Geologic Map and Geologic Hazards of the Three Points Quadrangle, Pima County, Arizona

by

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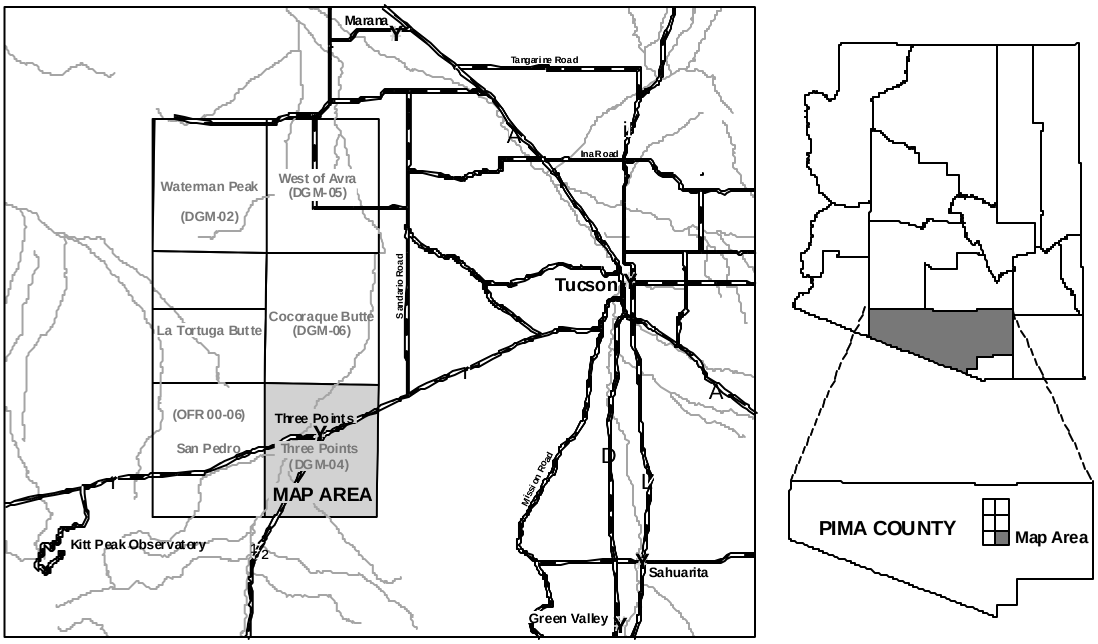
Introduction

This report and maps describe the geology, geomorphology, and geologic hazards in the Three Points quadrangle, on the southwestern fringe of the Tucson metropolitan area in unincorporated Pima County (Figure 1). The map area is located in the transition between the upland, moderately dissected Altar Valley to the south and the broad, undissected basin called Avra Valley to the north. The community of Three Points (also called Robles Junction) lies on the approximate boundary between these two geographic areas. The map includes a nine-mile-long reach of Brawley Wash, which cuts through the map area from southwest to northeast. Brawley Wash heads just south of the U.S. – Mexico border and drains all of Altar and Avra valleys before joining the Santa Cruz River northwest of Tucson. About 60 percent of the Three Points quadrangle consists of the northwestern piedmont of the Sierrita Mountains. The quadrangle also includes a small part of the northwestern piedmont of the Coyote Mountains and the southern fringe of the Roskruge Mountains. The quadrangle is generally undeveloped, and is currently used primarily for grazing. Some low-density suburban development has occurred around the community of Three Points and on the Sierrita and piedmont to the south. Much of the floodplain and terraces of Brawley Wash has been developed for agriculture. The Three Points quadrangle will likely experience much more urban/suburban development in the next few decades. This map and report may be of use in avoiding or mitigating geologic hazards in this area.

This geologic mapping in the southwestern portion of the Tucson area is part of continuing efforts by the AZGS to map the geology of the Phoenix – Tucson urban corridor. This map builds on and complements previous surficial geologic mapping efforts in the Tucson area (McKittrick, 1988; Jackson, 1989; Demsey and others, 1993; Field and Pearthree, 1993; Klawon and others, 1999; Pearthree and Biggs, 1999). The current mapping effort was conducted in conjunction with geologic mapping in the adjacent San Pedro quadrangle to the west (Ferguson and others, 2000) and the Corcoraque Butte (Skotnicki and Pearthree, 2000) and West of Avra (Pearthree and others, 2000) quadrangles to the north. This report is organized into a brief introduction and explanation of mapping methods, unit descriptions, a summary of the geologic and geomorphic framework of the area, and a discussion of geologic hazards. Ray Harris digitized the map information and provided quality control for the map compilation, and Tim Orr generated the final linework and map layout. Ray Harris contributed to the section on land subsidence and earth fissures. Mapping was conducted as part of the STATEMAP Program of the U.S. Geological Survey, contract #99HQAG0171.

Climate. Several weather stations close to the Three Points area, including a number in nearby Tucson, Arizona, have operated during intervals over the past century. The station at the University of Arizona in the central Tucson basin has records from 1894 to the present, whereas stations to the northwest of the quadrangle at Silver Bell (1906-1974) and Red Rock (1893-1973) provide data for the northern Avra Valley area. Using the records of seven stations in the greater Tucson metropolitan area, the average recorded daily maximum temperature was 83.9$^{?}$ F, and the average daily minimum was 54.0? F (Western Regional Climate Center, 1999). Average annual precipitation for the



INDEX MAP OF THE ROSKRUGE MOUNTAINS AND WESTERN AVRA VALLEY AREA
Showing the location of the map area in relation to Pima County, Arizona and the greater Tucson region

Figure 1. Location of the Three Points quadrangle in Pima County, southwest of Tucson.

area is about 10 to 12 inches (250 to 300 mm), with slightly more than 50% falling during the July through September monsoon thunderstorm season and about 35% occurring as winter precipitation. Early morning freezing temperatures are common during most winters, but snow is uncommon and not persistent. Late summer rainfall occurs as heavy thunderstorms when moist air sweeps northwards from the Gulf of California and the Gulf of Mexico. Occasional intense late summer to early fall precipitation occurs in this region as a result of incursions of moist air derived from dissipating tropical storms in the Pacific Ocean. A dissipating tropical storm generated the largest historical flood that has occurred on Brawley Wash in September, 1962 (Lewis, 1963; 1968). In that storm, up to 7 inches (180 mm) of rain fell in less than 48 hours on the Roskruge Mountains and Avra Valley (Lewis, 1968). Winter precipitation generally is caused by cyclonic storms originating in the Pacific. It is usually less intense and may be more prolonged, and therefore infiltrates into the soil more deeply than summer rainfall (summarized from Sellers and Hill, 1974).

Methodology

The surficial geology of the project area was mapped using black-and-white aerial photographs taken in 1974, with field checking of unit boundaries, and field observations of soils and stratigraphy. The physical characteristics of Quaternary alluvial surfaces (channels, alluvial fans, floodplains, stream terraces) evident on aerial photographs and in the field were used to differentiate their associated deposits by age. Surficial deposits of this quadrangle were then correlated with similar deposits in this region in order to roughly estimate their ages. Original mapping was done over aerial photos and compiled on the 7 ½' quadrangle map. The map compilation was then digitized and the final map was generated from the digital data.

Alluvial surfaces of similar age have a distinctive appearance on aerial photos and on the ground because they have undergone similar post-depositional modification. This allows for the mapping, correlation, and rough age estimation of Quaternary deposits and alluvial surfaces in this region. Surfaces of a similar age have different physical characteristics than both younger and older surfaces. Terraces and alluvial fans that are less than a few thousand years old, for example, still retain clear evidence of the original depositional topography, such as of bars of coarse deposits, swales (troughlike depressions) where low flows passed between bars, and distributary channel networks, which are characteristic of active alluvial fans. Young alluvial surfaces have little rock varnish on surface clasts and have little soil development, and they are minimally dissected. Old fan surfaces, in contrast, have been isolated from substantial fluvial deposition or reworking for hundreds of thousands of years. These surfaces are characterized by strongly developed soils with clay-rich argillic horizons or cemented calcium-carbonate horizons or both. They have well-developed tributary stream networks that are entrenched 1 to 10 m below the fan surface, and typically have strongly developed varnish on surface rocks. The ages of alluvial surfaces in the southwestern United States may be roughly estimated based on these surface characteristics, especially soil development (Gile and others, 1981; Bull, 1991).

In this map, late Cenozoic surficial deposits are subdivided based on their source (axial valley stream and smaller tributary washes on piedmonts) and estimated age of deposits. Surface and soil characteristics were used to correlate alluvial deposits and to estimate their ages. Surface pits and exposures along cut banks were used to assess soil characteristics associated with deposits of different ages and from different sources. Soils and surfaces documented in the map area were generally correlated with soils and surfaces described in Quaternary mapping studies of adjacent areas conducted by Katzer and Schuster (1984), Jackson (1989), Demsey and others (1993), Klawon and others (1999), Pearthree and Biggs (1999), Skotnicki and Pearthree (2000), and Ferguson and others (2000). These correlations were also used to estimate the ages of surficial deposits in the map area. The surficial geology of most of the quadrangle was mapped by P. Pearthree; the piedmont of the Roskruge Mountains in the northwestern part of the quadrangle was mapped by Steve Skotnicki.

Limited bedrock exposures in the northwestern part of the Three Points quadrangle were mapped by Wyatt Gilbert and Charles Ferguson. They identified rock types and collected rock samples from selected outcrops. The bedrock exposed in this quadrangle is relatively simple, consisting of middle Tertiary trachyandesite and late Tertiary basalt. Samples of each of these bedrock units were sampled and dated by the K/Ar method in the 1960's (Bikerman, 1967; 1968).

Map Unit Descriptions

Axial Stream Deposits

Holocene and late Pleistocene sediment deposited by Brawley Wash covers a southwest-northeast-trending strip through the quadrangle. Alluvial surfaces consist of channels, young stream terraces that compose the geologic floodplain, and older relict terraces that date to the Pleistocene. Deposits are a mix of gravel and sand and finer material; they exhibit mixed lithologies reflecting the moderately large and diverse drainage area of Brawley Wash. Most of the area covered by river deposits in this quadrangle has been altered by intense agricultural development, so there is greater uncertainty regarding the locations of unit contacts than in piedmont areas.

Qycr - Modern river channel deposits (< 100 years). River channel deposits of Brawley Wash. Deposits are composed primarily of sand and gravel. In most of the quadrangle, the modern channel is entrenched several meters below adjacent young terraces; entrenchment gradually decreases downstream. The current entrenched channel configuration likely began to evolve with the development of arroyos in this region in the late 1800's (Cooke and Reeves, 1976), and continued to evolve through this century. Channels have variable widths and are locally braided with multiple channels. Channels are extremely flood prone and are subject to deep, high velocity flow in moderate to large flood events. Channel banks are formed in weakly consolidated Holocene deposits and the banks are generally not protected by engineering structures. They may be subject to severe lateral erosion during floods.

Qy2r – Late Holocene proximal floodplain (<~2 ka). Deposits in small stream channels and on primary floodplains of Brawley Wash. Deposits generally consist of sand, silt, and clay, with local gravel concentrations. Shallow, small, discontinuous channels are common; many of them are linear, suggesting that channels developed along roads or wagon tracks. Vegetation typically is large creosote and low grass and shrubs, with local concentrations of mesquite, acacia, and palo verde trees. Variegated surface color depends mainly on vegetation density, dark brown color along channels and where vegetated, brown where more sparsely vegetated. Eolian features around bushes commonly have been streamlined by flow. Unprotected channel banks formed in Qy2r deposits are very susceptible to lateral erosion.

Qy1r – Holocene distal floodplain and terrace deposits (0 to ~10 ka). Deposits associated with upper or secondary floodplains of Brawley Wash. Typically, they are flat surfaces that are on the fringes of and less than 1 m above the primary floodplain. Small, weakly defined channels exist in some places within this unit. Deposits are generally fine-grained, but surfaces have weak, discontinuous gravel lags composed of mixed lithologies. Surface color typically is light brown, and surface clasts have no varnish. Very limited low (0.5 m high) coppice dunes associated with creosote bushes and bioturbated sand and finer sediment. Portions of these surfaces may be inundated in the largest floods. They gradually merge upslope into young lowermost piedmont deposits (units Qy2 and Qy1). Unprotected channel banks formed in Qy1r deposits are susceptible to lateral erosion.

Qyre - Holocene stream terrace deposits and eolian deposits (< ~10 ka). Mixed young river terrace deposits and eolian deposits. Landforms consist of low coppice dunes and intervening flat surfaces with minimal gravel lags and no pavement development, less than 1 m above adjacent floodplains. Drainage networks typically are discontinuous and channels are very small. Low coppice dunes are abundant. Soil development is weak, with cambic horizons and carbonate filaments (stage I calcic horizons). Surface color typically is light brown. Vegetation is sparse, desert shrubs are relatively concentrated in dunes and along small channels. The preservation of eolian deposits indicates that these areas have not been subject to substantial flooding recently.

Qyr - Holocene floodplain and terrace deposits in agricultural areas (0 to ~10 ka). The Qyr unit consists of floodplains and low terraces flanking the main channel system along Brawley Wash floodplain where natural surfaces have been obscured by agricultural activity. Most Qyr areas likely were part of the active floodplain prior to arroyo development in the past century or so. Terrace surfaces are flat and uneroded, except immediately adjacent to channels. Qyr deposits consist of weakly to unconsolidated sand, silt, and clay. Soils are weakly developed, with some carbonate filaments and fine masses and weak soil structure in near surface horizons. Locally, Qyr surfaces may experience sheetflooding during large floods in areas where the main channel is not deeply entrenched, and as a result of flooding on local tributaries that debouch onto Qyr surfaces. Unprotected channel banks formed in Qyr deposits are very susceptible to lateral erosion.

Qlr - Late Pleistocene river terrace deposits (~10 to 130 ka). Unit Qlr consists of late Pleistocene river terraces along Brawley Wash that are about 3 m higher than the historical floodplain (Qyr). Deposits consist of gravel, sand, and clay. Soils are somewhat reddened, have weak argillic horizons, and have moderate calcic horizon development. These terraces are generally narrow and have fairly irregular surfaces, implying that they have undergone substantial erosional modification.

Qmlr - Middle to late Pleistocene river deposits (~10 to 500 ka). Late or middle Pleistocene remnant river deposits on the basin floor. These Pleistocene surfaces are slightly higher than surrounding younger surfaces. In addition to topographic relief, Qmlr soils are substantially more developed than younger soils. Qmlr soils are classified as Calciorthids, Haplargids and Natrargids ; they are fine-grained, and generally have well developed structure and reddened argillic horizons and common soft carbonate nodules at a starting depth of 33 to 66 cm (Gelderman, 1972).

Piedmont Alluvium

Quaternary and late Tertiary deposits cover the piedmont areas southeast and northwest of Brawley Wash. This sediment was deposited primarily by streams that head in the mountains. Smaller streams that head on the piedmont have eroded and reworked some of these deposits. Deposits range in age from modern to Pliocene or late Miocene. Deposits derived from the Sierrita and Coyote mountains typically are finer-grained, primarily sand and pebbles with some cobbles. Alluvial fan deposits derived from the fine-grained volcanic rocks of the Roskruge Mountains typically contain more cobbles and boulders. The lower margin of the piedmonts are defined by their intersection with stream terraces and the basin-floor deposits of Brawley Wash. Approximate age estimates for the various units are given in parentheses after the unit name. Abbreviations are ka, thousands of years before present, and Ma, millions of years before present.

Qy2 - Late Holocene alluvium (<~2 ka). Unit Qy2 consists of channels, low terraces, and small alluvial fans composed of sand, cobbles, silt, and boulders that have been recently deposited by modern drainages. In areas proximal to the Roskruge Mountains, channel sediment is generally sand, pebbles and cobbles, with some boulders; terraces typically are mantled with sand and finer sediment. On lower piedmont areas, young deposits consist predominantly of sand and silt, and some cobbles in channels. Channels generally are incised less than 1 m below adjacent terraces and fans, but locally incision may be as much as 2 m. Channel morphologies generally consist of a single-thread channel or multi-threaded channels with gravel bars adjacent to low flow channels. Downstream-branching distributary channel patterns are common on the Sierrita piedmont. In these areas, channels typically are discontinuous, with small, well-defined channels alternating with broad expansion reach where channels are very small and poorly defined. Local relief varies from fairly smooth channel bottoms to the undulating bar-and-swale topography that is characteristic of coarser deposits. Terrace surfaces typically have planar surfaces, but small channels are also common on terraces. Soil development associated with Qy2 deposits is minimal. Terrace and fan surfaces are brown, and on aerial photos they generally appear darker than surrounding areas, whereas sandy to gravelly channels appear light-colored on aerial photos. Vegetation density is variable. Channels typically have sparse, small vegetation. The densest vegetation in the map area is found along channel margins and on Qy2 terraces along channels. Along the larger washes, tree species include mesquite, palo verde, and acacia; smaller bushes and grass may also be quite dense. Smaller washes typically have palo verde, mesquite, large creosote and other bushes along them.

Qy1 - Holocene alluvium (0 to ~10 ka). Unit Qy1 consists of low terraces and broad, minimally dissected alluvial fans. Qy1 surfaces are slightly higher and/or farther from active channels, and thus are less subject to inundation than Qy2 surfaces. Qy1surfaces are generally planar; local relief may be up to 1 m where gravel bars are present, but typically is much less. Qy1 surfaces are less than 2 m above adjacent active channels. Surfaces typically are sandy but locally have fine, unvarnished open gravel lags. Qy1 surfaces generally appear fairly dark on aerial photos, but where a gravel lag is present, surfaces are light colored. Channel patterns on alluvial fans are weakly integrated distributary (branching downstream) systems. Qy1 terrace surfaces support mesquite and palo verde trees, and smaller bushes may be quite dense. Qy1 fans support scattered trees along channels, but creosote and other small bushes are dominant. Qy1 soils typically are weakly developed, with some soil structure but little clay and stage I to II calcium carbonate accumulation (see Machette, 1985, for description of stages of calcium carbonate accumulation in soils).

Ql - Late Pleistocene alluvium (~10 to 130 ka). Unit Ql consists of moderately dissected relict alluvial fans and terraces found on the upper, middle and lower piedmont. Well-developed, moderately incised tributary drainage networks are typical on Ql surfaces. Active channels are incised up to about 2 m below Ql surfaces, with incision typically increasing toward the mountain front. Ql fans and terraces are commonly lower in elevation than adjacent Qm and older surfaces, but the lower margins of Ql deposits lap out onto more dissected Qm surfaces in some places. Ql deposits consist of pebbles, cobbles, and finer-grained sediment. Ql surfaces commonly have loose, open lags of pebbles and cobbles; surface clasts exhibit weak rock varnish. Ql surfaces appear light orange on aerial photos, reflecting slight reddening of surface clasts and the surface soil horizon. Ql soils are moderately developed, with orange to reddish brown clay loam argillic horizons and stage II calcium carbonate accumulation. Dominant forms of vegetation include creosote, bursage, and ocotillo.

Qm - Middle Pleistocene alluvium (~130 to 500 ka). Unit Qm consists of moderately to highly dissected relict alluvial fans and terraces with moderate to strong soil development. Qm surfaces are drained by well-developed, moderately incised tributary channel networks. On the low-relief Sierrita piedmont, Qm areas they are traversed by larger distributary channels that are typically one to several meters below adjacent Qm ridges. Well-preserved, planar Qm surfaces on the Roskruge piedmont are smooth with pebble and cobble lags; rock varnish on surface clasts is typically orange or dark brown. More eroded, rounded Qm surfaces typical of the Sierrita piedmont are characterized by loose cobble lags with moderate to strong varnish, broad ridge-like topography and carbonate litter on the surface. Well-preserved Qm surfaces have a distinctive dark color on aerial photos, reflecting reddening of the surface soil and surface clasts. More dissected Qm surfaces show up as complex, light-colored ridges. Soils typically contain reddened, clay argillic horizons, with obvious clay skins and subangular blocky structure. Soil carbonate development is typically stage III to IV, but indurated petrocalcic are uncommon. Qm surfaces generally support bursage, ocotillo, creosote, cholla, and saguaro.

Qmo - Middle to early Pleistocene alluvium (~500 ka to 1 Ma). Unit Qmo consists of moderately to deeply dissected relict alluvial fans with strong soil development. Qmo surfaces on the south flank of the Roskruge Mountains are typically 5 to 10 meters above adjacent active channels. Qmo surfaces are drained by well-developed, deeply incised tributary channel networks. Well-preserved planar Qmo surfaces are not common. Where they exist, they are smooth with pebble and cobble lags; rock varnish on surface clasts is typically orange to red or black. Well-preserved soils typically contain reddened, clay argillic horizons, with obvious clay skins and subangular blocky structure. Soil carbonate development is typically stage IV (cemented petrocalcic horizons, little or no laminar cap). More eroded Qmo surfaces are characterized by loose cobble lags with moderate to strong varnish, ridge-like topography and carbonate litter on the surface. On aerial photos, ridge crests on Qmo surfaces are dark, reflecting reddening of the surface soil and surface clasts, and eroded slopes are gray to white. Qmo surfaces generally support bursage, ocotillo, creosote, cholla, and saguaro.

Qo – Early Pleistocene alluvium (~1 to 2 Ma). Unit Qo consists of very old, high, dissected alluvial fan remnants with moderately well preserved fan surfaces and strong soil development. Qo deposits and fan surfaces are found in a few locations near the Roskruge mountain front. Qo surfaces typically are fairly smooth to broadly rounded and light-colored as a result of abundant litter from underlying petrocalcic horizons. Qo deposits consist of cobbles, boulders, and sand and finer clasts. Stage V petrocalcic horizons are typical, but clay-rich argillic horizons are poorly preserved or have been completely stripped away by erosion. Qo surfaces are dominated by creosote. Qo surfaces record the highest levels of aggradation in Avra - Altar Valley, and may be correlative with other high, remnant surfaces found at various locations throughout southern Arizona (Menges and McFadden, 1981).

Tc - Pliocene to late Miocene alluvial fan deposits (~2 to 10 Ma). Unit Tc consists of very old, deeply dissected and highly eroded alluvial fan conglomerate found in the Roskruge Mountain piedmont. Surfaces associated with this unit are alternating eroded ridges and deep valleys, with ridgecrests typically 30 to 50 ft (10 to 15 m) above adjacent active channels. The total thickness of Tc deposits is not known, but they are at least 50 ft thick based on available exposures. Tc landforms are drained by deeply incised tributary channel networks. Although remnant Tc deposits are roughly fan-shaped, the highest surfaces atop Tc ridges are broadly rounded and original highest capping fan surfaces are not preserved. Tc deposits are dominated by gravel ranging from boulders to pebbles. Deposits are moderately indurated quite resistant to erosion because of the large clast size and carbonate cementation. Soils typically are dominated by carbonate accumulation, which is may be as strong as stage V (cemented petrocalcic horizons with laminar cap) on ridgecrests. Carbonate litter is common on ridgecrests and hillslopes. On aerial photos, Tc surfaces are dark gray. They generally support creosote, with lesser amounts of mesquite, palo verde, ocotillo, cholla, and saguaro.

Hillslope Deposits

Qc – Quaternary hillslope colluvium. Unit Qc consists of very poorly sorted, angular deposits mantling bedrock on hillslopes. This unit is generally very thin, probably less than a few meters in all cases.

Bedrock

Tb – basalt of Brawley Wash (~10 Ma). Xenolith- and xenocryst-rich basalt lava is exposed along Brawley Wash north of Three Points and in one low hill west of the wash. A sample from the outcrop in the wash was dated at 10.99±1.30 Ma (K/Ar whole rock; Reynolds and others, 1986; recalculated from Bikerman, 1967). A series of dikes in the Corcoraque Butte quadrangle to the north are likely correlative with this basalt. One of them was dated at 9.86±1.70 Ma (K/Ar whole rock; Reynolds and others, 1986; recalculated from Bikerman, 1967). Thin section and geochemical analyses for this basalt (sample FO-1033) are reported in Ferguson and others (2000).

Tm – trachyandesite lava (~24 Ma). Multiple flow units of crystal-poor to moderately crystal rich trachyandesite lava, containing phenocrysts of orthopyroxene and clinopyroxene. The lavas are dark in color and display flow textures typical of mafic lava. The lava occurs in flow units ranging from 15 to 160 ft (5 to 50 m) thick that are generally amalgamated with rare instances of interbedded pyroclastic or sedimentary rocks. Bikerman (1967) reported whole rock K/Ar dates of 24.08±1.40 Ma and 14.74±2.41 Ma from a small hill at the northern edge of the quadrangle; the younger date is from a highly altered zone. In the San Pedro quadrangle to the west, Bikerman (1967) reported a whole rock K/Ar date of 23.91±0.70 Ma for a correlative unit. Rock samples FO-778, -1030, -1031, 1032; 00-WG-98, -99, -100, -101, -102.

Geologic/Geomorphic Framework

The Tucson metropolitan area is located along the eastern edge of the Sonoran Desert subprovince of the Basin and Range physiographic province. The Basin and Range province in Arizona is characterized by alluvial basins and intervening mountain ranges that formed as a result of normal faulting related to extension of the crust between about 30 and 6 Ma (Shafiqullah and others, 1980; Menges and Pearthree, 1989). The landscape of the Tucson area consists of alluvial basins between large, high mountain ranges to the east and small, low-lying mountain ranges to the west. The western part of the metropolitan area (Avra Valley and the west side of the Tucson Mountains) is typical of the broad, generally undissected basins that are common throughout the Sonoran Desert subprovince. Mountain ranges are low and mountain fronts are deeply embayed, with few outlying bedrock knobs (inselbergs) that rise above the broad plains surrounding the mountain ranges. The axial portions of valleys are typically occupied by unentrenched drainages with very broad floodplains. In stark contrast, the eastern and northern parts of the Tucson area have large, high mountain ranges and piedmont areas have been deeply dissected by erosion. In these areas, erosion has dominated landscape evolution at least through the Quaternary, but intervals of aggradation have punctuated the long-term trend toward downcutting along the major streams and their tributaries.

Bedrock Geology. There is very little exposed bedrock in the Three Points quadrangle. Bedrock units consist of early Miocene trachyandesite lava flows and late Miocene basalt. The trachyandesite lava flows are part of a moderately large volcanic field that was studied and mapped in more detail in the San Pedro quadrangle (immediately west of the Three Points quadrangle), where the sequence is at 500 ft (150 m) thick (Ferguson and others, 2000). The late Miocene basalt consists of dikes and flows, and is the youngest bedrock in the Roskruge Mountains (Ferguson and other, 2000; Skotnicki and Pearthree, 2000).

Subsurface Geology. Avra Valley and Altar Valley are underlain by thousands of feet of middle and late Cenozoic sediment filling a relatively deep structural trough. A major buried normal fault zone has been inferred on the eastern side of Avra Valley (Anderson, 1989), but other normal faults with lesser displacement likely exist along both sides of the valley in the Three Points area. The deepest part of the trough is about 5 miles (8 km) north of the Three Points quadrangle, where the total thickness of Tertiary deposits may be 11,000 ft (3400 m; Oppenheimer and Sumner, 1980). The basin is much shallower in the Three Points area, but is still at least 1000 ft (300 m) deep (Anderson, 1989). The trough then deepens again to about 5000 ft (1500 m) to the south in Altar Valley (Oppenheimer and Sumner, 1980). The uppermost 100 to 200 ft (30 to 60 m) of the basin is the Fort Lowell Formation, which is permeable sand and gravel that has been interpreted to be of Quaternary age (Anderson, 1989). Beneath the Fort Lowell Formation is several hundred to more than a thousand feet of deposits of the upper and lower Tinaja Formation, which is the major aquifer in Avra Valley. Water-bearing alluvial deposits in Avra Valley are evidently hydraulically interconnected to a depth of a least 700 ft, but water below 1000 ft or may locally be confined beneath fine-grained layers (Anderson, 1989).

Geomorphology. Broad bedrock pediments that surround all of the mountain ranges fringing Avra Valley indicate that millions of years have passed since there has been significant displacement on the normal faults that formed the basin. The highest levels of Plio-Quaternary deposits (units Qo and Tc) in the Roskruge Mountains overlying bedrock pediment represent the highest levels of basin-fill deposits in Avra Valley. They are approximately correlative with Qo and QT deposits mapped around the Tucson Mountains (Pearthree and Biggs, 1999) and in the Catalina foothills on the north side of the Tucson basin (Klawon and others, 1999). It is likely that in the late Pliocene to early Quaternary, the surfaces on the flanks of the mountains in this region were fairly planar, undissected piedmonts that graded downslope to the floodplains of the through-flowing ancestral Brawley Wash.

The geomorphology and surficial geology in Avra Valley is quite different from that of the Tucson basin to the east. The streams that drain this area are linked to Brawley Wash, which is a major tributary of the Santa Cruz River. Brawley Wash, like many streams in southwestern and south-central Arizona, flows through a broad, undissected floodplain in the middle of the valley. The floodplain is primarily covered by fine-grained Holocene deposits, although exposures of Pleistocene deposits on the valley floor are fairly common. Evidently, Brawley Wash has generally been aggrading through the Quaternary, so there has been slow base-level rise over that period. Because of this factor, dissection on the piedmonts of Avra Valley is far less than along the east side of the Tucson Mountains in the Tucson basin. The topographic front of the mountain range is deeply eroded and embayed, and small to medium bedrock hills extend far out onto the piedmont. A shallow bedrock pediment underlies all of the upper piedmont and much of the middle piedmont as well. Some older alluvial fan deposits near the western mountain front have been entrenched quite deeply, but the entrenchment on the middle and lower piedmont slopes is minimal and young alluvial fans cover much of this area.

Broad piedmont alluvial fans and terraces are evidence for periods of substantial aggradation (net sediment accumulation). We are not certain what caused these aggradation events, but changes in climate that increased the amount of sediment supplied to streams are likely culprits. The global climate has changed between glacial and interglacial conditions many times during the past two million years. Glaciers did not directly affect the Tucson area, but the glacial climate here was wetter and cooler than present, the vegetation was different, and there was more water in streams. Streams transported more and larger bed material than modern streams. The most recent change from glacial to interglacial climate, which occurred about 8,000 to 15,000 years ago, may be an example of many such changes that occurred in the past 2 million years or so. Decreases in vegetation on hillslopes due to increased aridity, coupled with an increase in intense thunderstorms associated with our hot summer monsoon season, resulted in removal of much sediment from hillslopes. This increase in erosion in turn triggered widespread stream aggradation during this time in southern and western Arizona (Bull, 1991).

Geologic Hazards

This section summarizes the character and distribution of the principal geologic hazards that exist in the Three Points quadrangle. This information is fairly general in nature. Detailed site-specific geologic, engineering, hydrologic, or soils investigations may be required to thoroughly assess potential hazards at particular locations. More specific information on soil properties may be obtained from the USDA Natural Resources Conservation Service, and information on mapped floodplain and flood-prone areas may be obtained from the Pima County Flood Control District (unincorporated areas).

Flood hazards. Hazards related to flooding in the Three Points area may be subdivided into three categories. Along the upper portion of Brawley Wash, where the channel is entrenched and well-defined, flood hazards consist mainly of lateral erosion of unprotected channel banks. Farther downstream along Brawley Wash, channel capacity diminishes and inundation during large floods may be very widespread (Lewis, 1963; Roeske, 1978). The most widespread flood hazards in the quadrangle are those associated with numerous smaller tributary drainages, where the extent of flood-prone area varies with the size of the stream and local topographic confinement of floodwater.

Brawley Wash is a regional drainage with a broad, intermittently entrenched floodplain. It experienced its largest historical flood in September, 1962, when much of the axial part of Avra Valley downstream of the Three Points quadrangle was inundated as a result of precipitation derived from dissipating tropical storm Claudia. Near Three Points, the estimated peak discharge on Brawley Wash was 13,000 cubic feet per second (cfs). Farther downstream in central Avra Valley, the peak discharge estimated for this flood was 38,800 cfs (Lewis, 1963; 1968). This is about twice as large as any other flood recorded since 1940 (Pope and others, 1998), and was probably the largest flood that has occurred on Brawley Wash since at least 1885 (Roeske and others, 1989). Brawley Wash also experienced large floods in 1970, 1983, and 1993, each of which occurred in the late summer or early autumn. There have been substantial alterations of channel patterns for agricultural purposes in the Brawley Wash floodplain. Nonetheless, all of the areas mapped as Qycr or Qy2r are probably flood prone, and areas mapped as Qy1r or Qyr may be inundated in extreme floods (see Roeske, 1978). Bank erosion during large flows is a major potential hazard. Nearly all of the channel banks along Brawley Wash are formed in weakly consolidated Holocene sediment, which are not resistant to lateral erosion and undercutting. Although development in the floodplain of Brawley Wash is now discouraged or prohibited, some homes are located in flood-prone areas.

Smaller tributaries that drain the mountain ranges, the piedmonts, and the basin floor are subject to flash floods. Floods on these drainages result from intense, localized thunderstorms that usually occur during the summer or early autumn, and stream stages typically rise and fall rapidly during floods. Flood hazards are relatively easy to manage where topographic relief contains floodwater to channels and adjacent low terraces. In these situations, the area that may be impacted by flooding is restricted and should be easy to avoid. It is much more difficult to assess and manage flood hazards associated with alluvial fan flooding. This type of flooding occurs where topographic relief is minimal and floodwater can spread widely. In these areas, channels may or may not be well defined, and their positions may shift during floods, and inundation is likely to be widespread during floods.

Surficial geologic mapping provides important information about the extent of flood-prone areas on the piedmonts, and it is the best way to delineate areas that may be prone to alluvial fan flooding. Floods leave behind physical evidence of their occurrence in the form of deposits. Therefore, the extent of young deposits on piedmonts is a good 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 the piedmont varies with the extent of young deposits (units Qy2 and Qy1). Active alluvial fans may exist in areas with both distributary (downstream-branching) channel networks and laterally extensive young deposits between channels (see Pearthree and others, 1992).

Most of the modern drainages on the Sierrita Mountains piedmont are complex, distributary networks and there is minimal topographic relief between channels and interfluve areas through most of this area. Along these drainages, potentially flood-prone areas are widespread. In the southeasternmost part of the quadrangle, channels are generally entrenched into older deposits (units Qm and Ql), and thus flood-prone areas are restricted to relatively narrow strips along the distributary channels. Farther downslope, however, topographic relief is very low and the piedmont is dominated by young alluvium indicative of widespread deposition in the Holocene. During floods, inundation is undoubtedly widespread across area. Flood hazards are greatest at the upslope end of these areas, at the transition from confined to unconfined flow, because of fairly deep flow, high flow velocities, and the potential for significant changes in channel position during floods.

Soil problems. Soils in the Tucson area present a number of problems to homeowners. Cracking of foundations, walls, driveways and swimming pools causes headaches and costs millions of dollars each year in repairs. Severe or recurring damage can lower the value of a house or commercial property. Leading in the list of potential soil properties that can cause structural failures are expansive soils and collapsing soils. Properties of problem soils are generally related to the type and amount of clay, and to the conditions under which the clay originated. Clay minerals can form in-place by weathering of rocks, or by deposition from water or wind.

Soils with the potential to collapse or compact are found in the floodplains and young terraces of Brawley Wash (map units Qy2r, Qy1r, and Qyr) (see Anderson, 1968). Compaction problems have been also associated with soils of the Cemetery Terrace in the Tucson basin (Platt, 1963; Abdullatif, 1969; Crossley, 1969); this terrace is broadly correlative with map unit Qmlr in this quadrangle. In the Tucson basin, these soils are characterized by low moisture content (less than 15%), porosity >40%, and low bulk density. In these soils, the particles are loosely-packed and have never been subjected to loading. The clay in these soils supports the framework of randomly-oriented larger soil grains. Upon wetting, the clay loses its cohesive strength, resulting in the displacement of the soil particles to a more densely-packed configuration. Soils with compaction potential may be treated by application of large amounts of water, followed by several weeks or months to allow settling to occur before construction on the site. A large weight, called a pre-load, can also be applied to fully compact the soil before building.

Potential soil problems in middle and upper piedmont areas consist of shrink-swell potential, low infiltration rates, and hard substrate. Shrink-swell problems may exist on clay-rich soils of unit Qm, although the gravel that is common in these deposits may minimize these problems. Excavation may be difficult and near-surface infiltration rates low on the oldest piedmont units (Qo, and Tc) due to the existence of carbonate- and silica-cemented hardpans (petrocalcic and duric horizons). In some upper piedmont areas, cemented horizons related to old surficial units exist in the shallow subsurface but are mantled by young deposits. In these situations, less resistant upper horizons of old soils were removed by erosion, and subsequently much younger sediment was deposited over the cemented horizons. Similar excavation and infiltration problems may be encountered on all surficial units in the uppermost piedmont areas because of the existence of bedrock at shallow depths.

Land subsidence and earth fissures. In the Tucson area, agricultural development and population increases have resulted in the heavy use of groundwater resources. Because groundwater recharge in the area is limited, groundwater levels have been lowered by up several hundred feet in parts of the Tucson area. The alluvial aquifer of Avra Valley has long been exploited for irrigated agriculture, and for the past 25 years southern Avra Valley has been a major source of municipal water for the City of Tucson. Earth fissures have developed in northern and possibly eastern Avra Valley, and recent measurements have indicated that the surface of the central part of the Tucson basin has begun to subside.

Withdrawal of groundwater at rates faster than natural recharge leads to declines in water tables. Water levels have declined by 50 to 150 ft in most of Avra Valley, but levels may not be declining in that area at present (Anderson, 1989). Dewatering of sediments causes compaction, which in turn results in lowering of the land surface. In every Arizona groundwater basin where major groundwater overdraft has occurred, subsidence has followed. Land subsidence is as much as 15.4 feet near Eloy (Slaff, 1993) and 18 feet west of Phoenix (Schumann, 1992). In the Tucson basin, subsidence was detected in re-leveling surveys in 1952 (Platt, 1963), but maximum total subsidence was only about 0.5 feet by 1980 (Anderson, 1988).

Recent surveys have indicated continuing subsidence as water levels decline under Tucson. Hatch (1991) measured an average subsidence rate of 1 cm per year over the Tucson basin from 1987 to 1991. Based on the amount and rate of past subsidence, parts of the Tucson basin can expect subsidence of more than 10 feet by the year 2030 (Anderson, 1988). In Avra Valley, 10 ft or more of subsidence is possible in the northern part of the basin if water levels continue to decline (Anderson, 1989). Measurements in the Tucson basin suggested that the rate of subsidence had increased markedly since 1980.

In Arizona basins where subsidence is more than a few feet, earth fissures have developed. A fissure developed in northern Avra Valley east of Marana High School adjacent to the Central Arizona Project aqueduct (Arizona Geological Survey, 1988). It was quickly filled and surface water was diverted from it, and it has not reopened. Tucson Water, the water utility for the City of Tucson, has begun a major recharge project in central Avra Valley (the Central Avra Valley Storage and Recovery project) utilizing Central Arizona Project water. It is projected that this facility will recharge

60,000 acre-ft of water each year, most of which will ultimately be recovered by water wells. This project will obviously impact ground water levels in the basin.

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