COMPILATION GEOLOGIC MAP OF THE RENO PASS AREA, CENTRAL MAZATZAL MOUNTAINS, MARICOPA AND GILA COUNTIES, ARIZONA

Jon. E. Spencer[1], Robert S. Leighty[1], Clay M. Conway[2],
Charles A. Ferguson[1], and Stephen M. Richard[1]

Arizona Geological Survey, Open File Report 04-03

September, 2004

Scale 1:24,000, with 18 p. text

[1]Arizona Geological Survey, 416 W. Congress St., Suite 100, Tucson, AZ 85701
[2]Gæaorama, Inc., 366 S. 300 E. (97-12), Blanding, UT 84511

Compilation geologic map of the Reno Pass area, central Mazatzal Mountains, Maricopa and Gila Counties, central Arizona

Introduction

The 1:24,000 scale geologic map that is the basis for this report covers part of the central Mazatzal Mountains in the area where the Beeline Highway (State Highway 87) crosses the range (Figure 1). The map area includes all of the Reno Pass 7 ½' Quadrangle, the eastern third of the Lion Mountain 7 ½' Quadrangle, and the western third of the Kayler Butte 7 ½' Quadrangle. Parts of this area have been mapped and studied by several investigators (Figure 2), whereas other areas remain unmapped, in part because Arizona interior chaparral is difficult to pass through and may require crawling under and climbing over for large distances. This map is an attempt to compile and synthesize maps and unit descriptions from these diverse studies. A stratigraphic correlation diagram is included as figure 3.

Regional Setting

The Mazatzal Mountains are part of the Transition Zone physiographic province in Arizona. The Transition Zone separates the Colorado Plateau, a region of gently dipping Paleozoic and Mesozoic strata that overlie Proterozoic bedrock, from the Basin and Range Province, which consists of numerous, structurally complex mountain ranges partially or completely surrounded by late Cenozoic, basin-filling sediments and sedimentary rocks. Unlike the Colorado Plateau, the Basin and Range Province is highly disrupted by Mesozoic and Cenozoic magmatism, faulting, and folding. The Transition Zone is only slightly to moderately broken by Cenozoic normal faults, and can be thought of as representing Colorado Plateau that has been stripped of its Paleozoic and Mesozoic cover. As a result of removal of these strata, as well as uplift and its largely unextended character, Proterozoic rocks are exposed over large areas.

Between 1.6 and 1.8 Ga (billion years ago) Arizona was created by tectonic and magmatic processes, and no rocks are known in the state that are older. The creation and assembly of ancestral Arizona occurred from northwest to southeast, and as sedimentary and volcanic rocks were added to the growing continent, they were squeezed in the northwest-southeast direction at the same time that they were heated due to burial and magmatism. This resulted in a steep, northeast-striking slatey or schistose foliation that is commonly characteristic of Early Proterozoic metamorphic rocks throughout the state. Voluminous and widespread granitic intrusions were emplaced in these metamorphic rocks during or shortly after deformation and metamorphism.

The Transition Zone has also been the site of scattered and widespread Cenozoic volcanic activity. Middle Cenozoic intermediate to felsic magmatism, including ash flow tuffs, affected the easternmost part of the Transition Zone as well as the Superstition mountains at the south end of the Mazatzal Mountains. Late Cenozoic basaltic magmatism, with local felsic and alkalic magmatism, has produced some large volcanic fields, especially north and west of the Mazatzal Mountains. Normal faulting at this time produced the Tonto and Payson basins as well as Verde and Chino Valleys.

Geology of the central Mazatzal Mountains

The geology of the map area in the central Mazatzal Mountains is dominated by a lithologically diverse suite of ~1.7 Ga metasedimentary and metavolcanic rocks that have been folded into the east-northeast trending Red Rock syncline and intruded by granites. These metamorphic and granitic rocks are overlain by late Cenozoic volcanic rocks that include alkalic mafic lava flows with local ultramafic inclusions. The Mazatzal Mountains are flanked to the east by the Tonto and Payson Basins, which together form a single, discontinuous, north-south trending graben containing Miocene basin-filling sedimentary rocks.

The Early Proterozoic metamorphic rocks that make up most of the Proterozoic bedrock in the map area are divided into three groups: (1) the lower, mafic volcanic and related rocks of the Mount Ord Formation of the Union Hills Group, (2) the middle, dominantly metasedimentary rocks of the Alder Group and (3) the upper, dominantly felsic volcanic rocks of the Red Rock Group (Wrucke and Conway, 1987; Anderson, 1989). The Red Rock rhyolite, which forms the core of the Red Rock syncline and much of the bedrock that flanks the syncline to the northwest, is the most significant member of the Red Rock Group. Zircon from this rock unit was dated at 1715±15 Ma (million years ago) by Silver (1965) using the U-Pb dating method. Silver et al. (1986) give a revised date of 1700±6 Ma, but do not specify if this new date represents recalculation of data from the previously reported date or if it represents new analyses. The Alder and Red Rock Groups, along with the stratigraphically higher Mazatzal Group, form the Tonto Basin Supergroup (Wrucke and Conway, 1987; Conway and Silver, 1989). The undeformed Granite near Sunflower, which intrudes the folded and metamorphosed strata of the Tonto Basin Supergroup, has yielded U-Pb zircon dates of 1660±15 Ma (Silver, 1965) and 1686±5 Ma (Spencer et al., 2003a). The Mazatzal Revolution was the term used by Wilson (1939) to describe the deformation and metamorphism that occurred after eruption of the Red Rock Rhyolite and before intrusion of the Granite near Sunflower.

The southeast limb of the Red Rock syncline is more deformed than the northwest limb. The southeast limb was termed the “Slate Creek movement zone” by Roller (1987) and the “Slate Creek shear zone” by Karlstrom et al. (1990) and Wessels and Karlstrom (1991), and was considered part of the “Slate Creek - Breadpan Canyon shear zone” of Karlstrom et al. (1987). The tectonic significance of this shear zone is discussed in these studies (see also Karlstrom and Conway, 1986; Conway et al., 1987; Karlstrom and Bowring, 1988; Conway and Silver, 1989) and is not reviewed in this report. Anderson (1989) considered the syncline to be fictional and inferred that different stratigraphic sequences occupied the opposite sides of the infolded Red Rock rhyolite. Roller (1987, 1991) studied in detail part of the Alder Group on the southeast side of the syncline and divided many of Ludwig’s (1974) units into generic map units. The names of the stratigraphically highest units of Ludwig (1974) were retained although contacts are those of Roller (1987, 1991). Roller’s modifications of Ludwig’s (1974) mapping are incorporated into this map and report, with discussion of unit-designation modifications in the unit descriptions. Also, Ludwig’s (1974) unit designations on the southeast limb are shown with a sequence of lines with arrows.

Ludwig (1974) analyzed U and Pb isotopes from three zircon fractions from a sample of rhyolitic breccia in the Telephone Canyon member of the Alder Group, and two fractions from a sample of rhyolitic breccia or conglomerate in the Oneida member. None of the U-Pb data points were concordant on a U-Pb concordia diagram. With the addition of three points from the Red Rock rhyolite (Silver, 1965), the array of 8 points define a chord with an older intercept of 1730±20 Ma. This was interpreted by Ludwig (1974) as encompassing the age of the upper Alder Group and Red Rock rhyolite (this date has not been recalculated using newer isotope decay and abundance constants). Silver et al. (1986) give an age of 1710 to 1700 Ma for the upper 1 km of the Alder Group.

The south-central part of the map area, an extensive area around upper Kitty Joe Canyon, is covered by middle to late Tertiary volcanic and sedimentary rocks. Volcanic rocks include alkalic, biotite-bearing basalt that contains ultramafic xenoliths in some areas. The Tertiary geology of this area was studied in detail and analyzed by Conway (1995). A copy of this unpublished report, produced for the Arizona Department of Transportation as part of a realignment of State Highway 87, can be obtained from C. Conway or inspected at the library of the Arizona Geological Survey.

This Open-File Report does not evaluate evidence and hypotheses for the origin of rocks and structures in the Reno Pass area, but it should be helpful to anyone who wants to locate and examine these rocks and structures and perhaps to improve upon existing knowledge.

Map Units

Cenozoic sedimentary and volcanic units

Qal **Alluvium (late Quaternary)—**Typically floors active channels and flanking, low lying areas.

Qtc **Talus and colluvium (late Quaternary)**

Ql **Landslide deposits (Quaternary)**

Qo **Old alluvium (Quaternary)—**Commonly forms terraces and incised alluvial deposits on the flanks of valleys. Near bedrock exposures this unit it typically cobble to boulder conglomerate.

QTs **Younger clastic sedimentary rocks (Quaternary to Miocene)—**Moderately to poorly sorted fanglomerate, sandy conglomerate and conglomeratic sandstone generally deposited in alluvial fans that are now incised. Commonly includes colluvium derived from Tertiary clastic sedimentary rocks that is now concealed by soil and vegetation.

Tcp **Post-tectonic conglomerate in Tonto Basin (Pliocene to Miocene)—**Massive or medium-to thick-bedded rounded boulder conglomerate with pebbly arkosic sandy matrix. Very poorly exposed unit consisting mostly of cobbles and boulders of upslope bedrock. The unit is essentially untilted and based on relationships observed in the southerly adjacent Tonto Basin quadrangle (Ferguson and others, 1998) it overlies older Tertiary strata with angular unconformity and is believed to overlap the basin-bounding fault scarp along the eastern escarpment of the Mazatzal Mountains. Northeast of Mount Ord at the mouth of Oak Spring Canyon this unit is a massive, poorly exposed, gray conglomerate with clasts to 40 cm. Most clasts are gray to greenish gray mafic to intermediate volcanic rocks, including plagioclase-phyric greenstone, greenstone with feldspar, mafics, and sparse quartz phenocrysts, fragmental volcanic rocks, black chalcedonic to flinty rhyolite with quartz phenocrysts, and pink aplite.

Ts **Sandstone in Tonto Basin (Pliocene to Miocene)—**Medium- to thin-bedded, light-colored, plane-bedded and cross-stratified arkosic pebbly sandstone associated with map unit Tms and located in the southeastern corner of the map area.

Tms **Mudstone, siltstone, and marl in Tonto Basin (Pliocene to Miocene)—**Thin- to medium-bedded, light-colored, laminated and ripple cross-laminated to plane-bedded mudstone and siltstone with interbeds of medium-bedded, laminated white marl and cross-stratified, pebbly, arkosic sandstone. Includes minor muddy limestone and gray, massive limestone that is not very hard or resistant and weathers into small, rounded fragments as if it were mudstone. Includes very rare thin-bedded to laminated white fine-grained ash-beds up to 1 meter thick. A biotite K/Ar date of 18.55 $\pm$ 0.56 Ma (Nations, 1987; Mayes, 1990) was obtained from one of these ash beds along the southern border of the Kayler Butte 7 ½' quadrangle, east of the map area.

Tv **Volcanic rocks, undivided (Pliocene to Miocene)**

Th **Felsic hypabyssal intrusion (Pliocene to Miocene)—**A sample of similar rocks about 2 km west of the map area yielded a K-Ar biotite date of 5.3±0.2 Ma (K-Ar sample #1 of Wrucke and Conway, 1987).

Tvf **Felsic volcanic rocks (Pliocene to Miocene)—**Rhyolite to dacite lavas and related rocks. Caps the eastern end of Black Ridge. A thick sequence of flows is also exposed at Saddle Mountain (Leighty, this report).

Tvfx **Felsic volcanic breccia (Pliocene to Miocene)—**In the Saddle Mountain area, volcanic breccia in sheet-like masses that overlie tuff of map unit Tt and are overlain by felsic lavas of map unit Tvf. A major element analysis of a sample of this unit revealed a silica content of 65.3% (sample #4 of Wrucke and Conway, 1987; plotted here on plate 1).

Tt **Felsic tuff (Pliocene to Miocene)—**White to gray lithic tuff, lapilli tuff, and tuff breccia. May be reworked locally. The lithic tuff contains clasts (typically <5 cm wide) of various Proterozoic rock types and gray-white Tertiary rhyolite to dacite fragments. This unit also includes thin basaltic sandstone and conglomerate beds. This unit grades (generally westward) into tuffaceous sediments of map unit Tts (Leighty, this report). Tuff of map unit Tt, mapped on the east side of Sycamore Canyon by Conway, is equivalent to tuffaceous sedimentary rocks of map unit Tts mapped by Leighty on the west side of the canyon. Contacts are not shown where they are gradational between these units.

Tb **Basalt lava (Pliocene to Miocene)—**Basalt lava flows and less abundant cinder, flow breccia, scoria, and dikes. Commonly contains olivine and, in the Kitty Joe Canyon area, locally contains dark pyroxene. Six to eight kilometers northwest of basalt flows at the west edge of the map area, similar basalt yielded K-Ar whole-rock dates of 13.4±0.4 Ma and 15.3±0.5 Ma (samples #12 and #14 of Wrucke and Conway, 1987).

This unit includes a series of amalgamated flows locally interbedded with pebbly, arkosic sandstone and conglomerate in the northeastern corner of the map area. Two of these flows in Tonto Basin yielded whole-rock K-Ar dates of 22.6 ± 1.2 Ma (Muehlberger, 1988; Mayes, 1990) and 27.16 Ma ± 1.2 Ma (Damon and others, 1996).

Tbi **Basalt intrusion (Pliocene to Miocene)**

Tts **Tuff, reworked tuff, and volcanic lithic sandstone and conglomerate, undivided (Miocene)**—In two areas Tts grades laterally into felsic tuff of map unit Tt and a contact between the two is not shown on the map.

Tsv **Volcaniclastic sandstone and conglomerate (Miocene)—**Basalt- and scoria-dominated sandstone and conglomerate that in part includes reworked felsic tuff. Well exposed between the Black Ridge and Kitty Joe Canyon areas. In the Kitty Joe Canyon area this unit includes up to 5% clasts of Proterozoic rocks.

Tbb **Biotite basalt (Miocene)—**Vuggy, dark gray basalt (biotite lamprophyre) with up to 25% biotite that is only moderately resistant to weathering and form low, rounded outcrops (Conway, 1995).

Tbbx **Biotite basalt with xenoliths (Miocene)—**Similar to biotite basalt of map unit Tbb but generally with less visible biotite and with highly altered, 1-4 cm, ultramafic xenoliths that are locally abundant (Conway, 1995).

Tcs **Conglomerate and conglomeratic sandstone (Miocene)—**Moderately to poorly sorted conglomerate, sandy conglomerate and conglomeratic sandstone. Outcrop areas are generally interpreted as incised alluvial fans. This rock unit overlies bedrock in most areas but overlies conglomerate of map unit Tcg along the west side of Mt. Ord.

In the Kitty Joe Canyon area, this unit consists of moderately well bedded, moderately to poorly sorted, granule to boulder conglomerate, with abundant arkosic matrix that was not derived from nearby bedrock. Clasts, which consist primarily of resistant metamorphic rocks and quartzite, form 10% to 50% of the unit. Along the old highway in upper Slate Creek and along the drainage divide with Sycamore Creek, clasts are dominated by tabular fragments of nearby metamorphic rocks and the matrix is similarly dominated by metamorphic rock debris. The contact along which this slatey-lithic-fragment conglomerate to the west overlies the arkosic-matrix gravel/conglomerate to the east (from Conway, 1995) is shown with a dash-dot line and the adjacent conglomerate rich in slatey debris is labeled “Tcs(sl)”. In the upper Alder Creek area in the southwestern corner of the map area, sediments of this unit are dominated by Proterozoic metamorphic clasts and display crossbedding and imbrications indicative of S-directed transport (R. Leighty, this report). These sediments are also labeled “Tcs(sl)”.

Clasts in this unit in the Kitty Joe Canyon area are dominated by the Cambrian Tapeats Sandstone, Proterozoic Troy Quartzite, and rocks of the Proterozoic Apache Group. Farther north, in the area where State Highway 87 crosses the crest of the Mazatzal Mountains (unnamed pass between upper Slate Creek and upper Sycamore Creek), clasts are dominated by the Tapeats Sandstone and a variety of Early Proterozoic rock types that crop out a few kilometers to a few tens of kilometers northwest of the study area (Conway, 1995).

Along east side of range in Tonto Basin clasts are derived from local bedrock (J. Spencer, this report).

Tx **Breccia (Miocene)—**Angular fragments of mafic metavolcanic rocks in a sparse tan sandy matrix exposed in one contiguous outcrop area on the east flank of Kitty Joe Canyon (Conway, 1995).

Tcg **Conglomerate (Miocene)—**Unconsolidated, unsorted, poorly bedded, boulder to cobble conglomerate with clasts of probably locally derived, mafic metavolcanic rocks (map unit Xoa) that make up much of the west flank of Mount Ord, and hypabyssal granodiorite porphyry (map unit Xgd) (Conway, 1995).

Intrusive Rocks

TXdd **Unfoliated diorite dikes (Tertiary to Early Proterozoic)**—Unfoliated equigranular to slightly porphyritic dioritic dikes.

Xfi **Unfoliated felsic hypabyssal intrusions (Early Proterozoic)**—Unfoliated rhyodacite porphyry sheets and dikes of Ludwig (1974). This unit also includes, at the mouth of Oak Spring Canyon at the east foot of the Mazatzal Mountains, an area of massive, reddish gray to reddish brown to dark reddish brown felsite (it is possible that this unit is extrusive). This felsite has an aphanitic groundmass that contains 1-2%, 1-2 mm quartz phenocrysts and 1-2%, 1-2 mm pink feldspar phenocrysts (S. Richard, this report).

Xpm **Pine Mountain porphyry (Early Proterozoic)—**Hypabyssal rhyodacite intrusions that are foliated near their margins. This unit was named the Pine Mountain porphyry by Wilson (1939).

Xggv **Green Valley Hills granophyre (Early Proterozoic)**—Described by Wrucke and Conway (1987) as aplite and granophyre consisting of quartzite and alkali feldspar in a micrographic groundmass. These rocks were considered to be part of the Diamond Rim Intrusive Suite.

Xgs **Granite near Sunflower (Early Proterozoic)**—Granite of this unit is considered to be the northern continuation of a granite body mapped in the northern part of the adjacent Tonto Basin (Ferguson et al., 1998) and Boulder Mountain (Skotnicki and Leighty, 1998a) 7 ½' Quadrangles. Ferguson et al. (1998) described this unit as medium to coarse grained, hypidiomorphic to idiomorphic granular granite that is characterized by blue quartz, rapakivi texture (K-feldspar rimmed by plagioclase), and a slightly porphyritic texture with both K-feldspar and plagioclase exhibiting well-formed, euhedral to subhedral crystal faces. Skotnicki and Leighty (1998a) described this biotite granite as coarse grained, slightly porphyritic, with distinctive milky bluish quartz, and recognized that it is foliated near Round Valley. Modal mineralogy of a sample of this granite, collected near State Highway 87 about 2 miles north of Round Valley, indicates that this unit is a monzogranite (a subfield of the granite field as defined by the IUGS; Spencer et al., 2003b). Conway (1995) described this unit near Sunflower as medium to coarse grained (5-15 mm) biotite granite that is tan, homogenous, and non-porphyritic. Northeasternmost exposures of this granite, at the mouth of Oak Spring Canyon, consist of bleached, shattered, silicified aplite or arkose (some clearly arkose) that could be a border phase of the granite to the south and appears to be finer grained toward somewhat similar rhyolite (contact between the two is sharp; S. Richard, this report). U-Pb analyses of five zircon crystals from this granite in the Boulder

Mountain 7 ½' Quadrangle yielded a well defined linear array on a $^{206}Pb/^{238}U$ – $^{207}Pb/^{235}U$ diagram, with one concordant point, that indicate an age of 1686±5 Ma (Spencer et al., 2003a). This map unit is almost certainly the granite that yielded a U-Pb date of 1660±15 Ma reported for the "postdeformational granite near Sunflower" by Silver (1965; age reported as 1640 Ma by Reynolds et al. [1986] who referred to this granite as the "Sunflower granite").

Xgr **Granite of Ram Valley (Early Proterozoic)—**Fine- to medium-grained (1-5 mm) leucocratic granite that is red-brown, non-porphyritic, and blocky weathering (Conway, 1995). Generally undeformed but contains steep, northeast to east-northeast trending shear zones, some of which are mylonitic. Possibly biotite bearing, but mafic constituents have been altered to hematite. This granite is similar to, and possibly a member of, the 1.7 Ga Diamond Rim Intrusive Suite in the northern Mazatzal Mountains and upper Tonto Basin region (Wrucke and Conway, 1987; Conway and Silver, 1989).

Distinction between the Granite of Ram Valley and a possible fine-grained border phase of the "granite near Sunflower" (map unit Xgs) is problematic in some areas. Conway (1995) mapped the Granite of Ram Valley in one area of the Boulder Mountain 7 ½' Quadrangle (south of the Reno Pass Quadrangle), whereas Skotnicki and Leighty (1998a) considered this granite to be part of the granite near Sunflower. East of Mt. Ord, at the foot of the Mazatzal Mountains, granite that intrudes the mafic metamorphic rocks of Mt. Ord is medium to fine grained and leucocratic, and is suspected to be a border phase of the granite near Sunflower (it is shown here as "granite near Sunflower"). However, it is also possible that this leucocratic granite is not a border phase of the granite near Sunflower but is part of the Granite of Ram Valley and is unrelated to the granite near Sunflower. [The Granite of Edwards Park in the Tonto Basin 7 ½' Quadrangle (Ferguson et al., 1998) and its westward continuation as "Intrusive rhyolite/granophyre" in the Boulder Mountain 7 ½' Quadrangle (Skotnicki and Leighty, 1998a), which together form the south margin of the granite near Sunflower, could also be a border phase of the granite near Sunflower.]

Xgd **Granodiorite porphyry (Early Proterozoic)**—Probably hypabyssal, quartz-feldspar porphyry forming a single, small outcrop area west of Mt. Ord (Conway, 1995). According to Conway (1995), this unit is "probably metamorphosed…but lacks obvious foliation."

Xoa **Mt. Ord Andesite (Early Proterozoic)**—Andesitic intrusion that makes up Mt. Ord and flanking areas (name from Ludwig, 1974). This unit was examined by Ludwig only along the Mt. Ord road, where it is unfoliated, dark gray to black on fresh surfaces, spheroidal weathering, and contains phenocrysts of sodic plagioclase, olivine, and clinopyroxene. Ludwig was not able to determine if this unit was intruded into or was faulted against the Alder Group (Ludwig, 1974, p. 157). This unit is the same as the Mt. Ord pyroxenite of Wilson (1939, p. 1128), who concluded that the unit intruded the Alder Group and that "Many dikes of this rock, generally less than 75 feet wide and trending northeastward, intrude the Alder Group for about 3000 feet from the [pyroxenite] stock." In contrast, Anderson (1989) interpreted this unit as part of the mafic volcanic basement to the generally more felsic Alder Group, labeled it part of the Mount Ord Formation, and correlated it with the Union Hills Group, a regionally extensive, submarine volcanic sequence that reflects initial Proterozoic crust formation and island arc magmatism in this area.

At the east foot of Mt. Ord adjacent to Tonto Basin this unit appears as hard, dark gray rock with sparse plagioclase phenocrysts up to 4 mm long and possible clinopyroxene. Shallow intrusion is suspected as no vesicles or flow breccias were seen in this area. Near the north edge of the outcrop belt pitted lenses a few cm thick are suggestive of flattened breccia with possible calc-silicate protoliths (J. Spencer, this report). At the mouth of Oak Spring Canyon this rock unit consists of texturally variable, commonly fragmental greenstone with very fine grained groundmass, 1-10% (locally up to 30%), 1-2 mm plagioclase, and very sparse pyroxene(?) or hornblende(?) locally up to 4 mm diameter. Boulders also reveal fragmental textures with subangular to angular fragments up to 30 cm diameter that in turn contain 1-2 mm white plagioclase and up to 5%, 1-4 mm pyroxene(?) phenocrysts (S. Richard, this report).

At the west foot of Mt. Ord in upper Kitty Joe Canyon this unit consists of foliated, green, mafic volcanic rocks metamorphosed to greenschist facies. Lithologies vary from vesicular flows to volcanic conglomerates, and from aphyric to porphyritic with abundant plagioclase and/or pyroxene. Intrusive hypabyssal rocks and mafic tuffs are present locally. Greenish color is due to presence of albite, chlorite, epidote, and actinolite (Conway, 1995).

Proterozoic volcanic and hypabyssal rocks of the Red Rock Group

Xrr **Red Rock rhyolite (Early Proterozoic)**—Described by Ludwig (1974) as welded vitric (now devitrified) and lithic tuffs, volcanic breccias, flows, and possibly intrusions, of rhyolitic and rhyodacitic composition. Rocks of this map unit are exposed in the core of the Red Rock syncline where they overlie the top of the Alder Group, and in the northwestern corner of the map area where they are in contact with the East Fork member. Ludwig identified a feeder dike to the Red Rock rhyolite in the lower Gold Creek area. Ludwig (1974, p. 72) stated that “the contact [with the East Fork member] itself is not exposed, but appears to be depositional, as no evidence of unusual shearing was detected in the regions giving best exposure near the contact (within 10 to 100 feet).” However, Wrucke and Conway (1987) interpreted this contact as a fault. In the core of the Red Rock syncline, Ludwig (1974) described the contact between the Red Rock rhyolite and the Telephone Canyon member as conformable but intruded by “mafic sheets” everywhere except at one location where faulting was suspected. In contrast, Wrucke and Conway (1987) considered the “mafic sheets” to be lava flows, and the contacts to be depositional. Roller (1987) described this unit as ash-flow tuffs with minor volcanic breccias and lava flows.

Near the northeast corner of the map area rocks of this unit consist of pink, tan, and light-gray, massive and locally autobrecciated, crystal-poor felsic lava containing up to 10% rectangular, euhedral to subhedral feldpsar and biotite phenocrysts. Quartz phenocrysts are rare to absent. Weak and discontinuous compositional layering that could be relict flow banding or flattened fragmental texture. Lensoidal blebs 1-3 mm long could be relict feldspar, small quartz crystals could be secondary (C. Ferguson and J. Spencer, this report).

Xfi **Felsic hypabyssal intrusions (Early Proterozoic)—**Consists of unfoliated to slightly foliated, plagioclase porphyritic (1-4 mm), felsite and crystal poor felsite with sparse fine quartz. Includes feeders to the Red Rock rhyolite and named the Gold Creek intrusives by Ludwig (1974). Considered to be part of the Diamond Rim Intrusive Suite (Wrucke and Conway, 1987; Conway and Silver, 1989).

Xmi **Mafic to intermediate lava flows and hypabyssal intrusions (Early Proterozoic)**—Basaltic andesite and less common dacite lava flows and dikes. This unit forms a thin layer at the base of the Red Rock rhyolite that was interpreted by Ludwig (1974) as a sheet-like intrusion, and by Wrucke and Conway (1987) as lava flows. Near the northeast corner of the map area, about 1 mile southwest of Cottonwood Spring, rocks of this unit consist of variably foliated, dark green, plagioclase porphyritic andesite lava and/or sills. Plagioclase phenocrysts are up to 2 cm, euhedral to subhedral, and make up between 5% and 30% of the flows. Some of the units may be hypabyssal intrusions, but most display amygdaloidal or auto-brecciated textures typical of lava flows (C. Ferguson, this report).

Proterozoic Sedimentary and Volcanic Rocks of the Alder Group

Xma **Mafic to intermediate lava flows and hypabyssal intrusions associated with the lower Alder Group (Early Proterozoic)**—Basaltic andesite and less common dacite lava flows and dikes on the north flank of Mount Ord. Includes porphyritic and aphyric lava flows, tuffs, and volcaniclastic sandstones and conglomerates. Along the east edge of bedrock exposures in the map area, adjacent to Tonto Basin, rocks of this unit consist of medium to dark gray metavolcanic rocks, in some areas with a clear fragmental texture (fragments 1-5 cm long) that appears to represent a flattened breccia. Possible relict vesicles are present locally (J. Spencer, this report). Rocks of this map unit are of uncertain and possibly mixed affinity, and could be (1) related to the Mount Ord andesite but faulted into the lower Alder Group, (2) part of the Alder Group, and (3) related to younger intrusions associated with the Red Rock Group (map unit Xmi).

Xp **Phyllite (Early Proterozoic)—**Includes rocks in the northwestern corner of the map area described by Wrucke and Conway (1987, map unit Xas) as thin-bedded shale with sparse interbeds of siltstone and sandstone, with a total thickness of 50 to 300 m. These rocks are probably equivalent to the northwesternmost belt of the East Fork member of Ludwig (1974). Also includes map unit "sl" of Roller (1987). Along the east edge of bedrock exposures in the map area, adjacent to Tonto Basin, rocks of this unit consist of fine-grained, micaceous, quartz-rich psammite and phyllite (J. Spencer, this report).

Xs **Psammite and minor phyllite (Early Proterozoic)—**Quartz-muscovite psammite with phyllite interlayers and minor granule conglomerate (map unit "qs" of Roller [1987, plate 1]). Along the east edge of bedrock exposures in the map area, adjacent to Tonto Basin, rocks of this unit consist of medium to fine-grained, micaceous, poorly sorted psammite and phyllite with well developed slatey cleavage, some of which could be tuffaceous or volcaniclastic (J. Spencer, this report). Near the northeast corner of the map area, southwest of Cottonwood Spring, rocks of this unit consist of black to silvery dark gray, pebbly, argillaceous granule sandstone containing abundant jasperoid and quartzite pebbles. Unit is mostly thin- to medium-bedded, with relict bed-scale cross-stratification preserved, and also occurs as massive, apparently matrix-supported units (C. Ferguson, this report). Northeast of Cottonwood Spring this unit consists of psammite, massive quartzite, gray and black phyllite, conglomerate, sparse greenstone, and poorly sorted, brown to gray, feldspathic quartzite that is cross bedded and plane bedded (beds 10-40 cm thick) and contains cross beds that locally have tangential bases that reveal top directions (S.M. Richard, this report).

Near the southwestern corner of the map area, rocks of this unit consist of a sequence of fine-grained metasedimentary rocks that are interbedded with the more mature quartzite (Xsq) unit. The pelitic rocks are very fine-grained, greenish gray to dark bluish gray phyllite and argillite. The psammitic rocks are largely fine-grained metasandstone, with minor metaconglomerate. Unlike in the quartzite unit, discrete primary sedimentary structures were not identified in these rocks (Leighty, this report).

Xq **Quartzite (Early Proterozoic)—**Quartzite with minor slate and phyllite (map unit "q" of Roller, 1987). Small exposure of quartzite directly east of the confluence of the west and east forks of Sycamore Creek, adjacent to old State Highway 87, that were considered by Wrucke and Conway (1987) as possibly related to the Mazatzal Quartzite. Along the east edge of bedrock exposures in the map area, adjacent to Tonto Basin, rocks of this unit consist of medium to fine-grained, micaceous, resistant quartzite (J. Spencer, this report).

Near the northeast corner of the map area, about 1 mile southwest of Cottonwood Spring, quartzite beds consist of medium- to thick-bedded, plane-bedded and bed-scale cross-stratified, pinkish or light gray quartzite (C. Ferguson, this report). Most of this quartzite is medium-grained, but includes some pebbly granule sandy units. The unit occurs as several units between 1 and 30 meters thick including up to 30% argillite or argillaceous sandstone interbeds.

Near the southwest corner of the map area, rocks of this unit consist of massive, highly resistant, well sorted and well bedded quartzite. Distinctive cross-bed heavy mineral laminations indicate stratigraphic younging to the northwest (Leighty, this report).

Xsc **Volcaniclastic sandstone and conglomerate (Early Proterozoic)**—Described by Wrucke and Conway (1987) as conglomerate grading upward into sandstone, both derived from rhyodacitic volcanic debris, with a total thickness of 500 to 1000 m.

Near the northeast corner of the map area, about 1 mile southwest of Cottonwood Spring, rocks of this unit, exposed over a small area at the south end of a hill, consist of massive, purple to dark gray, argillaceous, pebble conglomerate or volcanic breccia containing subangular clasts of andesitic lava and white pumiceous clasts, plus sub-rounded jasperoid. The matrix is argillaceous arkosic sand, and the unit grades down-section into massive purple argillite (schist) (C. Ferguson, this report).

Xt **Tuff (Early Proterozoic)—**"Light to dark green, fine to medium-grained tuff with graded bedding" (Roller, 1987) and coarse, dacitic to rhyodacitic, tuffs with inferred subaqueous deposition.

A small exposure of this rock unit near the northeastern corner of the map area, about 1 mile west of Cottonwood Spring, consists of pink to light gray, welded rhyolitic ash-flow tuff with well-developed eutaxitic foliation defined by dark gray fiamme up to 10 cm long. This tuff contains 10% feldspar phenocrysts and rare quartz and biotite (C. Ferguson, this report).

Xv **Volcanic rocks, undivided (Early Proterozoic)**—As described by Wrucke and Conway (1987), this unit consists of a belt of exposures in the northwesternmost part of the map that are composed of aphyric basalt pillow flows and breccia and porphyritic andesite (lower one third) overlain by phenocryst-poor rhyolite, mafic volcanic rocks and chert (upper two thirds). These rocks are probably equivalent to the northwesternmost belt of the Cornucopia member of Ludwig (1974).

Near the southwestern corner of the map area, this unit consists of meta-andesite flows that are typically massive, dark greenish gray, and very fine-grained, with feldspar phenocrysts (<1 mm), and meta-dacite flows that are medium greenish gray and more crystal-rich, with creamy white feldspar phenocrysts. Relative to the meta-andesite, the meta-dacite generally has more K-feldspar, is coarser grained, and has more pervasive epidote alteration. These metavolcanic rocks likely represent an assemblage of extrusions to hypabyssal intrusions (Leighty, this report).

Xsv **Sedimentary and volcanic rocks, undivided (Early Proterozoic)**—In the southeast limb of the Red Rock syncline, this unit consists of "complexly interleaved and transposed lenses of quartzo-feldspathic siltstone, volcanic and quartz wacke, carbonate, specularite, polymict conglomerate, jasper-hematite breccia, and tuff (in approximate order of abundance)" (map unit "sw" of Roller, 1987, plate 1). This unit includes the Ord member of the Alder Group of Ludwig (1974) which consists of fine-grained chloritic sandstone with intercalated dacitic tuffs in the Mt. Ord area and was inferred by Ludwig (1974) to be approximately correlative with the West Fork member (map unit Xp-wf) and crystal-lithic tuff member (map unit Xt) on the northwest limb of the syncline. This map unit also includes strata probably equivalent to rocks of the Alder Group located at the west edge of the map area west and southwest of Saddle Mountain (Wrucke and Conway, 1987), and rocks described as felsic schist, shale, siltstone, sandstone, conglomerate, with a large felsic volcanic component, and with minor mafic volcanic rocks (Conway, 1995).

At the east edge of bedrock exposures, adjacent to Tonto Basin, this unit consists of (from south to north) (1) strongly cleaved, quartz-bearing metafelsite, (2) fine- to coarse-grained, poorly sorted, quartz-poor metasandstone, probably derived from volcanic rocks, (3) mafic volcanic rocks, (4) dark gray, cherty siliceous rocks, (5) epidote-rich calc-silicate rocks of uncertain metasedimentary or hydrothermal origin, (6) fine-grained tuffaceous(?) pelitic rocks (J. Spencer, this report), and northeast of Cottonwood Spring, phyllite, tuffaceous phyllite, and tuffaceous conglomerate (S. Richard, this report).

Near the southwestern corner of the map area, south of Alder Creek, rocks of this unit consist of interbedded pelitic to psammitic meta-sedimentary and metavolcaniclastic rocks. These rocks typically include fine-grained to very fine-grained phyllites, with less abundant, more compositionally mature, quartzite beds. Thin, highly foliated, felsic tuff beds are also locally present. The meta-volcaniclastic and meta-sedimentary sequence may be correlative with similar rocks (i.e., Horse Camp and Ord members of the Alder group) exposed in the Reno Pass area to the northeast (Ludwig, 1974). However, the andesitic to dacitic lavas are not represented in the Reno Pass area (Leighty, this report).

Telephone Canyon member, Alder Group

Xss-tc **Cross-bedded quartzose sandstone, conglomerate, slate, and tuff (Early Proterozoic)**—Described by Ludwig (1974, p. 96) as "sandstones (quartzites, quartz-wackes, and lithic-feldspathic wackes), granule conglomerates, with subordinate conglomerates, slates, tuffs, and mafic flows," with "abundant massive and bedded tuffs and felsic volcanic breccias" in the Gold Creek area near the north edge of the map area. Medium to coarse grained, moderately to poorly sorted sandstones are most common. Thickness on the northwest limb of the Red Rock syncline was estimated at about 500 m for southwestern areas, increasing to about 1000 m in the Gold Creek area to the northeast. Thickness on the southeastern limb is estimated at about 1000 m. The contact with the underlying Oneida member was considered by Ludwig to be conformable, and the contact with the overlying Red Rock rhyolite was considered to be "conformable (or disconformable)."

Described by Wrucke and Conway (1987) as medium to coarse grained, moderately to poorly sorted, commonly cross bedded quartz, lithic, and feldspathic sandstone and graywacke, with "subordinate granule to pebble conglomerate, shale, tuff, volcaniclastic rhyolite, and mafic flow rocks" with a total thickness of 600 to 1000 m.

Some of the slate and quartzite assigned by Ludwig (1974) to the Telephone Canyon member, near State Highway 87 on the southeast limb of the Red Rock syncline, were reassigned by Roller (1987, p. 20) to her "East Fork unit." Contacts and unit assignments shown by Roller for the southeastern limb of the syncline are reproduced in this report. Roller described the more restricted "Telephone Canyon unit" as "medium to well-sorted quartzite, pebble conglomerate, quartz- and volcanic-rich lithic wacke, and interbedded slate and siltstone." Well sorted quartzite is more common at lower stratigraphic levels, and strata are more argillaceous at higher stratigraphic levels. Unit label used here (Xss-tc) emphasizes sandstone-dominant character of unit.

Xq-tc **Quartzite (Early Proterozoic)**

Xr-tc **Massive rhyolite, tuff, and breccia (Early Proterozoic)**

Xrc-tc **Rhyolite breccia grading into cobble conglomerate (Early Proterozoic)**

Oneida member, Alder Group

Xt-on **Tuff, tuff-breccia, and conglomerate (Early Proterozoic)**—According to Ludwig (1974), rocks of this unit consist primarily of felsic tuff and tuff-breccia. Many elongate fragments in the breccias are suspected to be flattened pumice. A 60-70 m thick, pebble to cobble conglomerate at the base of this map unit contains clasts of jasper and felsic volcanic rocks. A 90-100-m-thick conglomerate overlies the basal conglomerate in the East Fork of Sycamore Creek and contains clasts almost exclusively of felsic volcanic rocks. The basal conglomerate is in gradational contact with slates of the underlying East Fork member (Ludwig, 1974). Total thickness was estimated to be 530 m. This unit was described by Wrucke and Conway (1987) as felsic lapilli tuff and crystal tuff, tuffaceous shale, and minor conglomerate with a total thickness of 800 to 900 m.

Roller (1987) applied the name “Oneida unit” to only a subset of Ludwig’s Oneida member. On the north limb of the syncline, Roller applied the name to that part of the Oneida member that consists of lithic tuff containing fragments of highly flattened white, green, and pink felsic volcanic rock fragments and minor clasts of jasper, mafic volcanic rocks, and slate. Ludwig’s contacts are used in Plate 1 because Roller did not focus her mapping efforts in this area.

Tuffaceous rocks south of the Red Rock syncline, assigned by Ludwig (1974) to the stratigraphically highest part of the Oneida member, were reassigned by Roller (1987) to her “East Fork Unit” because of a higher content of non-volcanic fragments in conglomerates and less abundant tuffaceous material than in rocks assigned by Ludwig to the Oneida Tuff north of the syncline. Volcanic rocks and sparse quartzite south of the Red Rock syncline, assigned by Ludwig (1974) to the middle and lower stratigraphic part of the Oneida member, were reassigned by Roller (1987) to her “Movement Zone lithologies” and are here simply represented as lithologic units, following Roller (1987). Between these two re-assigned belts of rock is a thin conglomerate with abundant clasts of felsic and mafic volcanic rocks, jasper, and slate, that is labeled “Ot?” by Roller. This conglomerate is included here in the Oneida member of the Alder Group.

East Fork member, Alder Group

Xp-ef **Phyllitic sedimentary rocks of the East Fork member (Early Proterozoic)**—Described by Ludwig (1974) as “maroon-colored slates and phyllites with subsidiary limestones and limey siltstones.” Thin section examination by Ludwig revealed that some slates were tuffaceous. Limestone and limey slates and phyllites are interbedded with slates and phyllites near the base of the unit. Grain size and abundance of jasper pebbles increases upsection toward conglomerates at the base of the Onieda member. The northwesternmost belt of rock included in the East Fork member by Ludwig (1974) consists of maroon slates and phyllites with interbeds of volcaniclastic sandstone. The tuffaceous character of the slates is apparent in thin section. Estimated thickness is 460 to 760 m for the main belt northwest of the axis of the Red Rock syncline, and 150 to 550 m for the far northwestern belt. This unit was described by Roller (1987), primarily for rocks south of the Red Rock syncline, as blue gray slates and siltstones with quartzite layers up to 140 m thick (mapped separately) and minor carbonate and conglomerate. This unit was described by Wrucke and Conway (1987), primarily for rocks north of the Red Rock syncline, as “tuffaceous shale and siltstone containing minor interbeds of limestone and lithic graywacke, sandy to pebbly in upper part” with a total thickness of 500 to 800 m.

In the northwesternmost part of the Red Rock syncline, a northern belt of slate and phyllitic sandstone was assigned by Ludwig (1974) to the East Fork member, and a southern belt was assigned to the West Fork member. Both of these members were assigned by Roller to her “East Fork Unit” (Roller, 1987, p. 16) and shown on her cross section as opposite sides of an anticline cored by the Cornucopia member. Furthermore, the East Fork Unit is shown as cut and offset by a fault on the south flank of the anticline so that the East Fork Unit is juxtaposed with the Horse Camp member along a fault that parallels lithologic contacts in the area. This fault was not recognized by Ludwig (1974).

South of the Red Rock syncline and near State Highway 87, tuffaceous slates that Ludwig (1974) included in the upper part of the Oneida member, and slate and quartzite that Ludwig included in the lower part of the Telephone Canyon member, were assigned by Roller to her "East Fork Unit" (Roller, 1987, p. 16). Following Roller (1987), these rocks are shown here as part of the East Fork member on the south limb of the Red Rock syncline. The rocks in the south limb of the Red Rock syncline that were assigned to the East Fork member by Ludwig (stratigraphically below, and southeast of, Roller's "East Fork Unit") are within the "Slate Creek Movement Zone" of Roller and are here shown as psammite and phyllite of map unit Xs.

Xt-ef **Tuff (Early Proterozoic)**—Massive, fine grained tuff, about 75 m thick, in the northwestern belt of rocks of the East Fork member.

Xq-ef **Quartzite (Early Proterozoic)**—

Cornucopia member, Alder Group

Xsv-c **Dacitic volcanic breccia, subaqueous lithic tuff, mafic flows and pillow lava, and bedded chert (Early Proterozoic)**—Described by Ludwig (1974) as "coarse lithic tuffs, fine vitric tuffs, basaltic flows, bedded cherts, and felsic volcanic breccias." This unit conformably and gradationally overlies the Horse Camp member, and the basal contact was defined by the upward disappearance of sedimentary structures and textures and the appearance of volcanic textures such as relict shards and pumice fragments. The contact with the overlying East Fork member is not exposed or is intruded by dikes.

Ludwig (1974, p. 43) recognized a stratigraphy within the member that consist of the following, from bottom to top: (1) 120 m of lapilli crystal tuffs, (2) 30 m of fine-grained vitric tuffs, (3) 300 m of basaltic flows, pillow lavas, intercalated bedded chert, and (4) dacitic-rhyodacitic volcanic breccia and cobble conglomerate.

Tuff contains 5-30% phenocrysts of quartz and albite or sodic oligoclase. This unit was described by Wrucke and Conway (1987) as lapilli crystal tuff and local felsic tuff (150 m), overlain by basalt lava flows and pillows with minor jasper, chert, and dolomite (300 m), in turn overlain by dacite to rhyodacite breccia and cobble conglomerate (150 m). Polymetallic mineral deposits and bedded and brecciated jasper-dolomite are inferred products of volcano-exhalative hydrothermal alteration and mineralization in an environment where tholeiitic pillow basalts were erupted and interbedded with volcaniclastic debris, probably in an intra-arc setting (Orr, 1990).

Xch-c **Bedded chert (Early Proterozoic)**—Bedded chert and jasper interbedded with dolomite, mafic flows and pillow lavas. Some brecciated chert has dolomite matrix.

Horse Camp member, Alder Group

Xss-hc **Volcaniclastic sandstone, sedimentary breccia, with minor conglomerate, slate, limestone, and quartzite (Early Proterozoic)**—Described by Ludwig (1974) as "medium to coarse-grained, poorly sorted, faintly bedded volcanic sandstone" with less abundant "phyllites, gravelly volcanic wackes, sedimentary breccias, and cobble conglomerate" with local exposures of "limestone, dolomite, and bedded chert."

Described by Wrucke and Conway (1987) as volcanic sandstone and lithic graywacke with minor shale, pebbly graywacke, conglomerate, and breccia, with a total thickness of 650 to 1100 m.

West Fork member, Alder Group

Xp-wf Phyllitic sedimentary rocks of the West Fork member (Early Proterozoic)—Described by Ludwig (1974) as a fine-grained sequence of slightly metamorphosed shales and siltstones with minor interbeds of volcanic sandstones. The most common rock type is maroon phyllite. Rocks of this unit are exposed only in one belt near the base of the Alder Group in the northwestern part of the map area. They conformably overlie crystal-lithic tuff. Described by Wrucke and Conway (1987) as thin bedded shale, siltstone, and minor sandstone. Thickness varies from ~300 m in the southwest to ~600 m in the northeast.

This unit was correlated with the East Fork member by Roller (1987; see description of East Fork member).

Map Symbols

Bibliography

Alvis, M.R., 1984, Metamorphic petrology, structural and economic geology of a portion of the central Mazatzal Mountains, Gila and Maricopa Counties, Arizona: Flagstaff, Northern Arizona University, M.S. thesis, 111 p., 4 sheets, scale 1:6,000.

Anderson, Phillip, 1991, Stratigraphic framework, volcanic-plutonic evolution, and vertical deformation of the Proterozoic volcanic belts of central Arizona, *in* Jenney, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Arizona Geological Society Digest 17, p. 57-148.

Conway, C. M., 1995, Geology of the Kitty Joe Canyon area, Mazatzal Mountains, Arizona: Arizona Department of Transportation, unpublished map and report, scale 1:12,000, 33 p.

Conway, C.M., and Silver, L.T., 1989, Early Proterozoic rocks (1710-1615 Ma) in central to southeastern Arizona, *in* Jenny, J.P., and Reynolds, S.J., eds., Geologic history of Arizona: Arizona Geological Society Digest 17, p. 165-186.

Conway, C.M., Karlstrom, K.E., Silver, L.T., and Wrucke, C.T., 1987, Tectonic and magmatic contrasts across a two-province Proterozoic boundary in central Arizona, *in* Davis, G.H., and VandenDolder, E.M., eds., Geologic diversity of Arizona and its margins: Excursions to choice areas: Arizona Bureau of Geology and Mineral Technology Special Paper 5, p. 158-175.

Damon, P. E., Shafiqullah, M., Harris, R. C., and Spencer, J. E., 1996, Compilation of unpublished Arizona K-Ar dates from the University of Arizona Laboratory of Isotope Geochemistry, 1971-1991: Arizona Geological Survey Open-File Report 96-18 (updated April, 1997), 54 pp.

Ferguson, C. A., Skotnicki, S. J., and Gilbert, W. G., 1998, Geologic map of the Tonto Basin 7.5' Quadrangle, Gila and Maricopa Counties, Arizona: Arizona Geological Survey Open-File Report 98-16, 15 pp., 2 sheets, scale 1:24,000.

Ludwig, K. R., 1974, Precambrian geology of the central Mazatzal Mountains, Arizona (Part I), and lead isotope heterogeneity in Precambrian igneous feldspars (Part II): Pasadena, California, California Institute of Technology Ph.D. Dissertation, 218 p., 1 plate, scale 1:24,000.

Karlstrom, K.E., and Bowring, S.A., 1988, Early Proterozoic assembly of tectonostratigraphic terranes in south-western North America: Journal of Geology, v. 96, p. 561-576.

Karlstrom, K.E., and Conway, C.M., 1986, Deformation styles and contrasting lithostratigraphic sequences within an Early Proterozoic orogenic belt, central Arizona, *in* Nations, J.D., Conway, C.M., and Swann, G.A., eds., Geology of central and northern Arizona, Field trip guidebook for Geological Society of America, Rocky Mountain section: Flagstaff, Northern Arizona University, p. 1-26.

Karlstrom, K.E., Bowring, S.A., and Conway, C.M., 1987, Tectonic significance of an Early Proterozoic two-province boundary in central Arizona: Geological Society of America Bulletin, v. 99, p. 529-538.

Karlstrom, K.E., Doe, M.F., Wessels, R.L., Bowring, S.A., Dann, J.C., and Williams, M.L., 1990, Juxtaposition of Proterozoic crustal blocks: 1.65-1.60 Ga Mazatzal orogeny, *in* Gehrels, G.E., and Spencer, J.E., eds., Geologic excursions through the Sonoran desert region, Arizona and Sonora: Arizona Geological Survey Special Paper 7, p. 114-123.

Mayes, H. B., 1990, Cenozoic stratigraphy and depositional history of the northern Tonto basin, Gila County, Arizona: unpublished M.S. thesis, Northern Arizona University, Flagstaff, Arizona, 113 pp., 3 sheets.

Muehlberger, E. W., 1988, The structure and general stratigraphy of the western half of the Payson basin, Gila County, Arizona: unpublished M.S. thesis, Northern Arizona University, Flagstaff, Arizona, 85 pp.

Nations, J. D., 1987, Report on the Tertiary stratigraphy of the Tonto basin, central Arizona: unpublished report prepared for the U. S. Bureau of Reclamation, Denver, Colorado: Appendix A.

Orr, R.L., 1990, Geology and mineralization associated with the Early Proterozoic Alder Group, the Sunflower mining district, Maricopa and Gila Counties, Arizona: Tucson, University of Arizona, M.S. thesis, 143 p., 2 sheets, scale 1:12,000.

Reed, J.R., 1988, Geology and geochemistry of the Proterozoic age Alder Group, central Mazatzal Mountains, Arizona: Socorro, New Mexico Institute of Mining and Technology, M.S. thesis, 211 p.

Reynolds, S.J., Florence, F.P., Welty, J.W., Roddy, M.S., Currier, D.A., Anderson, A.V., and Keith, S.B., 1986, Compilation of radiometric age determinations in Arizona: Arizona Bureau of Geology and Mineral Technology Bulletin 197, 258 p., 2 sheets, scale 1:1,000,000.

Roller, J.A., 1987, Geometric and kinematic analysis of the Proterozoic upper Alder Group and the Slate Creek movement zone, central Mazatzal Mountains, central Arizona: Flagstaff, Northern Arizona University, M.S. thesis, 105 p., 2 sheets, scale 1:10,000.

Roller, J.A., 1991, Geologic map of the central Mazatzal Mountains, central Arizona: Arizona Geological Survey Contributed Map Series CM-91-F, 2 sheets, scale 1:10,000.

Silver, L.T., 1965, Mazatzal orogeny and tectonic episodicity [abs.], *in* Abstracts for 1964: Geological Society of America Special Paper 82, p. 185-186.

Silver, L.T., Conway, C.M., and Ludwig, K R., 1986, Implications of a precise chronology for Early Proterozoic crustal evolution and caldera formation in the Tonto Basin-Mazatzal Mountains region, Arizona [abs.]: Geological Society of America Abstracts with Programs, v. 18, no. 5, p. 413.

Skotnicki, S.J., and Leighty, R.S., 1998a, Geologic Map of the Boulder Mountain 7.5’ Quadrangle, Maricopa and Gila Counties, Arizona: Arizona Geological Survey Open-File Report 98-15, scale 1:24,000, 17 p. text.

Skotnicki, S.J., and Leighty, R.S., 1998b, Geologic Map of the Maverick Mountain 7.5’ Quadrangle, Maricopa County, Arizona: Arizona Geological Survey Open-File Report 98-14, scale 1:24,000, 18 p. text.

Spencer, J.E., Isachsen, C.E., Ferguson, C.A., Richard, S.M., Skotnicki, S.J., Wooden, J., and Riggs, N.R., 2003a, U-Pb isotope geochronologic data from 23 igneous rock units in central and southeastern Arizona: Arizona Geological Survey Open-File Report 03-08, 40 p.

Spencer, J.E., Skotnicki, S.J., and Richard, S.M., 2003b, Modal mineralogy of some granitic rocks from eastern Maricopa and northern Gila Counties, Arizona: Arizona Geological Survey Open-File Report 03-09, 18 p.

Wessels, R.L., and Karlstrom, K.E., 1991, Evaluation of the tectonic significance of the Proterozoic Slate Creek shear zone in the Tonto Basin area, *in* Karlstrom, K.E., ed., Proterozoic geology and ore deposits of Arizona: Arizona Geological Society Digest 19, p. 193-210.

Wilson, E.D., 1939, Pre-Cambrian Mazatzal revolution in central Arizona: Geological Society of America Bulletin, v. 50, p. 1113-1164.

Wrucke, C.T., and Conway, C.M., 1987, Geologic map of the Mazatzal Wilderness and contiguous Roadless Area, Gila, Maricopa, and Yavapai Counties, Arizona: U.S. Geological Survey Open-File Report 87-0664, 22 p., 1 sheet, scale 1:48,000.