Medium gray to greenish or olive-gray fine- to medium coarse-grained hornblende diorite or andesite. Phenocrysts are almost entirely hornblende (2-10 mm) with rare plagioclase. Equals Kh of Krieger (1974b, 1974c). Forms east- to northeast-trending dikes in Crozier Peak and Winkleman quadrangles.

Kd — Fine-grained light green quartz diorite (see Krieger, 1974b). North- to south-trending dike which intrudes Romero Wash fault yielded a K-Ar whole rock age of 80.6 m.y. (Keith and Damon, unpublished). Forms numerous east- to northeast-striking dikes south of Crozier Peak. Some of Krieger's Tku in this area is probably this rock.

Kha — Hornblende andesite. Light brown andesite dikes containing phenocrysts of hornblende (2-5 mm) and tabular white plagioclase "squares" (2-4 mm) scattered in a light brownish-gray groundmass. Intrudes Kdi, Kd, and Khd. Forms numerous east- to northeast-striking dikes south of Crozier Peak. Some of Krieger's (1974b, 1974c) Tku south of Crozier Peak is of this rock. Could be equivalent to Tka and Tkrh in Kearny quadrangle (Cornwall and Krieger, 1975a) and Tkr and Tkha in Sonora quadrangle (Cornwall, et al., 1971).

Khap — Hornblende andesite. Large (to 3 cm in diameter) hornblende phenocrysts set in a medium gray groundmass. Dikes which intrude Kw in Saddle Mountain area. Dikes appear to cut and by cut by Km and therefore are interpreted to be comagmatic with Km_1. Dated dike in Ray area Kha of Cornwall, et al. (1971) and hornblende andesite in Crozier Peak quadrangle (Kha of Krieger, 1974c) may be equivalent(?). Average of two dates from Christmas and Saddle Mountain areas (Table 1) is 76.8 m.y.).

Kt — Tortilla quartz diorite (see Cornwall, et al., 1971). Equals Sonora diorite of Schmidt (1971). Consists of a number of small stocks in the Kearny, Grayback, and Sonora quadrangles. The largest stock is west of Kelvin, Grayback,

and Sonora quadrangles. Composition ranges from pyroxene-hornblende diorite through biotite-hornblende diorite. Typically medium-grained hypidiomorphic granular rock, although local porphyritic patches with pyroxene and hornblende phenocrysts to 3 cm across are common. Average of 10 selected ages from 3 sources (Table 1) is 72.65 m.y. Banks, Cornwall, Silberman, and Marvin (1972) interpret the anomalously old hornblende ages to reflect extraneous or excess radiogenic argon introduced by late stage magmatic fluids.

Kdi — Diorite of Crozier Peak (see Krieger, 1974b, 1974c). Rock is petrographically similar to Kt; 65.6 m.y. age date (Table 1) reported by Krieger (1974) is interpreted by this worker to be a reset age produced by intrusion of Kgd at 66.6 m.y.

Km — Microdiorite. Equals microdiorite of Willden (1964). Comprises numerous dikes, sills, and stocks which intrude Williamson Canyon volcanics in northern Saddle Mountain and southern Christmas $7\frac{1}{2}$ minute quadrangles. Rock is petrographically and chemically similar to Kt. Average of two K-Ar dates (Table 1) is 80.7 m.y.

Kwi — Intrusive basalt or basaltic andesite. Equals Mzbp of Cornwall and Krieger (1975a). Mzbp of Cornwall, et al. (1971), andesite (Ta) of Metz and Rose (1966), Mesozoic(?) diabase (db) of Ransome (1923), and Qtb (in central Teapot Mountain quadrangle) of Creasey, et al. (1975). Widespread small dikes and sills which cut Paleozoic sedimentary rocks and Troy quartzite are assigned to this unit. Perhaps the best exposure of this rock unit is at Steamboat Mountain in the Hayden quadrangle. Fine- to medium-grained porphyritic (plagioclase) to hypidiomorphic granular rock composed of plagioclase, augite, magnetite-ilmenite, and olivine (altered to iddingsite and antigorite). Sills of this rock in Elder Gulch, Sonora quadrangle, questionably are northern apophyses of Kt stock in Elder Gulch. Numerous sills of this rock are present in close proximity to Kw in the Winkleman and Saddle Mountain areas. For this reason the basaltic sills are tentatively considered to be intrusive analogs of Kw, although overall field relationships strongly suggest that Kt, Km, Kdi, Kw, and Kwi are closely related.

Kw

Williamson Canyon volcanics (0 to 3,000+ feet thick), see Simmons (1964). Equals unnamed Cretaceous volcanics (Kv) of Willden (1964). Correlated by Krieger (1968d) with Williamson Canyon volcanics (Krieger's Tkw; also Kv of Barrett (1972) is this rock). Cornwall and Krieger (1975b) observed that Kw in Kearny quadrangle resembles Kt. In Saddle Mountain quadrangle, several thousand feet of flows are exposed. Flows are comprised of purplish lithic crystal tuffs with rare biotite and purplish lapilli tuffs suggesting a pyroclastic (see Barrett, 1972; Willden, 1964). Koski (personal communication) reports that flows in Christmas area are more fragmental in nature. Some flows contain lithic clasts of volcanics and a rock which strongly resembles microdiorite (Km). Chemically the rock is a calc-alkaline basalt containing less than 50% SiO_2 (see Clayton, 1975, unpub. KES report). Base of volcanics in N½ sec. 26, T. 5 S., R. 16 E. contains structure which resembles pillows, implying that some of the volcanics were deposited subaqueously.

Kwc

Boulder conglomerate (0 to 150+ feet thick). Coarse, poorly bedded to unbedded, poorly sorted conglomerate containing boulder clasts to 3 feet in diameter of Oracle quartz monzonite, an unidentified pink granite which resembles the Payson granite at Payson, Arizona (D. Shakel, personal communication), diabase, Dripping Spring and Troy quartzites, and very rare Paleozoic limestones. Matrix is a poorly sorted coarse- to medium-grained arkose of granitic composition. Occurs as irregular lenses 40 to 150 feet above the base of the volcanics. Source for Precambrian clasts is at least 10 miles distant (Tortilla Mountain exposures).

Kwm

Megabreccia (0-200 feet thick). Large megabreccia blocks of Troy quartzite and Paleozoic rocks intercalated in basal portion of Kw (not on S. Keith maps) and intruded by Khap; of probable landslide origin. Mapped by Willden (1964) as allocthonous masses in the upper plate of a thrust fault in Reed Basin of the Jerusalem Mountain quadrangle where it is intruded by Khap.

Kws

Sedimentary rocks intercalated in Kw (0-300 feet thick). Equals "continuous sequence" of Barrett (1972); clastic sedimentary rocks of variable composition intercalated about 1,000 to 1,500 feet above base of Kw. In Saddle

Mountain area south of Ash Creek, Saddle Mountain $7\frac{1}{2}$ minute quadrangle, light brown to brownish-yellow sediments are coarse grained, poorly sorted, well bedded arkosic sandstone, arkose, and graywacks with conglomeratic interbeds. The arkosic rocks grade laterally and vertically into conglomerates with an arkosic matrix (marked by a conglomerate symbol on the maps). The conglomerate fraction increases to the south. Clasts in the conglomerate are Precambrian Oracle quartz monzonite, diabase, Dripping Spring and Troy quartzites with rare Paleozoic limestone. North of Ash Creek this sequence contains a sizeable interval of shale (75 feet thick ±) in addition to the above coarse clastic rocks (see Barrett, 1972). Regional relations in conjunction with the sedimentological data suggest that the area of the Saddle Mountain mining district was a structural basin in late K time.

MESOZOIC ROCKS*

Kp

Pinkard formation (0-300 feet thick). Correlated by Krieger (1968d) with the section described at Klondyke, Arizona, by Simmons (1964) who correlated it with the type section at Morenci (Lindgren, 1905). In the Saddle Mountain quadrangle, the Pinkard is predominantly yellow to pinkish medium-grained arkosic sandstone with well-developed tabular planar crossbedding. Silica replaced petrified wood is common in exposures along Eskiminzin Wash. One log section 3.5 feet long and 2.5 feet in diameter was observed. The basal Pinkard is a pebble conglomerate. Pebble-sized clasts are chiefly of unidentified quartzite. Locally the sandstones are interbedded with light greenish shales which comprise a much greater proportion of the formation 5 miles to the northeast in Deer Creek Basin. The Pinkard has a well-established fossil date on Colorado age (± ~~100~~ 20 m.y.) based on molluscan-coral fauna collected in the Klondyke area (Simmons, 1974). The Pinkard probably represents the southernmost extension of Mancos age rocks from northwest New Mexico, southeast Utah, and northeast Arizona.

*See Figure 3 for northwest-southeast distribution and correlation of Mesozoic rocks.

Schematic Correlation of Precambrian, Paleozoic, and Mesozoic Rocks, Ash Creek to Superior, Arizona

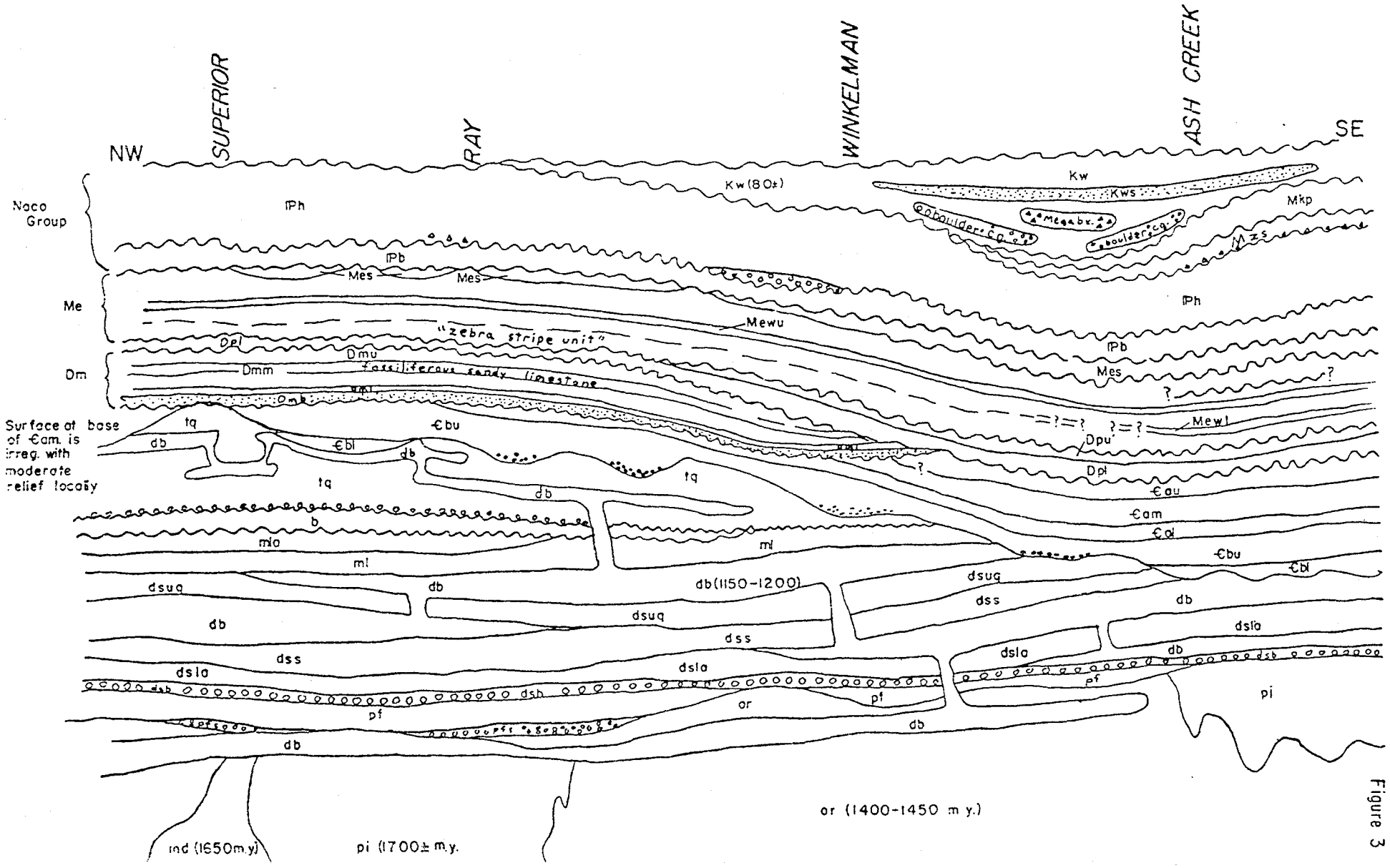


Figure 3

Mzs

Mesozoic sedimentary rocks (0-150 feet thick). Name given by Krieger (1968c) for redbeds and siltstone beneath Kp and above IPh. Best exposed section is in Eskaminzin Wash about three-quarter mile downstream from Eskaminzin Ranch. Here the section consists of a basal chert breccia (0-15 feet thick) composed of angular chert clasts (designated by triangles where mapped) derived mostly from chert lenses in IPh, pinkish-white quartzitic siltstone (10-20 feet thick) and pink shale (redbeds, 75-100 feet thick). Exposures of this unit in other areas have a basal siltstone 0 to 10 feet thick resting beneath the chert breccia locally. Locally the redbed equivalent is a green shale which is unconformably overlain by Kw. Exposures in this horizon north of Ash Creek could be either green shales of Kp or Mzs (mapped as Kp by Barrett, 1972). Molluscan beaks and valves collected from the siltstone unit by Krieger can be no younger than Triassic (Krieger, 1968c).

PALEOZOIC ROCKS*

IPs

IPn

Naco group. Name given by Ransome (1904) to a series of rocks above Mississippian Escabrosa limestone in the Naco Hills, southwest Mule Mountains, Cochise County, Arizona. Since Ransome, rocks in the unit have been subdivided by numerous workers into many formations. Only the lower two formations (Horquilla and Black Prince formations) are recognized in the Saddle Mountain to Superior area. All previous mapping in this area has referred these rocks under the name of Naco formation.

IPh

Horquilla formation (500 to 1,500 feet thick ±). Light grayish weathering alternating carbonates and clastics. Basal contact with IPb is variable. At Superior the contact is marked by a quartzite pebble conglomerate. At Ray it is a chert breccia. At Eskiminzin Wash it is a chert breccia and sandstone. The basal 150 feet of IPh is predominantly slope forming pinkish and reddish siltstones and shales interbedded with micrite. Resistant carbonate lithologies (100 feet ±) are encountered about 150 feet above base

*See Figure 3 for northwest-southeast distribution and correlation of Paleozoic rocks.

interbedded with clastics (20%). Above the ledge-forming carbonate sequence, IPh is a monotonous sequence of interbedded carbonates (65%) and clastics (35%) at regular intervals. In general the IPh carbonates (mostly crinoidal and fusilinid limestone with numerous chert lenses) have more grayish outcrop colors than Black Prince. IPh clastics (mostly pinkish to maroon siltstones and shales) form slopes so that a conspicuous regular-shaped ribbing or banding is observed when viewing IPh from a distance. Fossils common in IPh are crinoids, echinoid spines, composita productid, and spirifer brachiopods. Guide fossils in central Arizona are fusilinids, Caninia rugose coral, and prisma pora bryozoa. IPh in general forms slopes. See Ross (1973) and Reid (1969) for more detail on IPh.

IPb — Black Prince formation (100-150 feet thick). Basal unit is commonly a maroon shale or siltstone and forms topographic recesses. Basal bed is locally a chert breccia. Upper unit is a thick-bedded ledge to cliff-forming white crinoidal limestone (biosparite) with chert pods and lenses. Black Prince contains no fusilinids. Chaetetes "brain" coral is common in the upper limestone unit. See Ross (1973) and Berry (1975) for more detail on IPb.

Mes — Eskiminzin formation (new; 0-110 feet thick) named for exposures in Eskiminzin Wash, Saddle Mountain quadrangle (Keith and Purvis, unpublished). Conodants collected from this unit place the unit as Chester in age (Purvis, unpublished data). Formation consists of pink to yellowish-orange unfossiliferous fine-grained to aphanitic dolomite. Base of unit is a sedimentary breccia resting unconformably on a karst surface developed in underlying Escabrosa limestone. Sinkholes in this surface penetrate to 60 feet into Escabrosa and contain angular brecciated material of Eskiminzin which has collapsed into the void space. The karst is spectacularly exposed in a road cut on the north side of Highway 177 where it passes through Me in the core of an anticlinal fold 2 miles northeast of Winkleman, Arizona. Contact with Naco formation in other mapping is inconsistently placed above and below this unit (e.g., Krieger, 1968c).

Me — Escabrosa formation (approximately 500 feet thick). Unit forms prominant cliffs of massive bluish-gray crinoidal limestone (biosparite). Contains a series of conspicuous

white marker beds about 200-300 feet above base (Mew). Base of formation is a banded (light to dark bluish-gray bands) cliff-forming crinoidal biosparite (40-50 feet thick) with black chert bands locally at its base (referred to colloquially as the "zebra stripe" unit). Intervals between cliff-forming units are medium-bedded orangish-brown aphanitic dolomite with a few white chert pods and lenses. Two white marker beds were mapped in exposures in Saddle Mountain $7\frac{1}{2}$ minute quadrangle and are designated Mewl and Mewu. An unconformity about 350 feet above base was mapped in Me exposures along Ash Creek. Fossils are ostracods (oolites) crinoids, spirifer and composita brachiopods, and syringopora "organ pipe" coral. Zaphrenthis rugose coral are guides to Me. See Huddle and Dobrovolny (1952) for more information on Escabrosa formation in central Arizona.

Dp — Percha formation (30-150 feet). Recently recognized in central Arizona by Shumacher, et al. (1976). Separated from underlying Dm by conodont data and lithology. Basal unit (Dpl) is a slope-forming olive-green mud-shale 40 to 85 feet thick and grades into an upper unit (Dpu) of medium-bedded light yellow silty dolomite with white chert pods. Dp in Teapot Mountain quadrangle consists entirely of lower mud-shale unit.

Dm — Martin formation (300-400 feet). Consists of five units which were combined into four map units which in descending order are:

Dmu — Orange dolomite and siltstone unit (30-70 feet thick). Slope-forming thin- to medium-bedded fine-grained orange to orange-yellow silty dolomite interbedded with siltstone and shale. Scattered hematite concretions. Locally fossiliferous. Pachyphyllum and Hexagoraria corals have been collected from this unit (see Meader, 1976).

Dmm — Consists of two units which are in descending order:

Sandy limestone unit (30-50 feet thick). Ledge-forming dark bluish-gray, thin- to medium-bedded sandy limestone. Contains calcareous silt and sand interlenses. Very fossiliferous. Atrypa brachiopods common to abundant. Other fossils are pachyphyllum corals, bryozoa, and abundant

crinoid stems and hash. A few crinoid calyxes have been found. Fossils are locally so crowded that the rock resembles coquina. Biostratigraphy of this unit and Dmu is summarized by Meader (1976). Upper part of unit commonly contains hematite concretions.

Aphanitic dolomite unit (200 feet thick ±). Slope-forming light gray to light yellow aphanitic dolomite. Contains siltstone and sandstone interbeds in upper part.

Dml — Fetid dolomite unit (20-35 feet thick). Well-bedded, dark gray, laminated fetid dolomite. Commonly mineralized (the O'Carroll ore horizon of Eastlick, 1968, and others). Forms ledges.

Dmb — Beckers Butte sandstone member (see Teichert, 1965), approximately 40 feet thick. Friable, well-sorted, clean, well-bedded, medium- to coarse-grained sandstone. Weathers light brown to gray. Calcareous in its upper few feet. See Teichert (1965) for more information on Martin formation in central Arizona.

Ꞓa — Abrigo formation (0-450 feet thick). Divided into three members which grade into one another. Ꞓau and Ꞓam are not present north of the latitude of Hayden. Ꞓal is present in southern and central Dripping Spring Mountains but is absent in Teapot Mountain $7\frac{1}{2}$ minute quadrangle (Fig. 3), see Krieger (1961, 1968c, 1968d). Units in descending order are:

Ꞓau — Upper brown sandy member (50-75 feet thick). Cliff-forming, brown, medium- to thick-bedded sandy dolomite or dolomitic sandstone. Crossbed laminae common. Approximately 20 feet above base contains a red oolitic hematite bed marked on map by a dashed line where observed which contains abundant shell fragments of phosphatic inarticulate brachiopods.

Ꞓam — Middle sandstone member (150-250 feet thick). White ledge-forming, medium-bedded, fine-grained quartzitic sandstone. Weathers to a distinctive ribbed topographic expression (ribs parallel bedding). Contains excellent ripple-mark surfaces. Scolithus (worm tubes?) is common throughout unit.

Єal — Lower mudstone member (50-125 feet thick). Slope-forming olive-green, glauconitic mudstone and shale. Contains fossil trilobite and inarticulate brachiopod (Billingsella?) hash. Grades downward into Єba.

Єb — Bolsa quartzite (0-300 feet thick, typically 50-100 feet thick). Mapped as two units. Єbu is by far the most extensive. Bolsa is absent at Steamboat Mountain in Dripping Spring Mountains, Hayden 7½ minute quadrangle, where Єrests on Precambrian Troy quartzite. See Krieger (1961, 1968) for further discussion. Units in descending order are:

Єbu — Upper quartzite member (0-250 feet thick, typically 50-100 feet thick). Cliff-forming, fine-grained, medium-bedded, white, clean quartzite. Crossbedding laminae common. Generally rests on Troy quartzite but may rest on diabase. Basal pebble conglomerate containing clasts of Troy quartzite is present locally.

Єbl — Lower arkosic member (0-150 feet thick). Present locally in thicker sections of Єb. Dominately dark maroon to pinkish colored, poorly sorted, friable arkose and arkosic sandstone. Poorly sorted pebble conglomerates near base. Єbl commonly rests on db and much of its reddish color may be from reddish clays derived from db. Unit closely resembles lithologies in the Troy quartzite and fills channels and irregularities on an erosional surface of moderate relief. Grades upward into Єbu.

YOUNGER PRECAMBRIAN ROCKS*

A thick sequence of predominately clastic rocks which underlies the Cambrian Bolsa quartzite and overlies older Precambrian crystalline rocks is present throughout the mapped area. These rocks were originally considered Cambrian by Ransome (1903, 1919, 1923). These rocks underlie 1400 m.y. quartz monzonite and are intruded by 1150-1200 m.y. diabase sills which clearly place them in the Precambrian.

*See Figure 3 for northwest-southeast distribution and correlation of younger Precambrian rocks.

A well-exposed section of these rocks is present on Highway 177 in the central Teapot Mountain $7\frac{1}{2}$ minute quadrangle. For a detailed discussion of younger Precambrian stratigraphy see Schride (1967). For interrelations between younger Precambrian and lower Paleozoic stratigraphies see Krieger (1961, 1968d) and Schride (1967).

db

Diabase. Dikes and sills abundant in Precambrian Apache group and Troy quartzite. Medium- to coarse-grained ophitic texture is defined by plagioclase (laboradorite composition) poikilitically encased in a pyroxene (augite) groundmass. Accessory minerals include biotite, amphibole, olivine, and magnetite-ilmenite. Diabase and gabbro pegmatites are present locally. Sills are often composite and invariably have chilled borders with enclosing sedimentary rocks in areas of poor outcrop. Diabase weathers into distinctive olive-green soils. Diabase is locally depositionally overlain by Bolsa quartzite as at Ash Creek, Saddle Mountain $7\frac{1}{2}$ minute quadrangle (contact here is also moderately sheared) and in U.S. Highways 60 and 70 roadcuts at Superior, Arizona. Typical thicknesses for diabase sills are 300-600 feet, but large sills may range to +1,200 feet. The accepted age for the diabase is 1150 m.y., based on several dating techniques (see Silver, 1960; Granger and Raup, 1959; Livingston and Damon, 1968; and Banks, et al., 1972). For more detail on the diabase see Schride (1967), Smith (1969, 1970), and Nehru and Prinz (1970).

tq

Troy quartzite (named by Ransome, 1919, 1923, for exposures at Troy Mountain, central Dripping Spring range). Generally 300-600 feet thick where present. Thicknesses are variable due to post-diabase pre-Bolsa erosion which produced a surface of moderate relief. Composed of two units which were difficult to separate in the mapping due to abrupt lateral and vertical variations. See Schride (1967) for more detail. The units in descending order are:

Upper quartzite member. Cliff- and ledge-forming, fine-grained, locally medium-grained, medium-bedded, white to reddish quartzite and feldspathic quartzite. When Єbu was inferred to overlie this unit, contact was placed

somewhat arbitrarily based where possible on cleanness and grain size. Becomes sandier and more feldspathic in its lower part. Equals upper quartzite member in Troy quartzite of Schride (1967).

Lower arkosic sandstone member (mostly 100-300 feet). Slope- and ledge-forming; red, maroon, white, poorly sorted arkosic and conglomeratic sandstone. Becomes more arkosic, poorly sorted, and conglomeratic near base. Arkosic sandstones have prominent lenticular cross bedding locally. Arkose member is well exposed northeast of Walnut Gap along Highway 177 in Teapot Mountain $7\frac{1}{2}$ minute quadrangle. Probably equivalent to the Chedeski sandstone member of Schride (1967).

tqc Basal conglomerate (0-30 feet thick). Coarse pebble and cobble conglomerate which superficially resembles Barnes conglomerate except for clasts of Mescal limestone and Dripping Spring quartzite and slightly more angular clasts. Pebble and cobble sized clasts are composed mainly of Apache group rocks and reworked quartzite clasts and red chert from the Barnes conglomerate. Matrix is reddish to maroon, poorly sorted arkose of similar composition to the clasts which it encloses. Shown by a conglomerate symbol where observed.

Apache Group

A series of three formational units which rest under Troy quartzite and on older Precambrian rocks is referred to the name Apache group. Named by Ransome (1903) for exposures in the Globe 30 minute quadrangle. Includes in descending order basalt, Mescal limestone, Dripping Spring quartzite, and Pioneer formation.

b Basalt (0-300 feet, generally 75-150 feet thick). Flows of black to dark gray basalt. Commonly vesicular. Porphyritic varieties consist of plagioclase in a pyroxene groundmass of pyroxene and olivine largely altered to iddingsite and serpentine. Altered basalt has a greenish appearance and where coincident with diabase is difficult to distinguish.

m — Mescal limestone (0-350 feet, typically 150-250 feet thick). Two members mapped which in descending order are:

mla — Upper algal member (0-150 feet, typically 100-150 feet thick). Equals algal member of Schride (1967). Ledge- and cliff-forming, thick-bedded, yellowish brown dolomite. Algal stromatolyte bioherms are common in the lower one-third of the unit. Member is not present in Tortilla Mountains or Dripping Spring Mountains south of Troy Mountain (Fig. 3). See Schride (1967) for further discussion.

ml — Lower dolomite member (0-150 feet thick, typically 75-150 feet thick). Thin- to medium-bedded, white dolomite with abundant black chert bands and lenses locally. Rock weathers into closely spaced ribs where chert is present. Lower part of unit is commonly a sedimentary breccia which consists of angular chert and dolomite clasts in a matrix of brownish-gray, locally calcareous dolomite. Matrix of breccia becomes sandier in its lower part. See Schride (1967) for further discussion.

ds — Dripping Spring quartzite. Named by Ransome (1903, 1919) for exposures in the Dripping Spring Mountains. Divided by Schride (1967) and USGS mapping into three members (see also Granger and Raup, 1964). A four-member subdivision seemed more logical in the area of this mapping. In descending order the four units are:

dsuq — Upper arkosic quartzite member (50-100 feet thick). Light brown, reddish brown, and reddish green, fine-grained, medium-bedded arkosic quartzite interbedded with thin-bedded siltstone. Has a flaggy outcrop expression; forms cliffs and ledges. Joints are often stained with hematite and goethite and show liesegang rings where the arkosic quartzite is intruded by diabase sills.

dss — Middle siltstone member (40-150 feet thick). Slope-forming, interbedded, thin-bedded siltstones and shales. Weathered surfaces are strong shale of reddish-brown. Shale is locally phyllitic and weathers into small slaty shingles and flakes which have a white micaceous sheen. Reddish-brown goethite stain is derived from syngenetic

pyrite (1-5% locally). Rare torbernite is derived from sparse syngenetic uraninite(?). Unit commonly intruded by diabase sills.

dslq — Lower quartzite (40-80 feet thick). Light yellowish-brown to white, cliff-forming, thin- to thick-bedded, medium-grained, fairly clean quartzite. Lower portions more arkosic. Fractures commonly stained by goethite derived from overlying dss unit.

dsb — Barnes conglomerate member (0-50 feet, generally about 30 feet thick). This unit is the most easily identified, persistent, and reliable marker unit in the Apache group section and perhaps the entire Precambrian, Paleozoic, and Mesozoic section. Consists of very well-rounded ellipsoidal pebbles and cobbles of gray, brown, and grayish-red quartzite with minor quartz and red jasper set in a matrix of medium-grained, poorly sorted arkosic quartzite. Forms ledges but is not as resistant as dslq.

pf — Pioneer formation (0-300 feet thick, generally 150-200 feet thick). Slope-forming, dusky red-purple and brown arkose, and dusky purple siltstone and shale. Siltstone and shale are tuffaceous. Rocks of the Pioneer formation very commonly are speckled by distinctive white to light greenish-yellow spots which represent bleached areas around small (0.5 to 2 mm) pyrite cubes replaced by goethite. When spots are absent Pioneer may closely resemble dss.

pfs — Scanlan conglomerate member (0-20 feet; usually 2-6 feet). Matrix and clast composition variable and depends for its character on the rock immediately underlying it. In schistose terrains, clasts are subrounded to angular pebbles of white quartz (locally abundant) and angular pebbles and granules of Pinal schist in a grayish-red to purple matrix of poorly sorted rock chips and arkose. In granitic terrains, clasts are rounded to angular pebbles of white quartz and local pebbles and cobbles of quartzite in a coarse arkosic matrix of granitic composition. This variety may resemble clast-poor variations of Barnes conglomerate. Commonly, few if any pebble clasts are present and unit consists entirely of a coarse-grained granitic arkose.

OLDER PRECAMBRIAN ROCKS*

or

Oracle quartz monzonite of Peterson (1938). Referred to in recent USGS mapping in Tortilla Mountains as Ruin granite for a rock of similar composition and age in Ruin Basin 10 miles northwest of Globe, Arizona (see Ransome, 1903). The name Oracle is preferred because outcrops in Tortilla Mountains extend more or less continuously to an identical-looking rock at Oracle, Arizona. The quartz monzonite in Ruin Basin is separated from that in the Tortilla Mountains by a 30-mile-wide belt of Pinal schist. Oracle refers to extensive exposures of batholithic extent in the Tortilla Mountains.

Petrographically the rock is a medium- to coarse-grained yellowish-gray to grayish-orange porphyritic (K-spar) biotite quartz monzonite. Biotite is commonly altered to chlorite. Accessory minerals are apatite, magnetite, and zircon with rare sphene. K-spar phenocrysts are commonly large (to 6 x 3 cm) and may be either orthoclase or microcline and commonly exhibit microperthitic intergrowths. Locally "or" contains numerous xenoliths of clots of Pinal schist. Biotite from the Oracle granite of Oracle, Arizona, gave a K-Ar age of 1420 m.y. (Damon, et al., 1962). Silver has an unpublished U-Pb zircon age of 1450 m.y. for this rock. Oracle quartz monzonite is locally cut by aplite and pegmatite dikes designated "ap" on maps. Also, the porphyritic phase commonly grades into a "hybrid" aplitic equigranular phase which was only mapped in a few areas (designated "hor" on the maps).

Oracle quartz monzonite is locally cut by a cataclastic east-west- to east-northwest-trending high-angle foliation (especially in Kelvin Riverside area). Schmidt (1971) reports that this foliation is cut by 1150 m.y. diabase sills in the northern Tortilla Mountains.

md_2

Madera quartz diorite. Named by Ransome (1903) for exposures near Mt. Madera in the northern Pinal Mountains. Ransome (1923) refers to at least two varieties in the Pinal Mountains. Several varieties are present north of Ray where some useful crosscutting relationships were established.

The rock symbolized as md_2 has the following characteristics: The predominate phase is a medium-grained biotite granodiorite with 4-20% biotite (generally 4-6% biotite) and is foliated locally. A more mafic phase has hornblende and is better termed a hornblende biotite quartz diorite. The hornblende in this rock forms typical elongate prisms. Locally the biotite granodiorite is foliated. In some areas biotite-poor md_2 closely resembles Granite Mountain porphyry (Tgm). In gullies west of the picnic ground 2 miles north of Ray mine the biotite granodiorite phase clearly cuts a more mafic "phase" (md_1).

md_1 Quartz diorite. Medium- to medium-coarse-grained biotite hornblende quartz diorite. Texturally this rock is distinct from md_2 in that hornblende (and possibly pyroxene) are distributed throughout rock as blocky or stubby equant crystal clusters in a lighter phase of plagioclase and minor quartz. The result is a splotchy "salt and pepper" or "shot gun" texture. The occurrence of hornblende in md_2 is as more typical elongate prisms which are not clustered. md_1 is the prominant md rock type in the central Teapot $7\frac{1}{2}$ minute quadrangle, Telegraph Canyon of the Mineral Mountain $7\frac{1}{2}$ minute quadrangle, and Cedar Mountain area of the Winkleman $7\frac{1}{2}$ minute quadrangle.

Both types of md are commonly well foliated near their contacts with Pinal schist and grade into poorly foliated and unfoliated rock away from Pinal schist contacts suggesting a protoclastic deformational process during emplacement which is superimposed on an already regionally metamorphosed and deformed Pinal schist. Numerous attempts have been made to date Madera diorite. The age data are summarized in Table 2.

Fig. 4 Correlation of Older Precambrian Rocks
Ash Creek to Superior, Arizona

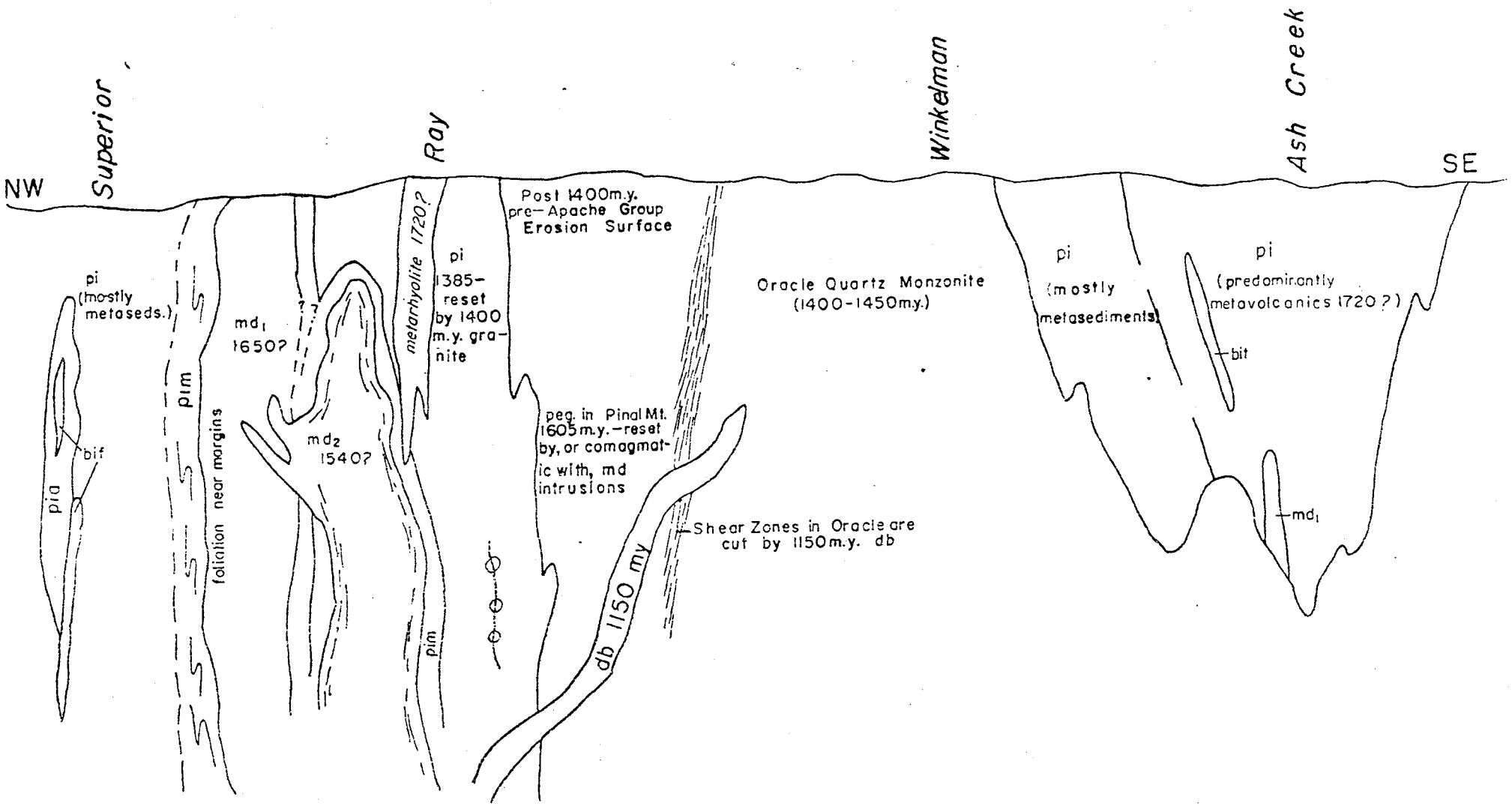


TABLE 2

AGE DATA FOR MADERA DIORITE

Comments	Method	Mineral	Date	Source
	K-Ar	biotite	1660	Damon, et al. (1962)
	K-Ar	hornblende	1630 ± 60	Banks, et al. (1972)
foliated granodiorite reset by intrusion of Tortilla quartz diorite	Rb-Sr	whole rock isochron	1775	Livingston and Damon (1968)
reset	K-Ar	biotite	68.6	Banks, et al. (1972)
reset	K-Ar	biotite	98	Banks, et al. (1972)
foliated Madera diorite	Rb-Sr	W.R. isochron A	1730 ± 30	Livingston (1970)
	Rb-Sr	mineral isochron B	1580 ± 60	Livingston (1970)
	Rb-Sr	mineral isochron C	1495 ± 60	Livingston (1970)
	Rb-Sr	mineral isochron	1630	Livingston and Damon (1968)

Livingston (1969) interprets his 1970 data (presumably updated from Livingston and Damon (1968) as intrusion of a foliated phase of Madera at 1730 ± 30 with possible intrusion of nonfoliated phases of Madera and metamorphism at 1540 m.y. If the U-Pb zircon dates of Silver (1964) on rhyolites in the Johnny Lyon Hills in the Pinal schist (approx. 1720 m.y.) are correct and if they correlate with metavolcanics at Ray and elsewhere, then the W.R. isochron is too old. Possibly the Madera was contaminated by radiogenic Sr from the Pinal schist during its emplacement. Given that there are at least two kinds of intrusions which have been mapped as Madera, the following scenario might best fit existing data: (1) depletion of Pinal schist (both volcanic and sediments) at about 1720 m.y., (2) regional metamorphism and deformation post-1720 but pre-1660, (3) emplacement of md_1 at about 1650 with accompanying contact metamorphism and deformation, (4) emplacement of md_2 (granodiorite and quartz diorite) at 1540 with

accompanying contact metamorphism and deformation, and (5) emplacement of 1400-1450 m.y. granitic batholiths with accompanying contact metamorphism and deformation. This writer would regard the regional 1720-1660 metamorphism and deformation to correlate with Mazatzal orogeny (Wilson, 1938; Silver, 1965). Post-Mazatzal events may reflect other as yet undefined orogenic episodes.

Pinal Schist

Named by Ransome (1903). Contains numerous lithologies which were hard to separate in mapping. The two principal types are metasedimentary and metavolcanics which generally occur in separate areas and are described below:

Metasediments:

In Telegraph Canyon area: Bluish-gray, fine- to medium-grained quartz muscovite schist and quartz muscovite chlorite schist with some feldspar. South of Telegraph Canyon the schist locally contains abundant porphyroblasts of prismatic chlorite pseudomorphosed after andalusite or sillimanite(?). Pods, veinlets, and veins of white quartz locally abundant. Rock weathers into small flakes and chips.

West of Telegraph Canyon schist is locally more phyllic and feldspathic and in places resembles metarhyolite.

In Ray area (north and west of Ray): Medium- to fine-grained reddish-brown, brown, and gray metagraywackes and arkoses (locally phyllitic). Rock is commonly spotted with porphyroblasts of chlorite and/or magnetite. Spotted appearance of schist near its contact with qmp is produced by the growth of andalusite.

Cedar Mountain (Winkleman quadrangle) and Ash Creek area: Dominantly metavolcanics. Dark to medium light gray, very fine-grained, dense metavolcanics of rhyolite to andasite composition. Lithologic units trend northeast. Separation was difficult and units were only partially mapped. Metavolcanics resemble massive flows, some with finely laminated flow banding, some may have been ash flow tuffs. A small patch of vesicular basalt was observed in the Ash Creek exposure. Cleavage is well developed in metarhyolite or dacite units at Ash Creek. Metarhyolite near Ray has a Rb-Sr age of 1500 ± 100 m.y. which Livingston (1969) interprets as

a metamorphic age. Livingston (1970) further suggests that the primary age of this rock is 1650 ± 100 m.y. Similar rhyolites intercalated in the Pinal schist is the Little Dragoon Mountains, Cochise County, Arizona, yield U-Pb zircon ages of 1720 m.y. Possibly the Rb-Sr age reflects metamorphism related to the emplacement of Madera diorite plutons.

pim — Recrystallized and deformed Pinal schist. This rock occurs in proximity to stocks of md and Tqm. Rocks are locally highly deformed and crenulated near plutonic centers. Here, rock is generally a spotted, coarse muscovite schist which is more resistant to erosion than regular pi. Spots are produced by andalusite(?). A highly deformed rock in upper Walnut Canyon west of Teapot Mountain was also mapped as pim.

bif — Banded iron formation. Lenses and pods common at Cedar Mountain, Winkleman area, associated with metavolcanics and at Telegraph Canyon associated with amphibolite. Rock consists of red cherty hematite interbanded with white chert. Locally the rock is isoclinally folded.

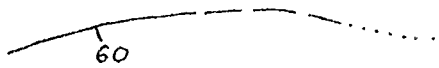
pia — Amphibolite. Large east-west to north-northwest-striking lenses up to several hundred feet wide and 1 mile long within Pinal schist west of Telegraph Canyon. Rock is about 80% hornblende. Thought by Schmidt (1967) to have a basic volcanic protolithology.

STRUCTURE

Primary Structures

Planar Elements

Layering...

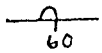


trace of contact showing dip where measured, dashed where uncertain, dotted where projected or concealed

...in sedimentary rocks

strike and dip of bedding

strike of vertical bedding



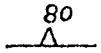
strike and cip of overturned bedding

strike and dip of overturned overturne bedding (>180° of rotation)

...in metamorphic rocks

strike and dip of bedding plane foliatic

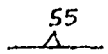
strike and dip of vertical foliation



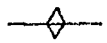
strike and dip of foliation in higher gr or severely deformed Pinal schist (pi:

strike of vertical foliation in "pim"

...in plutonic and volcanic rocks



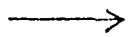
strike and dip of flow foliation



strike of vertical flow foliation

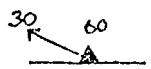
Linear Elements

...in sedimentary rocks

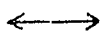


direction of material transport by water as determined from cross bedding, imbrication, or current ripple marks

...in metamorphic rocks

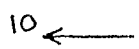


foliation showing trend and plunge of mineral lineation

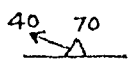


trend of horizontal mineral lineation

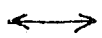
...in plutonic rocks



trend and plunge of mineral lineation aligned perpendicular to flow direction (a "b" lineation)

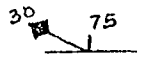


trend and plunge of mineral lineation contained within flow foliation. Direction of flow is at 90° to lineation



trend of horizontal flow lineation

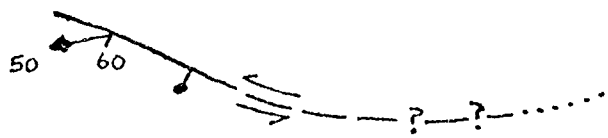
Secondary Structures



bedding showing trend and plunge of bedding plane slickensides

Faults

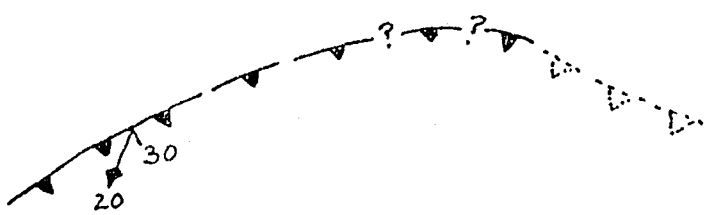
High angle faults:



trace of fault showing dip and trend and plunge of slickensides where measured, dashed where uncertain, questioned where extremely uncertain, dotted where projected or concealed. Ball and bar on relatively downthrown side; arrows show sense of lateral separation

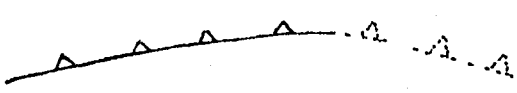
Low angle faults (<45°)...

...on maps

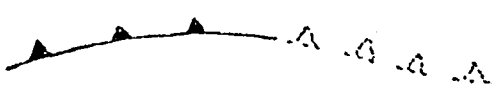


trace of low angle fault showing dip and trend and plunge of slickensides where measured, dashed where uncertain, questioned where extremely uncertain, dotted where concealed

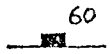
...on cross sections



low angle <u>normal</u> fault, dotted where projected

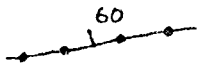


low angle <u>reverse</u> fault, dotted where projected

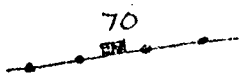


strike and dip of joint

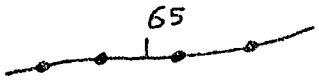
strike and dip of vertical joint



strike and dip of mineralized fracture

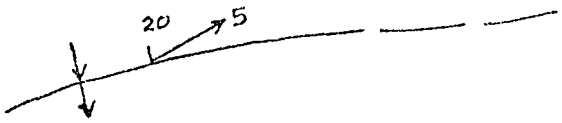


strike and dip of mineralized joint

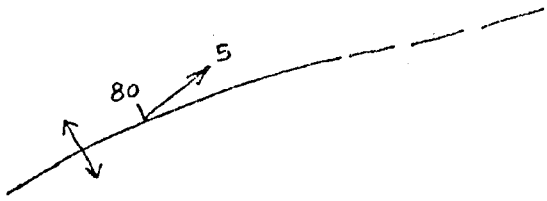


strike and dip of mineralized fault

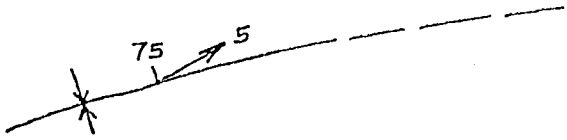
Folds



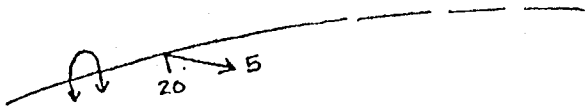
trace of flexure showing dip of axial plane and trend and plunge of axis; arrows indicate direction of limb dips, dashed where uncertain



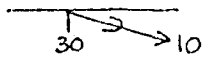
trace of antiform showing dip of axial plane and trend and plunge of axis, dashed where uncertain. All folds in unmetamorphosed Phanerozoic rocks are anticlines with the exception of Telegraph Canyon fold which is a synclinal antiform



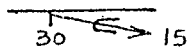
trace of synform showing dip of axial plane and trend and plunge of axis, dashed where uncertain. All folds in Phanerozoic rocks are synclines



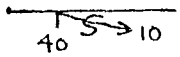
trace of shallowly inclined or recumbent fold showing dip of axial plane and trend and plunge of axis, dashed where uncertain



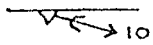
strike and dip of axial plane of minor antiform showing trend and plunge of axis



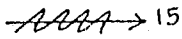
strike and dip of axial plane of minor synform showing trend and plunge of axis



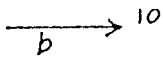
minor fold pair showing strike and di of axial plane and trend and plunge of axis; S or Z asymmetry determined by viewing down plunge of axis



foliation showing trend and plunge of crenulations



mean trend and plunge of cascade fol melange



mean trend and plunge of boudin axes

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Kennecott Exploration Services 230 [illegible] Salt Lake City, [illegible] • Phone 801 486-6211 • TWX 910 925-5624