Geologic Map of the New River SE 7.5' Quadrangle, Maricopa County, Arizona

by

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Arizona Geological Survey
Open-File Report 98-21

November, 1998

Arizona Geological Survey
416 W. Congress, Suite 100, Tucson, AZ 85701

Includes 25-page text and 1:24,000 scale geologic map.

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This report was supported by the Arizona Radiation Regulatory Agency, with funds provided by the U.S. Environmental Protection Agency through the State Indoor Radon Grant Program, the U.S. Geological Survey via the STATEMAP and EDMAP programs, Arizona State University, and the Arizona Geological Survey.

This report is preliminary and has not been edited
or reviewed for conformity with Arizona Geological Survey standards

INTRODUCTION

The New River SE 7.5-minute Quadrangle is located in the northern fringe of the Phoenix metropolitan area and is bordered by Biscuit Flat to the west, the Union Hills to the south, Paradise Valley to the southeast, and the New River and New River Mesa areas to the north (Figure 1). The quadrangle is bounded by latitudes 33°45'00"N and 33°52'30"N, and longitudes 112°00'00"W and 112°07'30"W. Given its location, the area has become highly urbanized during the last few decades and is still undergoing rapid population growth. Thus, the knowledge of the distribution and character of bedrock and surficial deposits is important to make informed decisions concerning management of the land and its resources.

Geologic mapping of the New River SE Quadrangle is related to other 1:24,000 scale mapping projects of the Arizona Geological Survey in and around the Phoenix metropolitan area (Figure 1). Geologic mapping of bedrock in the quadrangle was based on field mapping, whereas surficial mapping was based upon field observations, and the interpretation of aerial photographs and soils maps. The respective mapping coverage accomplished by each author (i.e., Leighty and Holloway) is shown on the map plate. A limited amount of unpublished Arizona Geological Survey mapping (by Steve Reynolds and Mike Grubensky for the Phoenix North 1:100,000 scale geologic map) augmented the new mapping of this report. Also, the mapping of Tertiary rocks by Jagiello (1987) is locally similar to that of this report. Aerial photographic coverage for different parts of the quadrangle is available from various sources (e.g., U.S.G.S., Bureau of Land Management, etc.), and includes black-and-white (1:40,000 scale, dated 9-6-92) and color (1:24,000 scale; dated 10-25-77) photographs. Soil information was compiled and interpreted from USDA Maricopa County soil surveys (Hartman, 1977; Camp, 1986). This project was supported by the Arizona Radiation Regulatory Agency, with funds provided by the U.S. Environmental Protection Agency through the State Indoor Radon Grant Program, the U.S. Geological Survey via the STATEMAP and EDMAP programs, and the Arizona Geological Survey. Support of Stephen Holloway was also provided by the Department of Geology, Arizona State University.

PREVIOUS STUDIES

Although several workers have described the Proterozoic and Cenozoic rocks and structures in the region, detailed study of the New River SE area has been relatively limited. The Proterozoic geology of the region has been summarized (Karlstrom et al., 1987; Karlstrom and Bowring, 1988, 1991; Anderson, 1989a,b; Karlstrom et al., 1990; Reynolds and DeWitt, 1991), but more detailed studies have typically concentrated in the Phoenix Mountains, New River, New River Mountains, and Bradshaw Mountains areas (Aylor, 1973; Shank, 1973; Thorpe, 1980; Thorpe and Burt, 1978, 1980; Maynard, 1986, 1989; Anderson, 1989b; Reynolds and DeWitt, 1991; Bryant, 1994; Shank and Péwé, 1994; Jones, 1996; DeWitt, unpublished mapping; Grubensky, unpublished mapping; Reynolds, unpublished mapping). Other geologic studies have emphasized the Tertiary rocks and structures of adjacent areas in areas adjacent to the New River SE Quadrangle (Gomez, 1978; Gomez and Elston, 1978; Elston, 1984; Jagiello, 1987; Doorn and Péwé, 1991; Leighty et al., 1995; Leighty and Reynolds, 1996; Leighty, 1997). The uranium potential of Tertiary sedimentary deposits of the region was described by Scarborough and Wilt (1979), some of which are considered potential radon hazards (Duncan and Spencer, 1993; Harris, 1997; Harris et al., 1998). The New River SE area is also included in the 1:100,000 scale Phoenix North 30' x 60' Quadrangle (Demsey, 1988; Reynolds and Grubensky, 1993). This report is contiguous with 1:24,000 scale geologic mapping recently completed in and around the Phoenix metropolitan area (Figure 1; see map plate), including the Hedgpeth Hills (Leighty and Huckleberry, 1998a), Biscuit Flat (Leighty and Huckleberry, 1998b), Union Hills (Holloway and Leighty, 1998), Cave Creek (Leighty et al., 1997), Wildcat Hill (Skotnicki et al., 1997), New River Mesa (Ferguson et al., 1998), and Humboldt Mountain (Gilbert et al., 1998) Quadrangles.

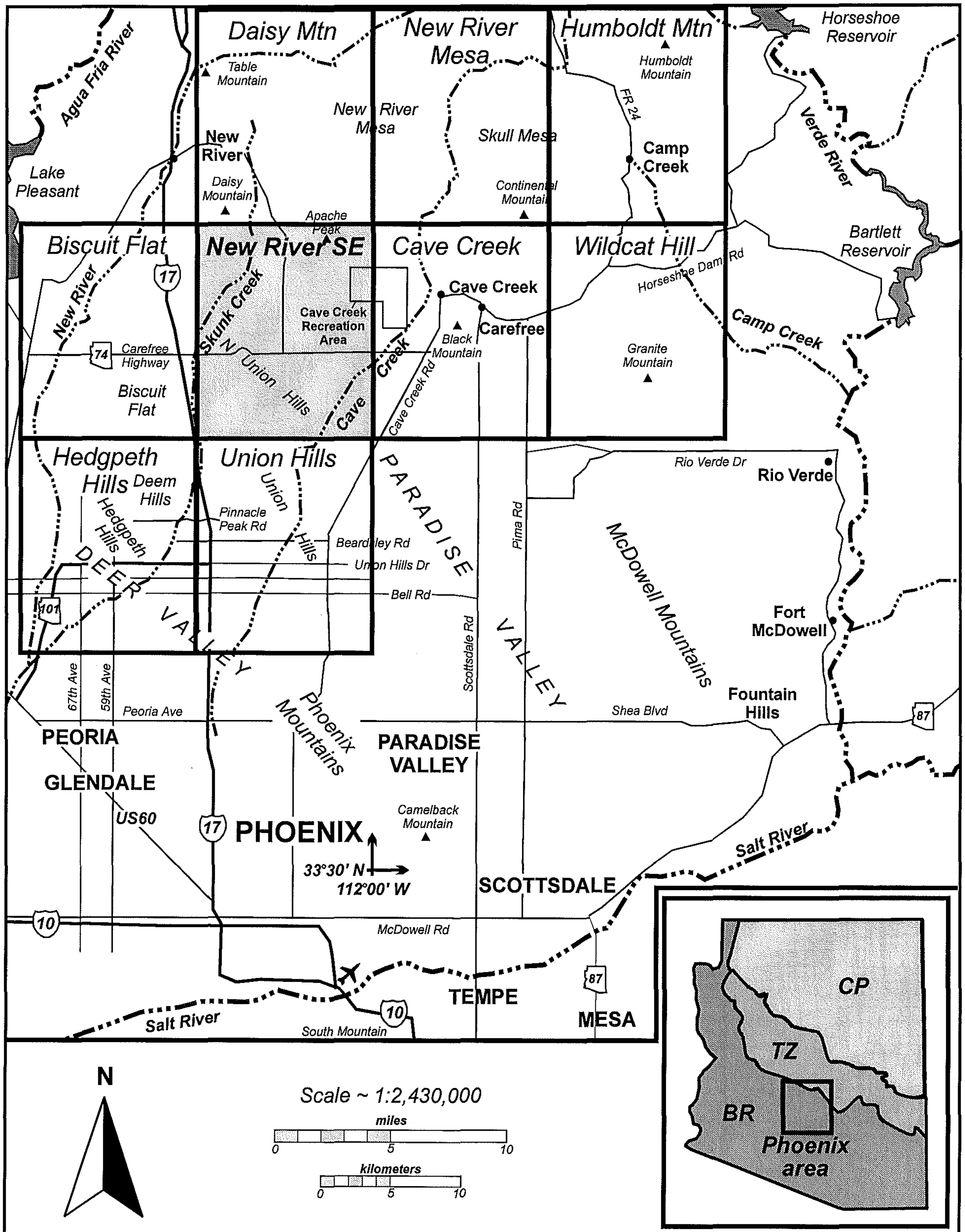

Figure 1. Location of the New River SE 7.5' Quadrangle in the Phoenix region. The inset map shows the location of the study area relative to the three physiographic provinces in Arizona: the Basin and Range (BR), Transition Zone (TZ), and Colorado Plateau (CP).

PHYSIOGRAPHY

Arizona can be divided into three physiographic/geologic provinces (Figure 1): the Colorado Plateau, the Transition Zone, and the Basin and Range. The New River SE Quadrangle lies within the Basin and Range province in central Arizona, where the terrain includes NW-trending mountain ranges separated by alluvial valleys. The northern Phoenix area includes several fault-bounded, NE-dipping, mountain ranges consisting of highly eroded Proterozoic and Cenozoic rocks. Paleozoic and Mesozoic rocks are absent in this area. The valleys are commonly filled with Cenozoic "basin-fill" sedimentary rocks and surficial deposits, with normal faults typically covered by alluvium. The New River SE Quadrangle contains a diverse suite of geologic units that range in age from Early Proterozoic to Latest Cenozoic. Proterozoic rocks include sequences of Early Proterozoic metavolcanic, metasedimentary, and intrusive rocks, as well as rocks correlative with a large Middle Proterozoic granite batholith (Figure 2). Cenozoic rocks include Early Miocene alkaline basalt, conglomerate, tuff, and tuffaceous sediment, Middle Miocene subalkaline basaltic lavas, Late Miocene basin-fill sediment, and Plio-Pleistocene to Holocene river terraces and alluvium.

The terrain encompassed by the New River SE Quadrangle includes small ranges and hills, piedmonts with coalescing alluvial fans, and broad alluvial plains. Topographic relief in the area ranges up to 700 feet in the North Union Hills and >1000 feet in the Apache Peak area, whereas the central and southeastern areas of the quadrangle are predominantly low relief alluvial surfaces that cover the northwestern end of Paradise Valley. Prominent drainages include Cave Creek, Skunk Creek, and Apache Wash. Cave Creek is the largest stream in the area and flows south from its headwaters in the Transition Zone to the north. Vegetation across the area is typical of the Sonoran Desert, with various desert grasses, ocotillo, brittle bush, creosote bush, buckhorn and teddy bear cholla, and other types of cacti, including saguaro.

Access for most parts of the New River SE Quadrangle is excellent (Figure 2). Numerous paved roads (e.g., Carefree Highway, New River Road, 24th Street, etc.) and well-maintained dirt roads make much of the quadrangle highly accessible. Access within the Cave Creek Recreation Area is limited to the established trail system, unless permission from the park rangers is obtained. Access to certain areas is limited as new home construction is active across the area.

PROTEROZOIC GEOLOGY

The New River SE Quadrangle contains a diverse assemblage of Proterozoic lithologies dominated by Early Proterozoic metamorphic and plutonic rocks. Metavolcanic rocks are exposed in the North Union Hills, Rodger Creek area, Cave Creek Recreation Area, and at Daisy Mountain. In the northern Union Hills and North Union Hills, these rocks are intruded by granitic rocks (i.e., YXg) that are Early or Middle Proterozoic in age (1700 to 1300 Ma; Reynolds et al., 1986). Similar Proterozoic rocks are also exposed in several nearby quadrangles (Anderson, 1989b; Reynolds and DeWitt, 1991; Reynolds and Grubensky, 1993; Leighty et al., 1997; Holloway and Leighty, 1998; Leighty and Huckleberry, 1998a,b).

Early Proterozoic metamorphic and plutonic rocks

Early Proterozoic metamorphic and plutonic rocks are exposed across the New River SE Quadrangle area, including in the North Union Hills and Union Hills, the Cave Creek Recreation Area, Daisy Mountain, and from Apache Wash to Skunk Creek (Figure 2). These metamorphic rocks are greenschist facies (or lower) and include intermediate to felsic metavolcanic and hypabyssal rocks, and volcaniclastic metasedimentary rocks. Several types of plutonic rocks are present in the area and are represented by dioritic, granodioritic, and granitic compositions.

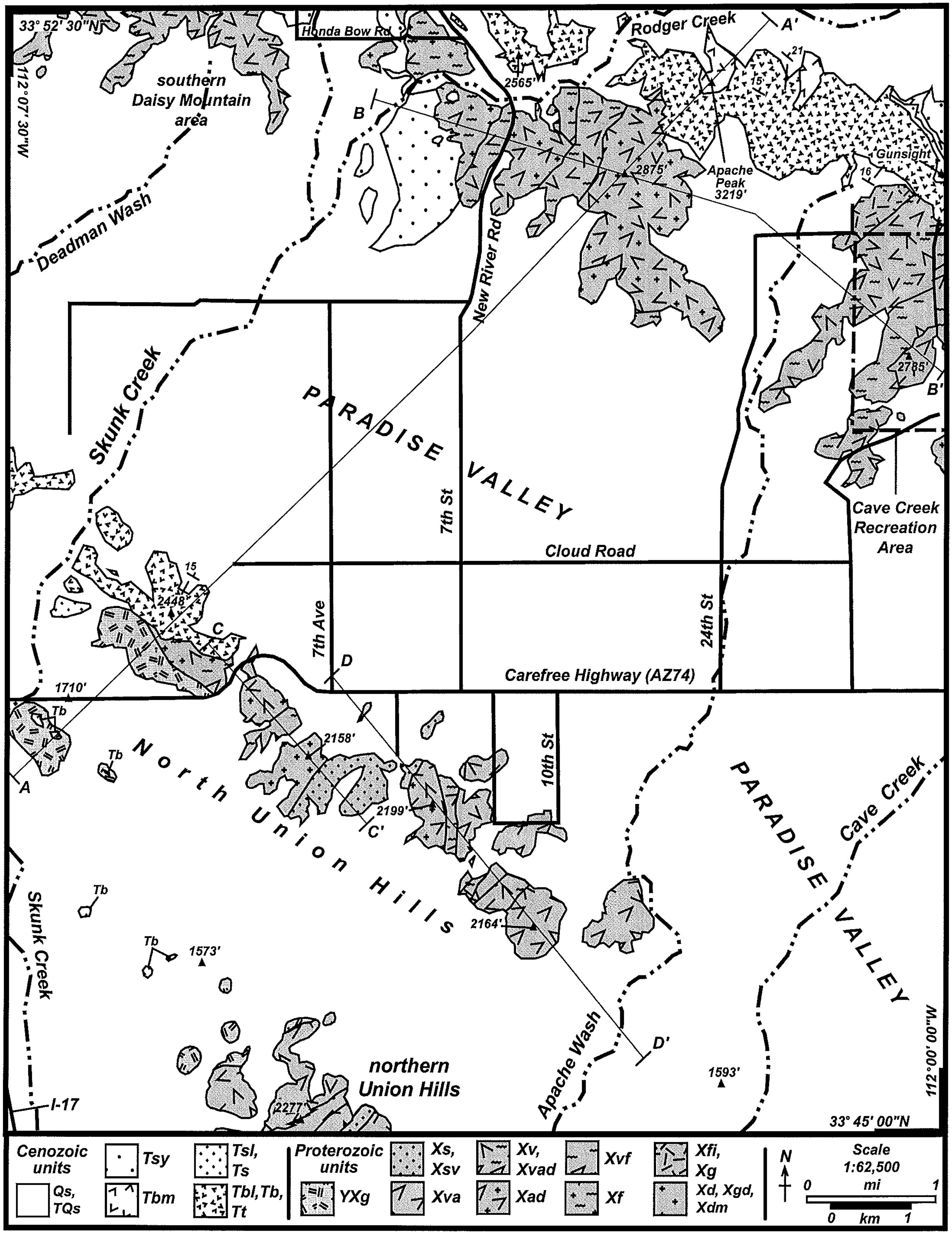

Figure 2. Generalized bedrock geology of the New River SE 7.5' Quadrangle with significant landmarks.

Metavolcanic and hypabyssal rocks. Metavolcanic lavas and tuffs, spanning a range of compositions from basaltic andesite to rhyolite, are exposed in the Union Hills, North Union Hills, Daisy Mountain, Rodger Creek, and Cave Creek Park areas. Metavolcanic rock types include basaltic andesite to andesite (Xva), andesite-dacite (Xvad), dacite (Xvd), dacitic tuffs (Xvdt), and rhyolite (Xvf), as well as

Andesitic to basaltic andesitic metavolcanic rocks (Xva) include massive, fine- to medium-grained, greenschist facies meta-andesite and meta-basaltic-andesite lavas and related fragmental rocks. The andesitic rocks are typically dark greenish gray, aphyric to hiatal porphyritic rocks (0 to ~15% phenocrysts), with euhedral to subhedral, white to glassy plagioclase phenocrysts (<1cm) in a dark grayish-green to greenish-gray, very fine-grained, chloritic groundmass. Amphibole and pyroxene are typically altered to biotite. Thin (1 to 3 m) felsic and intermediate micaceous tuff beds are commonly interbedded with the andesite. Lenticular, dark gray chert and slaty to phyllitic beds are also present locally. These rocks are commonly rich in epidote mineralization. In the southeastern North Union Hills, these lavas are typically greenish gray, fine-grained rocks that include minor amounts of quartz and K-feldspar. In the Rodger Creek area, the Xva unit likely includes basaltic andesite, andesite, and dacite. In the Union Hills Quadrangle to the south, this unit locally has discontinuous pillow-shaped masses with vesicular rinds and hyaloclastic haloes. These pillow basalts probably signify submarine eruption.

Interbedded greenschist facies andesitic and dacitic lavas and tuffs (Xvad) are exposed in the southern Daisy Mountain and North Union Hills. These rocks are variably porphyritic, with plagioclase phenocrysts (<2 mm) in a fine-grained matrix. The more dacitic compositions have similar textures as the andesitic rocks (i.e., fine-grained and granular), but are generally lighter in color than andesitic rocks, with more quartz and K-feldspar. Dacitic lavas and tuffs (Xvd) are lighter in color than andesitic rocks, with abundant plagioclase, quartz, and K-feldspar. In the southeastern North Union Hills, these fine-grained to granular lavas are interbedded with , highly foliated, fine-grained dacitic(?) fragmental rocks (Xvdt).

The Xad unit represents a heterogeneous assemblage of hypabyssal and volcanic rocks of intermediate composition exposed in the North Union Hills and southwestern Apache Peak areas. This greenschist facies unit includes fine-grained, seriate porphyritic to granular, plagioclase-phyric basaltic andesite to andesite that are gradational with fine- to medium-grained dioritic and granodioritic rocks. The more dioritic rocks are grayish green and coarse-grained, with 30-40% mafics, whitish plagioclase, trace K-feldspar, and are commonly rich in epidote. However, these hypabyssal rocks generally lack the equigranular textures of many of the plutonic diorites. Repetition of plutonic, hypabyssal, and volcanic lithologies locally varies on the scale of a few meters. These rocks may represent a complicated intrusive-extrusive volcanic flow sequence or pile that contains aphyric to porphyritic flows having microdioritic cores, hypabyssal intrusive bodies with aphyric to porphyritic chill margins, or both. These rocks have gradational to sharp contacts with small amounts of granodiorite and more leucocratic, aplitic rocks.

Felsic metavolcanic rocks (Xvf, Xvft) are exposed in the North Union Hills, Cave Creek Recreation Area, and Rodger Creek area. The felsic metavolcanic unit (Xvf) contains massive to highly foliated, fine-grained to granular, pinkish gray rocks that include rhyolite, rhyodacite, and minor dacite lava, with interbedded tuff. These units typically contain variable amounts of granular quartz and K-feldspar microphenocrysts, and minor biotite. The resistant, ridge-forming Xvf flow in the Cave Creek Recreation Area may continues to the northeast into the Cave Creek and New River Mesa Quadrangles. Highly foliated and altered rhyolitic tuffs and fragmental rocks (Xvft) are exposed in the Cave Creek Recreation Area. Undivided felsic metavolcanic and hypabyssal rocks (Xf) include medium- to fine-grained, aplitic leucocratic rocks exposed in the North Union Hills and in the Rodger Creek area. Along the Carefree Highway, this unit is a brick-red, very fine-grained felsic metavolcanic rock that is probably hydrothermally altered.

Heterogeneous, complexly interbedded andesitic, dacitic, and rhyolitic flows and tuffs, with minor pelitic metasedimentary rocks (Xv) are present in the North Union Hills, Cave Creek Recreation Area, and Rodger Creek area. Fine- to medium-grained andesitic rocks are typically interbedded with felsic tuffs that are typically fine-grained to aplitic, with small phenocrysts of quartz and/or sanidine. Thin, fine-grained, tan to reddish layers may represent felsic tuff or sedimentary beds, and bluish-gray phyllite is also present locally. Jasperoid rock is commonly associated with these rocks.

Metavolcanic and metasedimentary rocks. Complexly interbedded metavolcanic (lavas and tuff) and metasedimentary rocks (Xvs), tuffaceous metavolcanic and metasedimentary rocks (Xvts), and metasedimentary and metavolcanic rocks (Xsv) are exposed in the North Union Hills and the southwestern part of the Cave Creek Recreation Area. The schists, phyllitic schists, and phyllites of metavolcanic, metavolcaniclastic, or metasedimentary origin (Xvs) are similar to the Xsv unit, except that the intermediate to felsic metavolcanic rocks are probably more abundant than the metasedimentary rocks. Limited exposures of pelitic to psammitic metasedimentary rocks (Xs) are interbedded with andesitic rocks at the northern end of the Union Hills. These metavolcanic and metasedimentary rocks may represent complex lithologic facies changes between different Union Hills Group volcanic centers (Anderson, 1989b).

Plutonic rocks. Several types of plutonic rocks are present across the New River SE Quadrangle. In the Rodger Creek and southwestern Apache Peak areas, intermediate plutonic rocks (Xd) include diorite, alkali-feldspar-rich diorite, and granodiorite, with numerous aplitic, leucocratic pods. These rocks are generally fine-grained (<1 mm), except for larger K-feldspar crystals (when present). Plagioclase and pyroxene are abundant, but quartz is not. Massive granodioritic rock (Xgd) containing plagioclase, quartz, and K-feldspar in a fine-grained, olive-green matrix is exposed along the eastern edge of the quadrangle boundary, just south of the Cave Creek Recreation Area boundary. Equigranular, medium-grained quartz monzodiorite (Xdm) is exposed in the North Union Hills in the vicinity of the radio tower. This plutonic unit contains abundant plagioclase, biotite, and minor quartz. These rocks intrude the Xsv unit, which are schistose, biotite-rich, compositionally layered metavolcanic rocks that may have experienced some degree of recrystallization in proximity to the contact. This quartz monzodiorite unit may be plutonic equivalent to the adjacent felsic metavolcanic rocks (Xvf) or are a slightly younger intrusive body. However, Fine-grained, leucocratic, hypabyssal to plutonic rocks (Xfi) are exposed East of Apache Wash. This pinkish red unit is equigranular, with white feldspar (1-2 mm) and quartz crystals, but no mafic minerals. This unit may represent the hypabyssal equivalent of the Early Proterozoic Verde Granite or rocks of the New River felsic complex (Anderson, 1989b).

Regional stratigraphic relations. The metamorphic and plutonic rocks of the New River SE Quadrangle are part of an Early Proterozoic terrane that contains rocks having similar age, metamorphic grade, and deformational fabrics, largely correlative with the Tonto Basin Supergroup and Diamond Rim Intrusive Suite (1740 to 1680 Ma; Maynard, 1986, 1989; Reynolds et al., 1986; Anderson, 1989a,b; Conway and Silver, 1989). The metavolcanic and metasedimentary rocks of this terrane are distinctly different in lithology, petrology, chemistry, and geologic setting than the rocks of the Yavapai Supergroup (1800 to 1740 Ma), exposed to the north of the Moore Gulch fault zone in the Transition Zone (Anderson, 1968; Karlstrom et al., 1987; Karlstrom and Bowring, 1988, 1991; Anderson, 1989b). The Tonto Basin Supergroup was probably formed between 1740 and 1700 Ma, deformed largely between 1700 and 1650 Ma, and intruded by pre-1700-Ma granite and hypabyssal rocks (Reynolds et al., 1986; Anderson, 1989a,b; Conway and Silver, 1989; DeWitt, 1989; Karlstrom et al., 1990; Reynolds and DeWitt, 1991). Although the stratigraphy and nomenclature are still controversial, the Tonto Basin Supergroup includes four major groups (from oldest to youngest): Union Hills Group, Alder Group, Red Rock Group, and Mazatzal Group (Wilson, 1939; Anderson, 1989a,b; Conway and Silver, 1989; Reynolds and DeWitt, 1991).

The metavolcanic rocks of the New River SE Quadrangle may specifically correlate with the metavolcanic rocks of the Union Hills Group, the oldest part of the Early Proterozoic Tonto Basin Supergroup (Anderson and Guilbert, 1979; Karlstrom et al., 1987; Anderson, 1989b; Conway and Silver, 1989). The Union Hills Group (1740 to 1720 Ma) is composed of: 1) mafic, intermediate, and felsic volcanic rocks and related tuffs, that were deposited in proximity to submarine volcanic centers, and 2) intermediate composition volcanic and volcaniclastic rocks and sediments deposited distally from major volcanic centers (Anderson, 1989b). The Union Hills Group is compositionally diverse (i.e., basaltic andesite to rhyolite), but is dominated by basaltic andesite to dacite flows and tuffs, and related volcaniclastic rocks, with subordinate iron-formation, and dioritic to granodioritic intrusives (Anderson, 1989b; Leighty et al., 1997). Union Hills Group and correlative rocks are exposed in the Phoenix area, Cave Creek area, the Mazatzal Mountains and Payson area, and the Sierra Ancha (Anderson, 1989b; Reynolds and DeWitt, 1991; Leighty et al., 1997; Holloway and Leighty, 1998; Ferguson et al., 1998; Gilbert et al., 1998).

Early Proterozoic plutonism in the New River SE area was largely related to Union Hills Group volcanism. Anderson (1989b) and Reynolds and DeWitt (1991) have compared the mineralogy and geochemistry of some of the Early Proterozoic granodioritic and dioritic plutonic rocks in the area to the Bland quartz diorite (1719 ±9 Ma; Bowring et al., 1986) and the Bumblebee-Badger Springs Granodiorites (1740 ±10 Ma; Anderson et al., 1971). However, these rocks could have also been produced by a slightly younger period of plutonism that occurred during and after deposition of the 1725 to 1710 Ma Alder Group sedimentary rocks. Although not exposed in the quadrangle, the earliest major Early Proterozoic batholiths in the region, the voluminous 1710 to 1700 Ma granites (e.g., Verde River and Payson granites), were coeval with ignimbrites of the younger felsic complexes (e.g., the New River Mountains felsic complex; Anderson, 1989b). The Xfi unit may be a hypabyssal equivalent of these rocks.

Structural relations. The primary foliation across the quadrangle is typically steeply-dipping and N- to NE-trending, consistent with the orientation of the main foliation in rocks of similar age in other parts of the region. Cleavage is best expressed in the metasedimentary, metavolcaniclastic, and tuffaceous metavolcanic rocks. Mesoscopic and macroscopic, NE-plunging folds are present in several parts of the quadrangle (e.g., Union Hills, North Union Hills, Cave Creek Recreation Area). These folds are typically tight to isoclinal, shallow- to vertically-plunging. Discontinuous ferruginous chert layers that may represent bedding are sheared apart near fold axes, forming distinctive 'J' hooks. These structures are probably a result of compressional tectonism related to the Yavapai Orogeny (1710 to 1695 Ma) or possibly the Mazatzal Orogeny (1675 to 1650 Ma).

Early to Middle Proterozoic plutonic rocks

Relatively unfoliated, coarse-grained to porphyritic granite (YXg) is exposed in the North Union Hills and northern Union Hills. Most exposures of this variably porphyritic granite contain scattered K-feldspar phenocrysts (as long as 2 cm), plagioclase, quartz, and subhedral biotite. The granite weathers into large spheroidal boulders and erodes easily into grus that mantles the granitic bedrock. This unit is correlative with granitic rocks exposed to the west in the Biscuit Flat and Hedgpeth Hills Quadrangles that have been informally referred to as the granite of Pyramid Peak (Reynolds and DeWitt, 1991; Leighty and Huckleberry, 1998a,b). It may also be correlative with the large, regionally extensive Middle Proterozoic (1422-Ma, C. Isaacson, pers. comm.) granitic batholith exposed north of the McDowell Mountains to the east, as well as other Middle Proterozoic (1425 to 1335 Ma) megacrystic granites in Arizona (Silver, 1968; Livingston and Damon, 1968; Reynolds et al., 1986). However, it is also possible that this largely unfoliated granite is a post-tectonic Early Proterozoic granite.

CENOZOIC GEOLOGY

Cenozoic rocks in the New River SE Quadrangle include Early Miocene basaltic lavas, tuff, and fluvial sediments, Middle Miocene basaltic lavas, and Late Miocene to Pliocene "basin-fill" sediments, and Late Pliocene to Holocene surficial deposits. The Middle and Late Tertiary rocks are exposed in a few small tilt-block ranges (e.g., North Union Hills, Apache Peak area). Late Tertiary "basin-fill" deposits are exposed between Daisy Mountain and Rodger Creek beneath the cover of Late Pliocene to Holocene surficial deposits. Although voluminous ash-flow-related volcanism occurred across southern Arizona during the Middle Tertiary, rocks representing this volcanism are not exposed in the quadrangle.

Early to Middle Miocene rocks

Early and Middle Miocene Early basaltic rocks, felsic tuffs, and fluvial-lacustrine sediments are present across the New River SE Quadrangle, including the North Union Hills, Apache Peak, and Rodger Creek areas. Most of these rocks are correlative with the Early to Middle Miocene Chalk Canyon formation, whereas a small amount of basaltic lavas in the Apache Peak area represent rocks of the Middle Miocene Hickey Formation.

Chalk Canyon formation. The sequence of interbedded basaltic lavas and tuff in the New River SE Quadrangle are typical of the Early Miocene Chalk Canyon formation, which contains variable proportions of alkaline basalts, felsic tuffs, and fluvial-lacustrine sediments (Gomez, 1978; Jagiello, 1987; Leighty, 1997). The Chalk Canyon formation was informally named by Gomez (1978) for exposures located to the north of the Cave Creek Quadrangle, but its distinctive lithologic sequences can be recognized across the region (e.g., eastern Lake Pleasant, north Phoenix, New River, Black Canyon City, Cave Creek, etc.; Leighty, 1997). The Chalk Canyon formation can be subdivided into two distinct members: the lower member (23 to ~17 Ma) consists mainly of interbedded alkaline basalts and crystal/lithic tuffs, whereas the upper member is dominated by fluvial-lacustrine deposits (Lindsay and Lundin, 1972; Eberly and Stanley, 1978; Scarborough and Wilt, 1979; Leighty, 1997).

The basaltic rocks of the lower member of the Chalk Canyon formation are typically porphyritic olivine ± clinopyroxene alkaline basalts that locally contain modal biotite (Leighty, 1997). These basalts (Tbl, Tb) are interbedded with several felsic tuff and tuffaceous sandstone beds (i.e., Tt, Ttv, Tts) that aid in correlation across the region. Olivine-phyric basalts and interbedded crystal tuffs and tuffaceous sediments are exposed in the Apache Peak and North Union Hills areas that correlate with other sections exposed in nearby areas (e.g., Pyramid Peak, New River Mesa, Sugarloaf Mountain, etc.). To the north in the New River Mesa Quadrangle, one of the lowest exposed alkaline basalt flows east of Sugarloaf Mountain (21.34 ±0.46 Ma, Scarborough and Wilt, 1979) overlies a lithic tuff containing an oreodont fossil, the oldest known mammal in Arizona (Lindsay and Lundin, 1972; Leighty, 1997). At Pyramid Peak, just to the north of the quadrangle, basaltic and andesitic rocks (17.72 ±0.37 Ma, Scarborough and Wilt, 1979) are interbedded with several felsic tuffs, including a prominent vitrophyre.

The basaltic lavas generally have porphyritic (3-15% phenocrysts) to vesicular (3-30% vesicles) overall textures, and a range of groundmass textures (e.g., microcrystalline, cryptocrystalline, trachytic, and intergranular). Phenocryst assemblages include olivine, olivine + clinopyroxene, olivine + clinopyroxene + plagioclase, and olivine + plagioclase. Euhedral to subhedral olivine microphenocrysts are typically partially to totally oxidized, whereas subhedral clinopyroxene microphenocrysts are unaltered. Groundmass phases are dominated by plagioclase, ranging from euhedral laths to cryptocrystalline microlites, with euhedral clinopyroxene, altered olivine, and opaque oxide grains being less abundant. No modal biotite was observed in these rocks, unlike many other basal Chalk Canyon formation lavas that contain variable amounts of modal biotite. Fine-grained mono- and heteromminerallic glomerocrysts are also common.

Several tuff layers are interbedded with the basaltic rocks in the North Union Hills and Apache Peak areas. These tuffs correlate with the ones exposed at Pyramid Peak to the northwest, Elephant Mountain to the northeast, and New River Mesa to the north (Scarborough and Wilt, 1979; Jagiello, 1987; Leighty, 1997; Ferguson et al., 1998). The Apache Peak section contains at least three significant tuff layers (Tt_1, Tt_2, and Tt_3), with a well-indurated, vitrophyric tuff (Ttv) in the upper part of the second major tuff layer. This pinkish to reddish pink to black unit is glassy (30-40%), with pumice and crystals of sieved plagioclase, plagioclase, biotite, hematite, and hornblende also present. At Pyramid Peak, this vitrophyric tuff overlies a 17.72 ±0.37 Ma andesite flow (Scarborough and Wilt, 1979).

The upper member of the Chalk Canyon formation is largely composed of fluvial-lacustrine deposits and subordinate basaltic rocks (Gomez, 1978; Jagiello, 1987; Leighty, 1997). These rocks are not present in the New River SE Quadrangle, but are exposed in nearby quadrangles. The upper member is typically overlain by multiple basalt flows of the Middle Miocene Hickey Formation (16.2 to 13.4 Ma) that cap many of the mesas in the area (e.g., New River Mesa, Skull Mesa, Wild Burro Mesa, Squaw Creek Mesa). In the Cave Creek Quadrangle, basalt (15.4 Ma) and fluvial-lacustrine sediments of the upper member are overlain by a sequence of 13.4 Ma basaltic lavas (Doorn and Péwé, 1991; Leighty et al., 1997). To the west and northwest in the Biscuit Flat Quadrangle, Chalk Canyon formation dolomites are unconformably overlain by Middle Miocene basaltic flows (15.39 ±0.4 Ma, Scarborough and Wilt, 1979). Hickey Formation basaltic flows (15.40 ±2.10 Ma, Eberly and Stanley, 1978) overlie (and may be interbedded with) the fluvial-lacustrine rocks in the Black Canyon City area to the north (Leighty, 1997).

Hickey Formation. Basaltic volcanism during the Middle and Late Miocene (16 to <10Ma) was widespread across the Basin and Range and Transition Zone and is represented by the lavas of the Hickey Formation (Anderson and Creasey, 1958; McKee and Anderson, 1971; Eberly and Stanley, 1978; Gomez, 1978; Elston, 1984; Jagiello, 1987; Leighty and Glascock, 1994; Leighty, 1997). The thin basaltic sheet lavas that may have once extended across much of the northern Phoenix area cap many of the fault-block ranges in the north Phoenix area (e.g., Rifle Range, Shaw Butte, Deem and Hedgpeth Hills, eastern Lake Pleasant, etc.). These intergranular plagioclase ± olivine ± clinopyroxene subalkaline basalts and basaltic andesites correlate in their stratigraphy, petrography, and geochemistry with lavas of the Hickey Formation across central Arizona (Leighty, 1997). Intergranular vesicles and large, open vesicles (commonly in columns or trains) also make these lavas distinctive from older the Chalk Canyon formation lavas. These Hickey Formation lavas have been referred to as the New River Mesa basalt (Gomez, 1978; Jagiello, 1987), but they simply represent the local equivalent of the more regionally extensive Hickey Formation (Leighty, 1997). A series of Hickey Formation basaltic flows (16.2 to 13.4 Ma) are well-exposed along the Basin and Range/Transition Zone boundary to the north of the New River SE Quadrangle. At Lone Mountain, in the Cave Creek Quadrangle to the east, the tilted 13.4 Ma basaltic rocks of the Hickey Formation are overlain by basin-fill deposits (Tsy) that fan upward into subhorizontally bedded strata (Leighty et al., 1997). To the west, in the Biscuit Flat Quadrangle, Hickey Formation basaltic flows (15.39 ±0.4 Ma, Scarborough and Wilt, 1979) overlie Chalk Canyon formation dolomites with a slight angular unconformity. In the New River SE Quadrangle, exposures of basaltic rocks correlative with the Hickey Formation are limited to the Gunsight area east of Apache Peak, where they underlie Tsy sedimentary rocks.

Tertiary extensional tectonism

Middle to Late Tertiary extensional tectonism significantly affected the Phoenix area, forming the distinctive Basin and Range physiography. Across the region, Early Miocene extension was fundamentally different in magnitude, style, and orientation compared with the Middle to Late Miocene period of normal faulting. However, in the north Phoenix area, there are several similarities in the style and orientation of the two extensional phases.

Middle Tertiary. Following relative tectonic quiescence of the Early Tertiary, significant extensional tectonism occurred across the Arizona Basin and Range during the Middle Tertiary (Late Oligocene and Early Miocene), and has been referred to as the "mid-Tertiary orogeny" (Damon, 1964). The Transition Zone and Colorado Plateau did not experience significant upper crustal extensional deformation during this time, but the reversal of regional drainage and formation of the Mogollon Rim was a likely effect of middle to lower crustal deflation in response to extension in the adjacent Basin and Range (Spencer and Reynolds, 1989). Middle Tertiary tectonism was dominantly characterized by ENE-WSW-directed extension along low-angle normal faults (or detachment faults) and subsequent fault-block rotation, typically related to the development of metamorphic core complexes (Coney, 1973; Davis and Coney, 1979; Coney, 1980; Crittenden et al., 1980; Davis, 1980; Wernicke, 1981; Reynolds, 1982; Davis, 1983; Davis et al., 1983; Lister and Davis, 1983; Reynolds, 1985; Reynolds and Lister, 1987; Spencer and Reynolds, 1989). Middle Tertiary extension in Arizona was broadly related to the evolving plate-tectonic setting of the continental margin of western North America (Atwater, 1970), and more specifically to changes in plate motions and geometries compounded by overriding of the progressively thinner and hotter subducted Farallon plate (Coney and Reynolds, 1977; Coney, 1978; Damon, 1979).

In south-central Arizona, initiation of extension-related tilting occurred before or during felsic volcanism (roughly 25 to 20 Ma) and generally ended before 17-Ma, except in a NW-trending belt adjacent to the relatively unextended Transition Zone (Fitzgerald et al., 1994; Spencer et al., 1995). Movement on detachment faults related to the South Mountain-White Tank composite metamorphic core complex was responsible for relatively large amounts of Early Miocene extension in the Phoenix area (Spencer and Reynolds, 1989). In the northern Phoenix area, the South Mountain detachment fault is visible on seismic reflection profiles (Frost and Okaya, 1986) and projects in the subsurface to the northeast beneath the NW-trending, tilted fault-block ranges that represent the upper plate of the core complex (Spencer and Reynolds, 1989). This area of generally unidirectional, NE-tilting in the Basin and Range has been referred to as the Camelback tilt-block domain (Spencer and Reynolds, 1989). These NE-dipping tilt-blocks (e.g., the North Union Hills and Apache Peak Ranges) were likely rotated along large, SW-dipping normal faults that are antithetic to the NE-dipping South Mountain detachment fault (see cross section A-A'). In the New River SE Quadrangle, Late Cenozoic deposits cover these faults, so the amount of displacement along these faults is not known. However, the faults may be listric in geometry to account for the fault-block rotation. Well-log data are sparse and detailed gravity data are not available for much of the area, so the depth of "basin-fill" sediments (Tsy) is not well-constrained.

During the Early and Middle Miocene, synextensional basaltic lavas, sedimentary rocks, and tuffs of the Chalk Canyon formation (23 to ~15 Ma) and Hickey Formation (16 to <10 Ma) were erupted/deposited across central Arizona. Hickey Formation sheet lavas may have extended across the much of the northern Phoenix area, where the youngest dated lavas are 15.4-Ma in the eastern Biscuit Flat Quadrangle. Similar lavas cap many of the other ranges in the Phoenix area. Accordingly, the NE-directed tilt-block rotation occurred sometime after 15.4-Ma (and possibly <13.4-Ma), probably with movement along large, possibly listric, SW-dipping normal faults. This extension may have been related to waning metamorphic core complex extension and/or block faulting of the Basin and Range Disturbance (Menges and Pearthree, 1989; Leighty and Reynolds, 1996). However, the post-15.4-Ma rotation of these fault-blocks is significantly younger than the inferred age of active metamorphic core-complex extension. Indeed, this rotational style of faulting may have overlapped to some degree with the beginning of high-angle normal faulting of the Basin-and-Range Disturbance (Menges and Pearthree, 1989; Leighty et al., 1996). To explain these relationships, it has been suggested that the long duration and magnitude of core-complex extension adjacent to the Transition Zone are consistent with a more passive mechanism of extension where the gravitational potential energy of the thicker Transition Zone crust caused southwest-directed collapse (Spencer et al., 1995).

Late Tertiary. The Basin-and-Range Disturbance represents a period of graben subsidence that occurred along high-angle normal faults, largely without major crustal block rotation. In the Arizona Basin and Range, it began ~15-Ma and ended ~8-Ma (Eberly and Stanley, 1978; Menges and Pearthree, 1989). Basin subsidence was probably not simultaneous, but mostly occurred before 8-Ma, when differential vertical movement essentially ceased, pediments formed, and basins filled (Shafiqullah et al., 1980). Newly created basins filled with undeformed fluvial and lacustrine deposits and basaltic rocks that were deposited over tilted beds deformed by earlier mid-Tertiary normal faulting. Subsidence also disrupted the Early Miocene drainage, facilitating internal drainage in many basins (Shafiqullah et al., 1980). Similar elevations of pediment gravel layers suggest that basin subsidence occurred with little or no change in the absolute elevation of the surrounding ranges (Peirce, 1976; Peirce et al., 1979). From well log and geophysical data, the depth of several of the large, deep Miocene basins (e.g., the Paradise Valley basin, Luke basin) in the Phoenix metropolitan area exceed 10,000 feet (Oppenheimer, 1980). In the New River SE Quadrangle, the Paradise Valley basin is likely bounded by large, high-angle normal faults, but much of the area is entirely covered by Quaternary surficial deposits. However, existing geophysical evidence suggests that the Paradise Valley basin becomes more shallow toward the northwest (Lysonski et al., 1980; Oppenheimer and Sumner, 1980). In contrast, the valley between the Union Hills and North Union Hills is probably underlain by a relatively shallow basin and covered pediments.

Quaternary surficial sediments

Quaternary surficial deposits cover much of the New River SE Quadrangle, and include Late Pliocene to Recent piedmont and fluvial units. Piedmont deposits were shed onto broad plains that slope gently down from several small mountain ranges. These piedmont deposits are generally poorly sorted (e.g., silt or clay to cobbles or boulders), but generally grade or interfinger downslope into finer-grained deposits. The older alluvial units (e.g., TQo, Qo, Qm) are typically extensively eroded, leaving rounded ridges between modern channels. Fluvial sediments (Qmr_1, Qlr, Qyr, Qycr) include active channels and one or more terrace levels that record former, higher positions of stream channels. These deposits are differentiated from piedmont deposits by their diverse lithologic composition, clast rounding, and landform morphology that is commonly elongate and mimics the general trend of the modern rivers. Similar units have been described across the Phoenix region (Demsey, 1988; Pearthree et al., 1997).

Piedmont deposits. The oldest piedmont deposits (TQo) are restricted to the northeastern portion of the quadrangle and grade southeastward into the highest terrace related to the Cave Creek drainage (i.e., TQor, the Little Elephant terrace; Gorey 1988; Gorey, 1990; Doorn and Péwé, 1991). During the Late Pliocene, Cave Creek may have initially drained to the west along a strike valley between the main scarp of the high mesas and the first Basin and Range tilt-block. Early Pleistocene deposits (Qo) are weakly consolidated, with relatively weak soil development because the original depositional surface has typically been removed by erosion. These deposits are exposed marginal to the bedrock areas in the northern part of the quadrangle, with isolated exposures in the central part of the North Union Hills. Much of the quadrangle is covered by broad Middle Pleistocene piedmont deposits (Qm, Qm_1, Qm_2). These surfaces have typically been eroded into shallow valleys and low ridges, with original depositional surfaces possibly preserved along ridge crests. Late Pleistocene alluvium (Ql) is exposed in the central portion of the quadrangle. These deposits are typically moderately incised by stream channels, but still contains constructional, relatively flat, interfluvial surfaces. Holocene alluvial deposits (Qy) consist primarily of small active channels and low terraces. Qy terrace surfaces typically exhibit bar-and-swale topography, with the ridges typically being slightly more vegetated. Unconsolidated to moderately consolidated colluvium and talus deposits (Qc, Qct) are common on hillslopes. These undifferentiated Middle Pleistocene to Holocene deposits generally consist of poorly sorted, sand- to boulder-sized clasts. Adjacent bedrock lithologies typically dominate the clast compositions.

Fluvial deposits. Terrace and channel deposits include units related to Cave Creek, Skunk Creek, and Apache Wash. Early Middle Pleistocene (Qmr_1) to Late Pleistocene (Qyr) terrace deposits are present along Cave Creek. Other Late Pleistocene to Recent fluvial sediments (Ql, Qlr, Qyr, and Qycr) are restricted to fairly narrow bands along washes (e.g., Apache Wash, Skunk Creek, etc.).

GEOLOGIC HAZARDS

A variety of potential geologic hazards exist in the study area. The primary geologic hazards that may affect this area are flooding, soil problems, and possibly radon. The general character of these hazards and the areas that may be affected by them are summarized below.

Flooding

Flooding is probably the most serious geologic hazard of the New River SE Quadrangle. Potential flood hazards consist of inundation and erosion along the Cave Creek, Apache Wash, and Skunk Creek and their larger tributaries, and flash-flooding associated with the smaller tributary streams that flow across the piedmonts of the area. Cave Creek is a moderately large drainage that heads in the Transition Zone to the north of the New River SE Quadrangle. Large floods (e.g., 100-year floods) involve deep, high-velocity flow in channels, inundation of overbank areas, and may cause substantial bank erosion along the channels. Areas mapped as Qycr are likely to be affected by deep, high velocity flow during floods. Adjacent areas mapped as Qy are likely to be subject to shallower inundation, and local bank erosion. Areas near large streams covered by older deposits (Ql, Qlr, and older) generally are not subject to inundation, but they may be affected by lateral stream erosion.

Flood hazards associated with smaller tributaries 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; these hazards may be mitigated by avoiding building in or immediately adjacent to washes. 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. Accordingly, the extent of potentially flood-prone areas on a piedmont may be evaluated based on the extent of young deposits (Qy).

Soil/substrate problems

Several types of soil/substrate problems may be encountered in the New River SE Quadrangle. Soil compaction or expansion upon wetting or loading may be an important geologic hazard in limited portions of the quadrangle. Soil instability has caused extensive damage to buildings in Arizona (Christenson et al, 1978; 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 compaction are typically relatively fine-grained, young sediments. Deposits in the area that are candidates for compaction are the fine-grained terrace deposits of Qy, Qyr, and Ql, located along some of the major drainages and their tributaries. Clay-rich soils associated with the well-preserved Early and Middle Pleistocene alluvial fans (Qo, and locally, Qm) 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, so their shrink-swell potential is probably limited.

The presence of cemented caliche (petrocalcic soil horizons) or shallow bedrock may impact construction excavation and leaching potential. Calcium carbonate accumulates in soils in this desert environment over thousands to hundreds of thousands of years. Typically, the soils associated with Middle Pleistocene alluvium (Qm) in this area have significant accumulations of calcium carbonate, but strongly cemented carbonate soil horizons are not common. Petrocalcic horizons are common in Early Pleistocene alluvium (Qo), and are found in some Middle Pleistocene alluvium (Qm) and thin hillslope deposits (Qc, Qct). Progressively less carbonate accumulation is associated with increasingly younger surfaces, such that Ql and younger deposits have weak carbonate accumulations. Weathered bedrock typically found beneath the alluvial deposits is generally degraded and easily excavated, but construction may be affected if more resistant bedrock is encountered in the near subsurface.

Radon

Radon, a colorless, odorless, radioactive gas, can pose potential health problem in certain circumstances. Radon can escape from the ground into overlying homes and other buildings, and result in elevated radiation exposure, and associated risk of cancer, to human lungs. Radon is a decay product of uranium, so areas with higher uranium concentrations present greater risk of elevated indoor radon levels (Peake and Schumann, 1991; Spencer, 1992). Uranium is present in all geologic materials, generally in concentrations of 1 to 10 ppm. Levels greater than 6 ppm U can be considered slightly anomalous. The alluvial basin cover in the region is not a significant radon hazard, but certain types of bedrock can have highly variable concentrations of uranium. In the Phoenix area, lithologies that have demonstrated elevated uranium levels, thus posing a potential radon hazard, include certain Proterozoic granitic rocks and Middle Tertiary sedimentary rock (marl). Since much of the New River SE Quadrangle is covered by Quaternary deposits, radon is probably not a significant hazard for much of the area. From Harris et al. (1998), anomalous uranium values are present in the altered felsic rocks (Xf) along the Carefree Highway (9 to 10 ppm), but are significantly lower in the porphyritic granite along the Carefree Highway (5 ppm), the leucocratic hypabyssal felsic rocks (Xfi) exposed east of Apache Wash (2 to 5 ppm), and the Proterozoic felsic unit (Xf) along Honda Bow Road (3 ppm). The Carefree Highway Xf unit may pose a moderate radon hazard, but its outcrop exposure is limited and its extent in the subsurface is not known. Additionally, the Proterozoic metamorphic rocks in the North Union Hills have very low U concentrations (<<1 ppm) and are not a likely radon threat (Harris et al., 1998). The Chalk Canyon formation marl is not exposed in the quadrangle, but may be present at depth. Water wells may tap these uranium-rich rocks directly, but most wells are shallow and do not penetrate bedrock.

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UNIT DESCRIPTIONS

Quaternary piedmont deposits

Qc **Colluvium (<750 Ka)** - Unconsolidated to moderately consolidated colluvium on gently sloping hillsides. These deposits are typically weakly bedded, subangular to angular, poorly sorted sand and gravel. Adjacent and underlying bedrock lithologies dominate the clast compositions. These hillslope deposits probably range in age from Holocene to Middle Pleistocene.

Qct **Colluvium and talus, undivided (<750 Ka)** - Unconsolidated to moderately consolidated colluvium and talus deposits on steeper hillslopes (e.g., at Apache Peak). These deposits are typically include subangular to angular, poorly sorted, sand- to boulder-sized clasts. Adjacent and underlying bedrock lithologies dominate the clast compositions. These hillslope deposits probably range in age from Holocene to Middle Pleistocene.

Qy **Holocene alluvium (<10 Ka)** - Holocene alluvial deposits consisting primarily of small active channels, low terraces, and broad alluvial fans. This unit is characterized by unconsolidated, stratified, poorly to moderately sorted sand, gravel, cobble, and boulder deposits confined to the modern tributary drainages of Cave Creek, Skunk Creek, Apache Wash, etc. Alluvial surfaces exhibit bar-and-swale topography, with the ridges typically being slightly more vegetated. Frequently mantled by sandy loam sediment. Qy surfaces have minimal or no rock varnish or desert pavement development. Late Holocene soils are minimally developed, but Middle and Early Holocene soils typically contain cambic horizons, weak calcic horizons (≤Stage I), and are noticeably reddened. Surface colors are light brown to yellowish brown, with a slight reddening with depth due to oxidation. Some of the older Qy soils may contain weakly developed argillic horizons. Qy soils are classified as Torrifluvents, Torriorthents, Camborthids, and Calciorthids. Because surface soils are not indurated with clay or calcium carbonate, Qy surfaces have relatively high permeability and porosity. All areas mapped as Qy may be subject to inundation during large floods.

Ql **Late Pleistocene alluvium (10 to 250 Ka)** - Late Pleistocene alluvial fan surfaces and terraces consisting of moderately sorted, clast-supported sandstone and conglomerate. Portions of the central part of the quadrangle are covered by these deposits. Ql surfaces are moderately incised by stream channels, but still contain constructional, relatively flat, interfluvial surfaces. Subdued bar and swale topography is common. Desert pavement and rock varnish development ranges from nonexistent to moderate. Surface colors are slightly more red (light brown to reddish yellow) than Qy surfaces. Ql soils are also more strongly developed than Qy soils. Ql soils commonly contain tan to red-brown argillic horizons that are weakly to moderately strongly developed. These soils typically have Stage II-III calcium carbonate development. Ql soils are classified as Haplargids, Camborthids, and Calciorthids. The relatively low infiltration rates of these surfaces favor plants that draw moisture from near the surface. Ql surfaces are generally not prone to flooding, except immediately adjacent to active washes.

Qm **Middle Pleistocene alluvium (250 to 750 Ka)** - Dissected Middle Pleistocene alluvial fan and terrace deposits that include sandy to loamy, tan sandstone and minor conglomerate with sand- to boulder-sized clasts. These surfaces cover large parts of the quadrangle, generally in proximity to bedrock ranges (e.g., the North Union Hills). Locally, Qm has been subdivided into older (Qm_1) and younger members (Qm_2). Qm surfaces have typically been eroded into shallow valleys and low ridges. Original depositional surfaces may be preserved along ridge crests. Desert pavement and rock varnish development is moderate to strong on stable surfaces, but variable to weak on surfaces that have been significantly eroded. Qm soils are moderately to strongly developed, with surfaces ranging in color from strong brown to reddish brown. These soils typically contain reddened argillic horizons that are moderately to strongly enriched in pedogenic clay. Calcic horizon development is typically fairly strong (Stage II-IV), but Qm soils generally do not have cemented petrocalcic horizons (caliche). These soils are classified as Calciorthids and Haplargids. Qm surfaces are not prone to flooding, except near active washes.

Qo **Early Pleistocene alluvial fan deposits (750 Ka to 1.6 Ma)** - Sandy to loamy, brown-colored conglomerates. These deposits are moderately consolidated and commonly are indurated by soil carbonate. Deposits are moderaately to deeply dissected by the larger drainages. Reddish-brown argillic horizons are moderately- to well-developed on planar, relatively well-preserved alluvial surface remnants. Cemented petrocalcic are commonly exposed on side slopes below ridge crests. These deposits are exposed marginal to the bedrock areas in the northern part of the quadrangle, with isolated exposures in the central part of the North Union Hills.

TQo **Pliocene to Early Pleistocene alluvial fan deposits (1 to 3 Ma)** - Very old alluvial fan deposits located northeast of Apache Peak. These deposits grade into the highest preserved terrace (in the northwestern Cave Creek Quadrangle) of the ancestral Cave Creek drainage. Deposits are sandy with abundant basalt cobbles and boulders. Soils are brown and clay-rich. Cemented petrocalcic horizons are typically exposed in shallow gullies.

Quaternary river deposits

Qycr **Active channel deposits (<1 Ka)** - Deposits in the active channels of Cave Creek, Skunk Creek, Apache Wash, and their principal tributaries. Predominantly sand and silt, especially in areas subject to overbank flooding, with clasts ranging in size from pebbles to boulders. Clasts are subrounded to well-rounded and lithologies vary substantially. Distributary and anastomosing channel patterns are common. Most of the channel surfaces are modern in age, but vegetated bars may be several hundred years old. Alluvium in these deposits is typically well-stratified and lack any appreciable soil development. Qycr soils are typically classified as Torrifluvents or Torriorthents. Qycr surfaces are prone to flooding.

Qyr **Holocene river terrace deposits (<10 Ka)** - Low terrace deposits composed of unconsolidated, moderately to poorly sorted, subrounded to rounded sand- and gravel-sized clasts in a sandy to silty matrix. Landforms typically are low terraces, but minor channels are common locally. Primary fluvial bedforms (gravel bars, fine-grained swales) near the surface are absent or weakly expressed due to bioturbation. These deposits have weakly developed soils that are light brown to yellowish brown on the surface, with a slight reddening with depth. There is typically organic accumulation in the uppermost soil horizons, with slightly oxidized horizons at deeper levels. Minimal or no rock varnish or desert pavement development. Weak calcic horizons (≤Stage I) are present in Middle and Early Holocene soils. Qyr terrace soils are Torrifluvents and Camborthids. Portions of Qyr surfaces have been inundated during historical floods, and lateral bank erosion is also a hazard.

Qlr **Late Pleistocene river terrace deposits (10 to 250 Ka)** - Intermediate, moderately old terrace deposits of Cave Creek, Apache Wash, and Skunk Creek. Unconsolidated, moderately to poorly sorted, subrounded to rounded sand- and gravel-sized clasts in a sandy to silty matrix. Qlr terrace surfaces range from about 2 to 15 m above modern channels. Soils have moderate clay accumulation and carbonate development (Stage II), but no cementation. Desert pavement and rock varnish is nonexistent to moderately developed. These surfaces are not prone to flooding, but lateral bank erosion may occur where proximal to active channels.

Qmr **Middle Pleistocene river terrace deposits (400 to 750 Ka)** - Prominent, high, old terrace deposits of Cave Creek. Qmr alluvium is composed of unconsolidated sand, gravel, and cobble channel deposits with interbedded fine-grained overbank sediments. Locally consists of a slightly older member (Qmr_1). Some of the eroded Qmr landforms consist of low, rounded ridges and moderately incised stream channels. Desert pavement and rock varnish development is weak to moderate. Soils on Qmr terrace surfaces are strong brown to reddish brown and are strongly developed where they have not been highly eroded. Clay accumulation is variable, but well-preserved soils have strong, red argillic horizons with loam and clay loam textures. Well-developed calcic or petrocalcic horizons are also common (Stage III-V). Qmr terrace soils are classified as Calciortids, Paleorthids, and Paleargids.

Middle to Late Tertiary volcanic and sedimentary rocks

Tsy **"Basin-fill" conglomerate and sandstone (Late Miocene to Pliocene)** - Interbedded, moderately to poorly sorted "basin-fill" sandstone and conglomerate exposed in the north-central portion of the quadrangle. This unit is poorly sorted, matrix- to clast-supported, with rounded to angular clasts of Proterozoic metamorphic rocks and Tertiary volcanic and sedimentary rocks. Clast compositions and relative abundances are variable, and are largely dependent on the composition of nearby bedrock. Sand- to boulder-sized clasts are typically present in a grussy, carbonate-rich matrix. These rocks were likely deposited during and after the extensional tectonism of the Late Miocene Basin and Range Disturbance.

Tbm **Hickey Formation basaltic rocks (Middle to Late Miocene)** - Dark grayish brown to dark gray basaltic lava exposed in the Gunsight area east of Apache Peak. The lavas are characteristically intergranular to porphyritic in overall texture, with clinopyroxene and altered olivine phenocrysts within a framework of plagioclase crystals. Olivine phenocrysts are typically altered to reddish orange iddingsite. From Leighty (1997), chemical compositions are largely subalkaline (olivine-subalkali basalt and basaltic andesite), as defined by their major element (e.g., SiO_2, Na_2O+K_2O) and normative mineral abundances (e.g., normative hypersthene >> diopside, quartz ≥ 0, and nepheline = 0). Hornblende is locally present and may indicate more silicic compositions (e.g., basaltic andesite to andesite). Columnar jointing and zones of open vesicles are common in outcrop. The vesicles (1 to 5 cm) range from open to calcite-filled. These lavas are probably correlative to the Middle to Late Miocene (16 to <10 Ma) Hickey Formation that is present across the central Arizona Basin and Range and Transition Zone. In the northern Basin and Range area, these rocks (16.2 to 13.4 Ma) cap many of the mesas (e.g., New River Mesa, Skull Mesa, Wild Burro Mesa) and tilt-blocks (e.g., Rifle Range, Deem Hills, Shaw Butte, etc.) and have also been referred to as the New River Mesa Basalt (Gomez, 1978; Jagiello, 1987). In the Biscuit Flat Quadrangle to the west, a mesa-capping flow north of the Ben Avery Shooting Range has been dated at 15.39 ±0.4 Ma (Scarborough and Wilt, 1979). Hickey Formation basaltic flows (16.2-Ma, Reynolds, unpublished data) also cap the mesas in the Black Mountain area on the southeastern side of Lake Pleasant. A sequence of 13.4-Ma basaltic lavas underlie "basin-fill" sediments (Tsy) at Lone Mountain in the Cave Creek Quadrangle to the east (Doorn and Péwé, 1991; Leighty et al., 1997).

Tb **Basaltic rocks, undivided (Early to Middle Miocene)** - Basaltic lavas correlative with either the Early to Middle Miocene Chalk Canyon formation or the Middle Miocene Hickey Formation (most exposures are probably equivalent to the former). These lavas are exposed above the highest tuff beds or as isolated bedrock remnants. The basaltic flows locally contain minor scoria and basalt-related breccia. This unit forms dark, resistant hills.

Ts **Conglomerate and sandstone (Late Early Miocene to Middle Miocene)** - Heterolithic conglomerate and sandstone interbedded with basaltic lavas (between Tb and Tbm) in the Gunsight area east of Apache Peak.

Tbl **Chalk Canyon formation basaltic rocks (Early Miocene)** - Basaltic rocks of the lower member (22 to ~17 Ma) of the Chalk Canyon formation. In the Apache Peak area, these basaltic lavas generally have porphyritic (3-15% phenocrysts) to vesicular (3-30% vesicles) overall textures, and a range of groundmass textures (e.g., microcrystalline, cryptocrystalline, trachytic, and intergranular). Phenocryst assemblages include olivine, olivine + clinopyroxene, olivine + clinopyroxene + plagioclase, and olivine + plagioclase. Euhedral to subhedral olivine microphenocrysts are typically partially to totally oxidized, whereas subhedral clinopyroxene microphenocrysts are unaltered. Groundmass phases are dominated by plagioclase, ranging from euhedral laths to cryptocrystalline microlites, with euhedral clinopyroxene, altered olivine, and opaque oxide grains being less abundant. No modal biotite was observed in these rocks, unlike many other basal Chalk Canyon formation lavas that contain variable amounts of modal biotite (Leighty, 1997). Fine-grained mono- and heterominerallic glomerocrysts are also common. In the North Union Hills, north of the Carefree Highway, these lavas are dark gray, porphyritic olivine basalts with dark reddish brown olivine phenocrysts (1-3 mm). The sequence of olivine-phyric basalt and interbedded tuff and tuffaceous sediment exposed in the Apache Peak and North Union Hills areas correlates with other sections exposed in nearby areas (e.g., Pyramid Peak, New River Mesa, Sugarloaf Mountain, etc.). At Pyramid Peak, just to the north of the quarangle, basaltic and andesitic rocks (17.72

±0.37 Ma, Scarborough and Wilt, 1979) are interbedded with several felsic tuffs, including a prominent vitrophyre. To the north in the New River Mesa Quadrangle, one of the lowest exposed alkaline basalt flows east of Sugarloaf Mountain (21.34 ±0.46 Ma, Scarborough and Wilt, 1979) overlies a lithic tuff containing an oreodont fossil, the oldest known mammal in Arizona (Lindsay and Lundin, 1972; Leighty, 1997).

Tt **Tuff (Early Miocene) -** Light gray to white, nonwelded pumice-rich, vitric, and lithic tuff. These tuffs are variably reworked and are locally interbedded with tuffaceous sediments. This unit typically crumbles easily and forms slopes, but is locally well-indurated. Between the Gunsight area and Apache Peak, this unit can be subdivided into upper (Tt_3), middle (Tt_2), and lower (Tt_1) members. The uppermost tuff member is pumice-rich, and a vitrophyric tuff (Ttv) is part of the middle tuff layer. The lower tuffs include both pumice- and lithic rich varieties. Pumice-rich tuffs contain creamy white, fine-grained, massive zones that are interbedded with more coarse-grained layers rich in subrounded to subangular pumice clasts (<2 cm). Lithic tuffs dominantly contain Proterozoic metamorphic clasts that are typically angular to subangular (<3 cm). Very little (if any) Tertiary basalt is represented in the clast compositions. The tuff beds are interbedded with olivine-phyric basaltic lavas and are likely correlative with rocks of the lower member of the Chalk Canyon formation. These tuffs correlate with the ones exposed at Pyramid Peak to the northwest, Elephant Mountain to the northeast, and New River Mesa to the north (Scarborough and Wilt, 1979; Jagiello, 1987; Leighty, 1997; Ferguson et al., 1998).

Ttv **Vitrophyric tuff (Early Miocene) -** A well-indurated, ledge-forming vitrophyric tuff in the upper part of the second major tuff layer (Tt_2) exposed between Apache Peak and the Gunsight area. This pinkish to reddish pink to black unit is fine-grained to glassy (30-40%), with pumice and crystals of sieved plagioclase, plagioclase, biotite, hematite, and hornblende. This tuff typically has hackly fracture. At Pyramid Peak, this vitrophyric tuff overlies a 17.72 ±0.37 Ma andesite (Scarborough and Wilt, 1979; Leighty, 1997).

Tts **Tuffaceous sandstone and conglomerate (Early Miocene) -** Poorly exposed white tuff, reworked tuff, and tuffaceous sediment exposed north of Rodger Creek.

Tsl **Conglomerate and sandstone (Late Oligocene to Early Miocene) -** A discontinuous bed of Middle Tertiary conglomerate and sandstone exposed beneath Early Miocene basaltic lavas (Tbl) in the North Union Hills.

Early to Middle Proterozoic plutonic rocks

YXg **Granite -** Coarse-grained, relatively unfoliated, variably porphyritic biotite granite. Includes light gray to light pink microcline (0.5-2 cm), light gray to white plagioclase (<5 mm), clear gray quartz (<5 mm), and subhedral black biotite (2-4 mm). Exposed in the North Union Hills (north of the Carefree Highway) and at the northwesternmost end of the Union Hills. This unit is likely correlative with granitic rocks exposed to the west in the Biscuit Flat and Hedgpeth Hills Quadrangles that have been informally referred to as the granite of Pyramid Peak. This granite is possibly correlative with the large granite Middle Proterozoic batholith exposed north of the McDowell Mountains to the east.

Early Proterozoic plutonic and metamorphic rocks

Xd **Diorite -** Intermediate plutonic rocks that include diorite, alkali-feldspar-rich diorite, and granodiorite, with numerous aplitic, leucocratic pods. These rocks are generally fine-grained (<1-2 mm), except for larger K-feldspar crystals. Plagioclase and pyroxene are abundant, but quartz is not. This unit is typically massive, with spaced foliation/jointing. These rocks weather pale reddish orange.

Xgd **Granodiorite -** Granodioritic rock containing plagioclase (<2 mm), quartz, and K-feldspar in a fine-grained, olive-green matrix. These rocks are massive, but generally poorly exposed with crudely-developed foliation and jointing. Exposed along the eastern edge of the quadrangle boundary just south of the Cave Creek Recreation Area boundary.

Xdm **Quartz monzodiorite** - Equigranular, medium-grained quartz monzodiorite with abundant plagioclase, biotite, and minor quartz. Exposed in the North Union Hills in the vicinity of the radio tower. These plutonic rocks intrude the Xsv unit, with possible recrystallization in proximity to the contact. However, it is not clear whether this unit is related to the adjacent felsic metavolcanic rocks (Xvf) or are a slightly later intrusive body.

Xfi **Felsic hypabyssal to plutonic rocks** - Fine-grained, leucocratic, hypabyssal to plutonic rock exposed east of Apache Wash. Pinkish red, equigranular, fine-grained, with white feldspar (1-2 mm) and quartz crystals and no mafic minerals. May be a leucocratic phase of an Early Proterozoic granitic pluton.

Xva **Andesitic to basaltic andesitic metavolcanic rocks** - Massive, fine- to medium-grained, greenschist facies meta-andesite and meta-basaltic-andesite lavas and related fragmental rocks. The andesitic rocks are typically dark greenish gray, aphyric to hiatal porphyritic (0 to ~15% phenocrysts), with euhedral to subhedral, white to glassy plagioclase phenocrysts (<1 cm) in a dark grayish-green to greenish-gray, very fine-grained, chloritic groundmass. Amphibole and pyroxene are typically altered to biotite. Thin (1 to 3 m) felsic and intermediate micaceous tuff beds are commonly interbedded with the andesite. Lenticular, dark gray chert and slaty to phyllitic beds are also present locally. This unit is commonly rich in epidote mineralization. This unit weathers an orange-brown color with brown to black desert varnish. In the southeastern North Union Hills, these lavas are typically greenish gray, fine-grained rocks that include minor amounts of quartz and K-feldspar. In the Rodger Creek area, the Xva unit likely includes basaltic andesite, andesite, and dacite. In the Union Hills Quadrangle, this unit locally has andesitic or basaltic pillows (30-60 cm in diameter), with vesicular rinds, discontinuous pillow-shaped masses, and hyaloclastic haloes.

Xad **Andesite-diorite complex** - Heterogeneous assemblage of hypabyssal and volcanic rocks of intermediate composition exposed in the North Union Hills and southwestern Apache Peak areas. Minor amounts of laminated to massive chert and thin felsic tuff beds are also present. In the North Union Hills, these greenschist facies rocks include fine-grained, seriate porphyritic to granular, plagioclase-phyric basaltic andesite to andesite that are gradational with fine- to medium-grained dioritic and granodioritic rocks. These hypabyssal rocks generally lack the equigranular textures of many of the more plutonic diorites. Some of these rocks include euhedral to subhedral plagioclase (<1 cm). In the southwestern Apache Peak area, the dioritic rocks are grayish green and coarse-grained, with 30-40% mafics, whitish plagioclase, and trace K-feldspar. These rocks weather pale reddish orange and are commonly rich in epidote. Repetition of plutonic, hypabyssal, and volcanic lithologies locally varies on the scale of a few meters. These rocks have gradational to sharp contacts with small amounts of granodiorite and more leucocratic, aplitic rocks. These rocks may represent a complicated intrusive-extrusive volcanic flow sequence or pile that contains aphyric to porphyritic flows having microdioritic cores, hypabyssal intrusive bodies with aphyric to porphyritic chill margins, or both.

Xvad **Andesitic to dacitic metavolcanic rocks** - Interbedded greenschist facies andesitic and dacitic lavas and tuffs. In the southern Daisy Mountain area, andesitic rocks are medium dark greenish gray, fine-grained to granular, with open vesicles. These rocks are variably porphyritic, with plagioclase phenocrysts (<2 mm) in a fine-grained matrix. The more dacitic compositions have similar textures as the andesitic rocks (i.e., fine-grained and granular), but are generally lighter in color than andesitic rocks, with more quartz and K-feldspar.

Xvd **Dacitic metavolcanic rocks** - Dacitic lavas and tuffs. Typically fine-grained to granular, lighter in color than andesitic rocks, with abundant quartz and k-feldspar. In the southeastern North Union Hills, these lavas are dark gray, with fine-grained feldspar phenocrysts and flattened, large, open vesicles. In other areas, these rocks have small, white plagioclase phenocrysts in a creamy grayish tan, fine-grained groundmass.

Xvdt **Dacitic meta-tuff** - Light gray to light bluish-gray, highly foliated, fine-grained dacitic(?) fragmental rocks interbedded with dacitic lavas (Xvd) in the southeastern North Union Hills. These quartz-rich, phyllitic schists weather into blocky plates.

Xv **Intermediate to felsic metavolcanic rocks, undivided** - Heterogeneous, complexly interbedded andesitic, dacitic, and rhyolitic flows and tuffs, with minor pelitic metasedimentary rocks. Andesitic rocks are commonly green, brown, reddish brown, or olive drab and are usually fine- to medium-grained. Interbedded rhyolite tuffs are typically fine-grained to aplitic, with small phenocrysts of quartz and/or sanidine. Thin, fine-grained, tan to reddish layers may represent felsic tuff or sedimentary beds. Bluish-gray phyllite is also present locally. Jasperoid rock is also commonly associated with these rocks.Good exposures are found in the Cave Creek Recreation Area along the Overton Trail.

Xvf **Felsic metavolcanic rocks** - Massive to highly foliated and jointed, fine-grained to granular, pinkish gray felsic metavolcanic rocks that include rhyolite, rhyodacite, and dacite lava, and tuff. These units typically contain variable amounts of granular quartz and K-feldspar microphenocrysts, and minor biotite. These rocks are locally altered (ferruginous staining) and commonly display compositional streaking. Weathers tan to light bluish-gray. Commonly are more fragmental near the base. A basal conglomerate is locally exposed with rounded, light-colored rhyolitic clasts in a pale purplish-gray groundmass. Quartz veining and chrysocholla mineralization is common. The resistant, ridge-forming Xvf flow in the Cave Creek Recreation Area continues to the northeast into the Cave Creek and New River Mesa Quadrangles.

Xvft **Felsic fragmental metavolcanic rocks** - In the Cave Creek Recreation Area, this unit is a foliated, medium bluish-gray rhyolitic tuff locally stained (yellow to dull red) from alteration.

Xf **Felsic metavolcanic and hypabyssal rocks, undivided** - Medium- to fine-grained, aplitic leucocratic rocks exposed in the North Union Hills and in the Rodger Creek area. Along the Carefree Highway, this unit is a brick-red, very fine-grained felsic metavolcanic rock that is probably hydrothermally altered.

Xvs **Metavolcanic and metasedimentary rocks** - Schists, phyllitic schists, and phyllites of metavolcanic, metavolcaniclastic, or metasedimentary origin. This unit is similar to the Xsv unit, except that the intermediate to felsic metavolcanic rocks are probably more abundant than the metasedimentary rocks.

Xvts **Tuffaceous metavolcanic and metasedimentary rocks** - Bluish-gray, light gray, and olive drab intermediate to felsic tuffs and tuffaceous metavolcaniclastic and metasedimentary rocks. This unit is commonly altered (e.g., red, pink, green) and has limonitic discolorations. These rocks are also locally rich in hematite. Chert lenses are common. These rocks are exposed in the low ridges in the southwestern part of the Cave Creek Recreation Area.

Xsv **Metasedimentary and metavolcanic rocks** - Schists, phyllitic schists, and phyllites of metavolcanic, metavolcaniclastic, or metasedimentary origin. This unit is similar to the Xvs unit, except that the metasedimentary and metavolcaniclastic rocks are probably more abundant than the intermediate to felsic metavolcanic rocks. In the southeastern North Union Hills, this unit includes fine-grained to granular, schistose, leucocratic rocks that may represent reworked felsic metavolcanic lithologies. Color varies from greenish to olive drab to light tan to very pale orange-tan. Locally contains medium to dark gray, fine-grained, laminated pelitic rock (metasiltstone or argillite) with parting and hackly fracture. This pelitic rock weathers to a light yellowish tan rubble. Felsic tuff beds, jasperoid lenses (oxide-facies iron formation), and short, anastomosing quartz veins are also common. This unit includes blocky, greenish, seriate porphyritic to subporphyritic andesite/dacite with plagioclase (<2 mm) and pyroxene/hornblende phenocrysts. The andesite typically weathers reddish orange. Near the contact with the quartz monzodiorite (Xdm), this unit is a dark greenish gray schist, with fine-grained biotite and plagioclase and slight compositional layering.

Xs **Pelitic to psammitic metasedimentary rocks** - Weakly to moderately foliated, dark gray, pelitic to psammitic rocks exposed at the southern edge of the quadrangle in the northern Union Hills. Dominantly consists of poorly sorted angular to subangular quartz and feldspar grains (>60%) in a compact, chloritic matrix. Overall texture is granular with bands of more coarse (1-4 mm), angular grains. Outcrops weather white-tan, whereas fresh surfaces are dark gray. Contact with meta-andesitic rocks (Xva) is sharp and undulatory, but also occurs as thin (5-20 cm) lenses within the meta-andesitic rocks.

d **Disturbed area** - Areas of significant recent surficial disruption due to various human activities. Includes large sand and gravel operations (e.g., along Cave Creek), large cattle tanks (e.g., Burro Tank), etc.