Geologic map of the Sierra Ancha, central Arizona

by

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INTRODUCTION

The Sierra Ancha are a series of high plateaus, mesas, and ridges that extend from Theodore Roosevelt Lake in the south to the Mogollon Rim on the north. The southern margin is in some paces a steep escarpment or series of escarpments, in part defined by normal faulting and down-dropping of blocks to the south and by relatively little faulting to the north. Faulds (1986) and Potochnik (1996) suggested that the southern margin of the Sierra Ancha is an ancient paleocanyon through which the ancestral Salt River flowed to the east. Deep, narrow canyons separate the mesas. Some of the deeper canyons reveal older, early Proterozoic (~1.7 Ga) metamorphosed sedimentary and volcanic rock and weakly deformed early and middle Proterozoic granitic rocks. However, most of the Sierra Ancha are composed of very weakly metamorphosed to unmetamorphosed, nearly flat-lying sedimentary rocks of the middle Proterozoic Apache Group.

The lateral persistence of the basal Pioneer Formation indicates that the older, early and middle Proterozoic basement rocks in the region were beveled remarkably flat during a period of erosion that took place sometime between ~1.4 and 1.2 Ga (Shride, 1967). This hiatus probably lasted for at least 100 million years, and possibly longer. This ancient erosion surface was covered by a thin veneer (several meters thick) of fluvial gravels of the Scanlan Conglomerate member of the Pioneer Formation (Shride, 1967; Trujillo, 1984). This heralded a change from an erosional environment to a depositional environment. Previous workers (Burns, 1987; Trujillo, 1984; Weiss, 1986) have suggested that the change was related to either eustatic sea-level rise or tectonic activity, but the cause for this change is still uncertain.

The names for the middle Proterozoic units in this report have mostly been adopted from Shride (1967). Granger and Raup (1964) subdivided the Dripping Spring Quartzite into several members that aided them in identifying potential mineralized horizons. Since these members have not been mapped everywhere, and would be difficult to show at a scale of 1:100,000 even if they were, the Dripping Spring in this map is subdivided into the Lower Quartzite member and Upper Argillite member (map units Ydsl and Ydsu, respectively). Shride described a regional unconformity between the Dripping Spring and Mescal defined locally by a thin, locally derived conglomerate unit. Mapping during this study confirms the existence of this unconformity. The conglomerate (here named map unit Ymc) was mapped where it was extensive enough to map, only on several of the 1:24,000 scale maps (Copper Mountain, Picture Mountain, and Oak Creek Ranch). The silicified chert breccia at the top of the Mescal was mapped also where it was extensive enough to map, and was given the map label Ymx.

New geologic mapping during this study has resulted in the following: (1) compilation of approximately the southeastern half of the Buzzard Roost Mesa 7.5' quadrangle [unpublished]; (2) Geologic map of the Copper Mountain 7.5' quadrangle [Skotnicki, 1999b]; (3) Preliminary geologic map of the Gentry Mountain 7.5' quadrangle [Skotnicki, 2002b]; (4) Preliminary geologic map of the Oak Creek Ranch 7.5' quadrangle [Skotnicki, 2002a]; (5) Preliminary geologic map of the Parallel Canyon 7.5' quadrangle [Skotnicki, 2002c]; (6) Geologic map of the Picture Mountain 7.5' quadrangle [Skotnicki, 1999a]; (7)) Preliminary geologic map of the Salt River Peak 7.5' quadrangle [Skotnicki, 2002e]; (8) Preliminary geologic map of the Young 7.5' quadrangle [Skotnicki, 2002d]; (9) Preliminary geologic map of the Meddler Wash 7.5' quadrangle [in press?]; and geologic mapping in parts of the Chrysotile 7.5' quadrangle, Oxbow Mountain 7.5' quadrangle, O W Point 7.5' quadrangle, and McFadden Peak 7.5' quadrangle.

Portions of the eastern side of this map are within the Fort Apache and San Carlos Indian Reservations. The remainder of the map is within the Tonto National Forest. The map includes about 1/3 of the Tonto National Forest. Plant communities vary widely from Sonoran Desert in the Tonto Basin and other low-lying areas, to Chaparral and Pinyon-Juniper woodlands in the mid-elevations, to conifer Ponderosa Pine forests in the higher elevations.

PREVIOUS WORK IN THE SIERRA ANCHA

Wilson, Moore, Pierce, and others included reconnaissance mapping in the Sierra Ancha in the geologic map of Gila County (Wilson et al., 1959), the geologic map of Arizona (Wilson and Moore, 1969), and a geologic map of the Apache Indian Reservation (Moore and Pierce, 1967).

Chet Wrucke (unpub.), Andrew Shride (unpub.), Bergquist, J.R., Pat O'Hara and others (unpub.) did extensive reconnaissance mapping in the Sierra Ancha. These maps were used in this compilation. Bergquist and others (1981) compiled much of this unpublished mapping into a 1:62,500 scale geologic map of the Sierra Ancha Wilderness. Shride (1967) studied the rocks of the Apache Group in great detail and recognized that the locally silicified top of the Mescal represents a Precambrian karst. His detailed observations provide most of the basis for all subsequent studies in the Sierra Ancha. Burchard (1931) investigated the iron deposits associated with the top of the Mescal and made detailed descriptions of the geology before maps existed of the region. He also noted the similarity of curved, contorted banding in the chert to ‘fossil crytozoan algae.

In the eastern Sierra Ancha Finnell (1966) produced a color 1:62,500 scale geologic map of the Chediski peak 15' quadrangle in the northeast corner of the current study area. Cuffney (1977) studied the early Proterozoic metasedimentary rocks associated with the Hess Canyon Group along the Salt River. Labrenz (1991) mapped the rocks in the west-central part of the Young 7.5' quadrangle and in the far eastern part of the Buzzard Roost Mesa 7.5' quadrangle. In the western part of the Sierra Ancha Gastil (1958) mapped the early Proterozoic rocks in the eastern 2/3 of the Diamond Butte 15' quadrangle. Conway (1976) mapped and described the early Proterozoic rocks between Young and Payson. He has worked in the early Proterozoic rocks in the western and northwestern Sierra Ancha for several decades (Conway, personal comm.) and has gathered information about those rocks in hopes of compiling the Payson 1:100,000-scale quadrangle. As of this writing his work has not yet been published. Wessels (1991) mapped the geology of the early Proterozoic rocks in the northern half of the Kayler Butte 7.5' quadrangle and the southern part of the Gisela 7.5' quadrangle. Sherlock (1991) mapped the early Proterozoic rocks in and around Sheep Basin Mountain in the northern part of the Sheep Basin Mountain 7.5' quadrangle and the southern part of the McDonald Mountain 7.5' quadrangle. Brady (1991) produced a map of the early Proterozoic rocks in the southern half of the Sheep Basin Mountain 7.5' quadrangle. Skotnicki (1999a,b) made geologic maps of the Picture Mountain and Copper Mountain 7.5' quadrangles.

In the southern Sierra Ancha Spencer and others (1999a) mapped the rocks in the northern half of the Greenback Creek 7.5' quadrangle. Spencer and others (1999b) mapped the bedrock in the Windy Hill 7.5' quadrangle mostly north of Roosevelt Lake. Richard (1999) compiled a brief overview of the geology and mineral resources of the Tonto basin, and included a small-scale map of the Tonto Basin. Bergquist and others (1981) produced a 1:62,500 scale geologic map of a large region that includes the Sierra Ancha Wilderness and Salome Study Area.

Silver (1960, 1963) determined a middle Proterozoic U/Pb age of 1054 $\pm$ 50 Ma for the diabase intruding the Apache Group. McConnell (1972) later studied the Mescal Limestone in more detail and described its stromatolites. He also discovered silicified microfossils preserved in a thin orange chert bed at the top of the Mescal at Roosevelt Dam. Horodyski and Knauth (1994) examined the silicified karst in the Sierra Ancha and discovered microfossils within the secondary silica cement. Beeunas and Knauth (1984) measured the $\delta^{18}O$ and $\delta^{13}C$ of chert and dolomite in the Mescal and determined that the microfossil-bearing secondary cherts formed from meteoric waters. Kenny (1991) and Kenny and Knauth (1992) also analyzed the $\delta^{18}O$ values from both primary and secondary cherts in the Mescal and showed that continental paleotemperatures can be inferred from rocks at least as old as 1.2 Ga.

Several of Larry Middleton’s students at Northern Arizona University studied formations in the Sierra Ancha in detail. Weiss (1986) studied the Arkose member of the Troy Quartzite in the central Sierra Ancha. Burns (1987) studied the Chediski member of the Troy Quartzite in the Sierra Ancha and areas to the south. Both Weiss and Burns observed that the Arkose and Chediski members, respectively, contained braided stream and sand erg deposits consistent with deposition in an arid environment. Trujillo (1984) studied the Scanlan Conglomerate member of the Pioneer Formation in the northern Sierra Ancha. Collum (1995) studied the Pioneer Formation.

ACKNOWLEDGMENTS

This map was begun with the intention to include it in my Ph.D. dissertation at Arizona State University. Paul Knauth and his students have studied the cherts within the erosion surface at the top of the Mescal Limestone for many years. Along with Bob Horodyski, Paul co-discovered what may be the oldest known terrestrial microfossils entombed within the chert (Horodyski and Knauth, 1994) and subsequently enlisted me to decipher the stratigraphy and petrology of these cherts. The goal was to try to unravel the sequence of events that led to their formation, in an effort to better understand life on land in the Precambrian. As a result Paul helped to support this research during parts of two summers through a NASA Exobiology Grant #NAG5-4060. The U.S. Forest Service allowed me a permit to collect data on Forest land under what was until then the worst fire season in Arizona history (the Chediski-Rodeo Fire). Karen Harbour at the Tonto National Forest generously helped provide a grant through the U.S. Forest Service to complete the final stages of this map. Pat O'Hara graciously loaned me a copy of his unpublished map of part of the Sierra Ancha created by him and his former colleagues. Many of the surficial unit descriptions were written, with slight modifications, by Phil Pearthree who wrote them for the Theodore Roosevelt Lake100,000 scale map compilation. Likewise, some of the bedrock map unit descriptions were adopted from descriptions written by Jon Spencer, written for the same purpose. The section of this map that includes the Theodore Roosevelt 1:100,000-scale map was compiled by Jon Spencer and digitized by Tim Orr. All other areas were compiled and digitized by the author. Sources of mapping data are shown on sheet 2 of this map.

UNIT DESCRIPTIONS

Introduction to Surficial Map Units

On this map, surficial deposits are differentiated based on their position in the regional landscape (stream deposits within mountains and on the broad piedmonts that slope gently down from mountain ranges, and river deposits) and their ages. The distribution and physical characteristics of different surficial geologic units have environmental and engineering implications. For example, areas covered by young deposits of the major rivers generally are flood prone and have the greatest potential for ground-water recharge. Old river and piedmont deposits typically have strongly developed, clay- and calcium carbonate-rich soils, whereas young deposits typically have sandy soils with minimal clay or calcium carbonate accumulation. The distribution of deposits of different ages on piedmonts provides information about areas that might be flood prone (areas covered with young deposits) and areas where excavation might be difficult (areas covered with old deposits

This map was developed through compilation of large-scale surficial geologic maps and original reconnaissance mapping of areas that have not been previously mapped. Reconnaissance mapping involved review and compilation of alluvial deposits shown on existing geologic maps, interpretation of surficial geologic units utilizing aerial photographs, and limited field-checking of surficial geologic relationships. Phil Pearthree wrote many of the descriptions of surficial deposits listed below for his compilation of the Theodore Roosevelt Lake 100,000-scale map.

Anthropogenic Units

n **Not mapped**

w **Water**

d **Disturbed**

Quaternary and Tertiary Sedimentary Deposits

<u>Piedmont deposits</u>

Qs **Quaternary alluvium, undivided.**

Qyc **Active channel deposits (< 100 yrs)**

Very young deposits in the channels of larger ephemeral streams draining piedmonts and mountain areas are labeled Qyc. Qyc deposits are composed of unweathered sand, silt, pebbles, cobbles, and boulders. Qyc deposits are typically coarse and very poorly sorted within mountain areas and on upper piedmonts, with particles ranging from silt to cobbles or boulders. In areas subject to overbank flooding, however, Qyc deposits are primarily sand and silt. Drainage patterns of Qyc channels are generally dendritic in the mountains and on upper piedmonts. Within the larger Qyc channels and on the lower piedmonts distributary and anastomosing channel patterns are common. Many Qyc channels on lower piedmonts have discontinuous entrenched and unentrenched reaches.

Qyc alluvium is generally well-stratified and lacks any appreciable soil formation. Qyc soils are classified as Torrifluvents or Torriorthents. Most of the channel surfaces are modern in age, but vegetated bars may be several hundred years old.

Relatively large and dense vegetation tends to be associated with Qyc deposits because of the greater supply of moisture along modern drainages. Some of the larger drainages that originate in the mountains support streamflow in the mountains and upper piedmont areas during the winter and spring. These drainages may sustain large and lush riparian vegetation, such as cottonwood, sycamore, desert willow and tamarisk. Most Qyc channels only flow during or immediately after rainfall events, however. These channels typically are lined with palo verde, mesquite, or ironwood. Qyc surfaces are prone to flooding unless structures have been constructed to divert water from them. Due to relatively frequent wetting and high permeability, areas mapped as Qyc have high potential for ground-water recharge.

Qy **Holocene alluvial deposits (<10 ka)**

Holocene alluvial deposits are mapped as Qy. Unit Qy consists primarily of low terraces along active channels in the mountains and upper piedmont areas and broad alluvial fans on middle and lower piedmonts. Many small active channels are also included in unit Qy on piedmonts or in the mountains where they could not be differentiated from slightly older deposits at the map scale. In the map area Qy deposits typically are associated with relatively narrow stream channels on piedmonts and within the mountains. Qy terraces and alluvial fan surfaces are 0 to 2 m above active channels. In the mountains and on upper piedmonts particle sizes range from fine sand to boulders; on lower piedmonts, sand, silt, and pebbles predominate.

Qy soils are weakly developed and primary fluvial bedforms (gravel bars and finer-grained swales) are commonly preserved. Surface colors typically are light brown to yellowish brown (color hues of 10 YR to 7.5 YR); slight reddening deeper in the soil profile is common. Surfaces have minimal or no rock varnish or desert pavement development. Pedogenesis is generally limited to surface enrichment of silt from eolian sources, slight reddening due to oxidation, and weak calcium carbonate accumulation. Qy soils formed in higher altitude locations or areas with enhanced dust influx show more evidence of clay translocation and accumulation (Huckleberry, 1997). Generally, late Holocene soils are minimally developed, whereas middle and early Holocene soils typically contain cambic horizons, weak calcic horizons (Stage I or less; morphologic stages of calcium carbonate accumulation are after Gile and others, 1981, and Machette, 1985), and are noticeably reddened. Qy soils classify as Torrifluvents, Torriorthents, Camborthids, and Calciorthids.

Based soil development and a few radiometric dates (Huckleberry, 1997), we estimate Qy surfaces range in age from modern to 10 ka. Qy deposits here are correlated with the Q4, Q3c, and Q3b surfaces (< 8 ka) in the lower Colorado River valley (LCR) (Bull, 1991); and with the Fillmore alluvium (< 7 ka) in southern New Mexico near Las Cruces (SNM) (Gile and others, 1981).

Qy includes many small active channels, relatively low stream terraces, and active alluvial fans. All areas mapped as Qy may be subject to inundation during large floods and should be considered as potentially flood prone unless geomorphologic or hydrologic/hydraulic analyses indicate they are not. Due to relatively high permeability and the variable potential for inundation, areas mapped as Qy have moderate to high potential for ground-water recharge.

Qls Landslide deposits (Quaternary)

These deposits consist of masses of poorly sorted debris derived from rocks immediately uphill from their present location. Individual clasts are commonly angular to subrounded and range in size from sand and pebbles to large boulders several meters across. The surfaces of some of these deposits are locally hummocky, but it is not clear if this represents original surface topography or later stream entrenchment. These deposits were likely emplaced as either non-turbulent, coherent rock avalanche deposits or as slightly turbulent, localized debris flows.

Qtc Talus and colluvium (Quaternary)

Weakly to non-indurated gravel mantling hill slopes on bedrock. Consists of angular clasts of locally derived rock in a sand and clay matrix, derived by weathering of bedrock and downslope movement of regolith material. Mapped where hill slope deposits are thick enough to obscure the nature of the underlying bedrock. Non-conformably overlies all older deposits. Includes regolith of disaggregated Proterozoic diabase and Pioneer Shale of the Apache Group in the Sierra Ancha (Greenback Creek 7 ½' Quadrangle).

Ql Late Pleistocene alluvial deposits (10 to 250 ka)

Late Pleistocene alluvial fan surfaces and terraces with moderate soil development are mapped as unit Ql. These deposits are found along some mountain streams and on piedmonts. Ql units are typically alluvial fans on middle and lower piedmonts and terraces on upper piedmonts and in mountain areas. Alluvial sediment sizes range from sand to cobbles and boulders, coarser in upper piedmont and mountain areas. Drainage patterns on Ql surfaces are dendritic, with surface dissection varying from about 1 to 4 m. Desert pavement and rock varnish development is quite variable, ranging from nonexistent to moderate. Subdued depositional bar-and-swale surface topography is common.

Ql soils are more strongly developed than Qy soils, but their characteristics vary substantially. Ql surface colors typically are similar to or slightly redder than Qy surfaces (light brown to reddish yellow). Ql soils commonly contain argillic horizons (zones of clay accumulation) that are weakly to moderately strongly developed. These upper horizons of Ql soils are slightly (7.5 YR) to obviously (5 YR to 2.5 YR) reddened relative to their parent material. Calcic horizon morphologies are also quite variable, ranging from minimal carbonate accumulation in higher altitude locations to Stage III development in the western part of the quadrangle. Ql soils classify as Haplargids, Camborthids, and Calciorthids.

Unit Ql includes deposits of several different ages, probably ranging from slightly greater than 10 ka to as much as 100 to 200 ka. We correlate Ql deposits with the Q2c (12-70 ka) and possibly Q2b (70-200 ka) surfaces of the LCR (Bull, 1991), and the Isaac's Ranch (8-15 ka) and Jornada II (25-125 ka) surfaces of the SNM (Gile and others, 1981). All Ql soils have developed at least in part during times when the regional climate was wetter and cooler than the Holocene, but the oldest soils may be an order of magnitude older than the youngest soils. Although well developed, none of these soils have not yet reached the stage of pedogenic development when subsequent soil formation is impeded by plugged and indurated horizons. These late Pleistocene soils thus display greater morphological variability compared to older soils that have strong argillic horizons or petrocalcic horizons.

Ql units generally are not flood-prone, except immediately adjacent to active washes. In lower piedmont areas where topographic relief is minimal, some areas mapped as Ql may be subject to inundation during extreme floods or may become subject to inundation as a result of relatively minor changes in the stream systems. Areas mapped as Ql generally have low recharge potential; their soils have moderate permeability but they are isolated from major washes.

Qml Middle to Late Pleistocene alluvial deposits, undivided (10 to 750 ka)

Qml is a composite map unit that contains both middle Pleistocene (Qm) and late Pleistocene (Ql) terrace and alluvial-fan deposits. Qml is used where Qm and Ql surfaces interfinger in a complex fashion or in areas that were mapped on a reconnaissance basis. In the areas of reconnaissance mapping, it typically is difficult to confidently distinguish between middle and late Pleistocene deposits without extensive field investigations and soil descriptions, so an undifferentiated unit is employed. Areas mapped as Qml are not prone to flooding except in and immediately adjacent to washes, and they are not areas of significant recharge.

Qm Middle Pleistocene alluvial deposits (250 to 750 ka)

Dissected middle Pleistocene alluvial-fan and terrace deposits with moderate to strong soil development are mapped as Qm. Relict Qm alluvial fans cover much of the middle and upper piedmonts throughout the Tonto Basin. Sediment grain sizes range from sand to boulders, fining downstream. Qm alluvial-fan surfaces typically have dendritic drainage and are heavily dissected by streams that head on them. Qm surfaces typically are 2 to 10 m above modern channels, with dissection decreasing downslope as Qm surfaces converge with younger surfaces. Desert pavement and rock varnish development are moderate to strong on stable Qm surfaces, but may be variable or weak on surfaces that have experienced significant erosion.

Qm soils typically exhibit strong soil development. Surface color range from strong brown to reddish brown. Qm soils typically contain reddened argillic horizons (typically 5 YR to 2.5 YR) that are moderately to strongly enriched in pedogenic clay. Clasts within argillic horizons may be highly weathered. Calcic horizon development typically is fairly strong (Stage II-IV), but Qm units generally do not have cemented petrocalcic horizons (caliche). These soils classify as Calciorthids and Haplargids.

We estimate the age of Qm deposits to be 250 to 750 ka. Soils associated with the Qm unit typically are much more strongly developed than those associated with Ql, implying that Qm is substantially older than Ql. We correlate the Qm unit with Q2a surfaces (400-700 ka) of the LCR (Bull, 1991) the Jornada I (250-400 ka) and possibly Doña Ana (> 400 ka) surfaces of SNM (Gile and others, 1981).

Areas mapped as Qm are generally not flood prone except in and adjacent to washes. Because of their relatively impermeable argillic and petrocalcic horizons, Qm surfaces are not areas of significant ground-water recharge.

Qo Early Pleistocene alluvial deposits (750 ka to 2 Ma)

Deeply dissected remnants of very old Quaternary to late Pliocene alluvial fans with strong soil development are mapped as Qo. Qo surfaces range from 5 to about 100 m above modern channels. The highest levels of Qo mark the highest stand of basin deposits along the upper piedmont in some places. Older deposits underlying and downslope from preserved Qo surfaces are mapped as Tertiary basin-fill deposits (Ts). In the Tonto basin basin-fill deposits exist at levels substantially higher than Qo surfaces. Qo deposits typically are cobbly to bouldery and are very poorly sorted, with grain sizes ranging from sand to boulders. Desert pavement on Qo surfaces varies from none to moderate; rock varnish varies from none to strong. Qo surfaces exist in areas where the clasts are composed of relatively resistant lithologies, such as quartzites or other metasedimentary rocks.

Qo soils range are characterized by strong carbonate and silica cementation and variable clay accumulation, depending on their preservation. In areas where fairly extensive planar Qo surfaces are preserved, Qo soils typically include reddish brown to red (5 YR to 2.5 YR), clay-rich argillic horizons and cemented duric (silica cemented) or petrocalcic horizons with laminar caps (caliche; Stage V). In areas where Qo remnants are of limited extent, or on slopes below planar fan surfaces, argillic horizons may have been removed by erosion leaving a duric or petrocalcic horizon and caliche fragments at the surface. Qo soils classify as Paleargids, Durargids, and Durorthids. The common presence of cemented fragments on Qo surfaces indicates erosion or bioturbation of the original surface.

We estimate the age of Qo alluvium to be 1 to 2 Ma. Unit Qo correlates with the Q1 surface in the LCR (Bull, 1991) and possibly the Doña Ana surface of the middle Rio Grande Valley (Gile and others, 1981). Both of these surfaces have open-ended age estimates (> 1.2 Ma for Q1 and > 400 ka for Dona Ana). Qo also correlates with the Martinez surface and equivalent surfaces (Menges and McFadden, 1981; Morrison, 1985), that are common to the basins of southeastern Arizona. Menges and McFadden (1981) estimate the age of the Martinez surface as 1-3 Ma based on very strong soil formation and magnetostratigraphy of underlying sediments.

Areas mapped as Qo are not flood prone. Impermeable argillic and petrocalcic horizons, high topographic positions, and relatively steep slopes associated with unit Qo severely limit the amount of groundwater recharge in these areas.

Major-River Deposits

Deposits of the major rivers that traverse the map area are described in this section. The Salt River and Tonto Creek drain most of the map area. Deposits of each of these rivers and their major tributaries consist of active channels and one or more terraces that record former, higher positions of the stream channels. These river terraces, which range from Holocene to early Pleistocene or Pliocene in age, record the recent geologic evolution of the major rivers. The heights of river terraces of similar age increase relative to modern channels from west to east and south to north across the western boundary of the Transition Zone. This phenomenon has been interpreted by several authors as evidence for regional uplift of the Transition Zone of central Arizona relative to the Basin and Range province of south-central Arizona (Péwé, 1978; Menges and Pearthree, 1989; Huckleberry, 1993a). However, identification of other northeast-diverging stream profiles not associated with the Transition Zone, in comparison with Quaternary climate data and sedimentation rates, suggests northeast-divergence of terraces was caused by fluctuating climatic conditions in the Quaternary (Skotnicki and Spencer, 2000).

Major river deposits are distinguished from piedmont and basin-floor deposits by their diverse lithologic composition, their clast rounding, and their landform morphology. These rivers drain large, geologically-complex areas, so their sediment is composed of many different lithologies. River sediment typically has been transported a long distance prior to its deposition in this area, so clasts generally are much more rounded than those of piedmont gravels. River terraces typically are elongate landforms that mimic the general trend of the modern rivers. Terraces are bounded on at least one side by a scarp (or riser) that either drops down to the next younger terrace or rises up to the next older terrace. Modern river channels and terraces of different ages are similar sedimentologically, and are distinctly different from piedmont gravels (Kokalis, 1971).

Qycr (< 100 yrs)

Modern channels of the Salt and Verde rivers and their larger tributaries are mapped as unit Qycr. The channels of these major streams have been shaped primarily by large floods, with some modification by human activity. The form and extent of modern channels have varied substantially during the historical period (for example, Pearthree, 1996). The locations of channels shown on this map are as they existed when original, large-scale geologic mapping was completed (see Sheet 2 for data sources). Channel banks are commonly well-defined, ranging from 1 to 3 m in height. Along some stream reaches, however, channel depth decreases and the channel diverges into several smaller, anastomosing channels.

Channel deposits consist primarily of sand, cobbles, and boulders, with local accumulations of silt. The Salt River channel especially has distinctly coarse sediment, dominated by rounded cobbles and small boulders. Deposits within Qycr channels are modern to historical in age.

Areas mapped as Qyrc have been flooded one or more times during the historical period and should be considered flood prone. Even though upstream dams on the Salt and Verde rivers provide some mitigation of flooding, channel areas suffer serious inundation during large flow events. Due to the permeability of the sediment and the frequency of flow, major river channels are the areas with the greatest potential for ground-water recharge.

Qyr (< 10 ka)

Low terrace deposits with weak soil development are mapped as unit Qyr. Several different levels of terraces are included in this map unit. The lowest and youngest of these terraces are discontinuous and contain both channel (crudely bedded coarse sands, gravels, and cobbles) and overbank (finely laminated clays, silts, and fine sands) sediments. Soil development is limited to slight organic accumulation at the surface and some bioturbation; soils classify as Torrifluvents.

Somewhat older Holocene terraces comprise the majority of unit Qyr. Included in this subdivision are the Lehi terrace of the Salt and Verde rivers (Péwé, 1978). These terraces range from 1 to 5 m above active channels. They are fairly continuous and broad; they contain both channel and overbank deposits, with the latter dominating the upper part of the terrace. Alluvial bedforms near the surface are absent or weakly expressed due to bioturbation. There is organic accumulation in uppermost soil horizons, and slightly oxidized horizons exist at deeper levels. In places, fine nodules of calcium carbonate have begun to accumulate. Soils on the Qyr terraces are Torrifluvents and Camborthids.

Many areas mapped as Qyr may be subject to flood hazards. Portions of Qyr terraces have been inundated in large historical floods (Péwé, 1978), even after dams were constructed upstream. Lateral bank erosion during floods is also a major hazard, because major changes in channel form and position have occurred in large floods (Pearthree, 1996) and the weakly consolidated deposits of Qyr terraces typically are susceptible to erosion. Qyr terraces may be areas of significant ground-water recharge if they are inundated during large floods.

Qlr (10 to 250 ka)

Late Pleistocene river terraces with moderate soil development are mapped as unit Qlr. Terraces of this age include the Blue Point Terrace of the Salt River (Péwé, 1978) and the Cahava Ranch terrace of Cave Creek (Gorey, 1990). Qlr terraces are limited in extent in the Theodore Roosevelt Lake Quadrangle, and Qlr terrace deposits typically are thin. Qlr terrace surfaces range from about 2 to 15 m above modern channels. In mountain areas along the Salt River, Qlr terraces are relatively narrow straths eroded into bedrock, with thin (< 3 m) caps of alluvial deposits. Qlr terrace surfaces have undergone some dissection by small streams that flow across them.

Based primarily on soil development, we believe that Qlr terraces are moderately old, but substantially younger than the next older river terraces described below. Soil development on Qlr terraces is moderate, with 5 to 7.5 YR reddening, moderate clay accumulation, and stage II calcium carbonate accumulation (Anderson and others, 1986).

Qlr terraces are not prone to flooding from the major rivers, although minor flooding might occur along small drainages on the terraces. Lateral bank erosion could be a hazard where Qlr terraces abut the active river channels (unit Qycr). Qlr deposits are fairly permeable, but inundation is limited, so Qlr terraces are not areas of significant recharge.

Qmlr (250-400 ka)

Unit Qmlr includes intermediate terraces with moderately strong soil development along the Salt River. Terraces grouped in this map unit are equivalent to the McDowell terrace (Pope, 1974; Péwé, 1978). Qmlr terraces are about 30 m above the modern channel. Soil development includes relatively thick argillic horizons with clay textures and abundant carbonate, but no cemented petrocalcic horizons.

Qmr (400 to 750 ka)

Unit Qmr includes prominent high terraces with strong soil development. Terraces grouped in this map unit include the Mesa terrace along the Salt and Verde rivers (Péwé, 1978). Qmr terraces range in height above the modern channel from 5 to 10 m in the south and west to as much as 30 to 70 m in the east. Qmr alluvium is composed of sand, gravel, and cobble channel deposits with interfingered silty and clayey overbank sediments. Desert pavement and rock varnish development is weak to moderate. Some Qmr terraces have broad, well-preserved alluvial surfaces. In many areas, however, Qm surfaces do not have a planar morphology because they have been eroded by streams that head on them or that flow across them. Eroded Qmr landforms consist of series of low, rounded ridges and moderately incised stream channels.

Soils associated with Qmr terraces are strongly developed where they have not been seriously eroded. Clay accumulation in Qmr soils is variable; well-preserved soils have fairly strong, red argillic horizons with loam to clay loam textures (Anderson and others, 1987). Qmr soils typically have strongly developed calcic or petrocalcic horizons (Stage III-V) (Péwé, 1978; Anderson and others, 1986) and classify as Calciorthids, Paleorthids and Paleargids. Strongly developed surface soils and the extent of surface dissection suggest that Qmr terraces are at least several hundred thousand years, and possibly as much as 1 million years old (see Péwé, 1978). Using total carbonate accumulation in a Mesa terrace soil, Anderson and others (1986) estimated an age range of 350 to 775 ka for the terrace.

Qor (1 to 2 Ma)

Very old, very high, degraded river terrace remnants are mapped as Qor. Unit Qor includes the Sawik terrace along the Salt and Verde rivers (Péwé, 1978). Along the Salt Qor terraces exist as isolated remnants standing high above the Mesa (Qmr) terrace. They are found up to 180 m above modern stream channels in Tonto basin above Theodore Roosevelt Dam (Anderson and others, 1987). Because Qor terrace deposits have been exposed to erosion for most of the Quaternary, they seldom retain their original terrace form and instead form a series of isolated ridges and hills. Qor deposits are coarse, with clasts ranging in size from pebbles to boulders. Coarse-grained rocks at the surface are highly pitted, and fine-grained rocks are commonly fractured. There is no desert pavement development in areas that have undergone significant erosion, but in a few places where depositional surfaces are preserved desert pavement and rock varnish are moderately to strongly developed.

Qor soils are dominated by thick petrocalcic horizons with Stage IV-V morphology. Secondary silica incorporated within the petrocalcic horizons appears as light brown, thin laminae. Based on the extremely strong soil development and the height of Qor terraces above modern stream channels, their age is likely to be at least 1 million years old, and they may be as old as late Pliocene (Péwé, 1978; Anderson and others, 1986).

Quaternary or Tertiary Sedimentary Deposits

QTls Landslide deposits (Quaternary to Pliocene)

Poorly consolidated to unconsolidated, very poorly sorted mud to large boulders, characterized by a hummocky surface littered with boulders. Bedding or foliation in boulders (when present) varies greatly between outcrops. Landslides downstream from Theodore Roosevelt Dam appear to have failed in middle Dripping Spring Quartzite (just west of Theodore Roosevelt Dam) or in diabase (Yd) sheets in granitic rocks (Spencer and Richard, 1999). This unit is probably equivalent to map unit Qls but was mapped slightly differently by different authors.

QTs Quaternary alluvium and colluvium, and Pliocene to Miocene siltstone, sandstone, and conglomerate, undivided (Quaternary to Miocene)

Includes: (1) Non-indurated to weakly indurated cobble to boulder fanglomerate in the piedmont around Theodore Roosevelt Lake where Miocene conglomerate (Tct) is suspected, but is overlain by Quaternary deposits that are deeply weathered and commonly vegetation covered such that distinguishing between the two units is problematic. (2) Slightly to moderately tilted fanglomerate and local finer grained clastic sediments of probable or known Miocene age that are overlain by colluvium and alluvium. Deep weathering and vegetation cover prevent division of the two sediment types.

Clastic sedimentary rocks associated with the Tonto Basin and areas south

Tsy Younger clastic sedimentary rocks (Pliocene to middle Miocene)

Moderately to poorly sorted conglomerate, sandy conglomerate and conglomeratic sandstone generally deposited in alluvial fans that are now incised. At the east foot of the Mazatzal Mountains, this unit consists of generally untilted conglomerate that grades eastward from coarse, massive conglomerate at the foot of the Mazatzal Mountains to moderately coarse conglomerate. Toward the Tonto Basin axis this unit contains local lenses of rounded-clast conglomerate derived from outside the basin (Tonto Basin 7 ½' Quadrangle, Ferguson et al., 1998b). Downslope from the southwest escarpment of the Sierra Ancha, this unit consists of a thin, highly incised sheet of conglomerate containing clasts derived primarily from the Dripping Spring Quartzite and possibly Troy Quartzite and deposited on diabase below bluffs of Dripping Spring Quartzite and Troy Quartzite (Skotnicki, 1999a, b). Map units Tct and Tcsa are probably equivalent to map unit Tsy but were labeled differently by different authors.

Ts Late Tertiary siltstone deposits (2 to 38 Ma)

Unit Ts consists primarily of late Tertiary alluvial sediment that was deposited in basins formed during extensional tectonism. Dissection of these deposits is variable, but they typically are deeply eroded into ridges and intervening valleys with as much as 100 m of local relief between modern stream channels and the highest levels of unit Ts. In some portions of the Theodore Roosevelt Lake Quadrangle, Ts sediment is capped by fan gravels of unit Qo. Generally, however, no original depositional surfaces are preserved at the highest levels of this unit. Unit Ts consists primarily of untilted Pliocene to middle Miocene deposits in the Tonto Basin.

Tcsa Conglomerate on the southwest side of the Sierra Ancha (Miocene?)

Tan, massive to poorly bedded, cobble to boulder conglomerate with clasts derived from local granite, the Apache Group, and diabase (Spencer et al., 1999a; Skotnicki, 1999b). This unit forms rounded hills at intermediate to low elevations on the southwest flank of the Sierra Ancha. Probably correlative with map units Tsy and Tct. Strata of this unit are not generally tilted except in one small half graben(?) in the northwestern corner of the Greenback Creek 7 ½' Quadrangle where strata of this unit include sandstone (Spencer et al., 1999a).

Tmt Mudstone of Tonto Basin (Miocene)

Red mudstone and siltstone with local gypsiferous beds and green mudstone (Tonto Basin quadrangle, Ferguson et al., 1998b). Dips are generally 5° to 10° to the southwest, probably toward a concealed normal fault at the foot of bedrock exposures in the Mazatzal Mountains and toward the exposed El Oso fault in the southeastern part of the Tonto Basin quadrangle (Ferguson et al, 1998b). This unit interfingers with the conglomerate of Tonto Basin (map unit Tct), and is interbedded with an airfall tuff in the Kayler Butte quadrangle that is dated at 18.55±0.56 Ma (Mayes, 1990; Damon et al., 1996). This unit may be equivalent to map unit Ts.

Tst Sandstone of Tonto Basin (Miocene)

Tan to pale gray or pale reddish brown, thin bedded, very fine-grained sandstone and mudstone that grades laterally toward the Mazatzal Mountains into pebble and cobble conglomerate of map unit Tct (Spencer and Richard, 1999).

Tct Conglomerate of Tonto Basin (Miocene)

In northern Tonto Basin this unit consists of arkosic pebbly sandstone and sandy conglomerate containing locally derived clasts (Tonto Basin quadrangle, Ferguson et al., 1998). Dips are generally 5° to 10° to the southwest, probably toward a concealed normal fault at the foot of bedrock exposures in the Mazatzal Mountains and toward the exposed El Oso fault in the southeastern part of the Tonto Basin quadrangle (Ferguson et al, 1998b). This unit interfingers with the mudstone of Tonto Basin (map unit Tmt). This unit may be equivalent to map unit Tsy. In central Tonto Basin this unit generally consists of moderately to poorly bedded and sorted conglomerate (Spencer and Richard, 1999). Lithification is variable and generally fairly weak but is commonly sufficient to form steep slopes and small cliffs. Most clasts appear to be locally derived and largely supplied by the east flank of the Mazatzal Mountains. Faults that separate the conglomerate from bedrock are partially buried by the conglomerate, and it appears that sedimentation was related to normal faulting that, at least in part, produced Tonto Basin (Spencer and Richard, 1999).

Volcanic and sedimentary rocks associated with Black Mesa and the Superstition Mountains

Tri Intrusive rhyolite

This light gray hypabyssal rock is nearly aphanitic and contains minor phenocrysts of quartz and feldspar less than 2 mm across. Mapped by Faulds (1986) along the Salt River near Black Mesa.

Tai Intrusive andesite

Mapped by Faulds (1986) along the Salt River near Black Mesa.

Tbi Intrusive basalt

Mapped by Faulds (1986) along the Salt River near Black Mesa.

Tb Basalt (early Pliocene to middle Miocene)

Basaltic lava flows with minor scoria and flow(?) breccia. Two basalt units have been dated in the map area. They include what Pierce and others (1979) called the Canyon Creek Basalt dated at 20.62 ± 1.07 Ma (K-Ar, whole rock; 34° 0.49' lat, 110° 40.59' lon) and the Blue House Mountain Basalt, dated at 21.90 ± 1.92 (K-Ar, whole rock; 33° 58.33' lat, 110° 34.70' lon).

It is not clear if the basalts mapped as map unit Tb are all correlative or represent basalts of widely different ages. To the west of the map area basalts dated at 13.4 ± 0.4 Ma and 15.3 ± 0.5 Ma form gently dipping flows in the central Mazatzal Mountains (Wrucke and Conway, 1987). Basalt flows and related flow breccias, scoria, and local derivative clastic in the New River Mesa Quadrangle (Gilbert et al., 1998; Ferguson et al., 1998a) yielded whole-rock K-Ar dates of 14.8 ± 0.8 Ma and 14.7 ± 0.4 Ma (Scarborough and Wilt, 1979) and are probably correlative with the Hickey Formation (Leighty, 1998). Distinction of this basalt from underlying basalts that are commonly interbedded with 20 to 22 Ma tuffs and associated sedimentary rocks of the Chalk Canyon Formation of Leighty (1998) is problematic and rocks shown as basalt (map unit Tb) might in fact be older and correlative with map unit Tm (mafic volcanic rocks).

Tsl Lacustrine sedimentary rocks, undivided (middle Miocene)

Thin bedded mudstone, carbonaceous mudstone, marl, and minor fine grained sandstone (Faulds, 1986) This unit is equivalent to the White Eagle Mine Formation of Doorn and Pewe (1991) and to the upper member of the Chalk Canyon Formation (Gomez, 1978; Leighty, 1997). This map unit is known to contain elevated levels of uranium and is considered a radon hazard to homes built on it (Duncan and Spencer, 1990). Sanidine from a tuff interbedded with basalt near these lacustrine rocks within a section of conglomerate and basalt to the west in the Horseshoe Dam Quadrangle (Ferguson and Gilbert, unpublished mapping, 1998-1999) yielded a sanidine $^{40}Ar/^{39}Ar$ date of 15.41±0.21 Ma (sample F8-160; W. McIntosh, written communication, 1998).

Ta Andesite (middle to early Miocene)

Massive lava flows and breccias. This Andesite contains plagioclase and hornblende or pyroxene in a medium to dark gray aphanitic matrix. This unit was mapped in two places; at the top of Salt River Peak and on an unnamed hill 3 km to the southwest of Salt River Peak (both in the Salt River Peak 7.5' quadrangle; Skotnicki, 2002e). Both exposures overlie Apache Leap Tuff.

Tt Unwelded, bedded tuff

Tta Apache Leap Tuff (middle to early Miocene)

Crystal-rich ash-flow tuff in the Superstition Mountains formerly referred to a Superstition Tuff. Tuff contains 40-50% plagioclase, quartz, sanidine, and biotite. Sanidine from this tuff has been dated by the $^{40}Ar/^{39}Ar$ method at 18.6 Ma. This unit commonly forms buff-colored cliffs dissected by and deep canyons. This unit was probably erupted from either one of two calderas; the Superstition Caldera (Ferguson et al., in press) and/or the Haunted Canyon Caldera (Peterson, 1960).

Tfu Felsic lava flows (middle to early Miocene)

Generally rhyolitic lava flows along the Salt River on the north side of the Superstition Mountains. Includes crystal rich, crystal poor, and aphyric varieties, flow front and carapace breccias, and, locally, shallow intrusions.

Tfui Felsic to intermediate domes, dikes, and shallow intrusions (middle to early Miocene)

Crystal poor rhyolite to crystal rich rhyodacite that locally grades into lava flows of map unit Tfui.

Tm Mafic volcanic rocks, undivided (middle to early Tertiary)

These mafic lava flows (basalts) are found stratigraphically below the Apache Leap Tuff and below or within the sequence of felsic volcanic rocks in the Superstition Mountains. It is not clear how these flows correlate with basalts (map unit Tb) overlying conglomerate (map unit Tc) up on the higher plateaus in the eastern part of the map area.

Td Dacite (middle to early Miocene)

Dacite lava flows. Along Pinal Creek the dacite contains small biotite and plagioclase phenocrysts (Skotnicki, 2002e).

Tw Conglomerate and sandstone—"Whitetail conglomerate" (middle to early Miocene)

Generally prevolcanic conglomerate, pebbly sandstone, commonly arkosic sandstone, and rock avalanche breccia. Deposition of these rocks reflects the beginning of extensional faulting and associated basin formation, and was commonly followed by volcanism. Locally, conglomerate contains minor Tertiary volcanic clasts. This unit commonly forms the basal unit of the Tertiary rock section west of the Canyon Creek Fault and locally contains interbedded basalt flows. The distinction between map unit Tw and conglomerates assigned to the "Rim Gravels" (map unit Tc) may be arbitrary as mapped here. Both Tw and Tc rest on pre-Tertiary basement and both are overlain and contain interbedded basalt flows. Hence, it is possible that the two units may be equivalent.

Tc Conglomerate and sandstone—"Rim Gravels" (early to middle Tertiary)

This unit consists of medium bedded, moderately consolidated conglomerate interbedded with moderately sorted sandstone and conglomeratic sandstone. Early Tertiary "Rim Gravels" that were shed northeastward onto the Colorado Plateau when the Plateau was topographically lower than the Basin and Range Province (Peirce et al., 1979; Faulds, 1986; Potochnik, 1989; Spencer and Reynolds, 1989). However, as mapped the unit may include deposits of different ages, the younger of which may have been deposited after erosion and redeposition of the earliest deposits. For example, deposits at and north of the town of Young fill a basin topographically lower than similar deposits capping the Nagelin Rim immediately to the north. Deposits near Young also contain more siltstone and fine-grained sandstone than is revealed in exposures elsewhere.

Cretaceous Sedimentary Rocks

Ks Sandstone and shale (Cretaceous)

Sandstone and shale. Sandstone, feldspathic, pale yellowish gray to yellowish brown and pale red, fine- to coarse-grained, cross-bedded. Commonly contains coalified and ferruginous fossil plant fragments. Conglomerate at base contains pebbles of white to yellowish chert and drab quartzite. Shale, dark to medium gray and olive brown to reddish brown. Forms steep to moderate slopes and some flat-topped ridges (description from Finnell, 1966).

Paleozoic Sedimentary Rocks

Pk Kaibab Limestone (Permian)

Sandstone and limestone. Sandstone is light yellowish gray to light yellowish brown, fine- to very fine-grained, thin-bedded to massive, locally cross-bedded on a small scale, and commonly calcareous. Limestones are light gray to yellowish gray and pale olive gray, commonly sandy and dolomitic. Beds are generally 1-4 feet thick. Contains fossil pelecypods, brachiopods, and echinoid spines. Grades laterally into sandstone. Best preserved in thicker sections north of Carrizo Creek. Forms steep slopes and cliffs with a distinct bench on top (description from Finnell, 1966).

Pc Coconino Sandstone (Permian)

Light yellowish gray to pale orange. Local reddish brown beds as much as 50 feet thick. Fine- to medium-grained and well sorted. Fairly well cemented by quartz and iron oxides. Quartz crystal overgrowths on sand grains cause most of the sandstone to sparkle in sunlight. The sandstone is divided into flat-lying layers by extensive bedding planes spaced 10 to 50 feet apart. Within the layers in the upper half of the formation the sandstone commonly contains aeolian cross-bedding. In the lower part the beds are more commonly massive or flat-bedded. Local breccias in the lower 100 feet are composed of angular to rounded fragments of laminated sandstone as much as 18 inches in diameter enclosed in a matrix of fine-grained, massive sandstone (description from Finnell, 1966).

Psls Supai Formation, limestone and siltstone member (Permian)

Pale red, fine-grained, thin-bedded to massive sandstone, thinly laminated reddish brown siltstone locally interbedded with gypsum, and interbedded siltstone and limestone in beds 0.5 to 25 feet thick (description from Finnell, 1966).

Psfa Supai Formation, Fort Apache member (Permian)

Medium to light gray limestone, silty and with siltstone partings between beds. Beds are generally 6-18 inches thick. Contains silicified pelecypods, cephalopods, and brachiopods. Forms cliffs (description from Finnell, 1966).

Pss Supai Formation, sandstone and siltstone member (Permian)

Interbedded siltstone, sandstone, and limestone. Pale red to reddish brown, fine-grained, and massive to thin-bedded. A few lenticular beds of gypsum as much as 6 feet thick are enclosed by siltstone. Sandstone is fine-grained to silty, massive to faintly cross-bedded and calcareous (description from Finnell, 1966).

₽Psc Supai Formation, Cibeque member (Upper Pennsylvanian and Permian)

Sandstone and shale. Reddish brown to light gray sandstone predominates over shale in the upper half of the unit in the southeast and vise versa in the northwest. Shale forms lower part of unit. The entire unit is calcareous and contains a few nodular limestone beds. Locally contains lenses of limestone and chert pebbles. Sandstone beds are cross-bedded and fill channels cut in the underlying units. Some sandstone beds contain silicified plant stems and roots. Forms steep slopes that commonly merge upward into sandstone cliffs (description from Finnell, 1966).

₽Psl Supai Formation, limestone and sandstone member (Upper Pennsylvanian and Permian)

Gray, red and purple calcareous shale locally contains abundant fusulinids and veinlets of gypsum. Gray, finely crystalline limestone contains veinlets of red chert, as well as brachiopods, pelecypods, gastropods, and crinoid stems—all commonly replaced by orange chert. A thin-bedded silty facies of the uppermost limestone along Spring Creek contains coalified plant fragments, and a shale in the upper part of the lower unit contains silicified logs as much as 2 feet in diameter (about a mile south of Lonely Mountain). Sandstone is reddish brown to pale yellowish gray, fine-grained, ripple-marked, and calcareous. The member forms steep slopes broken by cliffs of sandstone and limestone except where dips are steep enough for the more resistant beds to form ridges (description from Finnell, 1966).

₽n Naco Formation (Pennsylvanian)

The Naco Formation consists of interbedded maroon and purple shale and light gray to blue-gray limestone. Limestone beds are commonly thin- to medium bedded, locally contain thin shale partings, are nodular, and contain light to dark orange cherts. The orange cherts are characteristic of the Naco as no other formation contains them. Limestone beds are locally fossiliferous and contain abundant braciopods, bryozoans, and crinoid stems and plates.

Mr Redwall Limestone (Mississippian)

Massive, light gray crystalline limestone. Most of the unit has been recrystallized into coarse, intergrown sparry calcite. Vague bedding partings appear to be slightly silty. The Redwall is commonly very fossiliferous. Crinoids are very common, and are most noticeable on weathered surfaces. Contains scattered horn coral. Stylolites parallel to bedding are common. The unit underwent regional karsting during the Mississippian and the red insoluble residue (“terra rosa”) fills vugs and cracks and imparts a characteristic red color to the rock (hence its name). The base is placed at bottom of first thick limestone bed overlying thin-bedded, tan-colored dolomite at the top of the Martin Formation.

Dm Martin Formation (Late Devonian to Middle Devonian)

Thin to medium bedded, generally light gray dolomite, sandy dolomite, sandstone and shale. Throughout the map area the character of the Martin Formation varies. At Theodore Roosevelt Dam and locally elsewhere the lower part of the section is mostly sandstone with a dolomitic matrix (possible the Beckers Butte member). Generally the unit contains light tan to buff, thinly bedded sandy dolomite beds that are distinct from the bluer gray limestone beds of the younger formations. However, near the middle and top of the formation in the north and eastern Sierra Ancha the Martin contains at least two massive, blue-gray limestone beds that appear very similar to the overlying Redwall Limestone. The formation in the northeastern Sierra Ancha also includes a clean sandstone bed several meters thick within the formation that appears very similar to the locally underlying Troy Quartzite.

Ꞓb Bolsa Quartzite (Middle Cambrian)-

Fine- to coarse-grained quartz arenite and feldspathic quartz arenite in the Theodore Roosevelt Dam Quadrangle (Spencer and Richard, 1999). Lower part is typically dark red brown. In thicker sections, grades up into buff to white sandstone with irregular zones of red brown sandstone, mostly along bedding planes. Picturesque Liesegang banding is developed in some outcrops. Small scale planar tabular and trough cross bedding is abundant. Unit is medium- to thin-bedded. Magnetite-rich laminations are common in some outcrops

Ꞓt Tapeats Sandstone (Middle? Cambrian)

Similar to the Bolsa Quartzite. Mapped in the southern Sierra Ancha by Bergquist and others (1991).

Paleozoic or Middle Proterozoic rocks

PzYu Sedimentary rocks, undivided (Paleozoic or Middle Proterozoic)

Sedimentary rocks east of the Canyon Creek Fault that probably consist largely of quartzose clastic rocks of the middle Proterozoic Troy Quartzite, and limestone and/or dolomite derived from the Martin and Redwall Formations.

Middle Proterozoic rocks

Yd Diabase (Middle Proterozoic)

Dark gray, dark greenish gray, and grayish black sills and dikes with typical sub-ophitic, diabasic texture. Consists of 35-45% 1-3mm plagioclase lathes in black groundmass of pyroxene(?); accessory magnetite(?) is common. Major sills are common intruding granitic rocks 200-400 feet (60-120 m) below the base of the Pioneer Formation and in the upper part of the Pioneer Formation.

Yt Troy Quartzite, undivided (Middle Proterozoic)

Ytq Troy Quartzite, Quartzite member (Middle Proterozoic)

The uppermost Quartzite member consists predominantly of fine- to medium-grained, well-sorted, rounded quartz grains and was probably deposited largely as eolian sand sheets (Weiss, 1986). Locally, cross-bedding is prominent, though locally it is faint and the unit is nearly structureless except for bedding.

Ytc Troy Quartzite, Chediski member (Middle Proterozoic)

The Chediski member is a medium- to coarse-grained, relatively clean sandstone and conglomerate (Burns, 1987). It commonly exhibits trough and planar cross-bedding in sets 10 or so centimeters thick up to about 1-2 meters thick. This member is generally lighter gray than either the Arkose or the Quartzite member and, hence, can generally be distinguished from the other two members relatively easily. Contorted and mottled bedding is common in the lower parts in the north near Shell Mountain and Canyon Creek.

Yta Troy Quartzite, Argillite member (Middle Proterozoic)

The Arkose member is restricted to the west-central part of the Sierra Ancha centered near Horse Camp Mountain. As its name suggests it is a medium- to coarse-grained arkosic sandstone and conglomerate containing abundant grains of quartz and feldspar. Locally, particularly in the southern part of the Young quadrangle and the western part of the McFadden Peak quadrangle, the base of the unit is a bedded to massive conglomerate containing well-rounded clasts of quartz, gray quartzite, and red metarhyolite. The conglomeratic part is nearly indistinguishable from the Scanlan Conglomerate.

Apache Group (Middle Proterozoic)

Yau Apache Group, undivided (middle Proterozoic)

Yb Basalt (Middle Proterozoic)

Dark gray to black, massive basalt. The rock is highly weathered and locally all that is left is a red residue of earthy and specular hematite, locally of ore grade. Hand samples locally show relict texture of intergrown plagioclase and pyroxene phenocrysts. The rock commonly contains amygdules filled by light gray quartz. Shown where outcrops are areally extensive.

Ya Argillite (Middle Proterozoic)

The argillite is best exposed in the road-cut on the south side of Theodore Roosevelt Dam, where it is composed of a sequence of interbedded finely laminated yellow and gray siliceous siltstones and purple shales. Though poorly exposed, exposures of the argillite below Copper Mountain are nearly completely replaced by silica. Exposures at Workman Creek resemble those at Roosevelt Dam and are composed of alternating shale and laminated chert. Poor exposures southeast of Young show the same lithologies. In the north, between Shell Mountain and Canyon Creek, a thin 1-2 meter-thick bed of laminated chert rests on top of chert breccias at the top of the Mescal.

Ymx Silicified chert breccia of the Mescal Limestone (Middle Proterozoic)

The Mescal underwent regional karsting during the middle Proterozoic. Dissolution of the host carbonate liberated the original primary chert nodules which were then cemented by secondary silica, forming a siliceous, very resistant horizon. Hematite is abundant within the cementing silica and imparts a reddish-gray color. In the northern Sierra Ancha locally the entire Mescal has been leached of dolomite and replaced by secondary silica. In the replaced sections the original stratigraphy of the primary cherts is preserved.

Ym Mescal Limestone (Middle Proterozoic)

Brown to reddish tan cherty dolomite. Dolomite weathers in some areas to reveal faint to moderately well developed, 1-2 mm laminations. Chert forms nodules and stringers that are more resistant to weathering than host carbonates and so form ribs and protruding stringers and nodules. The Mescal Limestone is divided into two major members (Shride, 1967), as follows in ascending order: (1) Lower member is chert-rich bedded dolomite containing a basal breccia a few meters thick probably created during dissolution of former evaporite minerals and subsequent collapse of caverns (“founder breccia” of Shride, 1967). Weathered outcrops reveal wispy radiating “sheaf structures” up to tens of centimeters across that may be replaced evoporite minerals. Chert nodules vary from black near base to light gray near top. (2) Upper member is variably cherty and consists of thick-bedded stromatolitic dolomite. Stromatolites near Theodore Roosevelt Dam grade upward from columnar to domal. In the southwest Sierra Ancha columnar and branching forms (*Tungusia*) are common. In the northern Sierra Ancha coniform forms dominate.

Yds Dripping Spring Quartzite, undivided (Middle Proterozoic)

Generally consists of three members, in ascending order as follows: (1) Orangish gray, indurated, medium- to coarse-grained, medium- to thick-bedded, sandstone or quartzite that weathers into angular blocks and forms bold outcrops and steep slopes and cliffs. Estimated content of 15-25% K-feldspar grains impart orangish color. Low-angle trough cross beds are locally abundant. Base of member commonly consists of conglomerate, known as the Barnes Conglomerate, containing rounded pebbles and cobbles of quartzite. (2) Yellowish-tan to light gray siltstone and very fine grained, silty sandstone that forms gentle slopes. Contains scattered quartzite beds that form subtle to prominent ledges (Shride, 1967). Though not as common in the lower member, both the lower and upper member of the Dripping Spring Quartzite contain mud cracks, showing that the sediments were at least temporarily subaerially exposed.

Ydsu Dripping Spring Quartzite, upper member (Middle Proterozoic)

Ydsl Dripping Spring Quartzite, lower member (Middle Proterozoic)

Yp Pioneer Formation (Middle Proterozoic)

This map unit consists primarily of lavender siltstone and fine grained sandstone. The basal Scanlan Conglomerate generally consists of 1-12 m of massive to poorly bedded, clast-supported conglomerate with subrounded to rounded quartzite cobbles up to 30 cm diameter. Overlying strata are typically maroon, maroonish gray, tan, and brown sandstone and silty sandstone that grade upward into and maroon, thin bedded siltstone and very fine grained sandstone and silty sandstone. Sandstone is generally medium to thick bedded, poorly sorted, and feldspathic. Includes reddish brown, fine-grained sandstone with silty layers where the rock has parted to reveal polygonal mudcracks, and locally contains conspicuous red K-feldspar grains presumably derived from underlying granite. Sandstone generally thins and fines up section, and dark red-brown shale partings are common, but no intervals of shale have been observed in the section. In the Sierra Ancha the Pioneer Formation consists mostly of fine- to medium-grained, dark gray to maroon quartzite and only minor siltstone. Farther south—south of the Salt River—the abundance of quartzite diminishes and dark maroon siltstone and shale dominate (Collum, 1995). A percentage of the Pioneer Formation apparently is composed of a large component of detrital volcanic tuff and contains many partially preserved glass shards (Shride, 1967).

Early and Middle Proterozoic Intrusive and Gneissic Rocks

Ygx Brecciated and altered porphyritic biotite granite (Middle Proterozoic)

Brecciated, hematite-stained granite derived from map unit Yg, as mapped by Faulds (1986) at the south end of the Cherry Creek Monocline, east of Black Mesa.

Yg Coarse-grained, porphyritic biotite granite (Middle Proterozoic)

Generally medium- to coarse-grained, unfoliated, porphyritic biotite granite. K-feldspar phenocrysts are commonly 2-4 cm diameter and may be rounded or rimmed with plagioclase (rapakivi texture). Rocks of this map unit are rarely foliated except by igneous flow foliation, and rarely contain quartz veins. These 1.4 Ga rocks can generally be distinguished from older 1.7 Ga granites because the latter are commonly tectonically foliated and contain quartz veins. Because the rock easily weathers and erodes this unit commonly forms extensive low-relief pediments mantled by decomposed granite (grus). Weathers to rounded boulders in many areas. In the Two Bar Ridge area this unit consists of coarse-grained biotite granite with sparse, 5-15 cm mafic enclaves. K-feldspar phenocrysts up to 4 cm diameter poikilitically enclose sparse, 1-2 mm plagioclase and biotite (Spencer and Richard, 1999). The rock here is more distinctly porphyritic than the Early Proterozoic granitoid in the map area, and is completely non-foliated. This granite (map unit Yg) is tentatively correlated with the Ruin Granite of Ransome (1903) and Silver et al. (1980).

YXg Granitic rocks, undivided (early to middle Proterozoic)

YXgo Porphyritic granite of El Oso (early to middle Proterozoic)

Coarse-grained, biotite granite with 1-4 cm diameter K-feldspar phenocrysts. This unit is very similar to the granite mapped as Yg and may be equivalent. It is named for good exposures along the El so Road that bisects the exposure as it crosses the Mazatzal Mountains.

Xg Early Proterozoic granite, undivided (early Proterozoic)

Generally medium to coarse grained, equigranular to porphyritic, biotite granite. Porphyritic and fine grained varieties are also present. Early Proterozoic age is based on regional, commonly steep and east- to northeast-striking foliation that does not affect middle Proterozoic granites.

Xg_1 Granitic rocks in Mills Canyon area (Early Proterozoic)

Ranges from granite to granodiorite to diorite or gabbro, commonly with gradational contacts between the various phases. This rock unit is exposed on the east flank of the southern Mazatzal Mountains in the western part of the Theodore Roosevelt Dam 7 ½' Quadrangle (Spencer and Richard, 1999).

Xg_2 Granitic rocks in Rock Creek area (Early Proterozoic)—Coarse-grained, leucocratic biotite granite and fine- to medium-grained aplitic granite. This generally pinkish weathering granite is exposed on the east flank of the southern Mazatzal Mountains in the northwestern Theodore Roosevelt Dam 7 ½' Quadrangle (Spencer and Richard, 1999).

Xg_3 Granitic rocks of Cottonwood Creek (Early Proterozoic)

Medium to coarse grained, granodiorite and less abundant quartz diorite, granite, aplitic granite, and aplite, some of which is fine-grained. Rocks of this unit commonly contain biotite. This rock unit is exposed along the Salt River west of Theodore Roosevelt Dam and southeast of Theodore Roosevelt Dam in the Cottonwood Creek area (Spencer and Richard, 1999).

Xg_4 Young Granite (early Proterozoic)

Dated at 1.65 Ma (Bowring, unpublished data in Karlstrom and Labrenz, 1991). Most of this granite is medium- to coarse-grained, partially porphyritic, contains locally biotite and muscovite, and contains abundant slightly perthitic microcline (Gastil, 1958; Karlstrom and Labrenz, 1991; Skotnicki, 2002d). Elliptical enclaves of metasedimentary rocks aligned within the granite near its margin suggests the granite may be late syntectonic (Karlstrom and Labrenz ,1991). Although apparently emplaced after deformation, weak foliation south of Young also indicates that part of the pluton is syntectonic, or it was deformed after 1.65 ma (Skotnicki, 2000). The Young Granite is very similar mineralogically and texturally to the granite south of Del Shay Basin (map unit Xg_7).

Xg_5 Granitic rocks near Klondike Mountain (early Proterozoic)

This medium- to coarse-grained granodiorite contains K-feldspar phenocrysts up to about 1 cm across. Mafic phases include biotite and minor amphibole. Poorly exposed south of Klondike Mountain in the Salt River Peak 7.5' quadrangle and not completely mapped (Skotnicki, 2002e).

Xg_6 Payson Granite (early Proterozoic)

This coarse-grained granite contains subhedral to euhedral K-feldspar phenocrysts between 1-2 cm across. Contains mostly thin, anhedral books of biotite, but locally rare amphibole. Mafic minerals are partially altered to hematite and impart a rusty orange color to the rock. This granite is non-foliated. It was unroofed at least prior to middle Cambrian deposition of the Tapeats Sandstone, where it underwent extensive weathering. Exposures are generally weathered and crumble easily. The Payson Granite, Green Valley Hills Granophyre (map unit Xgp), and Hell's Gate Rhyolite (not distinguished from Haigler Rhyolite on this map) constitute a hypabyssal suite (Conway, 1976, in Conway and Wrucke, 1986, p. 239).

Xg_7 Granite south of Del Shay Basin (early Proterozoic)

This rock is coarse-grained to locally medium-grained, and contains abundant phenocrysts of pink, subhedral K-feldspar a few mm to about 1 cm wide, in a matrix of gray quartz, light gray plagioclase, and biotite (locally muscovite?). Larger, sparsely distributed K-feldspar megacrysts up to 3 cm long are commonly zoned. Plagioclase is less abundant than K-feldspar, and locally seems to be absent. Biotite is commonly partially altered to hematite and occurs in small felty clumps up to about 5 mm wide. Overall the rock weathers light orange to tan and commonly exhibits a weak to moderate varnish. It erodes into steep, blocky outcrops that shed angular clasts. In most places the rock is unfoliated or exhibits a weak, spaced foliation. Only in one place, immediately south of Forest Road 71 near the west edge of the map, is the foliation strong. Spencer and others (1999) subdivided this unit into a coarse-grained phase and an aplite phase. A finer-grained more leucocratic rock with similar mineralogy as Xg_7 occurs as small irregular bodies with sharp contacts in the southwest part of the map area. The contacts were difficult to follow for very far and the two rocks were not mapped separately. The more leucocratic rock may be equivalent to the aplite phase of Spencer and others (1999). They also divided this unit into an older granite (their map unit Xg) and a younger granite (their map unit YXg) based on the presence or absence of foliation. The very similar mineralogy of these two rocks suggests that they are the same unit. This granite is mineralogically and texturally similar to the Young granite to the northeast (map unit Xg_4)

Xb Buckhorn Creek Crystalline Complex (early Proterozoic)

Igneous and metamorphic complex consisting of mineralogically variable feldspar-quartz-biotite-amphibole gneisses, and granitoid rocks ranging from pyroxene gabbro to muscovite granite. Lithology is quite variable from place to place. Exposed in the Theodore Roosevelt Dam 7 ½' Quadrangle (Spencer and Richard, 1999).

Xd Dioritic rocks, undivided (early Proterozoic)

Includes dioritic dikes and sills of the Diamond Rim intrusive suite in the Central Mazatzal Mountains (map unit Xdd of Wrucke and Conway, 1987).

Early and Middle Proterozoic Rocks Undivided

YX Early and middle Proterozoic rocks, undivided. This unit groups together all Precambrian rocks and is shown only on the cross-sections on sheet 2.

Early and Middle Proterozoic Metamorphic Rocks

Early Proterozoic metamorphic rocks in the Tonto basin area

Xms Metasedimentary rocks, undivided

Xss Metasandstone (psammite), undivided (early Proterozoic)

Primarily consists of metasandstones composed of grains of quartz, feldspar, and lithic fragments and appropriately termed psammites. Rocks of this unit also contain little or no pelitic and tuffaceous rocks. Includes the following: (1) In the Two Bar Ridge are this unit consists of thin bedded, light tan-colored, sericitic arkose grit and sandstone that do not appear significantly deformed. Conglomeratic beds in this unit contain pebbles of quartz (Spencer and Richard, 1999). (2) At the north end of Tonto Basin this unit includes "thinly layered gray slates" (Wessels, 1990) with "cm scale bedding with graded beds" (Wessels, 1991).

Xf Felsic volcanic rocks (early Proterozoic)

Rocks of this unit include the following: (1) Rhyolite porphyry, breccia, and local rhyolite clast conglomerate of the central Mazatzal Mountains (part of Tonto Basin Supergroup of Wrucke and Conway, 1987) and the northwestern Sierra Ancha (Ludwig, 1974; Roller, 1987, 1991; Wessels, 1991; Wrucke and Conway, 1987). (2) Felsic to intermediate-composition metavolcanic rocks that form a northeast-trending outcrop belt between Mills Canyon and Rock Creek in the western Theodore Roosevelt Dam 7 ½' Quadrangle (Spencer and Richard, 1999). These rocks separate the granitic rocks in Mills Canyon from the granitic rocks in Rock Creek. The unit consists mostly of light gray felsic metavolcanic rock that contains obvious 1-2 mm diameter quartz and less obvious feldspar crystals in a microcrystalline, granular groundmass of quartz and feldspar.

Early Proterozoic metamorphic rocks in the NW Sierra Ancha

Xal Fine- to medium-grained leucocratic biotite granite (alaskite) (early Proterozoic)

Xgp Granophyre and aplite (early Proterozoic)

Xgr Quartzite and metarhyolite, undivided (early Proterozoic)

Haigler Group

Xr Metarhyolite, undivided (early Proterozoic)

Xhr Haigler Rhyolite (early Proterozoic)

Rhyolite tuffs and flows. The 'lower member' is gray to brown and black and locally vitric. Contains anhedral to subhedral phenocrysts of albite in a matrix of fine-grained quartz, epidote, sericite, untwinned feldspar, chlorite, and ferruginous dust (Gastil, 1958). Apatite is locally abundant. Tuffs and tuff breccias contain coarse, irregularly shaped more mafic volcanic fragments. The boundaries of the fragments are typically rounded and poorly defined. Above the lower member massive rhyolite flows contain phenocrysts of quartz and perthite about 1 mm wide, in a fine-grained, locally recrystallized matrix. The rocks locally contain spherules 1 cm or more in diameter. Many spherules were flattened into disks before solidification. The phenocrysts of the tuffs are better preserved, of greater variety, and are more abundant than are the phenocrysts in the flows. Gastil (1958) differentiates columnar-jointed rhyolite that he called the Hell's Gate Rhyolite, from the Haigler Rhyolite and argued that the former was chemically more similar to the Oxbow Mountain Rhyolite. The Haigler and Hell's gate Rhyolites were not differentiated here.

Xor Oxbow Mountain Rhyolite (early Proterozoic)

Welded rhyolite tuff and porphyry of Oxbow Mountain area. The tuff forms the lower part of the unit and grades upward into the porphyry. The tuff is grayish white and consists of phenocrysts up to 4 mm across and welded glass shards. The phenocrysts are quartz and perthite and smaller albite (An_5) with chessboard or other twinning. The shards, many contrastingly dark, are flattened parallel to bedding and contorted around the phenocrysts, in sharp contrast to the angular, unflattened shards found a few hundred feet beneath in the Haigler Formation. Except for the lack of pyroclastic texture the petrography of the adjacent quartz porphyry resembles that of the tuff.

Xhc Winter Camp Formation (early Proterozoic)

Dark gray to brown rhyodacite flows and breccias, and conglomerate. The rhyodactie contains clasts of both rhyodacite and the underlying Board Cabin Formation (Conway and Wrucke, 1986).

Intrusive Rocks

Xri Intrusive rhyolite and quartz porphyry (early Proterozoic)

This rock is characteristically either light gray-green or moderate grayish-red. The red color is due to the presence of fine-grained iron oxide, whereas the more common gray-green phase owes its color to epidote and some chlorite. The deformation of the rock varies from slight to strong mylonitization. Quartz phenocrysts are large and conspicuous up to 5 mm in diameter. Where the rock has not been strongly deformed or epidotized feldspar phenocrysts of nearly equal size outnumber those of quartz. Albite (An 0-4) is the most abundant variety of feldspar, but there are also small laths of sodic oligoclase associated with green epidote in vesicles, untwinned phenocrysts of negative relief believed to be potassic feldspar, and phenocrysts of graphic quartz in potassic feldspar (?). Relict biotite consisting of muscovite, green chlorite, and red iron oxide are conspicuous. The devitrified glass groundmass consists of quartz, feldspar, and sericite, with accessory apatite, limonite, and leucoxene. Much of the porphyry occurs in roughly conformable sills and was at first mistakenly mapped as rhyolite flows.

Xbi Intrusive basic volcanic rocks (early Proterozoic)

Most of this rock is fine-grained and is probably the intrusive equivalent of the basic extrusive rocks found in the Board Cabin and Haigler Formations. It has a relict pilotaxitic or finely diabasic fabric in which the plagioclase has been altered to a sericite-like mineral. The groundmass is predominantly chlorite, with minor epidote, apatite, iron oxides, and leucoxene. In Brady Canyon this rock contains 60% plagioclase, 30% biotite, 8% quartz, and 2% apatite. Albite rims the plagioclase crystals and is intergrown with quartz in the interstices. The plagioclase cores have been serricitized.

Xub Ultrabasic rocks (early Proterozoic)

The body of pyroxenite on Walnut Creek, 1 mile east of Spring Creek contains augite up to 2 mm (31%), actinolite (42%, largely after augite), epidote (10%), chlorite (18%), leucoxene (2%), brown hornblende (1%) and traces of opaque minerals. The chlorite and epidote occur in small clusters and may be secondary. Outside the map area to the north another body is a uralized, serpentinized biotite-pyroxene honblendite(?) in which almost all of the pyroxene has been replaced by isotropic green serpentine, and the hornblende by actinolite.

Xui Unassigned intrusive rocks (early Proterozoic)

Commonly altered beyond recognition.

Alder Group

Xbc Board Cabin Formation (early Proterozoic)

As mapped the Board Cabin Formation (Gastil ,1958) contains several mappable units distinguished by Gastil (1958) on his map. They include: (1) **Porphyritic basalt flows.** Most exposures consist of tabular, complexly twinned, unzoned phenocrysts of albite set in a fine-grained matrix of secondary quartz, albite, sericite, calcite, chlorite, epidote, and opaques. The matrix was probably originally glass. In some rocks fine-grained aggregates of quartz-albite and sericite replace phenocrysts of plagioclase. Amygdules and veinlets of quartz, chlorite, green epidote, and calcite are common. (2) **Basic pyroclastics, pillow lava, and agglomerate.** These rocks contain albite and oligoclase microlites, relict ferromagnesian phenocrysts, and a matrix of quartz, chlorite, and calcite. (3) **Conglomerate.** These rocks typically consist of volcanic boulders and sandstone of such uniform appearance that the rock appears to be volcanic rather than sedimentary. The boulders are commonly well sorted and well rounded. (4) **Wacke, volcanic sandstone.** Includes some quartzite, arkose and slate. The volcanic sandstone consists of sorted grains of volcanic rock, with minor quartz and feldspar. The feldspar crystals are sericitized, and much of the groundmass appears to be replaced by iron ore. Between the detrital grains is a matrix of calcite, epidote, chlorite, sericite, quartz, and albite, with scattered clusters of iron oxide and apatite. The sedimentary rocks become coarser-grained upward in the section, and there are none finer than conglomerate in the upper half of the formation. (5) **Quartzite and arkose.** Unlike quartzites in the Houden Formation, these quartzites do not exhibit authigenic overgrowths, peripheral corrosion, or recrystallization. Grains of sodic plagioclase, although partially replaced by sericite, epidote, calcite, and fine-grained red hematite, are well preserved. The matrix contains sericite, quartz, and in places chlorite, coloring the rock green. Detrital epidote, tourmaline, apatite, and zircon are present. Authigenic tourmaline is also present. (5) **Slate.**

Xqu Upper quartzite near Sheep Basin mountain (early Proterozoic)

Mapped by Brady (1991) in the Sheep Basin Mountain area. May be equivalent to the upper quartzite member of the Houden Formation.

Xh Houden Formation (early Proterozoic)

As mapped the Houden Formation (Gastil ,1958) contains several mappable units distinguished by Gastil (1958) on his map. They include: (1) **Upper quartzite member.** The lower portion is vitreous, white quartzite containing tightly packed, ragged quartz grains with minor sericite. The middle part consists of 2-25 feet of slate, purple siltstone, coarse red and blue micaceous quartzite, fine gravel and conglomerate, and purple chert. The slate contains fine-grained quartz and sericite and exhibits thin laminations of quartz sand. The grains preserved in these laminations are angular to rounded, exhibit neither authigenic overgrowths nor corrosion, and show no recrystallization. They also contain grains of feldspar, chert, zircon, opaques, muscovite, blue tourmaline, and apatite. The upper part consists of cross-laminated quartzite in beds as much as 3 feet thick—the thickest cross-laminated beds observed in the older Precambrian rocks of the area. Grains of quartz and chert 1-1.5 mm wide are rounded and tightly packed. Sericite and specular hematite are minor. Authigenic quartz overgrowths and intergranular recrystallization are common. In the eastern part of the map area the upper quartzite member measures 390-420 feet thick. (2) **Middle slate and quartzite member.** The middle member is distinguished by its gray, purple or brick-red color and predominantly fine grain size. Its lower portion includes fine-grained conglomerate, coarse- to fine-grained quartzite, siltstone, and minor amounts of slate. Cross-lamination was not observed. The upper part of the member consists of slate and graded wacke. The quartzite of the middle member is argillaceous and contains more accessory detrital grains than the upper and lower quartzites (principally zircon, apatite, and muscovite). The slates contain varying amounts of sericite, blue-green tourmaline, green chlorite, jarosite after pyrite(?), and ragged grains of quartz. (3) **Lower quartzite member and basal conglomerate.** The base is a gravel conglomerate, locally 40-100 feet thick containing clasts up to ~1 cm of vein quartz, banded red chert, other fine-grained quartz-aggregate rock types, angular fragments of devitrified glass, and other fine-grained volcanic rocks. The lower portion of the lower quartzite member is cross-laminated in beds 3-8 inches thick. The quartz grains (0.5 to 1 mm in maximum diameter) show undulatory extinction, two sets of deformation lamellae, and extensive recrystallization between and within the grains. Grains of sodic plagioclase, adularia-albite, perthite, and untwinned potassic feldspar(?), although considerably smaller than the quartz grains, are more abundant than in the other members of the formation. The feldspar can be easily distinguished from quartz the fine dust of red iron oxide which colors it. The upper portion contains mostly quartz, with very minor feldspar and zircon grains. Jointing is more prominent than bedding.

Xql Lower quartzite near Sheep basin Mountain (early Proterozoic)

Mapped by Brady (1991) in the Sheep Basin Mountain area. May be equivalent to the lower quartzite member of the Houden Formation.

Xfw Flying W Formation (early Proterozoic)

As mapped the Flying W Formation (Gastil ,1958) contains several mappable units distinguished by Gastil (1958) on his map. They include: (1) **Basic volcanic rocks.** Pillow lavas are green and amygdaloidal and contain microscopic laths of sodic plagioclase, chlorite, sericite, quartz, calcite, and sparse iron oxides. The rock between the pillows has a woodlike fabric and consists of a colorless micaceous mineral together with alternating laminations of iron chlorite(?) and fine-grained quartz, as well as abundant opaque minerals, and patches of epidote and calcite. (2) **Rhyolite.** This rock is pale purple to red and contains megascopic phenocrysts of quartz and unaltered calcic albite (An_{4-10}). Its texture varies from coarsely fragmental to massive. Microscopically, the more massive rock consists of alternating bands of fine-grained sutured quartz, sericite, and devitrified glass. The phenocrysts occur in clusters, and many are broken or bent. Besides albite and quartz they include adularia-albite perthite, adularia, myrmekite, and graphic intergrowths. (3) **Conglomerate.** This rock is composed of well rounded gravel, cobbles, and boulders of volcanic rock—most of it identical to that with which it is interbedded. Notable exotics are boulders of red jasper (up to 10 inches in diameter).

Xsl Unassigned slate and minor limestone (early Proterozoic)

Contains muscovite, quartz, and specular hematite. 1200 feet thick. Does not include any interbeds of quartzite, unlike other Proterozoic formations. Contains thin, lenticular limestone beds composed of fine-grained equigranular calcite, with a small percentage of untwinned albite. The insoluble residue of the limestone contains no detrital grains. Beds are typically an inch thick and alternate with beds of slate of similar thickness, giving the rock a banded appearance.

Xbp Breadpan Formation (early Proterozoic)

As mapped the Breadpan Formation (Gastil ,1958) contains several mappable units distinguished by Gastil (1958) on his map. They include: (1) **Sandstone and conglomerate.** This upper member is argillaceous but, in contrast to the lower member, includes beds of chert and feldspathic wacke containing an abundance of heavy minerals. Typical quartzite consists of coarse, originally well rounded grains of quartz and chert. The original surfaces of some grains are visible beneath overgrowths of authigenic quartz, but more commonly the grains are serrated or embayed because of corrosion or partial recrystallization. A matrix of fine-grained quartz, sericite, bladed specular hematite, and small blue-green tourmaline prisms is commonly present. (2) **Wacke, conglomerate, and slate.** The wackes have a matrix consisting of sericite, chlorite, iron oxides, blue-green tourmaline, and quartz. What proportion of this material represents recrystallized detrital matrix, and how much has been derived by solution and recrystallization of the grains is difficult to judge. Most of the grains are very ragged in outline. Detrital grains include zircon and apatite, some well-rounded epidote and sphene, and minor tourmaline fringed with blue-green outgrowths, both for this member and the upper member. (3) **Slate, conglomerate, and sandstone.** Interbedded sericite-rich slate, thinly bedded quartzite, thin gravel conglomerates, and graded quartz wacke. Grain size fluctuates rapidly in a vertical sense, from slate to gravel in a few inches, but along strike variation is less marked, as beds of quartzite a few feet thick can be traced for several miles. Cross-laminations and ripple marks are rare.

Xsv Slate and volcaniclastic metasedimentary rocks (early Proterozoic).

Medium gray-green slightly metamorphosed sandstone and siltstone. Thinly bedded. Locally phyllite. Bedding, ripples, and minor cross-bedding features are still visible locally. Bedding is defined by thin laminations of detrital iron-oxide minerals. A weak foliation is parallel to bedding. South of Del Shay Basin in the Picture Mountain 7.5' quadrangle the unit is intruded by at least one intermediate dike and white quartz veins ~5 cm wide with attitude N130°E, 77°S (Skotnicki, 1999b).

Xq Quartzite (early Proterozoic)

This unit was mapped south of Del Shay Basin in the Picture Mountain 7.5' quadrangle, and may be equivalent to part of the Houden Formation (Skotnicki, 1999b)

Xm Mafic volcanic rocks (early Proterozoic)

Basaltic to andesitic volcanic flows. These green rocks consist of blue-green chlorite, green epidote, sericite, albite, and quartz. Small bodies of light colored, serricitized rock occurring both in the volcanic and sedimentary portions of the formation in the northwest part of the map area are probably metarhyolite. Together with tuff these rocks are over 1100 feet thick. Rocks of this unit are massive to brecciated, with local pillow structures, and include andesitic tuff and tuff breccia. Hyaloclastic textures, pillow structures, and fragmental textures associated with lithic-rich and pumice-bearing andesitic tuff all suggest subaqueous eruption (Gastil, 1958; Conway, 1976). At the north end of Tonto Basin this unit includes "strongly foliated vesicular, chloritized meta-basalts" (Wessels, 1991, p. 23).

Early Proterozoic metamorphic rocks of the Hess Canyon Group

Xbj Blackjack Formation (early Proterozoic)

Quartzite and siltstone (Livingston, 1969)

Xyj Yankee Joe Formation (early Proterozoic)

Thin-bedded, moderately to well sorted argillite, siltstone, and quartzite (Faulds, 1986).

Xw White Ledges Formation (early Proterozoic)

Thin-bedded, moderately to well sorted siltstone and quartzite (Faulds, 1986).

Redmond Formation

Massive sequence of felsic to intermediate porphyritic rocks of probable pyroclastic origin. 1715 ± 15 m.y. (Silver, as quoted in Conway, 1976, p.22; from Faulds, 1986).

Xru Upper rhyolite (early Proterozoic)

Upper member of the Redmond Formation (Cuffney, 1977).

Xrm Middle rhyolite (early Proterozoic)

Middle Member of the Redmond Formation (Cuffney, 1977).

Xrl Lower rhyolite (early Proterozoic)

Lower member of the Redmond Formation (Cuffney, 1977).

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