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GEOLOGIC MAP OF THE MAZATZAL WILDERNESS AND CONTIGUOUS ROADLESS AREA, GILA, MARICOPA, AND YAVAPAI COUNTIES, ARIZONA

by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

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STUDIES RELATED TO WILDERNESS

The Wilderness Act (Public Law 88-577, September 3, 1964) and related acts require the U.S. Geological Survey and the U.S. Bureau of Mines to survey certain areas on Federal lands to determine their mineral resource potential. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a geological survey of the Mazatzal Wilderness (NF 3048) and Contiguous Roadless Area in Tonto and Coconino National Forests, Gila, Maricopa, and Yavapai Counties, Arizona. The Mazatzal Wilderness contiguous roadless area (3-016) was classified as a further planning area during the Second Roadless Area Review and Evaluation (RARE II) by the U.S. Forest Service, January 1979.

INTRODUCTION

This map and text present information on the general geology of the Mazatzal Wilderness, the contiguous roadless area, and adjacent areas in the center of Arizona. Included in the map area are the crest at the northern end of the Mazatzal Mountains, high mesas to the north, a deeply incised stretch of the East Verde River, and a part of the broad valley of the Verde River. The nearest towns are Payson, 8 km to the east, and Pine, 3 km north of the northeastern corner.

Information is provided in this report on little known stratigraphic sections of Early Proterozoic and late Tertiary rocks as well as on Middle Proterozoic and Paleozoic rocks. Emphasis is placed on the stratigraphic makeup and complex relations of layered sequences of Proterozoic rocks, their relation to Proterozoic intrusive units, and on the structural history of the area.

Previous detailed geologic studies in the area were by Wilson (1939), who outlined the principal rock units and geologic structures high in the Mazatzal Mountains, and by Ludwig (1974), who mapped Proterozoic rocks in the southeastern part of the area. Field studies conducted by the U.S. Geological Survey and the U.S. Bureau of Mines at the time of this study included a mineral resource assessment of the Mazatzal Wilderness and contiguous Roadless Area (Wrucke and others, 1983), geochemical investigations (Marsh, 1983), and geophysical surveys (Moss and Abrams, 1985).

Geologic mapping for this study was conducted principally in the spring of 1979 and the spring and fall of 1980. A few areas were studied briefly in 1981 and 1982.

GEOLOGIC SETTING

The Mazatzal Wilderness and contiguous Roadless Area are in the transition zone, a northwest to southeast belt of mountainous terrane in central Arizona between the Colorado Plateau to the northeast and the Basin and Range Province to the southwest. The Mogollon Rim, marking the physiographic southern boundary of the Colorado Plateau, rises a few kilometers northeast of the area. Mountain ranges in the transition zone expose Proterozoic rocks and lesser amounts of Paleozoic and Tertiary strata. Adjacent down-faulted basins are partly filled with Cenozoic sedimentary rocks locally interleaved with lava flows and tuffs that together record deposition concurrent with extension southwest of the Colorado Plateau.

PROTEROZOIC ROCKS

Proterozoic rocks of the area comprise four stratified sequences of sedimentary or sedimentary and volcanic rocks. The oldest of these sequences is the East Verde River Formation. It is overlain by three stratified sequences that constitute the Tonto Basin Supergroup-- in ascending order, the Alder Group, the Red Rock Group and the Mazatzal Group (Conway and others, in prep.). Few areas of comparable size in Arizona expose so many well preserved sections of layered Proterozoic rocks as the Mazatzal Wilderness. The sedimentary rocks are marine and nonmarine and include shale, graywacke, quartzite, and conglomerate, and minor amounts of chert, jasper, and limestone. The volcanic rocks are subaqueous and subareal basalt, andesite, and rhyolite. A composite thickness of the exposed Proterozoic rocks is about 18,000 m. Approximately 12,000 m of this thickness consists of unfoliated and weakly foliated rocks. The remaining 6,000 m thickness is of moderately foliated to schistose rocks. Intrusive into various parts of the stratified sequences are gabbro, diorite, and rocks of the Diamond Rim Intrusive Suite (Conway and others, in press)--granite, granophyre, and hypabyssal rocks--that have wide distribution in adjacent areas of central Arizona.

In the general framework of Proterozoic rocks in Arizona, the map area lies in the broad boundary zone between a northwestern zone of older (1775-1700 Ma) greenschist to amphibolite grade volcanogenic rocks and granitic batholiths, and a southeastern province of younger (1710-1610 Ma) greenschist facies volcanic and sedimentary rocks (Conway and Karlstrom, 1986; Karlstrom and Conway, 1986b; Karlstrom and others, 1987; Conway and Silver, in prep.). Rocks having characteristics of the northwestern and southeastern provinces are found in the area, but rocks of the southeastern province dominate volumetrically.

EAST VERDE RIVER FORMATION

The East Verde River Formation, previously called the East Verde River sequence (Wrucke and others, 1983; Conway and others, in prep.) was named by Conway and others (in prep.) for a succession of stratified rocks extensively exposed along the East Verde River, along the eastern flank of the northern Mazatzal Mountains, and along the south rim of Buckhead Mesa. This sequence, composed up-section of mafic flows and volcaniclastic rocks, rhyolite and jasper, siltstone, and graywacke is at least 7,900 m thick. The City Creek series of Wilson (1939) is a locally thick part of the siltstone unit recently subdivided by Hobbs (1982). The East Verde River Formation is segmented by both Proterozoic and Tertiary faults. Parts of the succession are repeated in four structural blocks, but the complete sequence is found only south of the Verde fault. The rhyolite and jasper form a marker unit in all blocks. Consistent westerly facings throughout the westward-dipping graywacke section south of the Verde fault suggest that there is no major repetition by folding.

Strata of the East Verde River Formation are metamorphosed to the greenschist facies but are only mildly to imperceptibly foliated. The rocks are massive and texturally well preserved. The section is composed almost entirely of a lower mafic (basalt and andesite) unit and an upper graywacke unit but has minor intermediate rhyolite and jasper and siltstone. Pillow flows in the mafic section, jasper in the mafic section and in rhyolite breccia, and graded bedding in the siltstone and graywacke indicate the entire section was deposited subaqueously. The graywacke is a typical turbidite sequence in which the facies of the Bouma cycle (Bouma, 1962) are repeated. Petrographic studies indicate the feldspar- and lithic-rich sandstone is probably of volcanic arc derivation.

The lithologies of the East Verde River Formation seem more akin to the island arc suites (Anderson, 1978, 1986) of the Big Bug and Ash Creek Groups of the Yavapai Series (Anderson and others, 1971) to the west than to the Alder, Red Rock, or Mazatzal strata in central Arizona. The lithologies are like those of the Yavapai Series strata in having a high abundance of submarine mafic rocks and a high ratio of mafic to felsic rocks. The graywacke does not have a close analog in the Big Bug Group or Ash Creek Group but its suggested island-arc provenance is such that it may be derivative from and contemporaneous with these groups. The East Verde River Formation bears no resemblance to the Mazatzal Group or Red Rock Rhyolite, and a plausible correlation with the Alder Group would require pronounced facies changes. Alternatively, this sequence may be correlative with neither Yavapai nor Alder strata. No radiometric dates have been obtained for the East Verde River Formation.

TONTO BASIN SUPERGROUP

Alder Group

The Alder Group was originally named the Alder series by Wilson (1939) for exposures outside the southern boundary of the wilderness along Sycamore Creek, which at the time of Wilson's study was known as Alder Creek. Ludwig (1974) interpreted the Alder strata mapped by Wilson (1939) as synclinally folded (Red Rock syncline) and overlain by Red Rock Rhyolite. Approximately 4,300 m of Alder Group strata were subdivided by Ludwig (1974) into numerous units. An additional 2,400 m was found during this study down section in the wilderness in the northwestern limb of the Red Rock syncline. No base has been found. Equivalent strata in Tonto Basin have been subdivided by Gastil (1958) into formations. Because of facies changes and complex structure, only a few lithologic units in the Mazatzal Mountains appear to be correlative with units in Tonto Basin. Quartz sandstone beds and sparse andesite porphyry in the uppermost Alder strata in the map area thicken eastward to form, respectively, the quartzite-shale-quartzite sequence of the Houdon Formation and the andesite of the Board Cabin Formation in the upper Alder Group in Tonto Basin (Conway, 1976; Vance, 1983). However, our knowledge of Alder strata in the Mazatzal Mountains is not sufficient to permit the use of those formational names in this map area, and we have not established new formations. For this reason Alder strata in the Mazatzal Mountains are referred to as Alder Group undivided (Conway and others, in prep.).

The Alder Group consists chiefly of sandy to shaly tuff, graywacke, and shale, and minor conglomerate, mafic and felsic flows, chert, and carbonate rock. According to Ludwig (1974), the clastic rocks in the section are virtually all volcanogenic. Volcanic sandstones, tuffs, and platy lapilli tuffs are abundant. Mafic rocks are found primarily in two units, one low and one intermediate in the section. The proportion of felsic volcanic rocks increases upward in the section; rhyolite flows and volcaniclastic rocks petrographically similar to overlying Red Rock Rhyolite become important in the uppermost 450 m. An upward increase in maturity of sediments and a change from clearly subaqueous deposition to sub-aerial deposition (sub-aerial ash-flow tuff) indicates upward shoaling. Interbeds of gray crossbedded quartz sandstone appear in the uppermost part of the section.

The steeply to moderately dipping Alder strata are mildly to intensely foliated. Axial plane cleavage is commonly parallel to bedding. Consistent stratigraphic facings to the southeast in the northwest limb of the Red Rock syncline indicate that no major duplication by folding of the lower two-thirds of the strata occurs in this limb. However, structural complications, including zones of intense shearing, are present in the upper one-third of the strata in the northwestern limb of the syncline. We cannot be certain of stratigraphic continuity in this part of the section, which lies east of the wilderness boundary. The strata are truncated at a low angle by the steep Sheep Mountain fault. They are not found north of the fault except for possibly equivalent rocks in the northwestern part of the map area near the confluence of the Verde and East Verde Rivers (see below).

Red Rock Group

The type section of the Red Rock Group (Conway and others, in prep.), in the Red Rock syncline, near the southern border of the map area, is a 2-km-thick sequence composed primarily of alkalic ash-flow rhyolite which rests depositionally on the Alder Group. A thick rhyolite mass between the Sheep Mountain and Deadman faults is also considered to belong to the Red Rock Group because it is alkalic ash-flow rhyolite and because, like the Red Rock Group in Tonto Basin (Conway and others, in prep.), it is overlain by quartzite of the Mazatzal Group. Rhyolite near the confluence of the Verde and East Verde Rivers also may be a Red Rock equivalent (see below).

Strata of the Red Rock Group in the Mazatzal Mountains are rhyolite and minor interbedded rocks of other types. They have not been subdivided into formations in this area. Sedimentary and mafic(?) volcanic interbeds were found on the southwest slopes of Sheep Mountain but were not mapped. Flattened pumice lapilli are characteristic and the complete range of ash-flow textures

(Ross and Smith, 1961) are present in the rhyolite. Excellent exposures of several cooling units (Smith, 1960) are found on the southeast slope of Mt. Peeley. Flows, breccias and conglomerates of rhyolite composition are also present in the Red Rock sequences. The generally massive rocks of this group are moderately foliated to unfoliated in the Red Rock syncline, and are unfoliated in the Sheep Mountain block. Preservation of textures is excellent.

Mazatzal Group

Wilson's (1922, 1939) type exposures of Deadman Quartzite, Maverick Shale, and Mazatzal Quartzite occur in the Mazatzal Wilderness. We follow the proposal of Conway (1976) and Conway and others (in prep.) that this sequence be named the Mazatzal Group and the proposal of Anderson and Wirth (1981) and Conway and others (in prep.) that the Mazatzal Quartzite be renamed the Mazatzal Peak Quartzite. We subdivide the Mazatzal Peak Quartzite into a lower red member and an upper white member. The contact between these members as seen from a distance appears generally clear and sharp, but it is gradational over a few meters to several tens of meters. The Mazatzal Group is consistent in lithology and thickness in the structural block between the Sheep Mountain and Deadman faults, except that the Deadman Quartzite is nearly 10 times as thick along Cactus Ridge as it is along Deadman Creek and along the northeast flank of the Mazatzal Mountains. The Deadman at Cactus Ridge is in the upper plate of a thrust and may have been transported from many kilometers to the southeast (Wilson, 1939; Puls, 1986).

A tiny exposure of red-brown quartzite in the southernmost part of the map area near Highway 87 may be equivalent to the quartzite of the Mazatzal Group. It is surrounded by Tertiary deposits, but lithology and bedding attitude incompatible with upper Alder Group rocks on strike suggest this block may be faulted (probably thrust) into its position.

Quartzite at Pine Creek in the northeastern part of the area is comparable in thickness to the type Mazatzal Group and lithologically similar to the Deadman Quartzite and red lower member of the Mazatzal Peak Quartzite. A thin, silty quartzite in the Pine Creek section is possibly equivalent to the Maverick Shale, but the evidence to confirm this correlation is insufficient. Thus, the Pine Creek strata are designated Mazatzal Group undivided.

Prevalent crossbedded strata of the Mazatzal Group is largely coarse-grained quartz sandstone. Pebbly lenses are locally common; clasts are white bull-quartz, jasper, and minor chert. As noted by Wilson (1939), the quartzite, has a purplish tint, although colors vary in shades of brown and red. Even the upper white member of the Mazatzal Peak Quartzite is typically pinkish. The characteristic redness of the quartzite results from the oxidized state of the accessory minerals. Sedimentological analysis of the quartzite (Trevena, 1979, 1981) indicates deposition in fluvial to near-shore marine environments. Paleocurrent analysis (Trevena, 1979; Conway and others, 1981) indicates a general northwest to southeast sediment transport pattern.

Strata Near the Confluence of the Verde and East Verde Rivers

Two unconnected sections of Proterozoic stratified rocks near the confluence of the Verde and East Verde rivers have some similarities. The western section, near Squaw Butte, contains a quartzite overlain by rhyolite. The quartzite unit varies from light-gray quartzite to dark-gray or brown lithic sandstone. The rhyolite contains flow and ash-flow tuff facies. The lithologies and succession suggest equivalence to uppermost Alder Group and to the Red Rock Group. The other section, a few miles to the east near the Limestone Hills, is siltstone and conglomerate composed mostly of rhyolite clasts overlain by rhyolite and subordinate mafic volcanic rocks. This section rests with slight angular discordance on graywacke of the East Verde River Formation. The siltstone and conglomerate are red beds, in contrast with the largely unoxidized gray quartzites of the Squaw Butte section, but the rhyolite has ash-flow tuff lithologies similar to those at Squaw Butte. The red conglomerate with rhyolite clasts, similar to conglomerates in the Red Rock Group in Tonto Basin and at the base of the Mazatzal Group at Pine Creek and at Cactus Ridge, the ash-flow tuff rhyolite, and the bimodality suggest the Limestone Hills section may correlate with the Red Rock Group.

DIAMOND RIM INTRUSIVE SUITE

Much of the central to northern parts of the study area are underlain by generally oxidized, leucocratic, felsic hypabyssal rocks that are part of the Diamond Rim Intrusive Suite (Conway and others, in prep.). The suite is composed largely of granite, but includes granophyre, aplite, and intrusive rhyolite (including tourmaline-bearing dikes). These rocks intrude the East Verde River Formation, the Proterozoic sequences near the confluence of the Verde and East Verde rivers, and Red Rock Group near Deadman Creek. Felsic dikes and sills, including the Pine Mountain Porphyry, that intrude the Alder Group in the Red Rock syncline are also included in this suite. A body of rhyolite and granophyre 1.5 km north-northeast of North Peak intrudes graywacke of the East Verde River Formation and is nonconformably overlain by Deadman Quartzite.

The felsic hypabyssal suite has close analogs to felsic rocks of the Diamond Rim Intrusive Suite in Tonto Basin, which is documented to be of petrologic affinity (Conway, 1976) and identical age (Conway and Silver, in prep.) to rhyolite of the Red Rock Group. The granites appear to be identical to the Payson Granite and the granophyres to the Green Valley Hills Granophyre in Tonto Basin. The rhyolite and granophyre near North Peak, mentioned above, contains both spherulitic and micrographic textures as does a sill of Green Valley Hills Granophyre at King Ridge in Tonto Basin. Analyzed samples from the Diamond Rim Intrusive Suite in the Mazatzal Wilderness are compositionally identical to rocks fo the Diamond Rim Intrusive Suite in the Tonto Basin. The intrusion of granite and granophyre into the Red Rock Group, and the nonconformity between the granophyre and the overlying Deadman Quartzite constrain the age of the felsic hypabyssal suite approximately to Red Rock time.

A weakly porphyritic granite at East Cedar Mountain on the west-central margin of the map area is subtly but distinctly different than the widespread alkali granite. In addition to being porphyritic, it has a higher mafic mineral content than the alkali granite. A molybdenum anomaly in drainage sediments of this area is apparently related to this granite (Wrucke and others, 1983). The porphyritic granite is assumed to be of Proterozoic age and could be related to the granitic and hypabyssal rocks in the central and northern parts of the area. Alternatively, it might be younger.

GIBSON CREEK BATHOLITH

Diorite and minor gabbro, granodiorite, and quartz monzonite of the Gibson Creek batholith (Conway and others, in prep.) occur along the northeast margin of the area. This complex of mostly medium- to coarse-grained plutonic rocks is intruded east of the study area by Payson Granite and Green Valley Hills Granophyre (Conway, 1976). Our observations along the East Verde River northeast of the area mapped indicate that the Gibson Creek batholith intruded the East Verde River Formation.

Petrologically, the Gibson Creek batholith is similar to the batholithic suite which intrudes strata of Yavapai Series age in the Bradshaw Mountains and Black Hills near Prescott. Its felsic rocks have markedly higher calcium/alkalis than the felsic hypabyssal suite of the Tonto Basin (Conway, 1976) and Mazatzal Mountains. The batholith has a calcic alkali-lime index (Peacock, 1931).

GABBRO AND DIORITE IN THE LIMESTONE HILLS

Gabbro and diorite intrude the East Verde River Formation and the rhyolite-conglomerate section at Limestone Hills a few kilometers east of the confluence of the East Verde and Verde rivers. These plutonic rocks, although similar in appearance to rocks the Gibson Creek batholith, are probably younger. The intruded Limestone Hills section is presumed to be of Red Rock age, whereas the Gibson Creek batholith is probably older, the same age as the batholith of the Bradshaw Mountains and Black Hills.

PORPHYRITIC QUARTZ MONZONITE

Coarse-grained porphyritic quartz monzonite intruded undivided strata of the Alder Group at Bartlett Reservoir in the extreme southern part of the map area. Pegmatites and hornfels metamorphism in the Alder rocks are due to intrusion of this quartz monzonite. This plutonic body resembles coarse-grained porphyritic granitic rock widespread to the south (e.g. Ruin Granite, Oracle Granite) in Arizona and is therefore assumed to be of the anorogenic 1410-1430 Ma suite of Arizona (Silver, 1969).

PROTEROZOIC STRUCTURAL GEOLOGY

FRAMEWORK

The conspicuous arcuate Sheep Mountain and Deadman faults divide the region into three structural blocks. The block south of the Sheep Mountain fault contains the Red Rock syncline (Ludwig, 1974) in which the most complete known Alder Group section in central Arizona is overlain by the Red Rock Group. Foliation is mild to intense in these steeply dipping strata and is generally parallel or at a low angle to bedding. Although incompetent shaly units contain common small rootless folds and transposed bedding, strata in the northwest limb of the Red Rock syncline are not broadly disrupted and generally display stratigraphic tops and steep dips to the southeast.

The central structural block between the Sheep Mountain and Deadman faults contains broad exposures of the Mazatzal Group resting depositionally at low dip angles on the Red Rock Group in the south and west and on East Verde River Formation and spherulitic rhyolite and granophyre in the north and east. Numerous thrust faults in this structural block, largely within the Mazatzal Group, dip gently to moderately south to southeast. Slickensides, minor folds (primarily in the Maverick Shale), and flexures spatially associated with thrusts indicate thrusting was to the northwest. The Mazatzal and Red Rock strata are mostly broadly folded on shallowly plunging north- to northeast-trending axes and are weakly to imperceptibly foliated. The East Verde River strata and overlying Deadman Quartzite and Maverick Shale along the east flank of the mountains are moderately to steeply dipping, locally complexly folded and strongly foliated. On the lower east flank of North Peak, lithologic units and folds within the graywacke of the East Verde River Formation are truncated by the erosional surface beneath the Deadman Quartzite.

The third structural block, northwest of the Deadman fault, consists largely of unfoliated granite and granophyre which intruded unfoliated to mildly foliated strata of the East Verde River Formation. Although variations in bedding strike and rare reversals in stratigraphic tops indicate local flexures in the East Verde River strata, no major folds were recognized in the thick mafic volcanic and graywacke sections of this structural block. These beds constitute a steep homoclinal sequence facing to the northwest. The stratigraphic relation between the East Verde River Formation and the rhyolite and conglomerate beds of the Limestone Hills area is unclear. There may be a simple up section continuity or, as suggested by the lithologic change from reduced subaqueous turbidites to subaerial red-beds, there may be a stratigraphic or structural discontinuity. The rhyolite and conglomerate beds dip steeply northwestward south of the Verde fault and shallowly northward with gentle flexures north of the Verde fault. The section of gray quartzite and rhyolite a few miles to the west near Squaw Butte is intruded on the south by granite and folded into a syncline plunging moderately to the northeast. Mazatzal strata and underlying East Verde River Formation along Pine Creek and on the south slopes of Buckhead Mesa constitute a westward-dipping homoclinal sequence. A depositional break if possible beneath the quartzite and basal rhyolite flows and the underlying massive, coarsely porphyritic rhyolite (see below).

FOLDING, THRUSTING, AND THE MAZATZAL OROGENY

Wilson (1939) mapped folds and thrust faults affecting the Mazatzal Group, the underlying rhyolite, and granite in the northern Mazatzal Mountains and proposed the name Mazatzal revolution (orogeny now preferred) for the tectonic event that caused this deformation. Thus the

Mazatzal Wilderness contains the type area for the Mazatzal orogeny, the effects of which are widespread in central to southeastern Arizona but are as yet incompletely defined (Silver, 1978; Conway and others, 1982; Karlstrom and Conway, 1986a; Conway and Silver, in prep.). Wilson's (1939) conclusion that the deformation resulted from intense northwest-southeast compression is supported by our studies of fold and thrust geometries and by the recent detailed structural study in the Mazatzal Mountains by Puls (1986).

Our mapping in the high northern Mazatzal Mountains revealed a thrust fault pattern similar to that of Wilson (1939, Plate 10) but somewhat more complex. Slickensides and quartz fibers on and near these faults at more than a dozen localities, mostly in quartzite, consistently yield thrusting directions to the west to north-northwest. Most of the thrusting is within the Mazatzal Group and the major basal thrust between Mazatzal Peak and North Peak roots in the Maverick Shale. We agree with Wilson's (1939) suggestion that because the Deadman Quartzite is so much thicker in the upper plate than in the lower plate (270 m vs 30 m), the upper plate must have been thrust several kilometers to the northwest, opposite the direction in which the Deadman Quartzite would progressively thicken. Karlstrom and Puls (1984) postulated similar large movements on the thrust faults. Puls (1986) has recently mapped the thrust faults at 1:10,000 scale and suggested the presence of a roof fault, unrecognized by us, having a minimum offset of about 15 km. Anderson and Wirth (1981) suggested that Deadman Quartzite is only thicker at Cactus Ridge in the upper plate due to a thick channel deposit and, therefore, that little thrusting is required. Conway (1976) found that the Agate Mountain thrust fault, 20 km to the east in Tonto Basin, had from 7 to 10 km of displacement, assuming thrusting to the west or northwest.

Folds in the Alder, Red Rock, and Mazatzal Groups trend northeastward and thrusting in the Mazatzal Group was to the northwest, indicating a common cause. A thrust about 1 km north of Mazatzal Peak seems to die out along strike to become a fold axis. The low-angle faults in Deadman Quartzite along the eastern flank of the northernmost Mazatzal Mountains are minor breaks related to a sharp upward flexure of the strata. Puls (1986) has found evidence that some thrusting predated folding. Although thrusts were recognized only in the central structural block, an isolated exposure of probable quartzite of the Mazatzal Group near Highway 87 in the southern part of the area may owe its anomalous position to thrusting.

The folds affecting Early Proterozoic strata in the study area may be related to broad northeast-trending and gently plunging anticlinoria and synclinoria. An anticlinorium might exist approximately over the major granite mass in the center of the area and include on its southeastern flank the present exposure area of the Mazatzal Group. A synclinorium in the southeastern part of the area would include the Red Rock syncline, which is on strike with and likely a southwest extension of the Tonto Basin synclinorium (Conway, 1976). The syncline in the Squaw Butte section may be part of a second synclinorium to the northwest. Thus the granite complex, deep in the stratigraphy, as well as the East Verde River Formation, are exposed in the anticlinorium. In the flanking synclinoria the stratigraphic section is exposed as high as the Red Rock Group and possible related rocks. The Mazatzal Group would have been entirely eroded from the region had not faulting on the Deadman and Sheep Mountain faults dropped down a graben block approximately high on the southeastern limb of the anticlinorium.

LATE STEEP ARCUATE FAULTS

The Deadman and Sheep Mountain faults and similar smaller faults in the area are considered to be Early Proterozoic in age because they are similar in character to a set of faults in Tonto Basin that predate deposition of the Middle Proterozoic Apache Group (Conway, 1976). They are steeply dipping arcuate faults that trend from northeast to north. It appears that late movement on these faults was mostly normal, although there may have been an early period of extensive left-lateral strike-slip motion. Rotated and down-dropped fault slices along the northern part of the Deadman fault, attest to east-west tension during this faulting episode. On a larger scale, the entire block between the Deadman fault and the Sheep Mountain fault may be a graben because, as discussed earlier, the Mazatzal Group, the uppermost unit in the regional Early Proterozoic stratigraphy, is preserved only in this fault block. It follows that if thrusting predated normal faulting, as demonstrated in Tonto Basin (Conway, 1976), the thrust faults were also down dropped in the central block. Thus the extensions of these thrusts south of the Sheep Mountain fault would be at a higher level and were eroded away. This interpretation does not preclude thrusting in the other two blocks, but it has not as yet been recognized.

STRUCTURAL RELATION BETWEEN THE EAST VERDE RIVER FORMATION AND OVERLYING PROTEROZOIC ROCKS

The regional relation between the East Verde River Formation and the Alder, Red Rock, and Mazatzal Groups is unclear, but locally there is evidence of an intervening deformational and erosional episode. Along the eastern flank of the northern Mazatzal Mountains, the Deadman Quartzite rests in angular unconformity on the graywacke, rhyolite and jasper, and mafic volcanic units of the East Verde River Formation, and a fold in the graywacke 1.5 km northeast of North Peak is apparently truncated by the unconformity. In the Limestone Hills, rhyolite and associated strata that probably are equivalent to the Red Rock Group appear to rest unconformably on the East Verde River Formation. At Pine Creek several rhyolite flows beneath quartzite of the Mazatzal Group (and similar to a flow about 300 ft up section in the quartzite) rest, possibly unconformably, on a massive to locally flow-foliated rhyolite porphyry. The rhyolite porphyry is altered on its western margin near the rhyolite flows, but eastward is well-preserved. The distribution of alteration suggests weathering beneath an erosional surface prior to deposition of the rhyolite flows. The rhyolite porphyry, characterized by a high content of large (3-8 mm) phenocrysts of quartz, plagioclase, potassium feldspar and mafic clots, is dissimilar to any rhyolite of the Red Rock Group and possible equivalent units. On the south rim of Buckhead Mesa, this rhyolite porphyry is in contact with siltstone of the East Verde River Formation, but the nature of the contact could not be ascertained. Though unusual petrographically (abundant large quartz, plagioclase, and K-feldspar phenocrysts and mafic clots), this rhyolite is compositionally similar to Red Rock Group and cogenetic hypabyssal rocks of the region. It is possible, though unlikely, that the rhyolite porphyry is genetically akin to the East Verde River Formation. If so, its upper eroded surface would be another example of an unconformable surface on the East Verde River Formation.

PROTEROZOIC GEOLOGIC HISTORY

The East Verde River Formation and the Gibson Creek batholith apparently are unconformably overlain by the Alder-Red Rock-Mazatzal Group succession in the Mazatzal Mountains and the Tonto Basin region. This relation is inferred from the lithologic contrasts between the East Verde River Formation and the apparently younger supracrustal rocks, from the stratigraphic discontinuities discussed above, and from preliminary geochronologic data. The East Verde River strata and the Gibson Creek plutonic rocks have lithologic affinity to strata of the Yavapai Series and batholithic rocks of the Bradshaw Mountains and Black Hills, and a 1,738±4 Ma age for granodiorite of the Gibson Creek batholith (Silver and others, 1986) is in the range (1730-1760 Ma) for most of the stratified and plutonic rocks of those areas (Anderson and others, 1971; L. T. Silver, 1983, oral comm.). Rhyolite in the upper Alder Group, the Red Rock Group, and the rhyolite flow in quartzite at Pine Creek are indistinguishable in age at 1,700±6 Ma (Silver, 1965, 1967; Ludwig, 1974; Silver and others, 1986). Rhyolite of the Red Rock Group and the felsic hypabyssal units in the Tonto Basin are of the same age (Conway, 1976; Conway and Silver, in prep.; Silver and others, 1986). Thus the East Verde River Formation and the Gibson Creek batholith could be some 40 Ma older than the upper Alder-Red Rock-Mazatzal succession and affiliated felsic hypabyssal rocks and would have been deformed and eroded prior to deposition or intrusion of the 1700 Ma rocks.

There are problems, however, with this hypothesis. The absence of the Alder Group and Red Rock Group beneath the Deadman Quartzite at the unconformity in the northern Mazatzal Mountains suggests Alder and Red Rock strata, and thus the contemporaneous hypabyssal complex as well, may be part of a basement complex. This is apparently supported by the nonconformity of Deadman Quartzite on granophyre near North Peak and by our observations that ash-flow tuff layers in the Red Rock Group along Deadman Creek and uppermost City Creek are overlain by Deadman Quartzite at angles up to 30-40°. Thus an alternative hypothesis is that the Mazatzal Group rests unconformably on a deformed and eroded basement consisting of all other rocks in the region.

We prefer the first hypothesis because stratigraphic continuities, similar ages, and lithologic affinities require that the upper Alder Group and the Red Rock and Mazatzal Groups of the Tonto Basin-Mazatzal Mountains region constitute a continuous sequence (Ludwig, 1974; Conway, 1976; Conway and others, in prep.; this study). Only the undated middle to lower portion of the Alder Group, which has some lithologic dissimilarities to the overlying rocks, could possibly be discontinuous, but there is no evidence for this. Given this continuity through the Alder into the Red Rock, local absence of Alder and Red Rock (see above) would require relief on the pre-Alder erosional surface such that high areas precluded deposition of parts or all of the Alder and Red Rock Groups. This seems unlikely, inasmuch as the Alder Formation is 6,700 m thick. A possible explanation lies in relief developed from deformation and erosion associated with volcanism during late Alder and especially Red Rock time, as outlined in the following paragraphs.

The unconformable relations between Deadman Quartzite and the Red Rock Group and intrusive rhyolite and granophyre may be due to volcanic-related processes and local erosion rather than to regional orogenesis and erosion. Regionally, rhyolite volcanism and quartz arenite sedimentation were broadly synchronous from late Alder through Mazatzal time (Conway and Silver, 1984). Both quartzite and rhyolite occur in the upper Alder Group. There is little overlap of quartzite in the Mazatzal Group with rhyolite in the Red Rock Group perhaps because volcanoes rose above the levels of deposition in coastal plains and shallow offshore waters. Following a possible combination of subsidence and rapid erosion, quartz sandstone sedimentation dominated in Mazatzal time but was accompanied by some volcanism as shown by the rhyolite ash flow in quartzite at Pine Creek and the intrusion of rhyolite into Mazatzal Quartzite in eastern Tonto Basin (Conway, 1976; Silver and others, 1986). Calderas are an integral part of ash-flow tuff complexes and would have developed in connection with ash-flow volcanism of the Red Rock Group. Uplift, collapse, rotation of large blocks, and rapid erosion associated with caldera formation immediately prior to deposition of the Deadman Quartzite may explain the observed angular unconformity and nonconformity.

Huge blocks of ash-flow tuff dipping at high angles in the orogenically undeformed Middle Proterozoic ash-flow tuff complex of the St. Francis Mountains, Missouri are explained by caldera deformation (Kisvarsanyi and others, 1981; C. M. Conway, 1981, personal observations). Even without caldera deformation, erosion of naturally dipping volcanic strata could produce a surface at an angle to flow foliation.

It is well known that the great Phanerozoic ash-flow tuff complexes are continental and that the bimodal alkali rhyolite-basalt complexes form in either rifting (e.g. Basin and Range, Rio Grande Rift) or hot spot (e.g. Yellowstone) environments. Likewise, crossbedded quartzite formations are continental. The great thickness of quartzite and the voluminous subaerial ash-flow tuffs argue for a semi-stable, but subsiding, continental environment from late Alder through Mazatzal time (Conway and others, 1982, Conway and Silver, 1984).

Both local (caldera) and regional (rifting) deformation, including normal faulting, block rotation, and possible strike-slip faulting, may have been factors not only in deposition of quartzite on truncated ash-flow tuff and hypabyssal bodies but in contributing to local relief that exposed the presumed basement rocks (East Verde River Formation and Gibson Creek batholith) or juxtaposed them against younger rocks as late as Mazatzal time. This argument is weakened, however, by the apparent absence of detritus in the upper parts of the continental supercrustal sequence that should have been derived from high-standing eroded blocks of the lower part of this sequence or of the East Verde River Formation or the Gibson Creek batholith.

The slight degree of foliation in the East Verde River strata as opposed to commonly intense foliation in the Alder strata may be a function of different rock competencies and of inhomogeneous strain during the Mazatzal orogeny and cannot be taken as an argument that Alder rocks are older. The mostly massive strata of the East Verde River Formation have a low content of platy minerals and are not readily susceptible to penetrative deformation, whereas abundant shaly rocks in the Alder Group are highly susceptible to foliation and folding. Similarly, massive rhyolite and quartzite units of the Red Rock Group and the Mazatzal Group commonly show no foliation and are openly folded in contrast to isoclinally folded Alder strata in the Mazatzal Mountains. As an example of inhomogeneous strain, Alder Group rocks are openly folded and very weakly foliated in the Board Cabin area of Tonto Basin, whereas elsewhere in Tonto Basin, the same units are isoclinally folded and intensely foliated (Conway, 1976).

The Early Proterozoic geology of the Mazatzal Wilderness is complex and many questions of geologic history remain unsolved. Hypotheses other than the two presented above may be invoked. For instance, some of the tectonic boundaries in the study area, and possibly unrecognized boundaries, may be products of assembly by crustal-scale tectonics of tectonostratigraphic terranes of widely varying origin (Karlstrom and Bowring, 1987).

In summary, the East Verde River Formation accumulated in marine magmatic arc and marginal basin environments and was intruded by the Gibson Creek batholith. The East Verde River Formation, and possibly the Gibson Creek batholith, were folded but not penetratively deformed by an orogenic event apparently preceding deposition of the Alder Group, Red Rock Group, and Mazatzal Group. The absence of Alder Group where Mazatzal and possibly Red Rock strata rest unconformably on the East Verde River Formation, may be due to high relief on the eroded basement, to faulting during Red Rock time, or to unrecognized tectonic assembly. The Alder Group is largely a subaqueous, clastic and bimodal volcanic sequence dominated by fine-grained sediments and felsic pyroclastics, but uppermost crossbedded, mature sediments indicate shoaling. Ash-flow tuff of the Red Rock Group and quartzite, quartz sandstone, and siltstone of the Mazatzal Group were deposited on semi-stable continental crust. Quartz sandstone sedimentation and rhyolite volcanism occurred from late Alder through Mazatzal time probably in a fluvial to shallow marine coastal environment. The great thickness of the quartz sandstone successions suggest continued subsidence, and the alkalic composition of the rhyolite suggests continental rifting or hot spot magmatism. Quartz arenite sedimentation and rhyolite volcanism may have been interrupted by the regional northwest-southeast compression of the Mazatzal orogeny in which the supercrustal strata were folded and thrust toward a foreland to the northwest. Brittle, non-penetrative deformation, and extremely low grade of metamorphism preclude deep burial during the orogeny and suggest also that little strata, if any, were deposited above the Mazatzal Group. Either as a late stage in the Mazatzal orogeny, or at some later time, the regional stress changed, causing the development of northeast- to north trending normal faults and grabens. The arcuate trend of the faults, grabens on north-south segments, and evidence in Tonto Basin for left-lateral motion (Conway, 1976) suggest the new tectonic stress was that of a left-lateral couple influencing a broad region. In terms of plate tectonics, the foreland thrusting may have been caused by plate collisions roughly normal to the North American craton margin, and the normal faulting by non-orthogonal plate interaction. Subsequent to these deformations, intrusion by the coarse-grained porphyritic quartz monzonite (probably about 1.4 Ga) concluded the stabilization of the Proterozoic crustal complex.

The inference of two orogenic episodes, one accompanied by development of a regional unconformity before accumulation of the Alder Group and another, the Mazatzal orogeny, after deposition of the Mazatzal Group, has major implications for the Proterozoic history of the southwestern U.S. If substantiated, the proposed unconformity will provide the first evidence for the physical nature of an age boundary that extends from central Arizona eastward through northern New Mexico between the northern older and southern younger Early Proterozoic provinces (Silver, 1965, 1967, 1969; Silver and others, 1977).

PALEOZOIC ROCKS

Cambrian and Devonian rocks crop out in the Limestone Hills, along the East Verde River, and, together with Mississippian and Pennsylvanian strata, in upper Pine Creek. They consist of the Cambrian Tapeats Sandstone, the Devonian Martin Formation, the Mississippian Redwall Limestone, and Pennsylvanian Naco Formation. These formations were deposited on a surface of low relief developed on the Proterozoic basement. At most places the Tapeats Sandstone is the lowest Paleozoic formation, but locally the Martin Formation rests on the Proterozoic rocks. The Paleozoic formations are similar in lithology and thickness to their counterparts elsewhere in central Arizona. They have an aggregate thickness of about 240 m and are regarded as shelf deposits that accumulated at the edge of the North American craton.

TERTIARY ROCKS

Tertiary rocks crop out in about half the area and are extensively exposed north of the East Verde River and in the valley of the Verde River. They consist of fluvial and lacustrine deposits, basalt flows, and siliceous flows, tuffs, and breccias, forming sections as much as 700 m thick. These rocks record a complex interplay of sedimentary and volcanic processes beginning in the mid-Miocene and possibly continuing into the Pliocene. This record is one of crustal instability involving basin development and volcanic eruptions that resulted in abrupt lateral facies changes and the interfingering of sedimentary deposits with lava flows and tuffs.

SEDIMENTARY ROCKS

Tertiary sedimentary rocks are found chiefly in the north-trending valleys along the western and eastern margins of the area, but scattered exposures exist in the mountains areas. In the valley of the Verde River, a variety of sedimentary units were mapped separately, whereas in the lowlands on the east side of the area many of the sedimentary rocks were combined into a single unit designated as sedimentary deposits undivided. Although deposits of similar composition are found in both valleys, the correlation of the rock types from one valley to the other is poorly understood.

The oldest Tertiary deposits in the map area belong to the older conglomerate, which is widely exposed in the central and northeastern parts of the area. Clasts that make up the unit were derived from eroding Proterozoic terrane and consist principally of granite, granophyre, rhyolite, and quartzite. They were deposited as sandstone as well as conglomerate. As seen in good exposures in the Limestone Hills, reddish grus and pebbly conglomerate made of Early Proterozoic granitic and quartzitic clasts are dominant lithologies. In the central part of the study area, the older conglomerate rests on Proterozoic rocks, whereas northward in the Limestone Hills it lies on Devonian beds, and in the northeastern part of the area, in addition to resting on Proterozoic rocks, the conglomerate lies on Paleozoic strata as young as Pennsylvanian. Except for younger gravel containing flow basalt included in the unit in the southeastern part of the area, the older conglomerate is devoid of materials of Cenozoic age and, therefore, probably is older than 16 Ma, the age of the oldest Tertiary basalt dated in the area and the surrounding region.

Because the older conglomerate in the central and northern parts of the area rests on Paleozoic substrata, the Proterozoic clasts it contains can only have been derived from areas southwest of the Mogollon Rim. In this respect the deposit resembles early to middle Tertiary conglomerates that were deposited over much of central and northern Arizona by streams draining northward from a Precambrian highland once located in the present position of the Basin and Range Province (Conway and others, 1986; Peirce, 1986). However, the older conglomerate lies so close to the Mogollon Rim, as discussed below, and on strata near the base of the Pennsylvanian section, far below Permian rocks at the rim crest, that it probably accumulated after development of that escarpment and is, therefore, likely to be younger than the conglomerates that blanketed the region before faulting that produced the horst and graben structure of the transition zone in the Mazatzal area. Local transport of material for the older conglomerate in the Limestone Hills and northeastern parts of the area could have been from directions other than northward.

Additional indications that the older conglomerate may have been deposited by drainage other than northward is provided in the nearly continuous exposures of the unit from the crest of the Mazatzal Mountains west and southwest almost to Horseshoe Dam. Part of the westerly drop in altitude of the unit in this area is the result of faulting and tilting, but much of it results from deposition of the conglomerate in an integrated system of paleochannels that descends rapidly to the southwest. The base of the paleovalley in one tributary channel drops in altitude from 1,900 m near the crest of the range in the general vicinity of Mazatzal Peak to less than 1,100 m in the main channel in Davenport Wash, southeast of Table Mountain. This drop takes place in distance of about 11 km, as measured along the channels in one structural block. The older conglomerate in this part of the area is older than the 15 Ma flow near the base of the overlying older basalt that buries the southwestern end of the paleovalley.

Yet another indication that the older conglomerate predates the Mogollon Rim is based on a study by Peirce (1987) of exposures in the canyon of Fossil Creek, immediately north of the map area and west of the rim (Weir and Beard, 1984). Fossil Creek flows southwest and joins the Verde River in the northwestern part of the map area about 2 km north of the confluence of the Verde and East Verde Rivers. In the Fossil Creek area, Peirce found that a thick, nearly flat lying sequence of layered Tertiary volcanic rocks overlying a Tertiary gravel was deposited against a westerly facing paleoescarpment having a relief of 405 m in a lateral distance of less than 1.2 km. The escarpment was developed on Paleozoic strata. According to Peirce, the gravel is a fluvial deposit that accumulated in a topographic low at the base of the ancestral Mogollon Rim. We interpret this gravel as possibly equivalent to the older conglomerate, as it occupies a position beneath an exposed thickness of 540 m of volcanic rocks that demonstrably are coextensive with late to middle Miocene basalt flows at the northern edge of our map area. In composition the gravel is similar to the older conglomerate in consisting of debris derived form Precambrian rocks (Weir and Beard, 1984). Peirce's conclusion that development of the pre-gravel surface is the oldest Tertiary event detected in the Fossil Creek area is in accord with our interpretations that the surface on which the older conglomerate rests is mid-Miocene or older and was deposited after the rim was carved and topographically below it.

Above the basalt that rests on the older conglomerate is the younger conglomerate that is widely exposed along the Verde River. Upper beds of this conglomerate interfinger to the east with flows of the younger basalt and grade to the west and upward into the sandstone deposited along the axis of the valley of the Verde River. The conglomerate and sandstone contain a high percentage of clasts derived from Tertiary volcanic rocks.

Limestone at Chalk Mountain overlies the sandstone, is the youngest Tertiary deposit in the valley of the Verde River, and represents deposition in a closed basin. It contains algal mats and stromatolites suggestive of accumulation in shallow water, possibly in playas. Similar Tertiary limestone resting on 11 Ma basalt west of Pine Creek in the northeastern part of the area may be correlative.

The younger conglomerate rests on basalt as young as 12.3±8 Ma, and upper beds of the sandstone above the conglomerate contain a basalt flow dated at 8.3±,9 Ma. Possibly the limestone at Chalk Mountain, which lies at least 70 m above the 8.3 Ma basalt, is as young as Pliocene. No fossils were found in a brief examination. The K-Ar ages indicate that younger parts of the Tertiary sedimentary section in the valley of the Verde River correlate with the Miocene and Pliocene Verde Formation, whose southeasternmost exposures are upstream along the Verde River as close as 8 km to the northwestern part of the map area (Nations and others, 1981).

VOLCANIC ROCKS

Basalt flows, in addition to those interlayered with sedimentary deposits in the valley of the Verde River and in Pine Creek, form thick sequences along the northern, western, and southern borders of the area. Subdivision of these sequences into older and younger basalts could be made in the valley of the Verde River where they are separated by the younger conglomerate and in the mountains near the southern border, where individual flows generally cannot be recognized in the older basalt but can be identified in the younger basalt. Despite excellent exposures, no distinctive, laterally extensive stratigraphic breaks were identified in the basalt sequences west of the Verde River and north of the East Verde River. Thus, in these areas, the rocks are designated as basalt undivided.

The thickest and most extensive exposures of basalt in the area are north of the East Verde River. Here, numerous cliffs 100 m high reveal layer on layer of flows 2-40 m thick, locally interspersed with conspicuous sections of basaltic sandstone, and, at a few places, are interrupted by buried cinder cones. Between the East Verde River and Hardscrabble Mesa, this sequence is at least 700 m thick, and no top is exposed.

Throughout the map area, the basalt units are mostly olivine basalt in which many flows have large phenocrysts of dark-green pyroxene. Chemical analyses (Table l) show that the basalt has a high content of total alkalies and would be classed as alkalic, and that andesite is also present in the undivided basalt on the western border at Tangle Peak and trachandesite in the older basalt near the southern border at Lion Mountain.

K-Ar ages indicate that the basalt ranges in age from 16.1±15 Ma to 8.3±9 Ma (Table 2). The oldest K-Ar age is from a thin flow remnant near the crest of the Mazatzal Mountains, and the youngest age is from the highest flow in the younger basalt along the Verde River. Basalt in the northern part of the map area has yielded K-Ar ages from 13.4±8 Ma at the bottom of the East Verde River to 10.3±8 Ma on Cedar Bench, 3.6 km northeast of the junction of the Verde and East Verde Rivers. Basalts of the map area therefore have a somewhat greater range in age than the 14.6 to 10.1 Ma basaltic flows in the Hickey Formation of the Prescott area to the west (McKee and Anderson, 1971, p. 2769). Upper flows in the map area correlate with basalt in the Thirteenmile volcanics (Elston and others, 1974) along the Verde River a few kilometers northwest of the area.

Basalt of the Mazatzal Wilderness and the Hickey Formation are similar chemically and in geologic setting as well as in age. Most flows in the Hickey Formation are alkalic basalt, and, like the flows in the map area, they contain rocks that today would be classed as andesite, and they interfinger with trachyandesite (McKee and Anderson, 1971, p. 2776-2779). Twenter (1961), in a study of Miocene and Pliocene rocks in the transition zone of central Arizona, found that many of the late Tertiary sedimentary basins have rocks of the Hickey Formation or its equivalents. Basalt flows in these basins interfinger with and are overlain by fluvial and lacustrine beds of Miocene and Pliocene age.

The siliceous flows, tuffs, and breccias that interfinger with the basalt were erupted from intrusive centers represented by plugs at Squaw Butte and near Lion Mountain. Extrusive siliceous rocks are sparse around Squaw Butte and exist only within about 8 km of the plugs at Lion Mountain. A plug near the northwest corner of the area has no associated siliceous flows or tuffs, and only a miniscule amount of tuff occurs with the siliceous dikes a few kilometers to the west at Ikes Backbone. Siliceous tuff at Black Ridge north of Squaw Butte may have erupted from an ancient volcano at Hackberry Mountain, 12.5 km to the north (Elston and others, 1974; Lewis, 1983). The siliceous rocks range from dacite having 65.31 percent SiO_2 to rhyolite having 72.67 percent SiO_2 (Table 2). K-Ar ages obtained for the siliceous rocks are 11.0±6 Ma for tuff at Black Ridge, 8.9±6 Ma for the plug at Squaw Butte, and 5.3±2 for a plug near Lion Mountain.

TERTIARY STRUCTURAL GEOLOGY

North- and northwest-trending faults are the conspicuous structural features of Tertiary age in the map area. North-trending faults were active in the late Miocene, as the grabens they produced along the Verde River and the eastern border of the area became depositional basins at that time, and both basins are cut by northwest-trending faults. The existence of the basins indicates that extension has been active in this part of the transition zone.

In a general way, the north- and northwest-trending faults in the map area developed approximately contemporaneously because faults of both sets cut faults of the other, and some faults merge or curve from one trend to the other. A notable example of a fault that changes trends is near the west border west of Horseshoe Dam. This fault changes trend from northwest to north near the south border of the area, then trends north for many kilometers to the vicinity of East Cedar Mountain where it again curves to the northwest. Despite the apparent approximate contemporaniety, north-trending faults more commonly than not are offset by northwest-trending faults.

The dominant Tertiary structural feature in the area is the northwest-trending Verde fault, which extends from east of the Deadman fault, with which it merges, northwesterly to the Verde River. West of the Verde River the fault becomes a distinct lineament that can be traced northwest of the map area across central Arizona, and that finally curves gently north to near Jerome, a distance from the Deadman fault of about 95 km. At Jerome the fault is mostly steep, comprises a main strand and many subordinate faults, and has a throw, east side down, of more than 600 m (Anderson and Creasey, 1958, p. 80). In the Arnold Mesa area southeast of Jerome, the fault is discontinuous and broken into en echelon segments (Wolfe, 1983). The Verde fault in the map area is a continuous, single to multistrand structure having a down-to-the-northeast offset of about 600 m. It cuts a basalt section having flows as young as about 10 Ma, and terminates north-trending faults of the late Miocene to Pliocene basin in the valley of the Verde River. The strand of the Verde fault that wraps around the north end of the Mazatzal Mountains east of the Deadman fault, although undated, may be Pliocene or younger, as displacement along this segment of the fault could, in part, account for the present topographic prominence of the range.

Although Precambrian offset has been suggested for the Verde fault at Jerome (Anderson and Creasey, 1958, p. 80), no clear evidence for such early movement has been found for the fault in the Mazatzal area, and Lindberg (1986) claims that the Verde fault had no Precambrian movement. Some motion on the northernmost parts of the Precambrian Deadman fault might be Tertiary. The north-south fault segments that are on strike with the Deadman fault north of the Verde fault and that offset Paleozoic and Tertiary rocks may represent reactivation of the Deadman fault system.

The north-northwest-trending fault on the west side of the horst across the East Verde River from the Limestone Hills may be a reactivated Proterozoic fault. Shallow-dipping Proterozoic contacts having little offset across this fault in comparison with the considerably greater offset of Paleozoic and Tertiary contacts suggest east-side-down Proterozoic motion followed by west-side-down Tertiary motion. However, the fault may be entirely Tertiary and dying to the south like the companion fault bounding the east side of the horst.

TERTIARY HISTORY

Tertiary events in the map area can be dated from about 16 Ma. By that time erosion had obliterated the Paleozoic section from the southern two-thirds of the area and had cut deeply into the Proterozoic basement. Basalt, 16.1±0.15 Ma, deposited on this basement in the east-central part of the area indicates that the entire Paleozoic section from the Cambrian to the Permian between the Mazatzal Mountains and the Mogollon Rim had been truncated in a distance no greater than about 40 km. Considering the relative abruptness of this truncation, it would seem unlikely that material transported to the north or east onto the Colorado Plateau prior to about 16 Ma from the highland to the west or south (Conway and others, 1986; Peirce, 1986) would be preserved in the area.

By the time the first basalt flows reached the area about 16 Ma, the integrated network of paleochannels, described earlier, had developed that drained southwesterly across the Proterozoic basement from the present day Mazatzal Mountains to Davenport Wash, carrying debris eroded from Paleozoic and Proterozoic bedrock. Evidence that this drainage system existed before eruption of the basalt is that the channels are filled only with pre-Tertiary detritus, but the age of the channels remains uncertain. Reversal of drainage from transport northerly or easterly onto the Colorado Plateau to southerly near the Mogollon Rim is thought by some geologists to have begun possibly in the Oligocene (Peirce and others, 1979) and by other workers to have started about 16 Ma (Conway and others, 1986). Tertiary basalt actually flowed over the paleochannels about 15 Ma, and, together with local accumulations of sediments, slowly flooded the rest of the area for about the next 5 Ma, until little or no pre-Tertiary bedrock was exposed.

Sometime in the interval 13-11 Ma, fluvial and lacustrine deposition along the eastern border of the area was taking place during accumulation of the basalt flows, as indicated by the west-thinning tongues of sedimentary deposits in basalt south of Polles Mesa and the eastward wedging out of basalt flows southeast of the mesa.

After eruption of the 10 Ma basalt flow on Cedar Bench near the northern border of the area, major down-to-the-north movement on the Verde fault and the development of a north-trending graben in the western part of the area allowed the ancestral Verde River to cross the area from the northwest to the south and cut into pre-Tertiary bedrock. Sedimentation in the valley of the Verde River was mainly fluvial and outlasted basalt volcanism, which ended about 8 Ma. Damming of the river somewhere south of Chalk Mountain or infilling of an interior drainage system initiated lacustrine conditions in the valley after consolidation of the last basalt flow. Interior drainage that resulted in deposition of the limestone at Chalk Mountain may have continued into the Pliocene. Through-going drainage across the area could have resumed in the Pliocene and has continued to the present day.

Silicic volcanism in the vicinity of the area began about 10 Ma at Hackberry Mountain, 9 km north-northwest of the confluence of the Verde and East Verde Rivers and continued there until about 3 Ma (Elston and others, 1974), approximately spanning the duration of similar volcanic activity near Lion Mountain and at Squaw Butte in the map area. Silicic rocks, therefore, were emplaced during eruption of the younger basalt and continued until latest Miocene after accumulation of the last basalt flows in the area.

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Table 1. Chemical analyses of igneous, metaigneous, and metasedimentary rocks from the northern Mazatzal Mountains and adjacent areas, Arizona. [Analyses by U.S. Geological Survey using X-ray spectographic techniques. Analysts, J.F. Carr, for specimens 1-4,6-9,15,25,28-30; J.E. Taggart for specimens 5,10-14,16-24,26-27. Wet chemical techniques used for FeO, H_2O+, H_2O- and CO_2. Analysts, M. Taylor and J. Riviello, for specimens 1-4, 6-9, 15, 25, 28-30; P.R. Klock for specimens 5, 10-14, 16-24, 26-27 ND, not determined.]

Map unit	Tis	Tis	Tis	Tsb	Tit	Tbu	Tbu	Tyb	Tob	Ypq
Map no.	1	2	3	4	5	6	7	8	9	10
Field no.	18-1-137	18-1-149	16-1-1	18-1-141	19-1-218	16-1-55	WM-205	17-1-537	16-1-61	19-3-279
Si_2O	69.42	70.88	72.67	65.31	64.5	55.66	45.28	56.51	48.10	70.0
Al_2O_3	14.50	14.62	13.64	15.57	18.2	15.34	13.60	14.60	15.43	13.9
Fe_2O_3	1.26	1.80	.94	4.38	1.46	4.81	4.34	2.48	5.99	1.59
FeO	1.18	.34	.26	.08	0.07	1.80	4.75	5.95	4.51	1.78
MgO	1.10	.78	.41	1.62	0.23	4.59	11.65	6.49	7.41	0.74
CaO	2.59	1.77	.90	3.76	1.71	7.90	13.04	6.79	9.73	2.05
Na_2O	4.10	4.28	3.89	4.22	5.67	4.29	2.41	3.37	3.34	2.91
K_2O	2.68	4.17	4.47	3.01	5.88	2.19	.91	1.51	.86	4.68
H_2O+	2.02	.17	1.90	.25	ND	1.05	1.84	.45	1.32	ND
H_2O-	.15	.26	.52	.47	ND	1.14	.80	.21	1.06	ND
TiO_2	.30	.36	.20	.75	0.09	1.03	1.10	1.26	1.58	0.55
P_2O_5	.09	.17	.05	.27	<0.05	.51	.72	.24	.39	0.21
MnO	.06	.06	.07	.09	0.02	.13	.18	.13	.15	0.08
CO_2	.03	.06	.04	.15	0.79	.82	.15	.18	.16	0.17
SUM	99.51	99.73	99.96	99.94		101.29	100.78	100.18	100.05	98.66
Rock type	Intrusive Rhyolite	Intrusive Rhyolite	Rhyolite tuff breccia	Dacite tuff breccia	Intrusive trachyte	Basaltic andesite flow	Basalt flow	Andesite flow	Basalt flow	Granite porphyry

Table 1--continued.

	Diamond Rim Intrusive Suite						Red Rock Group		Probably Red Rock Group	
Map unit	Xgp	Xgp	Xqr	Xrp	Xdg	Xdg	Xrr	Xrr	Xry	Xra
Map no	11	12	13	14	15	16	17	18	19	20
Field no.	18-1-110	19-1-226	19-220	20-6-12	16-15	19-3-301	20-6-1	21-4-350	19-3-293	19-3-292
Si_2O	76.0	76.6	76.5	73.2	49.35	57.2	82.2	75.8	76.4	62.9
Al_2O_3	12.1	12.0	12.2	13.2	15.25	14.0	13.1	12.3	11.9	13.6
Fe_2O_3	1.56	1.16	0.83	1.01	2.93	5.78	1.33	0.92	3.04	6.77
FeO	.038	0.10	0.44	1.04	8.16	6.3	0.06	1.25	0.21	3.71
MgO	<0.10	<0.10	0.12	0.38	6.78	1.95	<0.10	0.11	0.19	0.87
CaO	0.44	0.39	0.37	1.24	7.36	3.50	<0.02	0.28	0.03	2.22
Na_2O	3.83	3.09	3.06	2.84	3.72	3.25	<0.15	3.10	2.12	3.21
K_2O	4.36	5.26	5.24	4.88	.30	3.60	0.25	4.65	4.32	3.74
H_2O+	ND	ND	ND	ND	3.69	ND	ND	ND	ND	ND
H_2O-	ND	ND	ND	ND	.37	ND	ND	ND	ND	ND
TiO_2	0.15	0.07	0.09	0.18	.99	1.52	0.08	0.17	0.17	0.99
P_2O_5	<0.05	<0.05	<0.05	<0.05	.13	0.48	<0.05	<0.05	<0.05	0.33
MnO	0.02	<0.02	0.02	0.05	.17	0.30	<0.02	0.07	0.03	0.20
CO_2	0.03	0.06	<0.02	0.65	.06	0.33	0.04	0.08	0.03	<0.02
SUM					99.28	98.21				
Rock type	Granophyre	Granophyre	Granite	Rhyolite porphyry	Gabbro	Diorite	Ryolite flow	Rhyolite flow	Rhyolite flow	Andesite flow

Table 1--continued.

		Alder Group			Probably Alder Group	East Verde River Formation				
Map unit	Xav	Xas	Xam	Xam	Xrb	Xug	Xrj	Xlg	Xmv	Xft
Map no	21	22	23	24	25	26	27	28	29	30
Field no.	16-1-85	18-119B	18-1-125B	18-1-132A	18-1-132	19-3-295B	19-3-297A	16-1-9	16-1-21	16-1-22
Si_2O	61.67	61.36	47.79	75.78	76.42	63.0	69.8	63.33	45.64	75.13
Al_2O_3	17.14	19.34	19.75	14.32	11.88	16.2	13.0	14.80	15.49	13.18
Fe_2O_3	3.05	2.67	3.83	1.68	2.74	4.90	2.93	4.69	4.91	0.89
FeO	2.21	1.06	7.37	0.15	0.06	1.78	0.17	2.65	7.25	0.24
MgO	2.32	1.29	5.01	0.72	0.65	2.48	0.51	2.97	7.47	0.13
CaO	5.14	2.44	9.71	0.23	0.95	2.03	3.44	2.53	12.54	1.48
Na_2O	3.46	5.94	2.10	0.86	3.08	2.76	6.28	3.87	1.64	2.64
K_2O	1.48	1.91	1.39	3.50	3.11	3.00	0.16	1.65	1.29	2.84
H_2O+	2.42	1.78	3.23	2.25	0.96	ND	ND	2.27	2.87	1.29
H_2O-	0.15	0.11	0.29	0.20	0.06	ND	ND	.24	.20	0.15
TiO_2	0.41	0.48	0.60	0.36	0.35	0.72	0.23	.87	.79	0.09
P_2O_5	0.18	0.22	0.29	0.08	0.10	0.18	0.06	.19	.18	0.02
MnO	0.09	0.16	0.17	0.03	0.02	0.06	0.04	.08	.20	0.05
CO_2	0.20	0.68	0.13	0.22	0.04	0.33	2.56	.10	.13	1.11
SUM	99.93	99.46	101.71	100.39	100.45	97.44	99.18	100.25	100.61	99.24
Rock type	Volcanic sandstone	Andesite cobble	Basalt flow	Rhyolite flow	Pumiceous rhyolite breccia	Gray-wacke	Rhyolite flow	Gray-wacke	Basalt flow	Rhyolite tuff

Table 2. Summary of K-Ar ages

[Analyses made by E.H. McKee. B, biotite; H, hornblede; WR, whole rock]

Map unit	Map no.	Date (Ma)	Material dated	Map unit	Map no.	Date (Ma)	Material dated
Tis	1	5.3±0.2	B	Tst	8	11.0±0.6	B
	2	8.9±2.6	H				
				Tyb	9	8.3±2.9	WR
Tbu	3	10.2±0.8	WR	Tob	10	9.9±0.5	WR
	4	10.3±1.8	WR		11	12.3±0.8	WR
	5	11.0±5.0	WR		12	13.4±0.4	WR
	6	11.2±0.9	WR		13	14.0±0.5	WR
	7	13.4±0.8	WR		14	15.3±0.5	WR
					15	16.1±0.15	WR