GEOLOGIC MAP OF PORTIONS OF THE FORT MC DOWELL AND MC DOWELL PEAK QUADRANGLES, MARICOPA COUNTY, ARIZONA

by

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Introduction

This map depicts both the bedrock geology and the general ages and distribution of Late Tertiary and Quaternary deposits and geomorphic surfaces in the northern part of the lower Verde River Valley, in Maricopa County. The map area includes portions of the Fort McDowell and McDowell Peak 7.5' U.S.G.S. topographic quadrangles (Figure 1). The region studied encompasses the region between the northern end of the McDowell Mountains on the west to about one mile east of the Verde River on the east.

Mapping of the surficial deposits was based both on field observations and interpretation of black-and-white, 1:48,000-scale aerial photographs (dated 12-9-90) purchased from the Arizona Department of Transportation Photogrammetry and Mapping Division.

With the exception of the western end of the map area, most of the land is administered by either the Tonto National Forest, the Fort McDowell Indian Reservation, or the McDowell Mountain Regional Park (Figure 2). By far the best access to the area is via the paved (Mc Dowell Mountain Road), which runs north-south on the east side of Lousley Hill. It runs north through the Tonto Verde development until it intersects (Rio Verde Road), which runs east west on the north side of the Asher Hills and eventually intersects Pima Road and developements around Pinnacle Peak. Field work was carried out in November, 1995. This study is contiguous with geologic mapping recently completed to the south (Skotnicki, 1995). This project was funded by the Arizona Geological Survey and the U.S. Geological Survey STATEMAP program, contract #1434-94-A-2222.

Previous Studies

Christenson (1975), Welsch (1977), Couch (1981), and Christenson and others (1978) mapped the bedrock and general surficial geology of the McDowell Mountains. Pewe and others (1985) mapped the bedrock geology of the northern end of the McDowell Mountains and the pediment north of Pinnacle Peak.

Pope (1974) made a detailed study of the Verde River terraces south of Bartlett Dam. Pewe (1978, 1987) described terraces along the lower Salt and Verde rivers, noting their height above the river, the degree of calcium carbonate cementation, and their downstream-converging longitudinal profiles. Morrison (1985) provided brief descriptions of these terraces and correlated them to other terrace sequences in central Arizona. Camp(1986) produced a series of soil maps which includes the study area. Cooley (1973) produced a map showing the distribution and estimated thickness of alluvial deposits in the Phoenix area, including the Lower Verde River Valley.

Physical Setting

The project area is in the northeastern part of the Phoenix Basin near the transition between the Basin and Range and Central Highlands (or Transition Zone) physiographic zones (Menges and Pearthree, 1983). The latter zone is also known as the Mexican Highlands section of the Basin and Range Physiographic Province (Morrison, 1985). The

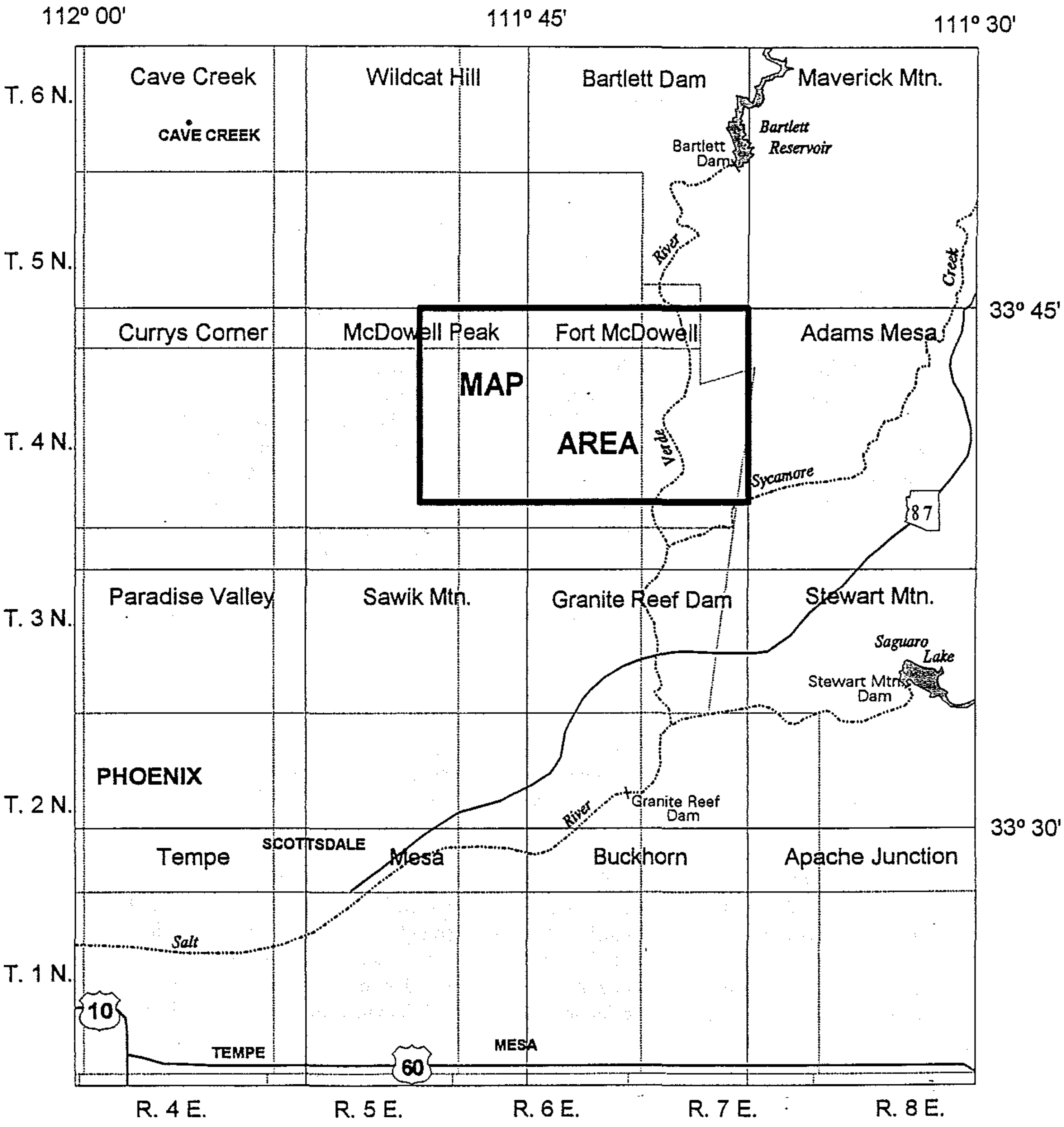

Figure 1. Index map showing the location of the study area and location of U.S.G.S 7.5' topographic quadrangles.

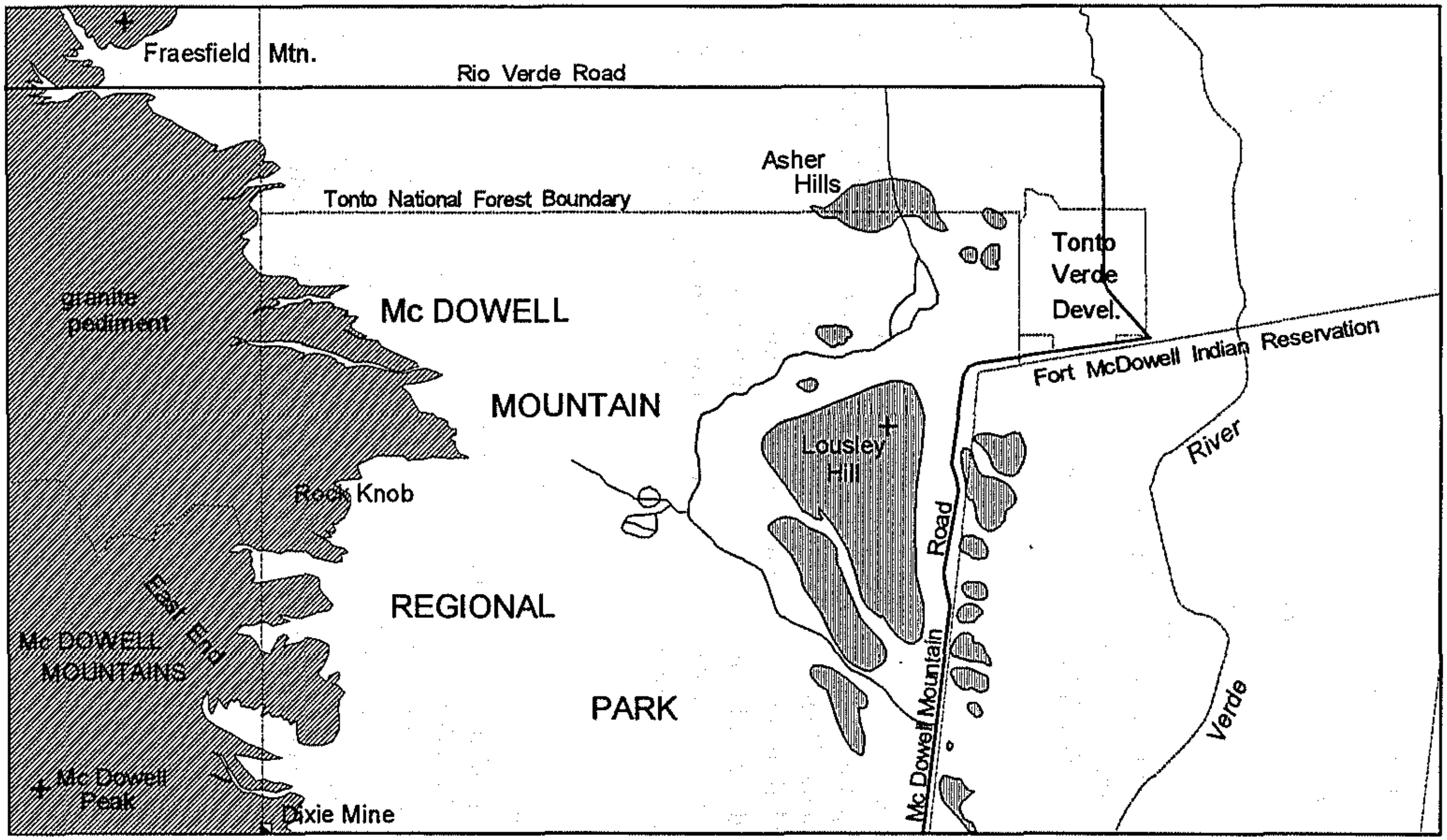

Figure 2. Index map showing place names and political boundaries.

Verde and Salt rivers head in the Central Highlands and each have a drainage basin area of more than 6,000 km^2. Most of the present landscape is a product of geological processes of erosion and deposition during and since the mid-Tertiary (the past 30 million years or so) (Shafiqullah et al., 1980). During the latest Miocene and Pliocene (8-2 Ma[1]), there was probably little normal faulting, but filling of basins with debris shed from adjacent mountains may have continued until about 2 Ma. Geologic deposits of this period are represented by coarsely bedded conglomerates. This was also the time when pediments were developed on granitoid rocks. Basins filled and streams became integrated into the Gila River system. The long-term trend during the last 2 My has been downcutting by the major rivers and their tributaries. Most of the different levels of alluvial fans and stream terraces have formed as a result of aggradation events probably caused by climatic fluctuations during the Quaternary (Morrison, 1985).

Although this region has experienced fluctuations in climate in association with glacial-interglacial cyles, it has likely been semiarid throughout the Quaternary. Today the vegetation is upper Sonoran thornscrub woodland dominated by palo verde (*Cercidium*) and ironwood (*Olneya*), with creosote (*Larrea*), bursage (*Franseria*) and assorted cacti. The climate is semiarid thermic. Nearly all of the annual rainfall of 20 to 25 cm falls in two distinct periods in the winter and late summer.

Vegetation type commonly is a useful indicator of the age of the surface, but in this area the technique did not help much. Almost all of the northern McDowell Mountains, McDowell Mountain Regional Park, and the Lousley Hill area was burned by fire in 1994. Some of the underbrush is just beginning to regrow, but generally all that remained at the time of this study were Saguaro (*Carnegiea*), paloverde (*Cercidium*), and few cholla. In addition, many of the relatively weakly dissected surfaces southeast of Lousley Hill on the McDowell Indian Reservation have been cleared (by man) of all vegetation.

General Geology

Bedrock Geology

Almost all of the bedrock in the map area consists of Proterozoic metamorphic and plutonic rocks. The oldest rocks in the area are Proterozoic metamorphic rocks exposed in the McDowell Mountains. They consist predominantly of quartzites and rhyolites, with minor mafic volcanic rocks. Primary (S1) foliations strike to the northeast and are locally perpendicular to bedding in the quartzite. Up-indicators in the quartzite (cross-beds) show that the top of the sequence is to the north. The rhyolite and quartzite are interbedded near the Dixie Mine and overlie greywacke, reworked(?) tuff, rhyolite, and mafic volcanic rocks to the south that are probably part of the Union Hills Group (Anderson, 1989, Skotnicki, 1995). The dominance of felsic volcanic rocks and clastic sedimentary rocks exposed in the northern McDowell Mountains implies that the sequence of rocks belongs to the Alder Group, which overlies the Union Hills Group. However, the absence of any purple slates, typically diagnostic of the Alder Group, and the presence of minor interbedded mafic volcanic rocks suggests that the rocks may not be part of the Alder

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[1] 1 My = 1,000,000 years; 1 Ma = 1 My ago. 1 ky = 1,000 years; 1 ka = 1 ky ago (North American Commission on Stratigraphic Nomenclature 1983).

Group. However, as suggested by Anderson (1989) it is possible these rocks represent a marginal or distal facies of the Alder Group and, hence, represent laterally continuous, though lithologically different, subunits.

The metamorphic rocks were intruded by diorite north of McDowell Peak and by a younger, nonfoliated, coarse-grained biotite-granite pluton. The granite makes up the steep, boulder-covered hills at East End and underlies the extensive pediment to the north. The contact between the granite and the diorite is sharp but is everywhere obscured by slope-wash. It is not clear whether the diorite is an older pluton or an earlier phase of the granitic intrusion. Wedged between diorite and metamorphic rocks, and occurring as small isolated outcrops surrounded by granite, are exposures of muscovite/sillimanite schist. The schist is always in contact with plutonic rock and probably represents contact-metamorphosed greywacke (map unit Xs) or pelitic rocks. Northwest of the Dixie Mine several quartz-rich, felsic, dike-like bodies (probably Miocene in age) intrude quartzites and mafic metavolcanic rocks.

Late Cenozoic Geology and Geomorphology

Overview

The late Cenozoic deposits and associated landforms of the area record the interplay between erosion and deposition during the late Cenozoic. This area contains extensive, deeply eroded late Tertiary basin-fill sediments that were deposited in aggrading basins that predate integration of the modern Salt and Verde river systems. These pre-river deposits include fine-grained lacustrine deposits (map unit Tsp), an underlying conglomerate inferred from well logs as mentioned by Pope (1974), and probably parts of map unit Tsm. The fact that these deposits are now deeply dissected indicates that stream downcutting has dominated the Quaternary evolution of the basin landscape. In addition, there are extensive Quaternary deposits associated with the Verde River and piedmont deposits associated with lesser tributaries. These alluvial surfaces of different ages probably reflect periods of aggradation caused by climatic changes that temporarily increased the amount of sediment supplied to streams.

During the late Miocene the region underwent a change from an active tectonic environment to a nontectonic regime. What is now the lower Verde River valley was a closed basin which filled first with coarse, clastic sediments and then by fine-grained lake bed deposits of the Pemberton “silt” (Pope, 1974) during the middle to late Miocene. Coarse, basalt-rich conglomerates (map unit Tsm) overlying the lake beds (map unit Tsp) in the central part of the valley represent a return to coarse, clastic terrestrial deposition in the basin, possibly as a response to increased sediment transport as a result of climatic change. The highest levels of basin aggradation are represented by the tan-colored basin-fill deposits rich in granitic and metamorphic clasts (map unit Tsy). By this time, most of the Tertiary volcanic rocks had been removed from the northern McDowell Mountains, as evidenced by the rarity of volcanic clasts within the deposits. Even so, the lithologies represented in the basin-fill deposits are fairly diverse, reflecting the complex, mostly Precambrian bedrock geology of the region. The Tsy deposits do not contain exotic lithologies nor well-rounded clasts indicative of major-river deposits. Basin-fill deposits in this area are not deformed, and thus they must post-date the major period of faulting that resulted in tilting of the older red-bed deposits exposed south of the map area.

Ancestral Verde River

The first evidence for external drainage in the lower Verde River valley is revealed by the presence of river gravels in the basaltic conglomerate in the Asher Hills, at Lousley Hill, and in the hills farther south (map unit Tsm). The gravels are contain well-rounded clasts and are composed of three principle clast-types: they are (1) basalt, (2) granite/quartz monzonite [mostly as grus but also as fine-grained cobbles, and (3) rusty orange porphyritic rhyolite/dacite, with minor purple quartzite (probably Mazatzal Quartzite) and dark grey phyllite. Source rocks for these clasts are currently exposed in the north-central Mazatzal Mountains and possibly near Cave Creek. Their abundance and sizes appear to increase slightly from south to north in the study area

The deposits containing river gravels and the basaltic conglomerate exposures containing no river gravels may be related. South of the map boundary along McDowell Mountain Road, exposures of basaltic conglomerate contain abundant subangular to subrounded basalt clasts and granite grus, but no river deposits. To the north (in this map area), however, almost all of the hills capped by Tsm contain some well-rounded, moderately sorted river gravels. These deposits were named the Lousley Hill deposits by Pope (1974) who mapped them separately from the basaltic conglomerate apparently because of the abundance of river gravels in deposits near Lousley Hill.

While the deposits certainly have differences, in this study they were mapped as the same unit because of their similar stratigraphic position, the similarity of clast types in the two deposits--especially in the non-river parts--and their probable contemporaneous deposition. South and east of Lousley Hill the lower parts of the basaltic conglomerate contain abundant, coarse, well-rounded river cobbles. Though the upper parts of the deposit are mantled with debris and are poorly exposed, they appear to contain mostly granite grus and basalt. Pope. The river deposits are moderately to strongly indurated and form a small cliff at the base of the unit. They are best-developed above the road-cut on the east side of Mc Dowell Mountain Road, east of Lousley Hill. Here the deposits are virtually indistinguishable form the Verde River gravels, except that they are very thick--at least 30 feet--and contain predominantly only the three clast types described. Such thickness has not been observed in any of the other river terrace deposits. It is not clear if this exposure is associated with the younger Verde River gravels or if it represents possibly a channel facies within the basaltic conglomerate. Because the deposit is so thick and contains similar clast lithologies to those within Tsm (although, not significantly different from those in the Verde River deposits), it seems likely that it is part of the basaltic conglomerate. Also, this deposit is above the level of the Mesa terrace (map unit Qmr) and below both levels of the Sawik terrace (map unit Qor) on Lousley Hill, which suggests, as well, that the exposure is different from the Verde River deposits (unless there is another formerly unrecognized terrace level between the Mesa and Sawik terraces, similar to the McDowell terrace between the Blue Point and Mesa terraces).

Interestingly, on the west side of Lousley Hill (where the flat alluvial plain begins) the lower part of Tsm contains no visible river gravels. In fact, the deposits are composed mostly of granitic grus, with minor basalt pebbles, and are capped by a flat surface mapped as a young level of the Sawik terrace. Because the grus-rich deposits on the west side of Lousley Hill are at the same stratigraphic level as the gravels on the east, the grus-rich deposits probably represent the alluvial fan facies of the deposit and the gravels exposed on the east side were probably deposited within an axial river system that existed close to the present axis of the valley--an ancestral Verde River.

In any case it is clear that at least part of the basaltic conglomerate capping the hills in the central part of the map area was deposited in a relatively high-energy river environment. The exposures show that there was integration of one or more major river systems in the basin during aggradation in the lower Verde River Valley--before the begining of the interval of down-cutting and erosion heralded by the deposition of the Sawik terrace. However, more work needs to be done to determine if the gravels interfinger with the finer-grained deposits at Lousley Hill (within map unit Tsm).

A small yet remarkable exposure of river gravels overlying lake bed deposits, and overlain by younger basin-fill deposits (map unit Tsy), is exposed on the east side of the Verde River, T. 5 N., R. 7 E., section 29. If the gravels here represent the same deposits at those at the base of Lousley Hill and Asher Hills, then most of the basaltic conglomerate had been removed in this area before deposition if the younger basin-fill deposits. If the gravels in fact represents a different deposit then they show that river deposition occurred prior to, and possibly sychronous with, younger basin-fill deposition. The fact that both the Lousley-Asher Hills gravels and the deposit just described occur at or near the base of their respective overlying deposits may indicate that each basin-filling event was heralded by an episode of river deposition in the basin.

Modern Verde River Entrenchment

Small remnants of very old Verde River gravels (the Lousley Hill deposits of Pope 1974) are preserved on top of very high levels of basin-fill (map unit Tsm) near Lousley Hill and on hills south of the map area. These deposits are about 100 m higher than the modern channel of the Verde River and are probably equivalent to the Sawik terrace of the Salt River (Péwé, 1978). The age of these old river gravels is not well-constrained, but previous workers have assigned a tentative late Pliocene age to the Sawik terrace deposits (Anderson et al, 1986). Since the deposition of these high river gravels several million years ago, long-term downcutting of the Verde and Salt rivers has resulted in deep dissection of the basin-fill deposits. This long-term downcutting of the major rivers may have been driven by regional uplift of the Transition Zone relative to the Phoenix basin during the Pliocene and Quaternary (Péwé, 1978; Menges and Pearthree, 1989). Periods of river stability or aggradation have been superimposed on the long-term downcutting trend, resulting in the formation of a suite of relatively thin river terrace deposits of different ages. Six distinct levels of the Verde and Salt river were identified in previous studies to the south (Péwé, 1978). Locally, each of these terrace levels can be subdivided into two distinct levels. These terraces range in age from historical (the modern channel and floodplain) to early Pleistocene-late Pliocene (Sawik terrace of Péwé).

The Verde and Salt rivers are the fundamental controls on the development of alluvial landforms throughout the map area because all tributaries are graded to them. Downcutting of the major rivers has driven downcutting of all of their tributaries, resulting in dramatic dissection of the piedmonts of the southwestern and eastern portions of map area. In these areas, most of the piedmonts are composed of dissected Tertiary basin-fill deposits (map unit Tsy). Quaternary terrace and alluvial-fan deposits on piedmonts represent periods of aggradation, probably caused by climatic changes that increased sediment supplied from the hillslopes to the tributaries.

Unlike the region to the south around Fountain Hills, Late Tertiary basin-fill deposits are quite limited in aerial extent on the west side of the Verde River in the study area. This may be in large amount due to the nature of the source area of the sediments. Most of the eastern piedmont of the northern McDowell Mountains (the area included in this study) has been derived from coarse-grained granite. This granite weathers almost exclusively into disaggregated feldspar crystals, or grus, ranging in size from sand and silt to pebbles. Unlike the basin-fill sediments to the south, which are composed of a large component of resistant, cobble- to boulder-size Proterozoic metamorphic clasts, the younger grus-rich sediments to the north are generally not as well consolidated and contain little carbonate cement and, hence, are more easily eroded and reworked.

Pediment

An extensive bedrock pediment makes up most of the low, moderately dissected country at the north end of the McDowell Mountains (named the Pinnacle Peak Pediment by Pewe and others, 1985, and Doorn and Pewe, 1991). It has been etched into coarse-grained biotite granite containing numerous small inselbergs of granite, many of which contain resistant outcrops of quartzite or vein quartz. On the lower elevations the pediment is covered locally with a thin vaneer of alluvium, typically no more than 2 meters thick, though most of the region near the low devide is exposed bedrock. The pediment does not extend into the metamorphic rocks of the McDowell Mountains, a phenomena which reflects the more easily erodable nature of the granite. In section 8, T. 4 N., R. 6 E., the granite pediment terminates abrubtly at a small cliff. This termination may represent the nick point of the westerly migrating drainage it faces, or it may represent the partially exhumed and eroded, fault-bounded basin boundary.

An unusual feature of the pediment is that it extends all of the way across the range from east to west, a distance of between 3 and 6 km. In this respect it resembles the "domelike pediments" in the Mohave Desert described by Mammerickx (1964), which are not bounded by mountain fronts but occupy the drainage divide. Mammerickx studied the slopes and lengths of pediments in the Mohave and Sanoran Deserts in an attempt to correlate the two morphological aspects (and , hence, the relative ages between pediments of different lengths). She concluded that the length of a pediment and its average slope showed no correlation and also that the slopes of domelike pediments were not significantly different from the slopes of mountain front pediments (or "piedmont pediments")--both slopes are between about 1° and 5°. Thus, although slopes on the Pinnacle Peak Pediment were not measured, if they had, it is not apparent that the measurements would help to constrain the age of the pediment. Although little quantitative information is available about the rates of pedmentation, Morrison (1985) agrees with previous authors that pediments can only form during periods of tectonic and climatic stability. Without information about the rate of pedimentation, it can probably be said, however, that erosion on the Pinnacle Peak Pediment probably did not begin only on one side of the range and progress all the way across to the other side, but began on both sides of the range and progressed mountain-ward until both sides met at the divide to form the broad pediment visible today.

Structure

The only visible fault displaces metarhyolite against quartzite, in the southwest corner of the map, north of McDowell Peak. Exposures are poor and no attitudes were visible, but based on the spatial distribution of units, the fault probably has some strike-slip displacement and probably extends eastward through section 25 (as drawn).

Two very narrow, well-defined shear zones cut across the granite at East End in the McDowell Mountains and in the granite pediment in the northwest corner of the map. Both of these zones are remakably linear and narrow. They are from two to 10 meters wide, but commonly closer to two or three. The margins are sharp and they are defined by an intense gneissic foliation to mylonitic foliation, both lineated. They closely resemble similar shear zones observed to the south at Arizona Dam Butte and in the Usery Mountains (Skotnicki, 1995, and Skotnicki and Ferguson, 1996). Since the shear zones in the northern McDowell Mountains cut a granite which is probably middle Proterozoic in age (~1.4 Ga), the shear zones are likely younger than middle Proterozoic.

In T. 4 N., R. 6 E., section 25, in a stream cut on the west face of the small hill directly across from the entrance to McDowell Mountain Regional Park, there is an exposure of a possible fault displacing basaltic conglomerate (Tsm?) against lake bed deposits (Tsp). The conglomerate is slightly tilted but it was not entirely clear if this is basaltic conglomerate (map unit Tsm) or a younger, mantling Quaternary deposit (map unit Qm). If it is Qm, then the supposed fault has been active during the Quaternary. Because of the confusion the conglomerate was mapped as basaltic conglomerate (Tsm).

Mineralization

Thin, black tourmaline veins a few centimeters across crop out throughout the metamorphic rocks in the McDowell Mountains. They are commonly intimately associated with white quartz. Veins and plugs of white quartz several meters across are exposed on small knobs on the pediment at the north end of the McDowell Mountains.

Exposures of map unit Xgc, though limited in extent, contain abundant garnet and neddle-like crystals of sillimanite. The only outcrops are in the northern McDowell Mountains west and north of East End, where they are everywhere in contact with plutonic rock and are probably contact-metamorphosed sedimentary rocks.

In the far southwest corner of the study area is the Dixie Mine. A vertical shaft at least 40 feet deep was dug into metarhyolite about 50 feet north of the contact between metarhyolite and greywacke (map units Xr and Xs). The shaft is covered with fencing but tailings reveal yellow-stained foliated quartz and quartz serecite veins containing smaller 1-2 cm-wide veins of massive and disseminated pyrite, chalcocite, and possibly bornite.

Geologic Hazards

A variety of potential geologic hazards may be encountered in the study area. The primary geologic hazards that may affect this area are flooding and soil problems; debris flows and rockfalls present localized hazards. The general character of these hazards and the areas that may be affected by them are considered below.

Flooding. Flood hazards of the area consist of flooding associated with the Verde River and flooding associated with the tributary streams that flow across the piedmonts of the area. The Verde and Salt rivers have experienced many large floods during the past century. The largest historical floods on these rivers occurred in 1891, but the floods of January and February, 1993 were nearly as large. Hazards associated with large floods on these rivers are inundation of the channels and low terraces, and erosion of banks and lateral migration of river channels. The channels and floodplains of the Verde River in the map area are natural, without artificial bank protection. Major changes in channel position and size have occurred in past floods (M. Pearthree and Baker, 1987; Péwé and Kenny, 1989; P. Pearthree, unpublished data for the lower Verde River), and should be anticipated in future floods as well.

Flood hazards on piedmonts may be subdivided into (1) localized flooding along well-defined drainages, where there is substantial topographic confinement of the wash; and (2) widespread inundation in areas of minimal topographic confinement (i.e., active alluvial fans). Delineation of flood-prone areas along well-defined drainages is fairly straightforward, and these hazards may be mitigated by avoiding building in or immediately adjacent to washes. Alluvial-fan flooding is a much more difficult problem to address because flood waters derived from mountain drainage basins may spread widely across portions of the piedmont and positions of channels may change drastically during floods.

Detailed maps of the surficial geology provide an excellent basis for delineating piedmont flood hazards (Pearthree, 1991). Floods leave behind physical evidence of their occurrence in the form of deposits. Therefore, the extent of young deposits on piedmonts is an accurate indicator of areas that have been flooded in the past few thousand years. These are the areas that are most likely to experience flooding in the future. Following this logic, the extent of potentially flood-prone areas on a piedmont varies with the extent of young deposits (units Qyc and Qy).

Active alluvial fans are well-developed on both the east and west sides of the Verde River east and southeast of Lousley Hill. They emanate from the mouths of wide, shallow drainages where they coalesce into broad aprons on the west side of the river. The lower and sometimes upper reaches of some tributaries to the Verde River have fairly broad valley floors. Flood inundation in these areas may be quite extensive, and channels may shift positions during floods.

In the northern part of the map area young sediments are confined to broad channels emanting from the dissected bedrock pediment. When the channels enter the upper piedmont, which is comprised mostly of Qm deposits, they merge and constrict. In the middle piedmost, in areas dominated by Ql deposits, the channels split and coalesce, and form shallow, anastamosing braided stream patterns. This is the part of the piedmont most vulnerable to flooding as channel positions can change rapidly. On the lower piedmont the channels once again merge and costrict. Closer to the Verde River, where dissection is most rapid, the channels dramtically widen. Here, flooding is confined to these channels which commonly have well-defined vertical walls a few meters high.

Soil/substrate problems. Several types of soil/substrate problems may be encountered in the study area. Soil compaction or expansion upon wetting or loading may be an important geologic hazard in portions of the mapped area. Soil instability has caused extensive damage to buildings in Arizona (Lacy, 1963; Murphy, 1975; Christenson et al, 1979; Péwé and Kenny, 1989). Changes in soil volume beneath structures may cause damage ranging from nuisance cracks to serious structural damage. Deposits that are susceptible to changes in soil volume are typically relatively fine-grained, young sediments. Deposits in the area that are candidates for soil instability are the fine-grained alluvial fans of unit Qy on lower piedmonts. Fine-grained overbank deposits on young Verde river terraces may also have the potential to compact upon loading. Clay-rich soils associated with the well-preserved middle and early Pleistocene alluvial fans (units Qm and Qo) may have some potential for shrinking and swelling during dry and wet periods, respectively. However, clay-rich horizons associated with these surfaces are generally less than 1 m thick.

The presence of cemented caliche or petrocalcic soil horizons may impact construction excavation and leaching potential. Calcium carbonate accumulates in soils in this desert environment over thousands of years. Typically, the older soils in this area have strong accumulations of calcium carbonate that form a cemented horizon in the soil. This cemented petrocalcic horizon may be 1 meter or more in thickness, and a laminar cap of calcium carbonate may form in the upper part of the horizon. In the map area, strongly cemented petrocalcic horizons are associated with the ridge lines of dissected basin-fill deposits and to a lesser extent with the deposits themselves (units Tsy and Tsm), and early and middle Pleistocene alluvial fans and terraces (units Qo and Qm) (see also, Christenson et al, 1979). Progressively less carbonate accumulation is associated with increasingly younger surfaces, such that Ql and younger deposits have carbonate accumulations but do not have cemented horizons.

Very thin alluvial deposits (typically 1-2 meters thick) mantle the granitic pediment in the northwest part of the map area. These deposits, though as old as Qm, are typically poorly indurated and are composed of granitic grus and much sand- and silt-sized material shed from the granite bedrock. The deposits are fairly easy to dig into but because they are so thin they do not act as a significant aguifer. After extensive rainfall most runoff collects in a myriad of younger channels and is funnelled downstream through an extensive system of shallow ravines cut through the deposits and into the bedrock. Construction is also hampered by the proximity of bedrock close to the surface.

Rockfalls and Debris flows. Rockfalls, small landslides, and debris flows are potential hazards on and immediately adjacent to steep slopes of the McDowell Mountains. Mass movement of material on steep slopes in this region typically is triggered by intense or prolonged periods of precipitation (Christenson et al, 1979). Debris flows are viscous slurries of sediment and water that may convey large boulders substantial distances downslope. In southern and central Arizona, nearly all of the documented historical debris flows have been restricted to mountain slopes and valleys. Rockfalls and landslides are potential hazards below bedrock cliffs and where bedrock outcrops exist at or near the top of steep mountain hillslopes. In these situations, large rocks that are loosened by weathering may cascade violently downhill. The existence of large boulders near the base of a steep slope should be considered evidence of potential rockfall hazard in most cases.

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Geologic Map Units

Mapping units described below are grouped into bedrock units, younger Tertiary sedimentary deposits, and Quaternary surficial deposits. Quaternary are further subdivided by age and origin. Age subdivisions of the Quaternary used in this report are Holocene (Qy; 0 to 10 ka); late Pleistocene (Ql, 10 to 250 ka); middle Pleistocene (Qm, 250 to 750 ka); and early Pleistocene (Qo, 750 ka to 2 Ma). Surficial deposits are also divided by origin. These categories are piedmont alluvium (no letter added; Qy, for example); and river channels and terraces (lower case "r" added; Qyr, for example). Active channels of the major rivers and their tributary streams are indicated by a lower case "c" at the end of the label (Qyrc and Qyc, respectively). Almost all of the piedmont deposits younger than Tsy are composed almost exclusively of granitic alluvium. In the map to the south (Skotnicki, 1995) these deposits were indicated by a lower case "g" at the end of the label (Qmg, for example), but in this study the "g" was omitted. Where map unit boundaries are indistinct or obscured by anthropogenic alterations, dashed lines are used.

Anthropogenic Deposits

a Agricultural fields

d Thoroughly disturbed areas where human modifications of the landscape have obscured the surficial geology.

Piedmont Deposits

Qyc **Modern alluvium (< 100 yr).** Unconsolidated sand and gravel in active stream channels. Deposits consist of stratified, poorly to moderate sorted sands, gravels, pebbles, cobbles, and boulders. These deposits are highly porous and permeable. Soils are generally absent.

Qy **Holocene alluvium (< 10 ka).** Unconsolidated sand to small boulders reaching sizes up to 25 cm in diameter upstream but smaller and fewer downstream. Larger clasts are metamorphic rocks and basalt. Smaller clasts are subangular granitic grus. Qy deposits are characterized by stratified, poorly to moderately sorted sands, gravels, and cobbles frequently mantled by sandy loam sediment. On this surface the main channel commonly diverges into braided channels. Locally exhibits bar and swale topography, the bars being typically more vegetated. Soil development is relatively weak with only slight texturally or structurally modified B horizons and slight calcification (Stage I). Some of the older Qy soils may contain weakly developed argillic horizons. Because surface soils are not indurated with clay or calcium carbonate, Ya1 surfaces have relatively high permeability and porosity.

Qy$_1$ **Older Holocene alluvium (<10 ka)**

Ql **Late Pleistocene alluvium (10 to 250 ka).** Moderately sorted, clast-supported sandstones and conglomerates containing much granitic grus in a tan to brown sand and silt matrix.. Ql surfaces are moderately incised by stream channels but still contain constructional, relatively flat interfluvial surfaces. Desert pavement is not developed as it is in the metamorphic-clast-rich deposits south of the map area. Ql soils typically have moderately clay-rich, tan to red-brown argillic horizons.. Ql soils contain much pedogenic clay and some calcium carbonate, resulting inrelatively low infiltration rates. Thus these surfaces favor plants that draw moisture from near the surface. Ql soils typically have Stage II calcium carbonate development.

Qml **Middle and late Pleistocene alluvium, undivided (10 to 750 ka).**

Qm **Middle Pleistocene granitic alluvium (250 to 750 ka).** Sandy to loamy, tan-colored sandstones and minor conglomerates west of the Verde River. The deposits are moderately consolidated and locally weakly indurated by carbonate. Argillic horizons typically are weak to moderate, probably because they have been eroded. The unit is fairly deeply dissected in the western part of the study area where it is best exposed as proximal fans. Argillic horizons are strongly developed where original depositional surfaces are well-preserved, particularly east of Lousley Hill, but are much weaker or nonexistent on ridge slopes. Southwest of Lousley Hill highly dissected deposits with surfaces at similar elevations to Ql probably contain both Ql and Qm. Deposits southwest of Lousley Hill are well-exposed in cross-section along the wide wash there. Along the wash the deposits are only about 5-8 meters thick and are poorly to moderately consolidated with minor carbonate in the matrix. Soils are tan to red and are particularly well-exposed in road cuts to the northwest along the Rio Verde Road. Dissection is deepest near the Verde river southeast of Lousley Hill.

Qo **Early Pleistocene alluvium (750 ka to 2 Ma).** Relatively thin (<4 m-thick) deposits of moderately sorted, clast-supported sandstones and conglomerates containing mostly pebble- to cobble-size clasts of granite, quartzite, and basalt in a sand to silt granitic matrix. Qo deposits rest on top of high levels of Tertiary basin-fill deposits (map unit Tsy) on the east side of the Verde River, though not on the very top surface. Qo soils are characterized by a relatively thin argillic horizon (<2 m) containing dark brown soil moderately rich in clay. Immediately underlying the argillic horizon, locally, is a petrocalcic horizon about 2 meters thick containing abundant thin laminae of caliche. Upper surface is flat and most clasts are varnished.

Major River Deposits

Qycr$_2$ **Active channel deposits.** Unconsolidated, well-rounded, moderately sorted to poorly sorted, clast-supported sand, cobbles, and small boulders. Well-rounded cobbles 10-30 cm dominate and are characteristically imbricated downstream. No carbonate in matrix. Little or no vegetation.

Qycr$_1$ **Modern flood plain deposits (0 to 100 yrs).** This surface is inundated during floods of the Verde and Salt Rivers. It consists of a moderately sorted, well-rounded, unconsolidated to poorly consolidated, sand, cobbles, and small boulders in recently active channels separate from the main active channel. Also consists of sandy overbank deposits.

Qyr **Holocene river terrace deposits (0 to 10 ka).** Equivalent to the Lehi terrace of Péwé (1978). Mostly unconsolidated well-rounded pebble- to cobble-sized river gravels surrounded by a sand and minor silt matrix. Also includes overbank (finely laminated clays, silts, and fine sands) sediments. Soil development is limited to slight organic accumulation at the surface and some bioturbation. Qyr terraces are slightly above the flood plains of the Verde and Salt Rivers. Exposures are mostly covered by fine silt 1-4 meters thick. Qyr surfaces along the Verde River are highly vegetated.

Qyr$_2$ **Younger member of the Lehi terrace.** May be inundated in largest floods.

Qyr$_1$ **Older member of the Lehi terrace.**

Qlr **Late Pleistocene river terrace deposits (10 to 250 ka).** Equivalent to the Blue Point terrace of Péwé (1978). Poorly consolidated well-rounded pebble- to cobble-size river gravels surrounded by a sand and minor silt matrix. Soil development includes moderate clay and calcium carbonate accumulation. Downstream from Granite Reef Dam this terrace is mostly covered by young fan deposits and crops out in isolated eposures.

Qlr$_2$ **Younger member of the Blue Point terrace.**

Qlr$_1$ **Older member of the Blue Point terrace.**

Qmlr **Middle to late Pleistocene river terrace deposits (~200 to 400 ka).** Equivalent to the McDowell terrace of Péwé (1978). Well-rounded, pebble- to cobble-size river gravels moderately indurated by caliche. Moderately strong clay and calcium carbonate accumulation. Found on west side of the Verde River in the east-central part of the study area.

Qmr **Middle Pleistocene river terrace deposits (~400 to 750 ka).** Equivalent to the Mesa terrace of Péwé (1978). Well-rounded pebble- to cobble-size river gravels strongly indurated by calcium carbonate. Well-developed argillic horizons where terrace surface is well-preserved. Strongly developed petrocalcic horizons capped with carbonate laminae locally form small resistant cliffs 1-4 meters thick below gravels. The unit forms small, isolated, resistant, high-standing mesas capped by loose lag gravel derived from the underlying deposit. Locally, the gravel has been removed and the petrocalcic horizon is exposed.

Qmr$_2$ **Younger member of the Mesa terrace.**

Qmr$_1$ **Older member of the Mesa terrace.**

Qor **Early Pleistocene river terrace deposits (750 ka to 2 Ma).** Equivalent to the Sawik terrace of Péwé (1978). Well-rounded pebble- to cobble-size river gravels very strongly indurated by caliche. Exposed only downstream from Granite Reef Dam, the unit forms high, flat mesas near Sawik Mountain and smaller, isolated mesas south of Mt. McDowell. In many places petrocalcic horizons or petrocalcic litter are exposed at the surface. Some of these petrocalcic exposures comprise most of the surface. Clasts exhibit strong desert varnish, and larger clasts are split and pitted. This unit includes the Lousley Hill deposits as defined by Pope (1974) which crop out above hills of basalt-rich conglomerate (map unit Tsm) in the north-central part of the map area.

Qor$_2$ **Younger member of the Sawik terrace.**

Qor$_1$ **Older member of the Sawik terrace.**

Younger Tertiary Deposits

Tsy **Younger sedimentary basin-fill deposits (late Tertiary).** Tan-colored, horizontally bedded, moderately sorted to poorly sorted, clast-suppprted sandstones and conglomerates. Fine-grained silt, sand and pebbles are composed mostly of subangular granitic grus. Coarser cobbles and small boulders are mostly subangular to subrounded metamorphic clasts and locally granite. These deposits are well-exposed on the east side of the Verde River where they form steeply dissected, well-indurated ridges composed of about 60-70% granitic clasts and about 30-40 basalt clasts. On the west side of the River exposures are limited to the southwest edge of the map area, where they from broad, deeply dissected, metamorphic-clast-rich fans eminating from the east side of the McDowell Mountains. This unit everywhere is very well indurated by carbonate and forms high-standing, resistant, rounded ridges and hills.

Tsm **Middle sedimentary basin-fill deposits (late Tertiary).** This unit varies from light tan to light grey, moderately consolidated, thinly bedded, clast-supported sandstones and conglomerates, to moderately well-sorted, thin- to medium-bedded river gravels. In the sandstones and conglomerates the largest clasts are about 30 cm in diameter, but sand, gravel and small cobbles are by far the most common. There is very little silt in the matrix. Finer-grained beds are composed mostly of subangular granitic sand and gravel. Coarser beds contain subrounded, gravel- to cobble-size clasts of basalt, metamorphic clasts, and granite, but basalt clasts are by far the most common. Both the sandstones and conglomerates, and the river gravels are dominated by three major clast types; they are, in order of abundance, 1) basalt, 2) granite [mostly as grus but also larger cobbles of fine-grained granite], and 3) rusty orange crystal-rich porphyritic rhyolite/dacite--with minor purple quartzite (probably Mazatzal Quartzite) and dark grey phyllite. River gravels are well-exposed in the Asher Hills, on the east side of Lousley Hill, and in the hills south and east of Luosley Hill. The river gravels appear to be exposed near the base of the unit and form a small resistant cliff. The unit crumbles easily yet forms high-standing, rounded hills. The matrix is carbonate rich and locally forms well-consolidated caliche laminae. Contains small lenses of silt several centimeter to a meter or so wide, some of which appear broken and may have been reworked into clasts.

Tsp **Pemberton formation (late Tertiary).** Very fine-grained, tan- to brown-colored silt. Generally, thinly bedded with bedding planes defined by fissle partings on weathered surfaces. Locally, silt layers are interbedded with very fine sand layers which form small lenses tens of centimeters wide. Mud cracks are visible locally as a well as small tubular carbonate concretions several millimeters in diameter and 1-3 cm long which may have a biologic origin (burrows? root casts?). The unit crumbles easily and forms light brown slopes. The road-cut east-southeast of Lousley Hill provides an excellent exposure. Named by Pope (1974) as the Pemberton Silt.

Bedrock Units

Ti **Felsic hypabissal intrusive rock (middle Tertiary).** Crystal-rich rock containing 1-10 mm subhedral phenocrysts of abundant white feldspar, clear rounded quartz, small subhedral to euhedral biotite up to 2 mm wide, and rare hornblende laths up to 1.5 cm long--all in a light pink to tan matrix. Fresh surfaces are light pink-grey. Weathered surfaces are light tan. Exposed in a few small hills south of Coon Bluff and in the steep bank immediately north of Granite Reef Dam.

YXg **Felsic Granitoid (middle or late Proterozoic).** Medium-grained to coarse-grained, leucocratic, K-fedspar porphyritic granite to quartz monzonite containing phenocrysts of subhedral white plagioclase, 1-4 mm black to dark green felty masses of biotite, grey to slightly pink 1-2 cm subhedral K-feldspar, and about 2-5% milky grey quartz. Less than 2% of the unit is foliated (estimated). Forms resistant, boulder-covered hills and ridges at the southeastern end of the McDowell Mountains. The rock is locally fresh and contains pink K-feldspar phenocrysts, but most weathered surfaces crumble easily into sandy grus. Resembles the Ruin Granite near Globe.

Metamorphic Rocks
(These rocks probably belong to the Union Hills Group and/or the Alder Group)

Xsc	**Sillimanite schist (middle Proterozoic).** Coarse-grained schist containing long, needle-like clear-gray crystals of sillimanite and up to 2 cm long in a dark gray-green matrix of dark red-gray garnet and muscovite. All crystals are anhedral. Rock is dark green, dense, and layered. Layering may represent relict primary sedimentary layering. The long axes of the sillimanite crystals are parallel to the plane of layering. In thin section sillimanite is embayed and surrounded by muscovite but it is not clear if the sillimanite is altering to or from muscovite.
Xvm	**Mafic volcanic rocks (middle Proterozoic).** Dark grey-green, fine-grained biotite-amphibole schist containing 1-3 mm anhedral black amphibole porphyroblasts. Generally, the unit is strongly to moderately foliated. In areas that are only weakly foliated or nonfoliated (particularly in T. 3 N., R. 6 E., section 6 to the south of the study area) subhedral, light grey plagioclase laths are abundant. Locally, white quartz veins and dark quartz-tourmaline veins several centimeters thick cross-cut the foliation.
Xr	**Rhyolite (middle Proterozoic).** Fine-grained, light grey to pink, quartz-sericite schist. Generally contains very small (<1mm) anhedral phencrysts of grey feldspar and quartz. Locally, the rock contains crystals of feldspar and milky quartz up to 4 mm wide and contains elongate lenses of fine-grained biotite with their long axes parallel to foliation. 1-3 mm wide magnetite porphyroblasts have been altered to hematite. Locally small (<2 mm) pyrope garnet porphyroblasts are visible. Locally contains 2-12 mm-long lenses altered to epidote (pumice?). Strongly foliated. Forms resistant, light-colored ridges in the southwest corner of the study area in the McDowell Mountains
Xs	**Greywacke (middle Proterozoic).** Fine-grained, light to medium silvery grey biotite-muscovite-quartz schist. Strongly foliated. Preferentially breaks into plates which crumble easily and have a gritty texture. Some surfaces have a pale rusty stain. Exposures are limited to small outcrops north of the McDowell Mountains where they form tiny, resistant knobs surrounded by granite pediment.
Xq	**Quartzite (middle Proterozoic).** Light pink and blue-grey clean quartzite. Bedding is visible locally, and trough and planar cross-bedding, defined by thin magnetite bands, show that up-section is to the north-northeast. The bedding locally forms a small northeast-plunging anticline in the quartzite north of McDowell Peak. Between McDowell Peak and East End the quartzite has been intruded by diorite and granite and has formed small isolated roof pendants between the two plutons. Most exposures are highly fractured and yet are very resistant, forming steep rugged ridges and cliffs in the McDowell Mountains.